Price Discovery in Illiquid Markets: Do Financial Asset Prices Rise Faster Than They Fall?*

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Abstract

In OTC bond markets many investors face high costs of trade, and these costs appear to be related to the lack of price transparency. We study the consequences this has for efficient price discovery. Prices of municipal bonds react sluggishly to macroeconomic news. Yield spreads over treasuries react dramatically to news because treasury yields move and municipal yields do not. As in consumer markets, prices appear to "rise faster than they fall." Round-trip profits to dealers on retail trades increase in rising markets but do not decrease in falling markets. Effective half-spreads increase or decrease more when movements in fundamentals favor dealers. Yield spreads relative to treasuries also adjust with asymmetric speed in rising and falling markets.

1 Introduction

Equities typically trade on centralized, transparent exchanges. Bonds trade in opaque, decentralized dealership markets. This need not be viewed as surprising. The need for immediacy and the extent of informational asymmetry are likely to differ across different types of securities, and the venues or mechanisms that most efficiently manage their exchange will differ too. Therefore, while we can see large and obvious differences in the costs of trade in these different settings, the reasons for it are not obvious. Understanding how well these different market structures perform is a central question for regulators, market participants, and academic researchers.

One of the central functions of financial markets is price discovery. In fragmented, decentralized markets price discovery may well be a more difficult task. Information is more difficult to gather. Dealers, who intermediate trades, play a pivotal role in price discovery in OTC markets. A natural question to ask is how well they are doing the job of setting prices that represent a best guess of the fundamental value of the asset. If the job is done well, prices should react quickly to information, and over short horizons should evolve like martingales.

The availability of large data sets of transactions prices for corporate and municipal bonds have increased our understanding of over-the-counter markets, and the intermediaries who make them, but the focus of this research has been on the cost of trading rather than on the price formation process. Recent papers such as Harris and Piwowar (2006), Green, Hollifield and Schürhoff (2007a), and Edwards, Harris and Piwowar (2007) have shown that the costs of trading differ greatly across institutional and retail investors in over-the-counter (OTC) markets. Often, indeed, the terms of trade for retail investors are quite punitive. Green, Hollifield and Schürhoff (2007b) document considerable price dispersion for new issues of municipal bonds with high retail participation. Bessembinder, Maxwell and Venkataraman (2006) and Goldstein, Hotchkiss and Sirri (2007) show that trading costs in the corporate market fall when transparency increases.

It is clear from these papers that OTC bond markets display some behaviors at odds with standard notions of how efficient financial markets should work. An unanswered question is whether prices in these markets reflect changes in information quickly, and in an unbiased manner. Yet, as noted above, in many respects this is the central question. Even if trade is costly and infrequent, the transactions that do occur can still be at prices that efficiently incorporate public information.

If retail investors face high costs of trade, financial intermediaries such as mutual funds will arise to limit the costs they incur. Unsophisticated shoppers for municipal or corporate bonds are only hurting themselves. Financial market prices, however, have consequences that reach beyond the investors and intermediaries directly involved in a given trade. They serve as signals for resource allocation more broadly. What consequences, then, do the costs of trade, price dispersion, and limited liquidity have for price discovery?

Addressing this question presents a number of challenges relative to the settings where price discovery has been extensively studied. In equity, treasury, and futures markets intraday data are particularly rich on the time-series dimension. They are high-frequency. In the market we study this is not the case. The municipal bond market has tens of thousands of bonds available for trade at any point in time, but the bonds trade very infrequently. To evaluate how changes in fundamentals are reflected in the prices at which investors trade we examine both aggregated bond price indices and develop panel-data methods that make use of disaggregated transactions data.

Our results suggest that prices in the municipal bond market respond very slowly to public news. When prices do respond, they respond more quickly when the response benefits intermediaries. In a variety of retail markets, prices "rise faster than they fall" (see, for example, Peltzman (2000)). We find similar forces at work in the municipal bond market, despite the manifestly "common value" nature of the objects traded.

First, we consider the response of municipal price indices and volume to major macro-economic news announcements. The Bond Buyer 40 index is constructed from the most liquid municipal issues, and based on institutionally sized trades of over $1 million. The bonds in the index are typically new issues, and Green, Hollifield and Schürhoff (2007b) have shown that institutional traders face very little price dispersion at a point in time.

The Bond Buyer 40 index does react in the same direction as do treasury securities, but there is evidence that the adjustment to news is delayed. Changes in municipal yields are autocorrelated and correlated with lagged changes in treasury yields. Granger causality tests reveal that treasury yields lead municipal yields, but not the reverse. In comparison to treasuries, percentage changes in municipal yields are more concentrated around zero on news days. They then gradually spread out through time to eventually exhibit dispersion similar to that in the treasury market over longer horizons.

Price discovery generally requires trade. Daily volume in the bond market shows considerable variation across days of the week. We show volume is not significantly higher on news days than on other days, controlling for day-of-the-week effects. Thus, price discovery, if it depends on trading activity, is evidently taking place in more liquid markets, such as those for treasuries and fixed-income derivatives. Municipal traders apparently rely on information in prices in these other markets.

We also document that price responses are asymmetric for good and bad news. Changes in yield show more dependence on past changes when prices are falling than when they are rising. Since volume does not show similar, statistically significant, asymmetries, it seems unlikely that the different price responses are due to differences in the amount of non-synchronous trading in the bonds composing the index.

The behaviors we observe in indices are also evident in disaggregated transactions data. To use our full data set we propose statistical models that aggregate all transactions in a bond at the daily level, and then construct proxies for effective bid-ask spreads and yield spreads over comparable treasuries. For a given bond on a given day, we estimate the common value of the bond as the midpoint between the lowest price (highest yield) at which a dealer sold to a customer and the highest price (lowest yield) at which a dealer bought. If we do not observe both sales and buys on a given day, we use the average (or the median) price for all interdealer transactions. The sale price on that day is then the average price at which bonds were sold to customers, and analogously for the buy price. This allows us to employ a portion of the millions of trades in our sample, and use panel data methods to examine price discovery and its effect on trading costs.

Our panel regressions show that, while treasury rates respond quickly to macroeconomics movements, municipal rates do not. Yield spreads also respond dramatically and persistently, because the price adjustment for the municipals is so slow. We show that yields respond sluggishly to news in part because they often do not respond at all. This price stickiness has been diminishing through time, and is more apparent in unrated, uninsured bonds we would expect to exhibit less liquidity.

To better understand the sources of delayed and asymmetric price response, we examine the dynamics of dealer markups and effective spreads. In a decentralized, broker-dealer intermediated market, there is no mechanism through which most investors can trade directly with each other, as they can through limit orders on an exchange. Instead, broker-dealers provide liquidity by taking bonds into inventory in purchases from customers, and then selling them to other customers. The MSRB transactions data we employ identifies trades as "buys from customers," "sales to customers," and "interdealer trades." While individual dealers are not identified, many bonds trade infrequently enough that we can reasonably infer two sides of the same trade. Alternatively, we can use observed transactions prices and interdealer prices to estimate mid-points, and consider half-spreads around these points.

A wide range of retail markets show asymmetric price adjustment. Prices rise more quickly in response to changes in costs than they fall (i.e., prices behave like "rockets and feathers"). The local market power suggested by asymmetric price adjustment might be due to product differentiation, or private values, or it might be attributable to search costs and a lack of price transparency. In financial markets the object of trade is typically viewed as a commodity with little private value that varies by customer. Do financial market prices exhibit asymmetries in price movements similar to those observed for consumer products? Some evidence that they do in retail banking is reported in Neumark and Sharpe (1992). They show that bank deposit rates fall (i.e., "prices" rise) faster than they rise, and that the asymmetry is more pronounced in local markets with greater concentration. We provide evidence of such behavior for financial assets traded in a public market.

We first focus on transactions that appear to be round-trip trades by a dealer. These are sequences of trade where a buy from a customer is followed by a sale to a customer of the same par value in the same bond. The percentage markup earned by the dealer(s) on the sequence of trades is the dealer's sales price less purchase price as a percentage of the purchase price. Since we are not attempting to directly measure dealer profits, the actual identities of the transacting brokers are not of critical importance. Even if, through coincidence, the sale is made by a different dealer, the price at which the first dealer bought is a signal of the value of the underlying security. If subsequent price changes are asymmetric across rising and falling markets, this will be reflected in the measured markup.

Regressions of the markups on changes in the Bond Buyer index, controlling for other factors known to affect the markup, show that for retail-sized trades markups rise when prices rise, but do not fall when prices fall. Thus, dealers resist lowering their prices when the value of the underlying securities falls, and have sufficient market power in dealing with their retail customers to succeed. This behavior is not evident for institutionally sized transactions.

The method described above ignores the many trades that cannot be conveniently categorized as round-trip transactions through a dealer, and implicitly orders buys and sales in time. To broaden the sample, therefore, we examine asymmetries in the price response using panel data methods.

We ask how effective half-spreads respond to changes in the midpoint, our proxy for the bond's common-value component. When the common value of the bond rises, the average sales price less the midpoint and normalized by the midpoint (the ask-side effective spread) is unaffected, but it rises when prices fall. Analogously, the bid-side effective half spread rises when prices rise, but is unaffected when prices fall. This pattern is consistent across all trade sizes, not just retail trades. In short, when underlying values move to their advantage, dealers' transactions prices reflect this movement on the same day. Dealers quickly adjust prices up or down to maintain a constant profit margin. When prices move to decrease the cost of a bond they are selling, or increase the cost of a bond they are buying, prices are sticky.

Evidence of asymmetric price responses is seen in the speed with which bid-ask spreads and half spreads adjust over time to changing conditions. We estimate a partial-adjustment model with random effects for bid-ask spreads and half-spreads. When spreads are narrow, relative to the latent "equilibrium" value, they rise immediately, at a daily frequency. When spreads are too wide, this adjustment is more gradual.

Finally, we consider the movement over time of yield spreads between municipals and treasuries, and in this way ask if prices "rise faster than they fall." We estimate a partial-adjustment model to examine the speed with which municipal prices adjust to movements in treasuries, and asymmetries in this adjustment. For each municipal bond for which we have estimates of the common value on consecutive days, we consider the yield spread relative to a maturity-matched treasury. When the spread of the treasury yield over the municipal's yield is abnormally high, relative to a latent "equilibrium" value, the municipal's yield tends to rise, and the municipal's price to fall. The reverse occurs when the spread is unusually narrow. Our estimates show that spreads widen faster than they shrink. Alternatively stated, municipal prices rise faster than they fall.

We use variation across states to verify that asymmetry in speed of adjustment for prices is more pronounced in settings where we would a priori expect dealers to have more local monopoly power. States that exclude out-of-state bonds from tax-exempt status have municipals markets that are segmented from the national market. Prices rise faster than they fall in a more pronounced manner in these states. Bonds issued in states with greater concentration in the market for underwriting services, and smaller primary markets, also show more asymmetry in price response.

The paper is organized as follows. In the next section we describe the data used. Section 3 evaluates how quickly the municipal market responds to macroeconomic news. Section 4 shows individual municipals often fail to respond at all to changing conditions, and considers the determinants of such price stickiness. Section 5 explores the asymmetries evident in the price adjustment, and on the speed with which bid-ask spreads, half-spreads, and yield spreads over treasuries adjust to movements in fundamentals. Section 6 summarizes and concludes.

2 Data

We study price discovery in the municipal bond market using both aggregated and disaggregated price data. Our primary source of aggregated price data is the Bond Buyer Municipal Bond Index. It is computed on a daily basis by Bond Buyer, the leading trade publication in the municipal-bond industry, using the 40 long-term, high-credit bonds they deem to be the most liquid. These tend to be large, recent issues by visible issuers. We use the "average yield to call" for the index, which is based on institutional trades of over $1 million in par value. The index yield is calculated by taking price estimates from Standard & Poor's Securities Evaluations for the 40 bonds. The average yield Bond Buyer reports daily is the yield to call on a hypothetical bond with the average coupon and average call date, at the average price of the 40 bonds.

In our comparisons to the treasury market, we generally use the yield on the ten-year benchmark Treasury bond, as reported daily by Bond Buyer. When we compute spreads over treasury yields for specific bonds, we use the daily constant maturity treasury rates provided by the St. Louis Fed. These rates are for maturities of 0.25, 1, 2, 3, 5, 7, 10, 20, and 30 years. For intermediate maturities we interpolate linearly.

The disaggregated price data we employ is provided by the Municipal Securities Rulemaking

Board (MSRB), a self-regulatory industry group. It includes all trades made by registered broker dealers in municipal securities from May 1, 2000 to October 19, 2006. There are 1,615 trading days during this period. Trades are reported in 1,559,894 bonds.

We apply a number of rule-based filters to clean the transactions data, eliminate bonds with missing observations, correct obvious clerical errors, and supply missing data items where possible. We exclude a small number of trades on holidays and weekends. For each bond issue, we search the MSRB database for the bond's coupon rate and maturity, since these are reported for some trades but missing for others. We eliminate all bonds with missing coupon or maturity after this search. This includes all variable rate bonds. Bonds with a recorded coupon in excess of 20%, or a maturity of more than 100 years are dropped. Green, Hollifield and Schürhoff (2007b) show that newly issued bonds exhibit some peculiar behaviors and high levels of price dispersion, so we focus on seasoned bond issues in this study. We eliminate transactions less than 180 days after the dated date. Our panel regressions require a minimal amount of time-series information, and so for these purposes we eliminate any bonds with fewer than 10 trades over the sample period. Our tests involving round-trip transactions do not impose this filter, as they require much more limited time-series information, but they do exclude new issues.

Along with the information in the MSRB transactions data, we have collected data on issuer and bond characteristics from other sources. We use the Thompson Financial SDC Platinum database on municipal securities, which covers new municipal issues from 1980 to 2006. The National Association of Securities Dealers also provides data on bonds and issuers through the Bond Market Association's web page, www.investingbonds.com. All explanatory variables that exhibit outliers in either tail are winsorized at 0.5% and 99.5% if they attain both positive and negative values. Variables that are only defined for positive values are winsorized at 99%. Table 1 lists the various conditioning variables we employ, along with their definitions.

Table 2 reports summary information about transaction volume in the MSRB data. From this table it is evident that sales and buys from customers are close in value, but that there are almost twice as many sales to customers. This reflects the manner in which dealers provide liquidity. They often break blocks of bonds purchased from a customer into smaller blocks before reselling them to others. Interdealer trades are a relatively small fraction of dollar volume (14%), but a more substantial portion of the number of trades (28%).

To evaluate the price response to major news events, we employ a number of periodic macroeconomic news releases commonly employed in the literature. These are detailed in Table 3, and cover the period January 2000 through October 2006.

3 Macroeconomic News and Price Discovery

Every month the U.S. Government releases major macroeconomic indicators such as the consumer price index and advance retail sales. Financial market participants watch these numbers closely to evaluate the state of the economy.

The values of tax-exempt bonds, like their taxable counterparts, depend on information about current and future economic outcomes. It is natural to ask where investors choose to trade across the two linked markets. How quickly are price changes in one market reflected in the other? How much trade is involved in this adjustment process? The tax-exempt market, unlike the treasury market, involves considerable trade by small investors. How do the terms of trade for retail investors respond to major announcements, and what can this teach us about the role of the broker-dealers intermediating the trades?

