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ARTICLE

The municipal government channel of monetary policy

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Abstract

Monetary policy in the USA affects borrowing costs for state and local governments, incentivizing municipal borrowing and spending, which in turn affects economic outcomes. Using municipal bond indices and transaction-level data, I find that responses to monetary policy are dampened relative to treasuries and heterogeneous across location and bond characteristics. In my baseline estimate, muni yields move 26 bp after a 100 bp monetary shock. To study implications for local fiscal policy, I model US localities as small open economies in a monetary union with independent fiscal agents. In a calibrated model, monetary transmission is significantly affected by municipal borrowing costs.

Keywords: Monetary policy; state and local governments; municipal bonds; small open economies; fiscal policy

JEL Classification: E52; E62; E63; F41; F45; G12; H72; H74

1. Introduction

State and local government debt is a significant sector in the US economy, with important implications for monetary policy. In 2019, the market for state and local government (municipal) bonds was valued at $3.9 trillion, over 1/3 the size of the corporate bond market and greater than 3% of the valuation of the global bond market. Additionally, while most state and local governments in the USA have measures in place to prevent an excessive use of debt financing for expenditures, debt financing is nevertheless a key component of municipal public finance and has been increasing over time. State and local government debt outstanding is about 100% of state and local government total expenditures, and interest payments on municipal debt take up around 5% of annual general fund expenditures. Furthermore, rather than "leaning against" monetary expansions, state and local government spending tends to expand when interest rates fall,[1] suggesting the presence of a municipal public finance channel of monetary policy transmission, by which national *monetary* policy affects local *fiscal* policy.

This paper seeks to be the first to describe and illuminate this "Municipal Government Channel" of monetary policy. The channel works primarily through the borrowing costs of state and local governments. When monetary policy lowers interest rates on treasuries, yields on municipal bonds fall, lowering borrowing costs for state and local governments. Low borrowing costs incentivize debt-financed spending and tax cuts, providing extra economic stimulus in addition to the traditional channels. The strength of the channel depends on the incentives of the local government, the response of borrowing costs to monetary policy, and the stimulative effects of local fiscal policy.

I explore this novel channel through empirical results on monetary policy's effects on borrowing costs, a theoretical model with local governments, and quantitative exercises using the model. In the empirical section of the paper, I use time series and panel data to study the size and source of the response of municipal borrowing costs to monetary shocks, finding that municipal yields decrease (increase) by 26 bp in response to a 100 bp decrease (increase) in the 10-year treasury yield, though there is sizeable heterogeneity across US states, driven in part by liquidity and default risk factors. I then outline a framework for modeling US localities as small open New Keynesian economies in a monetary union, each with a representative household and fiscal authority. These local fiscal authorities choose debt and public goods spending on locally produced goods, subject to borrowing costs which are *imperfectly* and *heterogeneously* linked to the risk-free interest rate. The elasticities of these borrowing costs to changes in the risk-fee rate determine the effect of monetary policy on the local government's budget; the more the government's budget relaxes after a monetary expansion, the more it can engage in stimulative spending.[2] Finally, I calibrate the baseline model to reflect US localities, showing that realistic municipal borrowing cost elasticities result in a significant departure from a "risk-free rate" assumption, imply monetary transmission heterogeneity of up to 25% across states in a full model, potentially explaining one determinant of the heterogeneity identified in the data.

The paper begins by exploring the effects of monetary shocks on municipal bond yields, the key to passthrough of monetary policy to local public finance. First, I use time series evidence from the yields on a series of S&P municipal bond indices. Yields on indices of all general obligation (GO) bonds in the USA increase 26 bp in response to a 100 bp monetary shock, with no difference between state bonds or local bonds. This response represents a far lower elasticity than that of corporate bonds. Additionally, I find evidence of significant heterogeneity across states, which exhibit coefficients implying responses of 22 bp to 44 bp to the same shock. While default risk does explain responses of municipal bonds to monetary shocks, as high-risk indices respond more strongly, persistently low responses across the board imply a role for illiquidity in determining these responses. I also connect transaction-level bond data for a subset of the sample with annual government finance data, yielding evidence that smaller governments' borrowing costs respond more strongly to monetary shocks; this could be due to risk or liquidity factors.