The processes through which price discovery occurs, and the speed with which prices react to important news, have been extensively studied in the market for U.S. treasuries. Like the municipal market, the treasury market is over-the-counter, but the treasury market is highly liquid. It is dominated by large institutional traders, and involves a great deal of trade in a relatively small number of bonds. We study a notoriously illiquid market, with a significant retail component and a relatively small amount of trade spread across a huge number of bonds.

Studies on the treasury market generally find that prices react almost instantaneously to surprises in scheduled macroeconomic announcements, and that there is little autocorrelation in returns after the first minute (Ederington and Lee (1993), Ederington and Lee (1995), Fleming and Remolona (1999), and Balduzzi, Elton and Green (2001)). Piazzesi (2005) studies the price reaction to the release of FOMC meeting statements and finds that price response to the surprise in the announcement is sluggish. In four of the five half-hour intervals starting after announcement, price changes are auto-correlated. She attributes the difference in reaction to the qualitative nature of the announcements and the unexpected timing of some of the announcements.

Price discovery in the treasury market clearly involves abnormal amounts of trading. Fleming and Remolona (1999) find that volume remains significantly elevated for about 90 minutes after consumer price index, employment, and producer price index announcements (examined together) while Balduzzi, Elton and Green (2001) report that volume remains elevated for at least an hour after a number of different types of announcements.

Treasury spreads also behave abnormally around major news announcements. Fleming and Remolona (1999) and Balduzzi, Elton and Green (2001) find spreads rising before announcement and peaking at announcement. The latter study finds persistently wide spreads after announcement for the employment report. Following news events inventory risks remain high because of continued volatility and informational asymmetries may be higher than usual, perhaps because some dealers have information about their own customers' order flow.

Note, finally, that in studies of treasury markets the time horizon for evaluating price adjustments is measured in minutes. We will show that price adjustments in the municipal market appear to be spread out over days.

3.1 Trading Volume and News Announcements

Given the obvious liquidity advantage of the treasury market, in which a large volume of trade is concentrated on a small number of bonds, it is not surprising that price discovery takes place there first. In fact, we show that virtually all news-related trade takes place there. There do not appear to be significant increases in trading volume in the municipal market. When there is significant abnormal volume, it is generally negative.

To evaluate the impact news announcements have on volume we regress total daily volume on indicators for whether the day saw a news announcement of a particular type, interacted with whether the news was good, bad, or neutral. We define the news as bad when the surprise in the announcement (the difference between the actual numbers and the survey median) is unfavorable to the bond market, such as a low unemployment rate, or surprisingly high advance retail sales. Across the 1,615 business days in our sample, 438 days have major economic announcements. There are 216 days that have at least one announcement that was good news. On days with multiple announcements some days have mixed news. In such cases, the day can simultaneously be "good news day" for one type of announcement and "bad news day" for another. There are also cases when news announcements meet expectation, and these are called "neutral news days". Daily volume is measured as par value traded and number of trades for each of the three trade categories—dealer buys, sales, and interdealer trades. Because volume in the municipal bond market shows day-of-the-week effects, we add dummy variables to control for this possibility. The model we estimate is

$$Vol_t = \beta_0 + \sum_{i=1}^{10} \sum_{s=g,n,b} \beta_{is} D_{ti} D_{ts} + \sum_{w=2}^{5} \beta_w D_{tw} + \varepsilon_t, \tag{1}$$

where $\varepsilon_t = \rho\varepsilon_{t-1} + \xi_t$, $D_{ti} = 1$ if an announcement of type i occurred on day t, and is zero otherwise, while $D_{ts} = 1, s \in \{g, n, b\}$ if the announcement on that day was good (g), bad (b), or neutral (n) news for bond prices. The remaining indicators in the regression control for day of the week.

Table 4 reports the results of this regression. Most of the announcements, regardless of whether the news is good or bad for bond prices, produce insignificant or negative abnormal volume. The one exception holding across all volume measures is adjusted retail sales on news neutral days. Because the extra volume for this variable is associated with the announcement meeting analyst expectations, it is unlikely that this response is trading activity associated with price discovery.

In Table 5 we report the results of regressions using the same measures of volume but with news events aggregated across types of news into good-news, bad-news, and neutral-news days. We also include indicators for days following the news events, to allow for a delayed volume response. On some days there were both good-news and bad-news announcements. Both indicators will be one for these days. Again, as in Table 4, there is little evidence of a volume response to news releases in the municipal market. The only (marginally) significant coefficients, for good news at a one-day lag, suggest there is *less* volume on such days than normally.

It seems clear then that traders wait on news days for price discovery to take place elsewhere. Comments from traders seem consistent with this view. For example, on October 19, 2006, the *Bond Buyer Online* reported the following:

> "The market is sideways for the most part," a trader in New York said. "However, there still seems to be some interest in bonds. There are some bidders, which is an

improvement in this situation from the last week. As far as the data goes, it's funny how we used to really focus and hang on the economic announcements and act accordingly. Now, we don't bother, we just wait to see what the Treasury market does in the wake of the economic data and take our cue from that. Instead of acting, we react."

3.2 Aggregated Prices and News Announcements

Municipal bond yields, of course, generally respond to news in the same direction as do treasury yields. Granger causality tests are a straightforward way of evaluating where price discovery is occurring first. We compare the Bond Buyer Index, constructed from institutional-sized trades of the most liquid municipal bonds, with the ten-year treasury bond. As first proposed by Granger (1969) and popularized by Sims (1972), testing causality of Y on X, in the Granger sense, uses F-tests to ask whether lagged information on a variable Y provides any statistically significant information about a variable X in the presence of lagged X. Consider the vector autoregression

$$y_t^M = \sum_{p=1}^{l} \alpha_p^M y_{t-i}^M + \sum_{p=1}^{l} \beta_p^M y_{t-i}^T + \varepsilon_t^M, \tag{2}$$

$$y_t^T = \sum_{p=1}^{l} \alpha_p^T y_{t-i}^T + \sum_{p=1}^{l} \beta_p^T y_{t-i}^M + \varepsilon_t^T. \tag{3}$$

To test if treasury yields (y_t^T) cause municipal yields (y_t^M), we compare the unrestricted model in equation (2) to the restricted model with $\beta_p^M = 0$ for all $p = 1, \ldots, l$. The P value for the F-test associated with this restriction is reported in Table 6. Similarly, testing if municipal yields Granger-cause treasury yields requires comparison of the model in equation (3) with and without the restriction that $\beta_p^T = 0$ for all $p = 1, \ldots, l$. In our tests we choose maximum lag length $l = 4$.

The first line of Table 6 reports the results of such tests for the yield to call on the Bond Buyer 40 Index and the 10-year treasury yield. The treasury yield Granger-causes the municipal yield, but not the reverse. We supplement this in the table with the same tests using indicative yields constructed by Lehman Brothers and reported by Bloomberg for different maturities of municipals and treasuries. At all maturities except the shortest one, where the two series Granger-cause each other, treasury rates lead municipal rates, but not vice versa.

3.3 Relative Speed of Aggregate Price Adjustment

One would expect that tax-exempt and taxable yields respond in the same direction to most news events. How quickly do municipal yields catch up to taxable yields? In Figure 1 we provide frequency plots of percentage changes in yield for the 10-year treasury and the yield to call on the Bond Buyer 40 Index on the days of news announcements (top panel), over the following five days (middle panel), and over the following ten days (bottom panel). The one-day percentage changes for the municipal yields are considerably more peaked at zero, in comparison to the treasury yields. This difference is less evident over longer horizons, where the two densities do not show such dramatic differences.

There is momentum in municipal bond yields, and the momentum evident when prices are falling is larger than when prices rise. In Table 7 we report estimates of the model in equation (4), which interacts lagged changes in the level of the Bond Buyer index with indicators for whether the previous change in level was positive or negative to explain price changes, $\Delta \log p_t$, or volume changes, $\Delta \log Vol_t$:

$$y_t = \beta_0 + \beta^+ \Delta \log p^+_{t-1} + \beta^- \Delta \log p^-_{t-1} + \varepsilon_t \qquad (4)$$

The first column in the body of Table 7 shows a mild asymmetry evident in the autocorrelation of price changes with $\beta^+ < \beta^-$. An F-test rejects the restrictions that the two coefficients are equal with a p-value of 5%. Price changes are more responsive to past price changes when prices are falling.[1] The Bond Buyer 40 index is constructed using the 40 most liquid bonds in the market based on institutionally sized trades. Nevertheless, some of the delayed adjustment evident in the regression (4) could be due to non-synchronous trading of the bonds in the index, or idiosyncracies in the yield calculations for the index. Therefore, we explore this asymmetric momentum in price adjustments in detail using disaggregated transaction prices in Section 5.

The remaining columns of Table 7 examine how different volume measures—par value traded, customer buys, customer sales, and interdealer trades—respond to lagged changes in prices. If there is less trade in falling markets, it is perhaps not surprising that we should also see more

[1] In unreported tests, we examined this asymmetry using the Lehman Muni Long Term Price Index, and the Municipal Market Advisors' 25-Year Yield for Insured Aaa General Obligation Bonds. Similar asymmetries were evident for these indices, with p-values for equality of the coefficients equal to 6% and 8%, respectively.

autocorrelation there. The estimates indicate this is not the case. Price rises lead to less trading, by all the measures, but price drops have insignificant effects on subsequent volume.

3.4 Macroeconomic News and Disaggregated Prices

In this section we use a comprehensive transaction dataset of municipal bond trades by registered broker dealers from 2000-2006. Our approach attempts to account for the nature of the data available. There are a large number of bonds outstanding, but most individual bonds trade very infrequently. Because of differences in the terms of trade across types of investors, intra-day price variation can be large compared to movements in fundamentals (see, for example, Green, Hollifield and Schürhoff (2007a)). Therefore, we employ panel-data methods and restrict attention to transactions data aggregated at a daily frequency. Daily municipal yields for specific bonds are constructed by taking the midpoint of the highest yield on all sales by dealers to customers and the lowest yield on all purchases by dealers from customers of a particular bond on a given day. If there are not both sales and purchases on that day, the daily yield is the average (or median) yield on interdealer trades. We compute midpoints for prices similarly as the midpoint of the lowest offer and the highest bid price. In many of the tests below, we also compute changes in yields, or require lagged yields over several days. We have fewer observations for these tests since many bonds do not trade on consecutive days. Yield spreads are calculated by matching the yield on a given municipal bond with a treasury yield of comparable maturity. We use the daily constant maturity treasury rates provided by the St. Louis Fed. These rates are for maturities of 0.25, 1, 2, 3, 5, 7, 10, 20, and 30 years. For intermediate maturities we interpolate linearly.

We provide descriptive evidence of slow price discovery in the municipal bond market when there is news that moves interest rates. Municipal bonds under-react to macroeconomic news. Yield spreads react dramatically to such news, because treasury rates respond quickly while municipal rates are extremely sluggish.

Table 8 reports estimates of the effect of macroeconomic news on yield spreads and daily changes in yields for municipals and treasuries. We include a large number of control variables that might be expected to explain yield spreads, including bond and issuer characteristics, and the order size of customer sales and purchases averaged across all trades on a given day. The results in

Table 8 are obtained from a standard panel-data regression with bond-specific random effects. The macroeconomic news variables on the ten most important announcements are the difference between the announced values and the consensus forecasts, standardized by the standard deviation across all observations of the announced variable as in Balduzzi, Elton and Green (2001).

The table shows that municipals under-react to macroeconomic news compared to treasuries. Treasury yields move significantly upon the arrival of news. The response of the municipals is much smaller, as evident in the point estimates, and generally statistically insignificant at standard confidence levels even though we have hundreds of thousands of observations. As a result the yield spread between treasuries and municipals moves significantly after the arrival of fundamental information, as evident in the significant coefficients on the macro surprise variables in the first two columns of Table 8.

Table 9 reports estimates for the impact of positive and negative news on municipal yields and yield spreads. The table shows that the under-reaction in municipals occurs for both positive and negative surprises.

The estimates in Table 10 show that lagged macroeconomic news releases affect yield spreads significantly, and predict changes in the yields of individual municipal bonds. Evidently, the effect of interest rate movements on yield spreads and on municipal yield changes persists for several days and is asymmetric. FOMC rate hikes widen yield spreads between treasuries and munis persistently, while FOMC rate declines leave yield spreads unaffected.

4 Price Stickiness

Our disaggregated data only reports transaction prices, not posted quotes. Thus, we are observing lagged adjustment in the prices at which bonds are actually being exchanged. Some of this slow response appears to be a failure of prices to move at all. In Figure 2 we plot the distribution of percentage changes in the yields of municipal bonds and in the yields of maturity-matched treasuries, at increasingly long horizons. The municipal yields are calculated at the midpoint between customer sales and purchases, as in the previous section. Analogous to the behavior for the aggregates, depicted in Figure 1, the distribution for the individual municipals is initially more peaked, and gradually assumes a shape similar to that evident for the treasuries. At the level of individual bonds, however, much of the more concentrated mass for the municipals is attributable to a spike at exactly zero. That is, prices are simply not moving across time, even as the maturity-matched treasury moves. In many cases, it appears that price adjustment is not only sluggish or slow—it is not occurring at all.

In Table 11 we investigate the determinants of stickiness in municipal bond prices. We run fixed-effect logit regressions explaining the probability that the midpoint price remains unchanged on two consecutive days. Recall that at least one customer purchase and one customer sale, or one interdealer trade, is required to calculate the midpoint price on a given day, so the midpoint reflects trades that are actually occurring. The estimates reveal that there is considerable cross-sectional variation in price stickiness. The model shows a strong negative time trend, which may suggest that the reforms made in the municipal market to encourage greater transparency are making prices more responsive to information. More dramatic movements in treasury yields lead to less price stickiness, as one would expect. Order flow imbalances and large dealer inventories also appear to pressure dealers to move prices in order to move inventory. Bond characteristics associated with liquidity in the market, such as ratings, also reduce the probability of observing price stickiness.

5 Delayed and Asymmetric Price Adjustment and the Costs of Trading

In a variety of markets for retail goods, prices rise faster than they fall. This is generally interpreted as evidence that sellers have local market power. Efficient price discovery in financial markets requires that, when underlying intrinsic values move, prices follow. We have seen in the previous sections that this process is delayed in the municipal market. Here we ask whether the terms of trade display asymmetric behaviors in rising and falling markets, and across retail versus institutional investors.

To address these questions we must utilize disaggregated transactions data. The municipal market involves trade in a large number of bonds, but trade is sparse on the time-series dimension. Since price discovery takes place through time, this presents challenges that we address through several different strategies.

5.1 Dealer Markups on Round-Trip Trades

Here we follow Green, Hollifield and Schürhoff (2007a) and measure the profits dealers earn on round-trip transactions, initiated by a purchase of bonds from a customer. The MSRB data identify trades as dealer purchases from customers, dealer sales to customers, or interdealer trades. The data do not reveal the identities of specific dealers or customers. Since trade is relatively infrequent, however, it is often evident that specific transactions are the legs of transactions intermediated by the same dealer. For example, when a purchase from a customer is followed by a sale of the same bond in the same par amount with no intervening transactions, or when a purchase is followed by two sales which sum to the initial par value.

We match purchases from customers with subsequent sales as follows. Trades that are customer sales to a dealer immediately followed by customer buy from a dealer at the same par amount are identified as a round-trip pair. The matched trades are then filtered according to the criteria: If the yield on either leg is missing, the yield is greater than 20%, the price on either side is smaller than \$20 or greater than \$150, the par value is less than \$5,000, or the percentage markup is greater than 10% or less than -10% then the record will be deleted. Since we are interested in price response to market price changes, we further eliminate round-trip pairs that happened on the same day. There are 1,127,398 pairs left after filtering. Among them, 89,095 (8%) pairs are institutional size (Par $\geq$ 100 thousand), 1,038,303 (92%) pairs are retail size.

Once transactions are matched, a simple measure of the profits a dealer (or dealers, if some trades are incorrectly "matched") makes on a given sequence of trades is the percentage markup over the purchase price—the difference between the proceeds from the dealers sales to customers and the cost of buying the bonds, divided by that cost.

We then investigate how this markup differs when prices are rising versus falling. If prices rise faster than they fall, as in markets for retail goods, then the markup should increase during market rallies by more than it falls when prices are decreasing. This is exactly what we find at the retail level. In fact, markups increase when prices rise but are insensitive to price movements when prices fall. Institutional investors are more sophisticated shoppers for the services of intermediaries. They are informed about market conditions, and have repeated interactions with them. This puts them in superior bargaining position when transacting with dealers. Institutionally sized trades do not show this asymmetry.

To measure the underlying price movements, we use the Lehman Brothers Long Term Municipal Price Index to proxy for the market price level. The Lehman Brothers Long Term Municipal index is a benchmark index that includes investment-grade, tax-exempt, and fixed-rate bonds with Long-term maturities (greater than 22 years) selected from issues larger than \$50 million.

We regress the markup on transaction i against the change in the index over the period between the initial purchase and final sale. The model in equation (5) separates rising and falling markets, and allows the coefficients to differ:

$$\text{Markup}_i\ (\%) = \beta_0 + \beta_1^-(r_t^{idx})^- + \beta_1^+(r_t^{idx})^+ + \beta_2\Delta T_i + \beta_3 Order\ Size_i + \beta_4 D_i^{mRound} + \varepsilon_i. \quad (5)$$

The variables $(r_t^{idx})^-$ and $(r_t^{idx})^+$ are the returns in the underlying index (computed as log changes), when that return is negative and positive, respectively. Control variables are the number of days between the legs of the transaction, ΔT, the log par value of the trade, $Order\ Size$, and an indicator, D^{mRound}, for whether the markup is rounded (to at least 1/8th of a dollar). All of these variables are known to be related to the size of the dealer markups (see, for example, Green, Hollifield and Schürhoff (2007a) and Li (2007)).

In Table 12 we report the results of estimating this model separately for institutional trades, where the par value exceeds \$100 thousand, and for retail trades. We expect institutions to be more aware of market conditions, and more effective bargainers. We also separate trades where the dealer holds the bonds for more than five days in inventory from those of more typical duration. As dealers begin to get desperate to unload their trades in falling markets, the terms of trade may become more responsive to price movements. The p-values in the table test the restriction that $\beta_1^- = \beta_1^+$.

As the table shows clearly, when prices rise markups rise, regardless of trade size, or the length of time the dealer holds the position. When prices fall, spreads also fall (there is a positive coefficient on $(r_t^{idx})^-$). For retail-sized trades of routine duration, however, this coefficient is only marginally significant (keep in mind the very large sample), and it is much smaller in magnitude than the corresponding coefficient for rising markets. Dealers selling to retail customers raise their prices sharply when the index rises but do not drop their prices comparably when the index falls. This stands in contrast to how the intermediaries deal with institutional investors, where the asymmetry appears to go in the opposite direction. Institutional investors may, indeed, be at a bargaining advantage when prices are falling and dealers hold bonds in their inventories.

5.2 Implicit Half-Spreads and Asymmetric Price Adjustments

The analysis of round-trip profits for dealers imposes an implicit ordering on transactions and excludes a great deal of data. It examines only trades that can be matched as likely round trips. Because we need index data to measure movements in fundamentals, we can use only round-trip trades that carry over across days.

As in Section 3.4, therefore, we aggregate data for specific bonds at the daily level. We compute daily bid, ask, and midpoint prices for each bond and for different transaction size categories. That is, we construct a daily proxy for the spread conditional on size, instead of estimating the bid-ask spread through a time-series regression on a trade-direction indicator, as in Schultz (2001) and others.

Our proxy for the ask (bid) price is the average transaction price associated with all customer purchases (sales) within a given size category on a given day. The common value of the bond is captured by the average of the highest bid and the lowest ask transaction on a given day if both buys and sales occur. If not, the common value of the bond is captured by the average price on all interdealer transactions. Results based on the median price are very similar and omitted.

First, we analyze how spreads and half-spreads respond to changes in the midpoint. Let p_{it}^{bid} and p_{it}^{ask} be bid and, respectively, ask transaction prices on bond i at date t. This will be the average prices at which dealers sell to customers (ask) or buy from customers (bid) on a given day. Assume bond i has common value v_{it} at time t. We measure the half-spreads by $sp_{it} = (p_{it}^{ask} - v_{it})/v_{it}$ and $sp_{it} = (v_{it} - p_{it}^{bid})/v_{it}$, respectively. The following model allows for the possibility that transaction prices react asymmetrically to gains and drops in the bond's fundamental value and is estimated using panel data methods:

$$sp_{it} = \beta^{+}(\Delta v_{it})^{+} + \beta^{-}(\Delta v_{it})^{-} + \gamma x_{it} + \alpha_i + \varepsilon_{it}, \tag{6}$$

where Δv_{it} is expressed in percent, x_{it} is a set of explanatory variables and ε_{it} is an error term, allowed to be autocorrelated due to measurement error.[2] The bond specific random effect is α_i.

Table 13 reports results on the effect of movements in the bond's fundamental value, estimated separately on sell-side and buy-side half-spreads. We also estimate the model for the bid-ask spread (average customer buying price minus average customer selling price on a given day, normalized by the midpoint). Results in the table are stratified by transaction size. Large trades involve par values in excess of \$250 thousand, medium sizes are between \$50 thousand and \$250 thousand, and small trades are less than \$50 thousand. The coefficient estimates suggest, first, that larger price movements increase the effective bid-ask spread.

In the first three columns, the reported coefficients are positive when the change in the midpoint is positive ($\beta^+ > 0$), and negative when the change in the midpoint is negative ($\beta^- < 0$). Together, these imply an expected increase in the spread in response to changes in the midpoint in either direction. The associated coefficients for the half-spreads display asymmetric magnitudes across price drops and increases. P-values for tests of equality for β^+ and $-\beta^-$ are virtually zero for every subsample in the table. The largest coefficients in absolute value are associated with the mid-price less the bid, when the midpoint is rising, and the ask less the mid-price, when the midpoint is falling. The ask-side effective spread increases dramatically when prices fall, and the bid-side effective spread rises the most when prices rise. This pattern occurs consistently across transaction size categories. This behavior is consistent with dealers responding relatively quickly to movements in fundamentals when it benefits them collectively to do so, while resisting the competitive pressure to change prices quickly when doing so erodes their markups. Holding the bid price fixed, for example, the bid-side spread increases when the midpoint rises. Holding the ask price fixed, the ask-side spread increases when the midpoint falls. The largest coefficients are for the bid-ask spread and the ask-side half-spread when prices fall. This suggests dealers are not revising the prices at which they sell to customers when prices are dropping.

We also estimate a partial adjustment model for the effective bid-ask spreads, for ask-side half-spreads (i.e., ask minus midpoint, normalized by midpoint) and bid-side half-spreads (i.e., midpoint

[2]We have estimated the model (6) also using instrumental variables. Our instruments for $(\Delta v_{it})^+$ and $(\Delta v_{it})^-$ are concurrent and lagged signed changes in maturity-matched treasury rates. The results are similar and omitted.

minus bid, normalized by midpoint) using panel data methods:

$$\Delta sp_{it} = \begin{cases} \delta^{+}(sp^{*}_{it} - sp_{it-1}), & \text{if } sp^{*}_{it} \geq sp_{it-1}, \\ \delta^{-}(sp^{*}_{it} - sp_{it-1}), & \text{if } sp^{*}_{it} < sp_{it-1}. \end{cases} \tag{7}$$

The term in parentheses in (7) captures the deviation from equilibrium, ϵ. The parameters δ^{-}, δ^{+} measure the adjustment speed since $\delta^{-} = \lim_{\epsilon \uparrow 0} \frac{\partial}{\partial \epsilon} \Delta sp$ and $\delta^{+} = \lim_{\epsilon \downarrow 0} \frac{\partial}{\partial \epsilon} \Delta sp$. We assume $sp^{*}_{it} = \beta x_{it} + \alpha_i + \varepsilon_{it}$, where x_{it} are observable characteristics of bond i and market environment on date t, α_i is a bond-specific random effect, and the residual ε_{it} is normally distributed. Appendix A contains the details on how we have constructed the maximum likelihood estimator of (7).

Table 14 reports maximum likelihood estimates for the parameters in (7). The results suggest that spreads and half-spreads adjust immediately (at the daily frequency) when they are too narrow, and sluggishly when they are too wide. The third and fourth rows from the bottom of the table report tests of whether the adjustment coefficients are equal to one. The adjustment coefficients δ^{+}, which measure speed of adjustment when spreads are below the latent "equilibrium" value, are economically close to unity, and have relatively small t-statistics associated with the deviation from unity for the bid-ask spread and the bid-side half spread. The adjustment coefficient when the spreads are larger than the latent value are in every case smaller, significantly so in both economic and statistical terms.

5.3 Asymmetric Yield Spread Dynamics

Next we provide evidence regarding how quickly spreads between municipal and treasury yields adjust to changes in fundamentals. Let $s_{it} = \ln(y^{T}_{it}) - \ln(y^{M}_{it})$ denote the log-yield spread between the municipal bond i, evaluated at the midpoint for day t, and a maturity matched treasury.[3] The model we estimate is:

$$\Delta s_{it} = \begin{cases} \delta^{+}(s^{*}_{it} - s_{it-1}), & \text{if } s^{*}_{it} \geq s_{it-1}, \\ \delta^{-}(s^{*}_{it} - s_{it-1}), & \text{if } s^{*}_{it} < s_{it-1}. \end{cases} \tag{8}$$

Again, the latent equilibrium value is modeled as $s^{*}_{it} = \beta x_{it} + \alpha_i + \varepsilon_{it}$, where x_{it} are observable controls, α_i is a bond-specific random effect, and ε_{it} is normally distributed.

[3] We have also estimated the models reported in this section using the spread $y^{T}_{it} - y^{M}_{it}$, and the results are virtually unchanged.

Note that when $s^*_{it} > s_{it-1}$, the previous day's spread was "too low" relative to the current predicted value. Alternatively, the treasury yield is "too low" relative to the municipal yield. Municipal yields should fall relative to treasury yields, or municipal prices should rise. Therefore, we interpret δ^+ as measuring the speed of adjustment when prices are rising, and δ^- as the speed of adjustment when prices are falling. Table 15 and Table 16 report the results, stratified by year and bond rating, respectively. Assuming treasury yields adjust quickly and appropriately to new information, it is evident that municipal yields adjust sluggishly. The partial adjustment coefficients are generally significantly different from one. In every case, the partial adjustment coefficient in rising markets, δ^+, is larger than that for falling markets, δ^-. Prices rise faster than they fall in the municipal bond market. The asymmetry does not tend to diminish in any obvious way over time, and is evident for all ratings categories.

5.4 Variation in Competitive Conditions Across States

We interpret the finding that prices rise faster than they fall as evidence of local market power for the broker-dealers who intermediate trades. Greater confidence can be placed in this interpretation if we can find exogenous variables we have reason to believe would be associated with local market power for dealers, and show the measured asymmetry in speed of adjustment varies in the expected direction with these variables.

The state tax treatment of municipal bond interest is a natural place to look for such variation. Most states exempt interest from state income tax only for municipal bonds issued within that state. Investors in such states therefore have a preference for in-state bonds, and trade in a segmented market. There are 37 such states, which we refer to as "segmented states." Investors in states with no state income tax, and in states taxing both in-state and out-of-state bonds, participate in a national market, as do investors in bonds issued in U.S. territories, which are exempt from state taxes due to federal law. Other factors equal, we would expect less competition between dealers in markets for bonds issued in segmented states.

To test this hypothesis, we allow the coefficients δ^+ and δ^- in the partial adjustment model (8) to depend on whether the state is segmented, and on other variables we would expect to be associated with local market power for broker-dealers. The model we estimate is

$$\Delta s_{it} = \begin{cases} \delta^+(z_{it})(s^*_{it} - s_{it-1}), & \text{if } s^*_{it} \geq s_{it-1}, \\ \delta^-(z_{it})(s^*_{it} - s_{it-1}), & \text{if } s^*_{it} < s_{it-1}, \end{cases} \tag{9}$$

where the speed of adjustment parameters (δ^+, δ^-) are log-linear functions of the explanatory variables z^j_{it}, $j = 1, \ldots, J$:

$$\begin{aligned} \delta^+(z_{it}) &= \delta^+_0 \prod_{j=1}^J e^{\delta^+_j z^j_{it}}, \\ \delta^-(z_{it}) &= \delta^-_0 \prod_{j=1}^J e^{\delta^-_j z^j_{it}}. \end{aligned} \tag{10}$$

As before, we model the latent value for the yield spread as $s^*_{it} = \beta x_{it} + \alpha_i + \varepsilon_{it}$, where x_{it} are observable characteristics of bond i at time t, α_i is a bond-specific random effect, and residual ε_{it} is normally distributed.

The explanatory variables z_{it} for bond i at time t include a dummy for issuance in a segmented state, the state's income tax rate interacted with the segmentation dummy, a measure of underwriter concentration, the size of the state's municipal market, and the amount of retail volume. Segmented states are AL, AR, AZ, CA, CO, CT, DE, GA, HI, ID, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NY, OH, OR, PA, RI, SC, TN, VA, VT, WV. The measure of underwriter concentration is the Gini coefficient for the state of issuance, computed using SDC Platinum's data on the lead underwriter for each issue to calculate the underwriter's market share of new issues in the state since January of 2000. The local market size is measured by the state's new issues over the sample period, as a fraction of the total new volume of new issues. The extent of retail participation in secondary market trading is measured by the average trade size across all bonds issued in the corresponding state. The explanatory variables x_{it} include the variables z_{it} and all order flow variables and bond characteristics included in the basic specification.[4]

Recall that δ^+ measures the speed of adjustment when municipal yields must fall, relative to treasuries, so that municipal prices must rise, while δ^- measures the adjustment speed when municipal prices fall relative to treasuries. The first row of Table 17 shows that tax segmentation for the state has no effect on the adjustment speed when prices are rising (column 1), but reduces the

[4]We also estimated the partial adjustment model in (8) state by state, and ran a t-test of the hypothesis that the difference between δ^+ and δ^- was larger for the segmented states as a group. This produced findings similar to those reported in the first row of Table 17.

adjustment speed when prices are falling (column 2). Tax segmentation thus increases the difference between δ^+ and δ^- (column 3). The adjustment speed is more asymmetric in tax-segmented states, consistent with the postulate that tax segmentation offers dealers greater opportunity to exercise local market power. Prices rise faster than they fall *more* in states where investors cannot shop in a national market.