To interpret the empirical results, I outline a model of state and local governments as small open economies in a monetary union, with local governments facing heterogeneous borrowing costs. Each locality is populated by two types of agents, intertemporal and hand-to-mouth, which work and consume to optimize the representative household's utility. Consumption is comprised of tradable and non-tradable goods; the non-tradable goods are produced locally by a New Keynesian production market, with Calvo-style price setting. The locality's representative government receives a stream of tax revenue and chooses debt issuance and public goods spending to maximize household utility, which also depends on public goods consumption on non-tradable goods. The municipal government does not borrow at the risk-free rate set by the monetary authority; rather, its idiosyncratic borrowing cost is determined on an external financial market and is imperfectly linked to the risk-free rate.

When the national monetary authority lowers the risk-free rate, borrowing costs for the local fiscal authority decrease, relaxing the government's budget constraint and incentivizing public spending. Because public spending occurs with non-tradable goods produced by a New Keynesian market, public spending is stimulative for both output and employment, amplifying the existing expansionary effects of a drop in interest rates. Consequently, the extent to which monetary policy passes through to municipal borrowing costs is of crucial importance for determining the size of this channel. Heterogeneity in municipal debt pricing as found in the empirical section could result in significant monetary transmission differences.

I calibrate the small open economy to represent average US localities and study the magnitude of the municipal government channel of monetary policy. Using the main response coefficient from the empirical section, I show that including the average passthrough of monetary shocks to municipal yields in the model dampens monetary transmission by over half, relative to a case in which one assumes the local fiscal authority has access to borrowing at the risk-free interest rate. One immediate conclusion is that the exact nature of municipal financial markets are crucial in any model of state and local governments over the business cycle.

Additionally, realistic heterogeneity over municipal debt pricing results in meaningful differences in monetary transmission. Increasing a locality's borrowing cost responses from the 10th percentile of empirical estimates to the 90th percentile of estimates results in up to a 25% increase in monetary transmission to output and employment. Furthermore, the dispersion of peak monetary transmission implied by the state-level empirical estimates can account for a nonzero portion of observed dispersion of monetary transmission across US localities, based on estimates from the literature. Data confirm a positive relationship between municipal yield movements and monetary transmission to the economy after a monetary shock. While localities in the USA differ on a multitude of dimensions affecting monetary transmission, the ability of monetary policy to influence their borrowing costs is a factor policymakers should consider.

Related Literature. This paper provides meaningful contributions to a number of important strands of economic literature. The baseline model is, in most ways, a canonical open economy New Keynesian model. In this vein, it adds to papers such as Galí and Monacelli (2008), Beetsma and Jensen (2005), Farhi and Werning (2017a, b), Nakamura and Steinsson (2014), and Chodorow-Reich (2019), which study monetary and fiscal policy in monetary unions, by highlighting that interest rates for the member governments of a monetary union may differ substantially in response to the same monetary policies. Similarly, in showing how monetary policy works *through* municipal fiscal policy, this paper merges the monetary union literature with the literature on monetary policy passthrough, exemplified by Bernanke et al. (1999), McKay et al. (2016), and Kaplan et al. (2018). More specifically, although focused on local governments, this paper contributes to a literature on international monetary transmission to small open economies, as in Auer et al. (2019) and Cesa-Bianchi et al. (2016). In contrast to papers which study optimal fiscal policy for a member of a monetary union, I study the government as an agent in the model, whose behavior in response to monetary policy is taken as part of the passthrough effect.

By analyzing a model of a locality in the USA, this paper enters in to the discussion on regional effects of monetary policy, and macroeconomic models with regions in general, as in Beraja et al. (2019a) and (2019b). Other papers, such as Seegert (2015), Cashin et al. (2018), and Fisher and Wassmer (2014), examine the responses of state and local governments to significant macro events; I use the model in this paper as a playground to study the behavior of state and local governments in the aftermath of the financial crisis. Clemens and Miran (2012) characterizes the cyclicality of subnational spending and computes some associated multipliers. Finally, the over-the-counter (OTC) markets version of the model in Appendix B builds on the work of Duffie et al. (2005), who model OTC markets for financial assets, and Bethune et al. (2019), who model the issuance side of OTC markets. I show in the paper how such a model can be connected to a DSGE macro model as a microfounded explanation for why borrowing costs may differ from the risk-free rate for local governments.