While state of issuance is arguably exogenous, the state's decisions to tax income for state residents, or to exempt in-state bonds, are not. The segmented states include the most populous states with the highest tax rates, with the most high-net-worth residents, and with the largest bond issues that attract high levels of retail participation. The remaining rows of Table 17 attempt to control for these factors. The asymmetry between the speed with which prices rise and fall decreases with the state income tax, for states that do not tax municipal bond interest. The asymmetry is also reduced in states with a larger municipal market. By these measures, big, high-tax states with more sophisticated, high-net-worth investors, such as California, New York, and Pennsylvania, appear to have more competitive and efficient municipal-bond markets. The speed of adjustment in rising markets increases, while that for falling markets decreases, in states where underwriting business is more concentrated across dealers. This is consistent with our interpretation of the asymmetric speed with which prices rise and fall as evidence of local market power for intermediaries. All of these effects are significant at the 99% level. The amount of retail participation slightly lowers the speed of adjustment in both directions, and so does not affect the asymmetry with a high level of statistical significance. Overall, the results in Table 17 show that the asymmetric speed of adjustment is associated in the data with variables we would expect to be related to the local market power broker-dealers exercise.

6 Conclusion

Intermediaries in over-the-counter markets facilitate price discovery as market makers, and earn profits by trading with customers. Past research has shown the terms of trade are onerous for many participants in the municipal bond market. Our paper has studied whether these high costs of trade are associated with inefficient price discovery.

We have shown that prices in the municipal market react in a sluggish manner to macroeconomic news and interest rate changes. They also react asymmetrically, rising faster than they fall. This is reflected in the behavior of bid-ask spreads and half-spreads, and thus inefficient price discovery and the costs of trading for customers are interrelated.

A Derivation of Panel Estimator of Asymmetric and Sluggish Response

Denote by y_{it} the realization of the dependent variable at time t for bond i, and let its equilibrium value be y^*_{it}. The variable y_{it} can be the bid-ask spread or the yield spread of municipals over treasuries. Let x_{it} be observable characteristics of bond i at time t. The observed sample is (x_{it}, y_{it}) for bond $i = 1, ..., N$ and date $t = 1, ..., T$.

The adjustment of y_{it} towards its new equilibrium value can be expressed as follows:

$$\Delta y_{it} = f(y^*_{it} - y_{it-1}; x_{it}), \tag{11}$$

where $f : \mathbb{R} \to \mathbb{R}$ is a monotonic function with $f(0) = 0$, $f'(\epsilon) > 0$ for $\epsilon \in \mathbb{R}$. Denote the inverse by $g = f^{-1} : \mathbb{R} \to \mathbb{R}$. The model (11) allows the speed of adjustment to depend on the endogenous deviation from equilibrium and on exogenous determinants through their effects on the functional form of f. Assume $y^*_{it} = \beta x_{it} + \alpha_i + \varepsilon_{it}$ where α_i is a bond-specific unobserved effect and $\varepsilon_{it} = y^*_{it} - E(y^*_{it}|x_{it}, \alpha_i)$ is the residual. We can now rewrite (11) in the form of a nonlinear panel regression model. For $i = 1, ..., N$ and $t = 2, ..., T$,

$$g(\Delta y_{it}) + y_{it-1} = \beta x_{it} + \alpha_i + \varepsilon_{it}. \tag{12}$$

We now make a standard random effects assumption. Assume that like in Ahn and Thomas (2004) the random vector $(y_{i1}, \alpha_i, (\varepsilon_{it})_{t=2,...,T})' \in \mathbb{R}^{T+1}$ exhibits a Gaussian distribution:

$$\begin{pmatrix} y_{i1} \\ \alpha_i \\ (\varepsilon_{it})'_{t=2,...,T} \end{pmatrix} = \mathcal{N}\left[\begin{pmatrix} m \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma^2_y & \sigma_{y\alpha} & 0 \\ \sigma_{y\alpha} & \sigma^2_\alpha & 0 \\ 0 & 0 & \Sigma_{it} \end{pmatrix}\right]. \tag{13}$$

Introduce the parameters $\gamma_0 = \frac{-\sigma_{y\alpha}}{\sigma^2_y} m$ and $\gamma_1 = \frac{\sigma_{y\alpha}}{\sigma^2_y} - 1$. First-differencing (12) yields a system of equations with autocorrelated error $\Delta\varepsilon_{it}$:

$$\begin{aligned} &g(\Delta y_{it}) - g(\Delta y_{it-1}) + \Delta y_{it-1} = \beta \Delta x_{it} + \Delta\varepsilon_{it}, \quad \text{for } t = 3, ..., T, \\ &g(\Delta y_{it}) - \gamma_1 y_{it-1} = \gamma_0 + \beta x_{it} + u_i, \qquad\qquad \text{for } t = 2, \end{aligned} \tag{14}$$

where the error term $u_i = \alpha_i + \varepsilon_{i2} - E(\alpha_i + \varepsilon_{i2}|y_{i1})$, with $E(\alpha_i + \varepsilon_{i2}|y_{i1}) = \gamma_0 + (1+\gamma_1)y_{i1}$, has zero mean and variance equal to $\sigma_{iu}^2 = \sigma_{i2}^2 + s_u^2$ with

$$s_u^2 = \sigma_\alpha^2 - \frac{\sigma_{y\alpha}^2}{\sigma_y^2}. \tag{15}$$

Under the random-effects assumption (13), the error distribution $\mathbf{f}$ of (14) is jointly Gaussian. Let $\mu_{it} = E(\Delta\varepsilon_{it}|\Delta\varepsilon_{it-1}, ..., \Delta\varepsilon_{i3}, u_i)$ and $s_{it}^2 = V(\Delta\varepsilon_{it}|\Delta\varepsilon_{it-1}, ..., \Delta\varepsilon_{i3}, u_i)$ be the conditional mean and variance of the error given past observations. The properties of the normal distribution yield the following recursive structure: $\mu_{i3} = \frac{-\sigma_{i2}^2}{\sigma_{iu}^2} u_i$, $s_{i3}^2 = \sigma_{i3}^2 + \sigma_{i2}^2 - \frac{(\sigma_{i2}^2)^2}{\sigma_{iu}^2}$, and for $t = 4, ..., T$,

$$\mu_{it} = \frac{-\sigma_{it-1}^2}{s_{it-1}^2}(\Delta\varepsilon_{it-1} - \mu_{it-1}), \qquad s_{it}^2 = \sigma_{it}^2 + \sigma_{it-1}^2 - \frac{(\sigma_{it-1}^2)^2}{s_{it-1}^2}. \tag{16}$$

The initial observation y_{i1} is uncorrelated with the error vector $(u_i, \Delta\varepsilon_i')'$. The likelihood conditional on y_{i1} becomes

$$\begin{aligned} \mathcal{L}(y_{iT}, ..., y_{i2}|y_{i1}) &= \mathcal{L}(g(\Delta y_{i2})|y_{i1}) \left| \frac{\partial g(\Delta y_{i2})}{\partial \Delta y_{i2}} \right| \\ &\quad \times \prod_{t=3}^{T} \mathcal{L}(g(\Delta y_{it})|\Delta y_{it-1}, ..., \Delta y_{i2}, y_{i1}) \left| \frac{\partial g(\Delta y_{it})}{\partial \Delta y_{it}} \right|. \end{aligned}$$

Under the random-effects assumption, we can now easily derive the log-likelihood of $(y_{i2}, ..., y_{iT})'$:

$$\begin{aligned} \ln \mathcal{L}(y_{iT}, ..., y_{i2}|y_{i1}) &= \ln \mathbf{f}(u_i|y_{i1}) + \sum_{t=3}^{T} \ln \mathbf{f}(\Delta\varepsilon_{it}|\Delta\varepsilon_{it-1}, ..., \Delta\varepsilon_{i3}, u_i, y_{i1}) + \sum_{t=2}^{T} \ln \left| \frac{\partial g(\Delta y_{it})}{\partial \Delta y_{it}} \right| \\ &= -(T-1)\ln\sqrt{2\pi} - \ln \sigma_{iu} - \frac{1}{2}\frac{(u_i)^2}{\sigma_{iu}^2} \\ &\quad + \sum_{t=3}^{T} \left(-\ln s_{it} - \frac{1}{2}\frac{(\Delta\varepsilon_{it} - \mu_{it})^2}{s_{it}^2} \right) + \sum_{t=2}^{T} \ln \left| \frac{\partial g(\Delta y_{it})}{\partial \Delta y_{it}} \right|. \end{aligned} \tag{17}$$

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Table 1: Definitions of the Explanatory Variables.

Table 1 describes the conditioning variables. More detailed information on the various types of municipal bond securities can be found at http://www.msrb.org.

Variable	Description
Order Size Ask	Average par size of all transactions constituting sales to customers.
Order Size Bid	Average par size of all transactions constituting purchases from customers.
Volume	Total par size of all transactions constituting sales to customers or purchases from customers on a given day or over the last 90 days, respectively.
Order Imbalance	Total par size of all transactions constituting purchases from customers net of all transactions constituting sales to customers on a given day.
Dealer Inventory	Total par size of all transactions constituting purchases from customers net of all transactions constituting sales to customers over the last 90 days.
Rating	Median bond rating assigned by S&P, Moody's, and Fitch. Coded on the scale: $1 = AAA$, $2 = AA^{+}$,. . . .
Rating Available	Bond issue is rated and the rating at issuance is available to us.
Insured Bond	Bond is backed by bond insurance, guarantee, letter of credit, or line of credit.
Callable Bond	Issuer is permitted or required to redeem the bond between the transaction date and maturity.
Taxable Bond	Bond is not tax exempt.
Zero Coupon Bond	Bond carries no coupon.
Coupon	Coupon rate of the bond.
Duration	Modified duration of the bond on the transaction day.
Maturity	Years between date of transaction and maturity of the bond.
Revenue Bond	Bond is backed by revenues.
Certificate of Participation	Revenue bond evidencing a pro rata share in a specific pledged revenue stream, usually lease payments by the issuer that are subject to annual appropriation.
Tax Revenue Bond	Bond backed directly by tax revenues from a specific source.
Industrial Development Bond	Capital flows from bond issuance are used for industrial development.
Housing Bond	Capital flows from bond issuance are used for single-, multi-family, or student housing constructions.
Health Care Bond	Issuer is a health care provider.
Utility Bond	Issuer is a public utility.
Facilities Bond	Capital flows from bond issuance are used for facilities construction.
Tobacco Settlement Bond	Tobacco settlement asset-backed bonds.
School District Issuer	Issuer is a school district.
Financial Authority Issuer	Issuer is a financial authority.
Development Authority Issuer	Issuer is a development authority or agency.
State	U.S. state in which the bond is issued.

Table 2: Summary Statistics for MSRB Volume.

Volume measures are reported for sales to customers, purchases from customers, and interdealer trades.

Type of Trade	Total No. Trades (mil)	Daily No. Trades (thou.)	Total Par Value (tril.)	Daily Par Value (bil.)
Sales to Customers	21.36	13.22	10.18	6.31
Purchases from Customers	10.60	6.56	8.51	5.27
Interdealer Trades	8.90	5.51	2.54	1.57

Table 3: Macroeconomic News Events.

	Number of Events
Advance Retail Sales (ARSales)	85
Capacity Utilization (CU)	70
Change in Nonfarm Payrolls (NONFARM)	84
Consumer Price Index (CPI)	13
GDP Annualized (GDP)	82
Industrial Production (IP)	85
Producer Price Index (PPI)	24
U. of Michigan Confidence (UMICH)	166
Unemployment Rate (UNEMP)	86
FOMC Rates Decision (FOMC)	49

Table 4: Volume response to news events.

The table reports estimates of the volume response to macroeconomic news. For columns 1-3 in the body of the table, the dependent variable is the total par value of daily customer buys, interdealer trades, and customer sales. For columns 4-6, the dependent variable is the daily number of trades of each type. Independent variables are defined in Table 3. Indicator variables for the day of the week are included but not reported. 'UNEMP bad news' and 'NONFARM bad news' are dropped due to collinearity. Disturbance terms follow an AR(1). t-stats are in parenthesis.

	Volume			Number of Trades		
	Customer Buys	Inter-Dealer	Customer Sales	Customer Buys	Inter-Dealer	Customer Sales
IP bad news	-0.125	-0.098	-0.147	-0.013	-0.057	-0.034
	(-0.34)	(-0.16)	(-0.36)	(-0.07)	(-0.10)	(-0.13)
IP neutral news	-0.075	-0.087	-0.067	-0.011	-0.046	0.018
	(-0.16)	(-0.11)	(-0.13)	(-0.04)	(-0.06)	(0.05)
IP good news	-0.114	-0.160	-0.143	-0.054	-0.110	-0.071
	(-0.32)	(-0.30)	(-0.38)	(-0.35)	(-0.20)	(-0.25)
CU bad news	0.134	0.129	0.173	0.009	0.068	0.040
	(0.36)	(0.20)	(0.41)	(0.05)	(0.11)	(0.15)
CU neutral news	0.058	-0.033	0.184	0.040	0.097	0.041
	(0.08)	(-0.04)	(0.26)	(0.11)	(0.08)	(0.09)
CU good news	0.176	0.209	0.214	0.071	0.123	0.077
	(0.47)	(0.37)	(0.50)	(0.44)	(0.22)	(0.25)
GDP bad news	0.013	0.046	0.002	0.035	0.049	0.035
	(0.11)	(0.32)	(0.01)	(0.61)	(0.39)	(0.48)
GDP neutral news	0.125	0.111	0.091	0.054	0.115	0.088
	(0.44)	(0.41)	(0.27)	(0.79)	(0.52)	(0.70)
GDP good news	-0.021	-0.001	-0.036	0.008	-0.007	0.002
	(-0.13)	(-0.01)	(-0.18)	(0.15)	(-0.05)	(0.03)
UNEMP neutral news	-0.001	-0.102	-0.015	-0.021	-0.014	-
	(-0.01)	(-0.51)	(-0.08)	(-0.36)	(-0.09)	-
UNEMP good news	0.108	0.055	0.111	0.039	0.065	0.047
	(0.81)	(0.32)	(0.76)	(0.65)	(0.46)	(0.69)
NONFARM neutral news	0.109	0.392*	0.143	0.071	0.147	0.055
	(0.73)	(2.23)	(0.91)	(1.40)	(1.04)	(1.07)
NONFARM good news	0.175	0.373**	0.162	0.094	0.165	0.082
	(1.57)	(2.65)	(1.27)	(1.65)	(1.40)	(0.99)
CPI bad news	0.009	-0.031	-0.215	0.028	0.043	0.024
	(0.01)	(-0.04)	(-0.57)	(0.13)	(0.05)	(0.09)
CPI neutral news	0.022	0.151	0.077	0.069	0.030	0.008
	(0.09)	(0.40)	(0.22)	(0.71)	(0.12)	(0.06)
CPI good news	0.019	0.207	0.075	0.031	0.126	0.079
	(0.02)	(0.20)	(0.12)	(0.10)	(0.14)	(0.20)
PPI bad news	0.035	0.036	0.023	0.007	-0.022	-0.016
	(0.26)	(0.19)	(0.14)	(0.08)	(-0.14)	(-0.15)
PPI neutral news	-0.054	-0.044	-0.229	-0.028	-0.085	-0.076
	(-0.03)	(-0.02)	(-0.19)	(-0.06)	(-0.06)	(-0.15)
PPI good news	-0.265	-0.182	-0.318	-0.117	-0.212	-0.168
	(-0.93)	(-0.35)	(-0.76)	(-0.89)	(-0.68)	(-1.10)
ARSales bad news	-0.014	-0.011	-0.019	0.008	0.006	0.026
	(-0.14)	(-0.06)	(-0.17)	(0.11)	(0.04)	(0.24)
ARSales neutral news	0.371***	0.575***	0.364***	0.143***	0.347***	0.196***
	(5.13)	(5.57)	(3.75)	(4.48)	(4.33)	(4.44)
ARSales good news	0.074	0.055	0.121	0.002	0.027	0.032
	(0.75)	(0.40)	(1.01)	(0.04)	(0.24)	(0.44)
UMICH bad news	0.124	0.173*	0.085	0.095***	0.086	0.063
	(1.47)	(2.10)	(0.87)	(3.85)	(1.25)	(1.58)
UMICH neutral news	0.160	-0.019	0.002	0.038	0.079	-0.071
	(0.16)	(-0.01)	(0.00)	(0.04)	(0.05)	(-0.07)
UMICH good news	0.124*	0.192*	0.100	0.081***	0.125*	0.084*
	(2.13)	(2.52)	(1.41)	(3.69)	(2.19)	(2.51)
FOMC bad news	0.093	-0.339	0.060	0.014	-0.108	-0.058
	(0.01)	(-0.28)	(0.01)	(0.00)	(-0.01)	(-0.04)
FOMC neutral news	0.023	-0.001	-0.020	-0.005	0.005	-0.016
	(0.23)	(-0.01)	(-0.17)	(-0.10)	(0.04)	(-0.22)
FOMC good news	0.037	-0.063	0.048	0.067	-0.066	-0.127
	(0.02)	(-0.03)	(0.04)	(0.03)	(-0.02)	(-0.10)
Constant	8.412***	6.774***	8.271***	9.387***	8.382***	8.711***
	(208.84)	(112.84)	(185.85)	(547.84)	(233.44)	(447.08)
Auxiliary Parameters:						
$AR(1)$	0.468***	0.533***	0.427***	0.546***	0.425***	0.459***
	(38.40)	(48.36)	(34.07)	(74.01)	(41.94)	(50.53)
σ	0.439***	0.638***	0.501***	0.212***	0.456***	0.265***
	(128.58)	(138.08)	(122.28)	(188.25)	(161.81)	(200.03)
Observations	1,615	1,615	1,615	1,615	1,615	1,615

Table 5: Volume response to macro news.

The table reports estimates of the volume response to macroeconomic news events categorized as `good` (at least one good news item on the day), `bad` (at least one bad news item) and `neutral` (news item released meeting expectations). Lagged news indicators are included. Disturbance terms follow an AR(1). t-stats are in parenthesis.

	Volume			Number of Trades		
	Customer Buys	Inter-Dealer	Customer Sales	Customer Buys	Inter-Dealer	Customer Sales
Good News_t	0.051	0.064	0.035	0.018	0.029	0.010
	(0.90)	(0.80)	(0.53)	(0.76)	(0.51)	(0.30)
Good News_{t-1}	-0.057	-0.153*	-0.109*	-0.053*	-0.115*	-0.085**
	(-1.15)	(-2.20)	(-2.00)	(-2.46)	(-2.48)	(-3.00)
Good News_{t-2}	-0.001	-0.076	-0.037	-0.015	-0.038	-0.036
	(-0.02)	(-1.07)	(-0.68)	(-0.66)	(-0.78)	(-1.22)
Good News_{t-3}	0.033	0.046	0.026	0.030	0.042	0.019
	(0.53)	(0.52)	(0.36)	(1.06)	(0.62)	(0.49)
Good News_{t-4}	0.001	-0.023	0.008	0.002	-0.003	-0.003
	(0.02)	(-0.33)	(0.12)	(0.08)	(-0.05)	(-0.09)
Bad News_t	0.034	0.092	0.041	0.038	0.049	0.034
	(0.56)	(1.24)	(0.60)	(1.68)	(0.85)	(1.04)
Bad News_{t-1}	-0.058	-0.087	-0.042	-0.030	-0.060	-0.035
	(-1.32)	(-1.40)	(-0.87)	(-1.48)	(-1.38)	(-1.36)
Bad News_{t-2}	0.010	0.019	-0.010	-0.000	0.023	-0.001
	(0.21)	(0.28)	(-0.18)	(-0.01)	(0.45)	(-0.02)
Bad News_{t-3}	-0.040	-0.002	-0.004	-0.006	0.008	0.003
	(-0.76)	(-0.03)	(-0.08)	(-0.22)	(0.14)	(0.08)
Bad News_{t-4}	-0.027	-0.013	0.000	0.003	0.004	0.011
	(-0.51)	(-0.19)	(0.00)	(0.12)	(0.07)	(0.36)
Neutral News_t	0.032	0.042	0.020	0.011	0.035	0.021
	(0.50)	(0.45)	(0.24)	(0.45)	(0.50)	(0.57)
Neutral News_{t-1}	-0.042	-0.050	-0.048	-0.002	-0.030	0.009
	(-0.78)	(-0.64)	(-0.79)	(-0.09)	(-0.55)	(0.28)
Neutral News_{t-2}	0.053	0.068	0.075	0.005	0.038	0.032
	(0.81)	(0.76)	(0.99)	(0.17)	(0.54)	(0.81)
Neutral News_{t-3}	0.075	0.056	0.064	0.034	0.063	0.049
	(0.91)	(0.56)	(0.67)	(1.04)	(0.84)	(1.16)
Neutral News_{t-4}	-0.029	-0.003	-0.033	0.011	-0.005	0.016
	(-0.56)	(-0.03)	(-0.58)	(0.41)	(-0.09)	(0.50)
Tuesday	0.225***	0.433***	0.171***	0.140***	0.214***	0.117***
	(5.37)	(7.09)	(3.40)	(7.11)	(4.57)	(4.60)
Wednesday	0.379***	0.494***	0.331***	0.128***	0.198***	0.088**
	(6.80)	(7.26)	(5.08)	(6.24)	(3.90)	(3.04)
Thursday	0.316***	0.434***	0.258***	0.078***	0.143*	0.033
	(5.42)	(5.74)	(3.85)	(3.42)	(2.41)	(1.00)
Friday	-0.010	-0.052	-0.170***	-0.158***	-0.210***	-0.266***
	(-0.29)	(-1.15)	(-4.30)	(-11.53)	(-6.03)	(-13.79)
Constant	8.466***	6.884***	8.341***	9.420***	8.456***	8.757***
	(153.71)	(84.01)	(140.62)	(382.49)	(160.14)	(302.43)
Auxiliary Parameters:						
$AR(1)$	0.467***	0.526***	0.425***	0.541***	0.420***	0.455***
	(36.87)	(45.29)	(33.15)	(68.55)	(39.60)	(48.19)
σ	0.440***	0.640***	0.501***	0.213***	0.455***	0.265***
	(117.28)	(122.37)	(116.44)	(148.39)	(136.56)	(155.51)
Observations	1,611	1,611	1,611	1,611	1,611	1,611

Table 6: Granger Causality test for yields of all maturity.

The body of the table reports p-values for Granger tests of causality between municipal yield indices and treasuries of matched maturity. The first row compare the Bond Buyer 40 yield to call to the 10 year treasury rate. The remaining rows consider Lehman Brothers indicative yields to treasuries of comparable maturity.

Maturity	P-value	Trsy Causes Muni	P-value	Muni Causes Trsy
BBI vs. 10Y Treasury Note	0.001	TRUE	0.459	FALSE
3M	0.000	TRUE	0.006	TRUE
6M	0.000	TRUE	0.840	FALSE
1Y	0.000	TRUE	0.175	FALSE
2Y	0.000	TRUE	0.960	FALSE
3Y	0.000	TRUE	0.930	FALSE
5Y	0.000	TRUE	0.719	FALSE
7Y	0.000	TRUE	0.830	FALSE
10Y	0.000	TRUE	0.646	FALSE
20Y	0.000	TRUE	0.256	FALSE

Table 7: Dependence of Price and Volume Changes on Lagged Price Changes.

Each column reports the coefficient estimates, with standard errors in parentheses, from a regression of the variable heading the column against positive and negative changes in the Bond Buyer 40 Index lagged one day. Errors are allowed to follow an AR(1).

	Price Change in Muni Index	Volume Change			
		Par Value Traded	Customer Buys	Customer Sales	Interdealer Trades
β^+	0.24	-33.81	-29.43	-31.64	-68.79
	(0.06)	(7.05)	(6.79)	(7.36)	(10.33)
β^-	0.36	15.63	14.08	15.92	24.18
	(0.05)	(8.18)	(7.77)	(8.47)	(11.81)
Constant	0.00	0.05	0.04	0.05	0.09
	(0.00)	(0.02)	(0.02)	(0.02)	(0.02)
Auxiliary Parameters:					
$AR(1)$	-0.09	-0.37	-0.36	-0.39	-0.33
	(0.04)	(0.01)	(0.01)	(0.01)	(0.01)
σ	0.00	0.54	0.51	0.59	0.75
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
P-value for $\beta^+ = \beta^-$	0.05	0.00	0.00	0.00	0.00
Observations	1,613	1,613	1,613	1,613	1,613

Table 8: Effect of Macro News on Yield Spreads.

The table documents the effect of macro announcements on municipal bond yields and spreads between municipal bonds and treasuries. The yield spread is the difference between the maturity-matched treasury rate and the midpoint yield on the muni bond. The yield log-spread is the natural logarithm of the ratio of the corresponding yields. Yields and yield spreads are measured in basis points. The explanatory variables capturing the effect of macro news are the standardized surprise component in the macro announcement, computed as in Balduzzi, Elton, Green (2001). The standardized surprise in the announcement is the actual value minus the consensus forecast divided by their standard deviation across all observations. Additional explanatory variables are omitted from the table. They include macro announcement dummies that equal one if there is an announcement of the corresponding item on the given day and zero otherwise. The estimation results are from a panel regression with bond-specific random effects and first-order autocorrelated errors.

	Yield Spread		Yield Log-Spread		Δ Muni Yield		Δ Treasury Yield	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Macro Surprise:								
Advance Retail Sales	0.00	(-0.01)	0.03	(1.60)	0.14	(2.15)	1.87	(74.30)
Capacity Utilization	5.23	(39.49)	1.25	(36.62)	0.13	(1.14)	1.61	(36.84)
Nonfarm Payrolls	1.76	(19.50)	0.49	(21.03)	0.68	(9.34)	4.38	(156.25)
CPI	1.93	(14.26)	0.64	(18.33)	0.25	(2.20)	1.39	(31.72)
GDP	1.22	(14.31)	0.33	(14.90)	0.20	(2.89)	1.11	(41.17)
Industrial Production	-2.12	(-15.87)	-0.52	(-15.11)	-0.14	(-1.20)	-1.14	(-26.26)
PPI	-2.12	(-17.40)	-0.70	(-22.26)	-0.12	(-1.23)	-0.98	(-25.81)
Consumer Confidence	0.41	(6.30)	0.10	(5.62)	0.07	(1.37)	0.24	(11.86)
Jobless Rate	0.37	(4.16)	0.12	(5.38)	-0.11	(-1.57)	0.37	(13.43)
FOMC Rate Decision	4.30	(35.81)	1.29	(41.51)	0.16	(1.59)	0.04	(0.95)
Order Flow, Bond Issue & Issuer Characteristics:								
1/Order Size Ask_t	-0.04	(-73.51)	-0.01	(-86.03)	-0.04	(-96.69)	-	-
1/Order Size Bid_t	-0.13	(-267.37)	-0.03	(-225.58)	0.06	(144.40)	-	-
No Ask $Trades_t$	-9.36	(-191.89)	-2.36	(-187.22)	2.07	(43.21)	-	-
No Bid $Trades_t$	3.02	(66.34)	1.02	(87.05)	-2.12	(-50.79)	-	-
Rating	-5.06	(-69.74)	-1.08	(-68.10)	-0.03	(-1.99)	-	-
Rating Available	15.72	(73.28)	4.41	(93.14)	0.43	(7.42)	-	-
Insured Bond	13.02	(79.20)	2.57	(70.54)	0.17	(3.15)	-	-
Callable Bond	-45.42	(-249.81)	-9.53	(-235.58)	-1.01	(-17.54)	-	-
Taxable Bond	-93.40	(-138.58)	-18.98	(-127.00)	-0.07	(-0.32)	-	-
Zero Coupon Bond	-238.76	(-415.47)	-50.14	(-393.41)	-10.66	(-59.47)	-	-
Coupon	-40.37	(-468.35)	-8.33	(-435.97)	-0.92	(-32.62)	-	-
Duration	1.12	(25.04)	0.17	(16.54)	1.19	(65.05)	-	-
Maturity	3.06	(118.34)	0.60	(102.16)	-0.13	(-14.03)	0.00	(-3.74)
Revenue Bond	-12.61	(-67.81)	-2.86	(-69.43)	-0.78	(-14.08)	-	-
Certificate of Participation	-11.53	(-25.53)	-2.54	(-25.28)	-1.06	(-6.90)	-	-
Tax Revenue Bond	1.03	(2.56)	0.36	(4.08)	0.26	(2.18)	-	-
Industrial Development Bond	-40.03	(-55.38)	-7.10	(-44.58)	-1.10	(-5.38)	-	-
Housing Bond	-23.43	(-81.50)	-4.79	(-74.95)	-1.53	(-15.08)	-	-
Health Care Bond	-18.69	(-43.20)	-3.91	(-40.84)	-1.51	(-12.90)	-	-
Utility Bond	3.44	(12.93)	0.76	(12.97)	-0.28	(-3.47)	-	-
Facilities Bond	-1.73	(-5.58)	-0.37	(-5.31)	0.12	(1.34)	-	-
Tobacco Settlement Bond	-60.95	(-19.23)	-12.82	(-18.36)	-0.60	(-1.24)	-	-
School District Issuer	-0.09	(-0.41)	0.10	(2.03)	0.22	(2.65)	-	-
Financial Authority Issuer	-12.30	(-25.00)	-2.61	(-23.91)	-0.27	(-1.72)	-	-
Development Authority Issuer	-12.22	(-26.07)	-2.35	(-22.63)	-0.20	(-1.43)	-	-
State:								
California	-5.14	(-20.84)	-0.66	(-12.15)	-0.48	(-6.67)	-	-
New York	6.42	(22.16)	1.37	(21.30)	0.30	(3.37)	-	-
Florida	-5.53	(-15.97)	-1.20	(-15.64)	-0.83	(-8.59)	-	-
Texas	-4.24	(-13.72)	-1.14	(-16.59)	-0.66	(-6.55)	-	-
Pennsylvania	-9.20	(-25.51)	-1.87	(-23.34)	-0.23	(-2.01)	-	-
Constant	199.68	(424.23)	42.47	(405.75)	-6.90	(-41.71)	-0.28	(-22.51)
Auxiliary Parameters:								
$AR(1)$	0.67		0.57		-0.30		-0.08	
σ_u	42.72		9.23		3.73		0.00	
σ_e	33.71		9.09		13.12		5.28	
Observations	5,182,763		5,182,763		814,733		814,733	
Bonds	388,083		388,064		165,883		165,883	
R^2	0.30		0.29		0.11		0.05	

Table 9: Effects of Good and Bad Macroeconomic News on Yield Spreads.