The results from the empirical section of this paper contribute to a number of strands of literature. First, and most obviously, this paper adds to recent work on the effect of US monetary policy on various asset prices. Rosa (2014) does this for municipal bonds; I expand on his work by including a host of indices and exploiting a trade-level panel dataset to investigate potential determinants of muni responses to monetary shocks. Haughwout et al. (2024) shows how the Federal Reserve's emergency actions in the municipal bond market in early 2021 assisted state and local public finances during the COVID-19 crisis. Gilchrist et al. (2019) studies the response of international sovereign yields to US monetary shocks; I perform similar exercises to their paper, but in the US municipal bond market. Anderson and Cesa-Bianchi (2020) study how firm leverage affects corporate bond responses to monetary shocks.

By shedding light on the relationship between municipal bond yields and US monetary policy, I also add to a robust literature on municipal bond pricing. Two important papers, Schwert (2017) and Ang et al. (2014), debate the relative importance of risk and liquidity in municipal bond spreads, with the former emphasizing risk and the latter liquidity. Another strand of papers

(Harris and Piwowar (2006), Green et al. (2007a, b), Garrett et al. (2018), Moldogaziev (2018), Brancaccio et al. (2020)) highlights explicit frictions in the secondary market for municipal bonds, such as information asymmetries and market power, that result in price dispersion over given bonds. A number of other papers explore determinants of municipal bond prices, from state laws on bankruptcy (Yang (2019)) to climate change (Painter (2020)). Other relevant municipal bond pricing papers include Gao et al. (2019), Grigoris (2019), Adelino, et al. (2017), and a host of others.

2. The effect of US monetary shocks on municipal bonds

State and local government debt is a significant component of public finances: over \$3 trillion in outstanding debt matches the size of current expenditures for these governments, and interest payments make up about 5% of municipal budgets. As a result, monetary policy might have a significant effect on local public finances and incentives of state and local governments. My baseline estimate of the response coefficient of municipal yields to monetary policy shocks is 0.26. Additionally, heterogeneity across municipalities in the responses of their borrowing costs to monetary shocks will imply heterogeneity in the transmission of monetary policy to households, as shocks will induce dispersion of borrowing costs. This section documents the average effects of monetary shocks on municipal borrowing costs, as well as the variance of such effects across state and local governments. I also investigate whether we can identify root causes of response heterogeneity, such as bond ratings and public finance, finding evidence for both possibilities.

I begin the section with a brief description of the municipal bond market, explaining the similarities and differences between munis and treasuries. Next, I present summary statistics from the muni market, highlight its behavior during the financial crisis, and discuss the monetary shock identification strategy. I also argue that municipal bond yields on the secondary market are valid representations of municipal borrowing costs; in short, secondary market yields both reflect primary market prices and affect municipal government behavior, in line with previous literature. After this, I move on to the main empirical exercises.

The first set of exercises investigate the time series evidence on the effect of monetary shocks on a set of muni indices; this section is in the spirit of Rosa (2014), who looks at munis, and Gilchrist et al. (2019), who study foreign bond responses to US interest rate shocks. I find that an index of GO municipal bonds responds to a 100 bp monetary shock by an average of 26 bp; furthermore, I find evidence of substantial heterogeneity by state, as responses vary from 22 bp to 44 bp across space, despite little difference between state and local bonds. High-risk indices respond more strongly to monetary shocks, as one might expect, but the coefficients remain persistently low, suggesting a role for illiquidity in dampening these coefficients.[3]

The second set of exercises exploits a trade-level dataset of the municipal bond market, in which certain factors can be explored further as possible drivers of monetary transmission (or lack thereof). I take a sample of munis from the largest state and local governments, for which I can match annual finance data from the Census of Governments, finding that correlates of government size tend to lower the response coefficient. My overall results suggest dampened (relative to, say, corporate bonds) but heterogeneous responses of municipal borrowing costs to US interest rate shocks, with which I can use a municipal open economy model introduced in Section 3 to evaluate the characteristics of monetary passthrough via state and local governments.

2.1 The municipal bond market

State and local governments in the USA rely heavily on debt markets to finance a wide range of activities, from covering budget shortfalls to infrastructure investment. When a government decides to raise funds through a debt issue, it issues municipal bonds through a financial broker,