The table documents the effect of macro announcements on municipal bond yields and spreads between municipal bonds and treasuries. The yield spread is the difference between the maturity-matched treasury rate and the midpoint yield on the muni bond. The yield log-spread is the natural logarithm of the ratio of the corresponding yields. Yields and yield spreads are measured in basis points. The explanatory variables capturing the effect of macro news are the standardized surprise component in the macro announcement. We compute the standardized surprise, as in Balduzzi, Elton, Green (2001), as the actual value minus the consensus forecast divided by their standard deviation across all observations. Positive macro surprise variables equal the standardized surprise if its value is larger than zero, and zero otherwise. Negative macro surprise variables equal the standardized surprise if its value is less than zero, and zero otherwise. Additional control variables are omitted from the table. They include macro announcement dummies that equal one if there is an announcement of the corresponding item on the given day and zero otherwise. The estimation results are from a panel regression with bond-specific random effects and first-order autocorrelated errors.

	Yield Spread		Yield Log-Spread		Δ Muni Yield		Δ Treasury Yield	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Positive Macro Surprise:								
Advance Retail Sales	-0.05	(-0.51)	0.06	(2.23)	0.09	(1.07)	1.98	(59.89)
Capacity Utilization	17.99	(66.76)	4.62	(66.36)	0.03	(0.15)	0.91	(10.52)
Nonfarm Payrolls	-2.48	(-11.03)	-0.67	(-11.55)	1.32	(7.16)	7.40	(105.19)
CPI	-2.13	(-9.99)	-0.49	(-8.86)	0.22	(1.20)	1.02	(14.77)
GDP	3.94	(25.52)	1.05	(26.20)	0.24	(1.93)	2.25	(46.51)
Industrial Production	-9.84	(-37.39)	-2.52	(-37.21)	-0.58	(-2.61)	-0.76	(-9.01)
PPI	-9.75	(-47.46)	-2.52	(-47.55)	-0.30	(-1.79)	-2.52	(-39.31)
Consumer Confidence	-0.14	(-1.03)	-0.11	(-3.06)	0.02	(0.21)	0.65	(14.98)
Jobless Rate	1.58	(8.59)	0.42	(8.76)	-0.08	(-0.51)	0.93	(16.45)
FOMC Rate Decision	3.56	(20.64)	1.03	(23.23)	0.27	(1.87)	0.08	(1.53)
Negative Macro Surprise:								
Advance Retail Sales	0.55	(2.61)	0.05	(0.85)	0.28	(1.61)	1.73	(25.74)
Capacity Utilization	-1.89	(-10.12)	-0.62	(-12.94)	0.25	(1.57)	2.06	(33.56)
Nonfarm Payrolls	3.64	(27.24)	1.02	(29.29)	0.38	(3.58)	2.92	(71.49)
CPI	5.19	(18.29)	1.60	(21.69)	0.46	(1.98)	2.18	(24.29)
GDP	-1.08	(-7.79)	-0.28	(-7.89)	0.17	(1.45)	0.14	(3.19)
Industrial Production	-0.63	(-3.24)	-0.16	(-3.10)	0.25	(1.45)	-1.31	(-20.08)
PPI	8.38	(34.62)	1.82	(29.17)	0.11	(0.56)	0.87	(11.72)
Consumer Confidence	1.54	(13.94)	0.41	(14.31)	0.14	(1.54)	0.06	(1.87)
Jobless Rate	0.07	(0.47)	0.07	(1.94)	-0.21	(-1.85)	-0.40	(-9.20)
FOMC Rate Decision	5.03	(29.64)	1.54	(35.03)	0.05	(0.38)	-0.01	(-0.18)
Order Flow, Bond Issue & Issuer Characteristics:								
1/Order Size Ask_t	-0.04	(-73.28)	-0.01	(-85.75)	-0.04	(-96.55)	-	-
1/Order Size Bid_t	-0.13	(-267.40)	-0.03	(-225.70)	0.06	(144.39)	-	-
No Ask Trades_t	-9.35	(-191.54)	-2.35	(-186.96)	2.08	(43.28)	-	-
No Bid Trades_t	3.01	(66.23)	1.02	(86.86)	-2.12	(-50.82)	-	-
Rating	-5.03	(-69.32)	-1.07	(-67.30)	-0.03	(-1.95)	-	-
Rating Available	15.58	(72.57)	4.38	(92.33)	0.42	(7.25)	-	-
Insured Bond	12.66	(77.79)	2.53	(70.11)	0.15	(2.76)	-	-
Callable Bond	-45.79	(-252.16)	-9.61	(-237.87)	-1.05	(-18.22)	-	-
Taxable Bond	-93.73	(-138.91)	-19.03	(-127.20)	-0.13	(-0.58)	-	-
Zero Coupon Bond	-240.38	(-419.32)	-50.46	(-396.95)	-10.78	(-60.33)	-	-
Coupon	-40.42	(-468.75)	-8.34	(-436.38)	-0.93	(-33.08)	-	-
Duration	1.14	(25.36)	0.17	(17.00)	1.19	(65.08)	-	-
Maturity	3.05	(117.80)	0.60	(101.59)	-0.13	(-14.23)	0.00	(-4.34)
Revenue Bond	-12.87	(-69.72)	-2.92	(-71.30)	-0.80	(-14.69)	-	-
Certificate of Participation	-13.50	(-30.46)	-2.81	(-28.48)	-1.25	(-8.24)	-	-
Tax Revenue Bond	-0.37	(-0.94)	0.16	(1.86)	0.15	(1.23)	-	-
Industrial Development Bond	-39.90	(-55.20)	-7.08	(-44.47)	-1.08	(-5.27)	-	-
Housing Bond	-23.29	(-81.38)	-4.77	(-75.06)	-1.49	(-14.78)	-	-
Health Care Bond	-19.32	(-44.82)	-4.08	(-42.77)	-1.52	(-13.13)	-	-
Utility Bond	2.37	(8.96)	0.53	(9.02)	-0.39	(-4.92)	-	-
Facilities Bond	-0.94	(-3.03)	-0.17	(-2.42)	0.18	(1.96)	-	-
Tobacco Settlement Bond	-58.18	(-18.34)	-12.20	(-17.45)	-0.46	(-0.96)	-	-
School District Issuer	-0.98	(-4.40)	-0.08	(-1.67)	0.13	(1.62)	-	-
Financial Authority Issuer	-11.95	(-24.28)	-2.56	(-23.48)	-0.23	(-1.46)	-	-
Development Authority Issuer	-11.66	(-24.89)	-2.26	(-21.78)	-0.08	(-0.59)	-	-
Constant	199.54	(425.64)	42.44	(407.20)	-6.91	(-42.07)	-0.27	(-21.55)
Auxiliary Parameters:								
$AR(1)$	0.67		0.57		-0.30		-0.08	
σ_u	42.81		9.25		3.74		0.00	
σ_e	33.76		9.10		13.12		5.26	
Observations	5,182,763		5,182,763		814,733		814,733	
Bonds	388,083		388,064		165,883		165,883	
R^2	0.30		0.29		0.11		0.05	

Table 10: LAGGED EFFECTS OF MACROECONOMIC NEWS ON YIELD SPREADS.

The table documents the effect of macro announcements on municipal bond yields and spreads between municipal bonds and treasuries. The yield spread is the difference between the maturity-matched treasury rate and the midpoint yield on the muni bond. The yield log-spread is the natural logarithm of the ratio of the corresponding yields. Yields and yield spreads are measured in basis points. The explanatory variables capturing the effect of macro news are the standardized surprise component in the macro announcement. We compute the standardized surprise, as in Balduzzi, Elton, Green (2001), as the actual value minus the consensus forecast divided by the standard deviation across all observations, since units of measurement differ across economic variables. Positive macro news are defined as the standardized surprise in a macro indicator if it tends to increase treasury rates, or as minus the standardized surprise if it tends to decrease treasury rates. Negative macro news are defined accordingly. We determine whether macro indicators tend to increase or decrease treasury rates based on the sign of the coefficient on the surprise in a panel regression explaining treasury rate changes. The FOMC rate change is defined as actual minus prior rate, expressed in per cent. Additional explanatory variables are omitted from the table. They include indicator variables for the issuer type variables in Table 1 and macro announcement dummies that equal one if there is an announcement of the corresponding item on the given day and zero otherwise. The estimation results are from a panel regression with bond-specific random effects and first-order autocorrelated errors.

	Yield Spread		Yield Log-Spread		Δ Muni Yield	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Positive Macro News:						
t	2.27	(44.52)	0.61	(46.58)	0.17	(4.16)
$t-1$	2.65	(50.59)	0.70	(52.40)	0.15	(3.30)
$t-2$	1.88	(37.46)	0.50	(39.43)	0.10	(2.23)
$t-3$	1.15	(23.30)	0.35	(28.07)	0.06	(1.45)
Negative Macro News:						
t	1.76	(34.69)	0.44	(33.85)	0.33	(7.88)
$t-1$	1.62	(30.85)	0.39	(29.03)	0.35	(7.76)
$t-2$	1.67	(33.83)	0.42	(33.78)	0.22	(5.12)
$t-3$	1.43	(29.00)	0.34	(26.55)	0.11	(2.68)
Positive FOMC Rate Changes:						
t	26.21	(41.71)	7.36	(45.70)	1.07	(2.04)
$t-1$	27.16	(41.16)	7.25	(43.08)	1.40	(2.63)
$t-2$	27.39	(40.47)	7.02	(40.70)	0.77	(1.39)
$t-3$	20.93	(28.81)	5.80	(31.05)	0.55	(0.92)
Negative FOMC Rate Changes:						
t	0.01	(0.02)	-0.35	(-2.82)	0.27	(0.66)
$t-1$	3.75	(7.55)	0.22	(1.76)	-0.32	(-0.79)
$t-2$	3.58	(6.76)	0.08	(0.57)	0.10	(0.24)
$t-3$	0.12	(0.21)	-0.91	(-6.24)	0.78	(1.61)
Order Flow, Bond Issue & Issuer Characteristics:						
1/Order Size Ask$_t$	-0.04	(-73.32)	-0.01	(-85.86)	-0.04	(-96.54)
1/Order Size Bid$_t$	-0.13	(-267.79)	-0.03	(-226.01)	0.06	(144.36)
No Ask Trades$_t$	-9.34	(-191.64)	-2.35	(-186.99)	2.08	(43.35)
No Bid Trades$_t$	3.00	(66.13)	1.02	(86.84)	-2.12	(-50.75)
Rating ($1 = AAA$, $2 = AA^+$,...)	-5.03	(-69.21)	-1.07	(-67.22)	-0.03	(-1.95)
Rating Available	15.23	(70.93)	4.30	(90.69)	0.41	(7.13)
Insured Bond	12.66	(77.76)	2.53	(70.14)	0.15	(2.83)
Callable Bond	-46.21	(-254.35)	-9.70	(-240.05)	-1.05	(-18.21)
Taxable Bond	-93.70	(-138.86)	-19.03	(-127.20)	-0.13	(-0.60)
Zero Coupon Bond	-240.66	(-419.77)	-50.51	(-397.43)	-10.77	(-60.23)
Coupon	-40.41	(-468.67)	-8.34	(-436.38)	-0.92	(-32.94)
Duration	1.18	(26.24)	0.18	(17.65)	1.19	(65.12)
Maturity	3.09	(119.23)	0.61	(103.15)	-0.13	(-14.22)
Auxiliary Parameters:						
AR(1)	0.68		0.57		-0.30	
σ_u	42.81		9.25		3.74	
σ_e	33.68		9.08		13.12	
Observations	5,182,763		5,182,763		814,733	
Bonds	388,083		388,064		165,883	
R^2	0.30		0.29		0.11	

Table 11: DETERMINANTS OF PRICE STICKINESS.

The table documents the determinants of sticky municipal bond prices. The dependent variable equals one if the midpoint price for a given municipal bond remains unchanged between date $t-1$ and t. It equals zero otherwise. The estimation results are from logit regressions with state-specific fixed effects (Specification (1)) and with bond-specific fixed effects (Specification (2)), respectively. The reported coefficients are elasticities, representing the relative change in the probability of price stickiness due to a one percent change in the value of the explanatory variable.

	(1)		(2)	
	Elasticity	t-Stat	Elasticity	t-Stat
Time Trend	-18.72	(-19.10)	-35.83	(-3.12)
Interest Rate Movements:				
$+(\Delta y_t^T)^+$	-3.16	(-10.58)	-2.25	(-5.04)
$+(\Delta y_{t-1}^T)^+$	-3.46	(-11.57)	-2.11	(-4.91)
$+(\Delta y_{t-2}^T)^+$	-0.96	(-3.39)	-0.38	(-1.45)
$-(\Delta y_t^T)^-$	-2.62	(-7.74)	-1.87	(-4.36)
$-(\Delta y_{t-1}^T)^-$	-3.44	(-10.22)	-2.57	(-5.02)
$-(\Delta y_{t-2}^T)^-$	0.01	(0.03)	0.24	(0.84)
Order Flow:				
Dealer Inventory$_{t-1}$	-1.03	(-5.60)	-1.13	(-5.70)
(Order Imbalance$_{t-1}$)$^+$	-7.27	(-28.75)	-4.64	(-6.09)
(Order Imbalance$_{t-1}$)$^-$	-0.38	(-2.62)	-0.01	(-0.03)
Volume$_{t-1}$	5.73	(23.41)	-1.63	(-3.63)
Volume$_{t-90,t-1}$	3.02	(9.76)	3.36	(4.33)
No Trades$_{t-1}$	-6.82	(-34.71)	-3.42	(-6.26)
No Trades$_{t-90,t-1}$	0.17	(3.83)	-0.01	(-0.39)
Order Size Ask$_t$	0.89	(12.79)	0.35	(4.63)
Order Size Bid$_t$	-0.07	(-1.24)	-0.45	(-4.34)
Bond Issue & Issuer Characteristics:				
Rating	0.95	(2.39)	-	-
Rating Available	-18.97	(-23.59)	-	-
Insured Bond	-9.10	(-14.60)	-	-
Callable Bond	5.77	(9.46)	-	-
Taxable Bond	0.62	(12.46)	-	-
Zero Coupon Bond	-9.60	(-47.91)	-	-
Coupon	-182.27	(-56.16)	-	-
Maturity	-26.35	(-23.79)	-7.27	(-0.23)
Revenue Bond	-2.16	(-4.57)	-	-
Certificate of Participation	0.47	(8.05)	-	-
Tax Revenue Bond	0.07	(0.70)	-	-
Industrial Development Bond	0.45	(6.72)	-	-
Housing Bond	0.95	(10.09)	-	-
Health Care Bond	0.20	(1.28)	-	-
Utility Bond	-0.57	(-3.21)	-	-
Facilities Bond	-0.27	(-1.41)	-	-
Tobacco Settlement Bond	-1.01	(-11.40)	-	-
School District Issuer	0.89	(7.25)	-	-
Financial Authority Issuer	0.29	(4.10)	-	-
Development Authority Issuer	0.23	(2.40)	-	-
Observations	811,879		454,661	
Log-likelihood	-180,346		-81,422	

Table 12: Percentage Markups in Rising and Falling Markets.

The table documents percentage markups on round-trip transactions in rising and falling markets. The sample is split into four categories depending on the time between two legs of the round-trip (ΔT) and the par size of the order. The variables $(r_t^{idx})^-$ and $(r_t^{idx})^+$ are the returns in the underlying index (computed as log changes), when that return is negative and positive, respectively. Control variables are the number of days between the legs of the transaction, ΔT, the log par value of the trade, *Order Size*, and an indicator, D^{mRound}, for whether the markup is rounded (to at least 1/8th of a dollar). t-stats are in parenthesis.

Markup (%)	$\Delta T \leq 5$, $Par < 100K$	$\Delta T \leq 5$, $Par \geq 100K$	$\Delta T > 5$, $Par < 100K$	$\Delta T > 5$, $Par \geq 100K$
$(r_t^{idx})^+$	0.088	0.080	0.174	0.321
	(12.01)	(3.89)	(24.21)	(16.54)
$(r_t^{idx})^-$	0.017	0.146	0.316	0.483
	(2.50)	(7.24)	(49.27)	(30.15)
D^{mRound}	0.002	0.001	0.001	0.003
	(36.58)	(4.66)	(11.75)	(6.87)
Order Size	-0.005	-0.003	-0.006	-0.004
	(-254.31)	(-89.14)	(-141.43)	(-49.75)
ΔT	0.000	0.000	-0.000	-0.000
	(16.87)	(1.55)	(-15.04)	(-1.83)
Constant	0.039	0.031	0.044	0.032
	(540.78)	(125.68)	(263.42)	(63.75)
P-value for $\beta^+ = \beta^-$	0.000	0.000	0.041	0.000
R^2	0.079	0.107	0.103	0.165
Observations	812,332	66,997	225,971	22,098

Table 13: The Effect on Spreads of Movements in Fundamentals.

The table documents the asymmetric effect of movements in a municipal bond's common value on bid-ask spreads and half-spreads. The explanatory variables $(\Delta v_{it})^+$ and $(\Delta v_{it})^-$ are the positive and negative components, respectively, of the change in the midpoint bond price, expressed in per cent. Additional explanatory variables are omitted from the table. They include indicators for the US state of issuance and indicator variables for the issuer type variables in Table 1. The estimation results are from a panel regression with bond-specific random effects and first-order autocorrelated errors. The estimation sample is the panel of all transactions in the municipal bond market between May 2000 and October 2006, aggregated at daily frequency. Small trades are less than \$50K in par value, medium are between \$50K and \$250K, and large trades exceed \$250K. t-stats are in parenthesis. P-values for the hypothesis $\beta^+ = -\beta^-$ are less than 0.001 for each column.

	Bid-Ask Spread			Half-Spread (Ask-Mid)			Half-Spread (Mid-Bid)		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
$(\Delta v_{it})^+$	4.25	9.22	8.03	-2.16	-1.16	-0.25	7.94	7.97	8.72
	(10.39)	(11.44)	(11.67)	(-16.35)	(-4.23)	(-0.87)	(37.30)	(25.54)	(29.05)
$(\Delta v_{it})^-$	-31.86	-27.46	-15.89	-28.48	-43.26	-35.14	-5.23	-3.58	-5.02
	(-73.45)	(-23.70)	(-15.93)	(-149.04)	(-106.43)	(-82.65)	(-25.88)	(-8.09)	(-11.65)
Order Flow, Bond Issue & Issuer Characteristics:									
No Trades$_{t-90,t-1}$	23.84	1.43	-14.12	3.98	-20.13	-26.69	12.55	2.81	-3.41
	(4.86)	(0.28)	(-3.82)	(2.00)	(-8.62)	(-11.83)	(6.64)	(1.41)	(-2.08)
Volume$_{t-90,t-1}$	0.34	0.23	-0.31	0.44	0.23	-0.06	-0.01	-0.12	-0.45
	(14.02)	(6.36)	(-10.93)	(51.28)	(21.47)	(-5.17)	(-0.70)	(-8.70)	(-37.27)
Rating	3.91	3.87	1.70	2.52	2.36	1.70	1.96	2.41	1.68
	(15.73)	(12.94)	(6.03)	(28.89)	(24.27)	(15.52)	(18.03)	(25.12)	(17.42)
Rating Available	-18.00	-1.36	-0.36	-8.77	-1.81	0.15	-7.47	-4.64	-1.93
	(-12.48)	(-0.74)	(-0.22)	(-23.30)	(-3.82)	(0.30)	(-11.27)	(-6.56)	(-2.88)
Insured Bond	-9.76	1.66	7.69	-6.43	1.65	3.33	-6.05	0.13	1.44
	(-7.64)	(1.01)	(5.12)	(-18.26)	(3.70)	(6.90)	(-10.14)	(0.20)	(2.45)
Callable Bond	56.51	50.78	49.14	23.02	22.88	23.22	25.09	27.90	24.62
	(42.96)	(28.79)	(30.74)	(61.43)	(47.58)	(44.66)	(41.06)	(43.12)	(39.21)
Taxable Bond	22.59	22.53	-10.86	8.12	12.34	-3.02	-2.88	0.72	-3.58
	(4.31)	(3.70)	(-1.99)	(5.56)	(6.44)	(-1.46)	(-1.22)	(0.35)	(-1.69)
Zero Coupon Bond	127.06	113.43	62.93	22.38	30.96	22.22	91.55	61.68	52.99
	(27.44)	(19.20)	(11.18)	(19.48)	(19.67)	(12.73)	(43.26)	(27.53)	(24.25)
Coupon	-2.24	-4.51	-3.74	-5.07	-6.10	-6.26	4.73	-0.77	-0.08
	(-3.10)	(-4.81)	(-4.42)	(-26.83)	(-23.69)	(-22.60)	(14.65)	(-2.14)	(-0.23)
Duration	-8.51	-2.68	1.03	1.43	2.53	2.56	-2.86	-0.07	0.10
	(-21.99)	(-5.50)	(2.38)	(12.59)	(17.93)	(16.42)	(-16.02)	(-0.42)	(0.59)
Maturity	10.76	6.42	3.52	3.83	2.93	2.61	4.28	2.56	1.95
	(58.75)	(26.28)	(16.48)	(65.81)	(41.12)	(33.23)	(50.35)	(31.28)	(24.25)
Auxiliary Parameters:									
$AR(1)$	0.11	0.16	0.21	0.24	0.18	0.18	0.05	0.09	0.12
σ_u	48.85	28.70	41.15	22.42	12.00	16.62	21.15	0.00	5.99
σ_e	124.70	110.14	97.59	69.49	72.57	73.29	76.85	69.20	64.11
Observations	193,361	36,594	44,662	521,197	203,392	190,763	252,542	84,458	85,728
Bonds	33,082	15,820	18,141	117,292	69,218	66,483	42,781	26,120	27,463
R^2	0.22	0.36	0.25	0.31	0.37	0.30	0.15	0.23	0.20

Table 14: Bid-Ask Spread Dynamics.

The table reports parameter estimates for an asymmetric- and partial-adjustment model of spreads. Let sp_{it} be the effective spread in bond i at time t, and denote by sp^*_{it} the unobserved equilibrium value. The specification we estimate is the following:

$$\Delta sp_{it} = \begin{cases} \delta^+(sp^*_{it} - sp_{it-1}), & \text{if } sp^*_{it} \geq sp_{it-1}, \\ \delta^-(sp^*_{it} - sp_{it-1}), & \text{if } sp^*_{it} < sp_{it-1}. \end{cases}$$

This specification allows for asymmetric partial adjustment. The parameters δ^-, δ^+ measure the adjustment speed since $\delta^- = \lim_{\epsilon\uparrow 0} f'(\epsilon)$ and $\delta^+ = \lim_{\epsilon\downarrow 0} f'(\epsilon)$. Further, we assume $sp^*_{it} = \beta x_{it} + \alpha_i + \varepsilon_{it}$, where x_{it} are observable characteristics of bond i at time t, α_i is a bond-specific random effect, and residual ε_{it} is normally distributed. The estimation sample is the panel of all transactions in the municipal bond market between May 2000 and October 2006, aggregated at daily frequency.

	Bid-Ask Spread		Half-Spread (Ask-Mid)		Half-Spread (Mid-Bid)	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Structural Parameters:						
δ^+	0.99	(198.16)	0.93	(305.38)	0.99	(237.68)
δ^-	0.92	(202.81)	0.87	(309.62)	0.90	(244.78)
Explanatory Variables β:						
Dealer Inventory$_{t-1}$	1.10	(5.20)	1.12	(18.89)	-0.46	(-4.78)
Volume$_{t-90,t-1}$	-0.01	(-2.99)	0.01	(9.11)	-0.01	(-16.30)
1/Order Size Ask$_t$	-0.00	(-2.02)	0.00	(10.51)	0.01	(33.64)
1/Order Size Bid$_t$	0.05	(80.37)	0.02	(57.35)	0.03	(85.81)
Rating ($1 = AAA$, $2 = AA^+$,...)	0.46	(33.18)	0.23	(39.45)	0.25	(42.32)
Rating Available	-1.02	(-11.10)	-0.44	(-13.74)	-0.47	(-11.19)
Insured Bond	0.67	(8.65)	0.04	(1.45)	-0.03	(-0.85)
Callable Bond	4.06	(48.63)	1.97	(62.34)	1.98	(51.73)
Taxable Bond	-1.14	(-3.66)	-0.19	(-1.56)	-0.65	(-4.49)
Zero Coupon Bond	4.99	(15.36)	1.01	(9.36)	5.18	(35.50)
Coupon	-0.48	(-9.23)	-0.47	(-25.90)	0.20	(8.79)
Duration	-0.03	(-1.06)	0.24	(25.04)	0.06	(5.17)
Maturity	0.38	(33.21)	0.14	(31.60)	0.17	(31.78)
Auxiliary Parameters:						
σ	9.93	(145.81)	6.11	(234.01)	6.41	(182.34)
s_u	6.25	(136.99)	3.72	(219.48)	2.66	(86.95)
γ_1	-0.63	(-189.87)	-0.65	(-290.76)	-0.79	(-254.28)
γ_0	3.78	(11.48)	3.16	(30.62)	-0.11	(-0.79)
t-Stat for $\delta^+ = 1$	2.61		24.17		3.19	
t-Stat for $\delta^- = 1$	16.78		46.91		26.58	
Observations	187,928		449,796		264,877	
Log-likelihood	-717,316		-1,465,738		-872,105	

Table 15: YIELD SPREADS DYNAMICS: STRATIFIED BY YEAR.

The table reports parameter estimates for the asymmetric and partial adjustment model. Let s_{it} be the yield log-spread of the maturity-matched treasury rate s_{it}^T over the yield s_{it}^M on muni bond i at time t, and denote by s_{it}^* the unobserved equilibrium value. The specification we estimate is the following:

$$\Delta s_{it} = \begin{cases} \delta^+(s_{it}^* - s_{it-1}), & \text{if } s_{it}^* \geq s_{it-1}, \\ \delta^-(s_{it}^* - s_{it-1}), & \text{if } s_{it}^* < s_{it-1}. \end{cases}$$

This specification allows for asymmetric partial adjustment. The parameters δ^-, δ^+ measure the adjustment speed since $\delta^- = \lim_{\epsilon\uparrow 0} f'(\epsilon)$ and $\delta^+ = \lim_{\epsilon\downarrow 0} f'(\epsilon)$. Further, we assume $s_{it}^* = \beta x_{it} + \alpha_i + \varepsilon_{it}$, where x_{it} are observable characteristics of bond i at time t, α_i is a bond-specific random effect, and residual ε_{it} is normally distributed. The estimation sample is the panel of all transactions in the municipal bond market between May 2000 and October 2006, aggregated at daily frequency.

	2000		2001		2002		2003		2004		2005		2006	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Structural Parameters:														
δ^+	0.95	(137.16)	0.84	(138.44)	0.94	(160.66)	0.83	(141.54)	0.95	(171.45)	0.90	(146.08)	0.89	(174.25)
δ^-	0.80	(125.12)	0.69	(129.07)	0.72	(148.13)	0.63	(131.62)	0.75	(155.41)	0.74	(130.37)	0.79	(148.16)
Explanatory Variables β:														
Dealer Inventory$_{t-1}$	2.54	(5.86)	4.93	(7.03)	8.76	(13.41)	16.33	(19.06)	9.73	(14.56)	8.86	(12.93)	7.58	(16.82)
Volume$_{t-90,t-1}$	-0.07	(-7.87)	-0.08	(-8.30)	-0.11	(-10.90)	-0.15	(-10.67)	-0.13	(-10.64)	-0.14	(-10.83)	-0.08	(-9.87)
1/Order Size Ask$_t$	0.07	(29.43)	0.07	(25.93)	0.08	(29.50)	0.09	(29.07)	0.09	(35.16)	0.09	(32.32)	0.06	(34.80)
1/Order Size Bid$_t$	-0.13	(-54.61)	-0.19	(-62.17)	-0.19	(-67.54)	-0.23	(-63.53)	-0.18	(-65.73)	-0.19	(-60.90)	-0.17	(-74.05)
Rating	-1.01	(-16.53)	-1.61	(-23.10)	-1.79	(-25.18)	-2.98	(-31.39)	-2.47	(-34.22)	-2.11	(-28.75)	-1.18	(-21.42)
Rating Available	3.76	(12.19)	8.71	(21.65)	7.12	(19.14)	12.33	(25.40)	6.72	(16.30)	4.72	(10.83)	2.84	(10.94)
Insured Bond	0.06	(0.24)	0.34	(1.00)	0.67	(2.04)	1.05	(2.41)	1.76	(4.82)	2.39	(6.64)	2.85	(12.05)
Callable Bond	-3.28	(-11.16)	-4.57	(-12.01)	-3.88	(-10.71)	-7.00	(-15.47)	-10.08	(-24.88)	-7.82	(-18.52)	-6.72	(-24.20)
Taxable Bond	-21.68	(-19.01)	-20.40	(-16.81)	-26.73	(-23.32)	-26.12	(-14.93)	-29.15	(-19.75)	-26.82	(-16.81)	-34.29	(-30.97)
Zero Coupon Bond	-22.96	(-18.10)	-33.42	(-21.58)	-16.75	(-12.06)	-36.41	(-21.16)	-44.88	(-32.25)	-33.88	(-25.81)	-34.11	(-39.62)
Coupon	-5.38	(-30.33)	-6.39	(-28.12)	-4.69	(-21.83)	-8.30	(-30.46)	-10.01	(-45.00)	-9.25	(-42.72)	-10.25	(-67.53)
Duration	-2.06	(-18.85)	-1.79	(-13.45)	-3.20	(-25.88)	-4.40	(-28.71)	-4.14	(-33.61)	-5.16	(-39.75)	-6.03	(-64.03)
Maturity	-0.23	(-4.88)	-0.19	(-3.15)	0.48	(8.41)	0.85	(12.09)	0.79	(13.52)	0.95	(15.14)	1.37	(29.17)
Auxiliary Parameters:														
σ	16.93	(99.34)	24.15	(105.86)	23.31	(120.81)	33.30	(109.28)	25.13	(127.34)	24.92	(106.38)	19.92	(120.59)
s_u	22.88	(142.76)	33.17	(144.59)	34.50	(164.56)	43.48	(146.53)	39.17	(172.72)	35.57	(148.44)	26.78	(175.37)
γ_1	-0.09	(-56.53)	-0.10	(-61.50)	-0.08	(-65.10)	-0.10	(-67.21)	-0.11	(-78.25)	-0.11	(-70.77)	-0.12	(-96.21)
γ_0	64.39	(48.45)	65.65	(43.65)	57.24	(41.95)	79.50	(47.29)	94.14	(70.21)	94.94	(68.76)	108.75	(105.51)
t-Stat for $\delta^+ = 1$	7.65		27.28		10.67		29.22		9.05		15.54		21.64	
t-Stat for $\delta^- = 1$	30.39		57.98		57.55		78.35		51.31		46.68		40.34	
Observations	84,067		106,073		118,588		126,393		129,692		105,775		138,440	
Log-likelihood	-381,123		-504,465		-573,868		-633,616		-646,175		-518,804		-648,414	

Table 16: Yield Spreads Dynamics: Stratified by Rating.

The table reports parameter estimates for the asymmetric and partial adjustment model. Let s_{it} be the yield log-spread of the maturity-matched treasury rate s_{it}^T over the yield s_{it}^M on muni bond i at time t, and denote by s_{it}^* the unobserved equilibrium value. The specification we estimate is the following:

$$\Delta s_{it} = \begin{cases} \delta^+(s_{it}^* - s_{it-1}), & \text{if } s_{it}^* \geq s_{it-1}, \\ \delta^-(s_{it}^* - s_{it-1}), & \text{if } s_{it}^* < s_{it-1}. \end{cases}$$

This specification allows for asymmetric partial adjustment. The parameters δ^-, δ^+ measure the adjustment speed since $\delta^- = \lim_{\epsilon \uparrow 0} f'(\epsilon)$ and $\delta^+ = \lim_{\epsilon \downarrow 0} f'(\epsilon)$. Further, we assume $s_{it}^* = \beta x_{it} + \alpha_i + \varepsilon_{it}$, where x_{it} are observable characteristics of bond i at time t, α_i is a bond-specific random effect, and residual ε_{it} is normally distributed. The estimation sample is the panel of all transactions in the municipal bond market between May 2000 and October 2006, aggregated at daily frequency.

	Unrated		Rating AAA		Rating AA		Rating A		Rating BBB-B		Rating CCC-D	
	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat	Coef.	t-Stat
Structural Parameters:												
δ^+	0.95	(201.21)	0.88	(296.02)	0.92	(116.54)	0.94	(98.59)	0.55	(75.35)	0.57	(26.87)
δ^-	0.68	(182.42)	0.76	(268.10)	0.86	(103.58)	0.86	(89.64)	0.49	(72.39)	0.54	(26.24)
Explanatory Variables β:												
Dealer Inventory$_{t-1}$	12.83	(30.15)	5.12	(15.93)	2.63	(2.97)	5.06	(4.40)	3.76	(2.17)	3.67	(0.90)
Volume$_{t-90,t-1}$	-0.17	(-14.11)	-0.06	(-13.60)	-0.06	(-3.97)	-0.11	(-6.79)	-0.13	(-7.08)	-0.10	(-2.29)
1/Order Size Ask$_t$	0.11	(52.23)	0.07	(56.33)	0.08	(19.86)	0.06	(15.21)	0.11	(19.34)	0.14	(8.18)
1/Order Size Bid$_t$	-0.24	(-93.72)	-0.15	(-122.29)	-0.24	(-48.43)	-0.19	(-41.13)	-0.22	(-35.26)	-0.27	(-15.08)
Insured Bond	3.47	(15.56)	1.31	(7.07)	1.65	(1.78)	-0.17	(-0.19)	4.76	(2.55)	0.11	(0.05)
Callable Bond	-6.05	(-24.23)	-7.55	(-41.22)	-7.19	(-12.56)	-5.28	(-8.32)	-8.78	(-8.97)	-7.40	(-1.89)
Taxable Bond	-19.64	(-19.73)	-31.26	(-52.22)	-39.50	(-12.37)	-27.30	(-9.32)	-14.20	(-4.75)	5.07	(0.20)
Zero Coupon Bond	-27.93	(-31.33)	-31.10	(-49.28)	-34.41	(-18.20)	-21.29	(-9.43)	-2.95	(-0.56)	-	-
Coupon	-9.01	(-63.22)	-7.30	(-73.33)	-9.32	(-30.04)	-4.52	(-13.57)	-2.08	(-3.93)	2.03	(1.72)
Duration	-5.83	(-61.09)	-4.11	(-69.72)	-6.49	(-33.35)	-3.49	(-15.80)	2.17	(7.37)	11.04	(9.68)
Maturity	1.30	(27.33)	0.75	(26.83)	1.57	(17.02)	0.69	(6.96)	-1.04	(-11.05)	-2.34	(-8.31)
Revenue Bond	-0.75	(-3.03)	-0.49	(-3.30)	-1.70	(-3.51)	-0.05	(-0.09)	-1.36	(-2.09)	-2.59	(-1.11)
Certificate of Participation	0.85	(1.28)	0.52	(1.20)	-4.80	(-1.80)	2.49	(1.04)	7.95	(2.57)	-	-
Tax Revenue Bond	1.50	(2.74)	1.81	(5.62)	1.82	(1.91)	0.90	(0.25)	10.64	(2.68)	-	-
Industrial Development Bond	-8.83	(-9.85)	-2.45	(-3.70)	-0.58	(-0.24)	-5.88	(-4.27)	-0.63	(-0.56)	3.50	(1.06)
Housing Bond	0.38	(0.88)	-0.17	(-0.47)	-4.27	(-5.30)	-0.30	(-0.22)	7.94	(4.54)	2.17	(0.27)
Health Care Bond	1.07	(2.06)	0.92	(3.07)	-0.85	(-0.97)	-3.07	(-3.46)	-2.52	(-2.36)	13.00	(2.62)
Utility Bond	3.01	(8.57)	1.17	(5.68)	2.17	(2.72)	4.02	(2.35)	4.95	(2.13)	-	-
Facilities Bond	0.13	(0.33)	-0.66	(-2.64)	-0.04	(-0.05)	-0.95	(-1.11)	1.18	(1.03)	-4.97	(-2.40)
Tobacco Settlement Bond	-27.59	(-3.69)	-4.85	(-0.94)	-20.68	(-0.99)	-5.38	(-1.24)	1.03	(1.00)	-	-
School District Issuer	-0.12	(-0.34)	0.24	(0.90)	0.59	(0.59)	2.56	(0.93)	28.90	(2.11)	-	-
Financial Authority Issuer	-2.10	(-3.14)	-0.97	(-2.07)	-0.25	(-0.18)	-2.76	(-1.65)	-2.54	(-1.61)	-14.01	(-0.75)
Development Authority Issuer	-1.95	(-3.31)	-1.12	(-2.72)	0.17	(0.10)	1.52	(1.54)	-2.77	(-2.32)	-1.59	(-0.67)
Auxiliary Parameters:												
σ	26.05	(143.75)	21.52	(218.92)	27.42	(81.23)	22.70	(71.60)	37.52	(63.34)	40.31	(21.83)
s_u	40.32	(207.98)	28.46	(304.33)	37.65	(120.27)	31.15	(101.65)	33.89	(78.57)	35.83	(32.76)
γ_1	-0.09	(-112.10)	-0.11	(-143.17)	-0.16	(-71.72)	-0.08	(-37.88)	-0.05	(-23.48)	-0.07	(-12.02)
γ_0	91.33	(99.71)	84.13	(126.44)	108.42	(56.49)	60.79	(28.53)	17.51	(5.11)	-81.78	(-6.22)
t-Stat for $\delta^+ = 1$	10.30		41.75		10.05		5.88		62.77		19.89	
t-Stat for $\delta^- = 1$	85.23		82.96		17.12		14.81		74.58		22.50	
Observations	255,159		397,698		64,750		38,901		45,982		6,640	
Log-likelihood	-1,283,420		-1,866,063		-327,838		-188,976		-211,421		-31,548	

Table 17: LONGITUDINAL DIFFERENCES IN SPEEDS OF ADJUSTMENT & ASYMMETRY.

The table reports parameter estimates for the asymmetric and partial adjustment model. Let s_{it} be the yield log-spread of the maturity-matched treasury rate s^T_{it} over the yield s^M_{it} on muni bond i at time t, and denote by s^*_{it} the unobserved equilibrium value. The specification we estimate is the following:

$$\Delta s_{it} = \begin{cases} \delta^+(z_{it})(s^*_{it} - s_{it-1}), & \text{if } s^*_{it} \geq s_{it-1}, \\ \delta^-(z_{it})(s^*_{it} - s_{it-1}), & \text{if } s^*_{it} < s_{it-1}, \end{cases}$$

where the speed of adjustment parameters (δ^+, δ^-) are log-linear functions of the explanatory variables z^j_{it}, $j = 1, \ldots, J$:

$$\delta^+(z_{it}) = \delta^+_0 \prod_{j=1}^J e^{\delta^+_j z^j_{it}},$$
$$\delta^-(z_{it}) = \delta^-_0 \prod_{j=1}^J e^{\delta^-_j z^j_{it}}.$$

Further, we assume $s^*_{it} = \beta x_{it} + \alpha_i + \varepsilon_{it}$, where x_{it} are observable characteristics of bond i at time t, α_i is a bond-specific random effect, and residual ε_{it} is normally distributed. The explanatory variables z_{it} of bond i at time t include a dummy for issuance in a segmented state, the state's income tax rate interacted with the segmentation dummy, the Gini coefficient of underwriter concentration in the state's primary market, the local market size proxied by the state's new issues over the sample period as a fraction of total new issuance volume, and the extent of retail participation in secondary market trading proxied by the average trade size across all bonds issued in the corresponding state. States classified as segmented are all states in which state tax is levied only on bonds issued out-of-state. Segmented states are AL, AR, AZ, CA, CO, CT, DE, GA, HI, ID, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NY, OH, OR, PA, RI, SC, TN, VA, VT, WV. Bonds of segmented states are traded mostly in the state of issuance due to local tax advantages. Non-segmented states include all states with no state tax, states in which state tax is levied on bonds issued in-state and out-of-state, and all US territories. Bonds of US territories are tax exempt for bondholders in every state due to federal laws designating the territories as "specialty states." Non-segmented states and territories are AK, DC, FL, GU, IA, IL, IN, NV, OK, PR, SD, TX, UT, VI, WA, WI. The explanatory variables x_{it} include the variables z_{it} and all order flow variables and bond characteristics included in the basic specification. The estimation sample is the panel of all transactions in the municipal bond market between May 2000 and October 2006, aggregated at daily frequency. In parentheses we report χ^2-statistics for Wald tests of $H_0 : \delta^+_j = 0$, $\delta^-_j = 0$, and $\delta^+_j = \delta^-_j$, respectively.

	δ^+_j	δ^-_j	$\delta^+_j - \delta^-_j$
	Coef. (χ^2-Stat)	Coef. (χ^2-Stat)	Coef. (χ^2-Stat)
Segmented state (0/1)	0.00	-0.06	0.06
	(0.01)	(93.98)	(48.65)
State tax rate (%) × Segmented state (0/1)	0.28	1.34	-1.06
	(15.09)	(222.46)	(73.20)
Primary market concentration (Gini)	0.15	-0.07	0.23
	(49.52)	(7.11)	(36.55)
Local market size (% of new issues)	-0.35	0.22	-0.56
	(120.19)	(30.41)	(106.38)
Retail participation (Avg sale size)	-0.02	-0.03	0.01
	(19.30)	(34.44)	(2.62)

Figure 1: Frequency Plots for Percentage Changes in 10-Year Treasury and Bond Buyer Municipal Index Yields.

The different panels plot the distribution of daily percentage changes in the 10-year treasury yield (dashed) and the Bond Buyer 40 yield index (solid) at increasingly long horizons. The muni yields are daily midpoints for each bond issue traded. The treasury rates are maturity-matched.

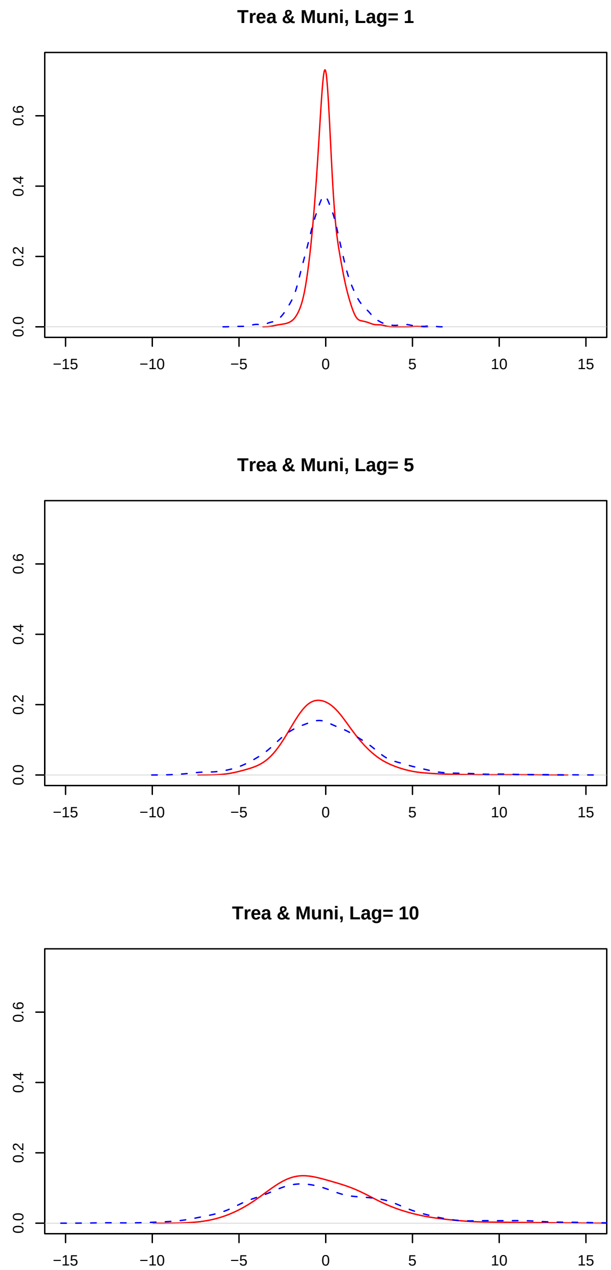

Figure 2: Distribution of Changes in Yields on Munis and Treasuries.

The different panels plot the distribution of daily percentage changes in yields on municipal bond transactions (solid) and the corresponding distribution of percentage changes in treasury rates (dashed) at increasingly long horizons. The muni yields are daily midpoints for each bond issue traded. The treasury rates are maturity-matched.