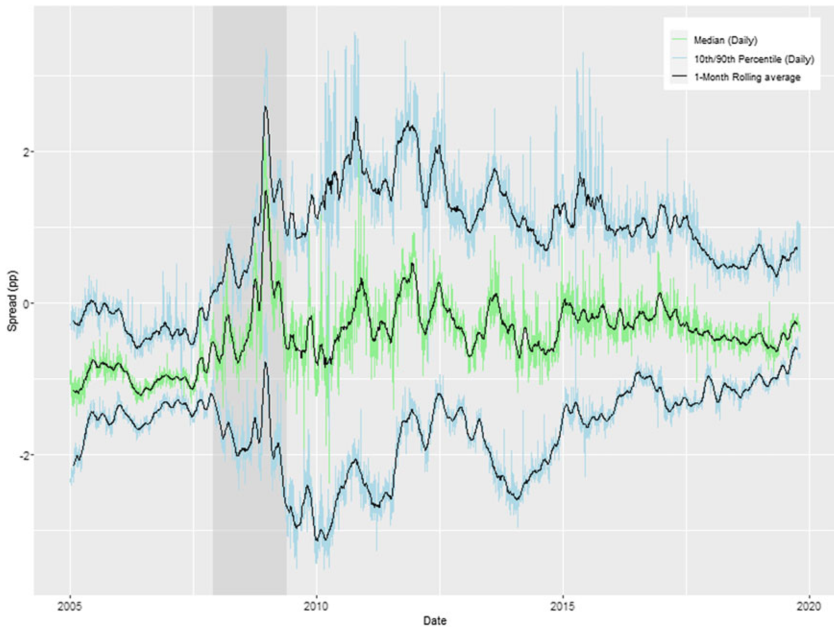

Figure 1. The distribution of muni spreads changes over time.
Note: Municipal bond spreads are reported in percentage points. Colored lines plot the indicated daily moments for all MSRB municipal bond trades in my cleaned sample; black lines are 1-month rolling averages of daily moments.

one of a number of bidders for the rights to issue the bonds. At the time of issue, the broker sells the bonds on a "primary market" investors and other broker-dealers.

After the primary market sale, municipal bonds are traded in OTC markets, rather than on a central exchange. The OTC nature of the municipal secondary market requires a specific buyer–seller match for a sale to take place. Harris and Piwowar (2006) and Green et al. (2007) show that buyer characteristics, namely size, influence prices on the secondary market, such that there is price dispersion even on the same day for a given bond; some investors may have better information and market power than others. Municipal bonds are not like treasuries in that they are tax-free and not entirely risk-free; additionally, the OTC market induces and amount of transaction costs into this market. The average municipal bond is traded every 10 days, suggesting that price adjustment may be slower in this market than in other markets.

There is a wide dispersion on the yields of municipal bonds, reflecting a high degree of heterogeneity in municipal borrowing costs. Municipal bond spreads—determined by tax advantage, risk, and liquidity—also vary substantially over time. Fig. 1 shows the evolution of the 10th, 50th, and 90th percentiles of spreads on municipal bond transactions at the daily frequency from 2005 to 2019.[4] Both the average level and disperison of municipal bond spreads are elevated during the financial crisis and subsequent years and vary at a higher frequency than local marginal tax rates, suggesting a meaningful role for risk and liquidity.

The increased variance of spreads during a time of monetary expansion also suggests that monetary policy may have important heterogeneous effects on municipal yields. Indeed, in this paper I show that there is also a heterogeneity over the degree to which muni prices respond to monetary shocks. This heterogeneity in response implies that different types of governments not only have varying borrowing costs over the long run, but will also encounter differing changes in borrowing costs after short-run shocks. As a result, the transmission of shocks through municipal borrowing costs should be expected to have both level and distributional effects, as governments are affected differentially by shocks, depending on factors such as trading costs and liquidity.

Finally, it is important to note that municipal bond yields do indeed have an effect on the behavior of state and local governments. The key result from the literature on this count is found in Adelino et al. (2017), who use exogenous variation in a municipal bond rating recalibration by Moody's to identify "windfall" spending by local governments. Local governments whose bonds were upgraded (and therefore experienced lower yields) increased their spending in subsequent years by two to ten percent relative to local governments that did not experience a ratings upgrade. Appendix D.2 provides further supporting evidence for the effect of market muni yields on real government behavior. That market yields reflect real costs for state and local governments which incentivize public finance decisions is key to the logic of the monetary policy channel highlighted in this paper.

2.2 Time series evidence

2.2.1 Strategy

The main results of the paper are time series estimates of the response of municipal yield indices to monetary shocks. The exercise is in the spirit of Rosa (2014), who studies the effect of monetary shocks on indices of AAA and AA bonds exclusively. I expand on Rosa's work by considering indices representing a broader set of munis, as well as specific geographic and sectoral indices, reminiscent of Gilchrist et al. (2019), who study the effects of US interest rate shocks on the sovereign bond yields of several small open economies. While my results for highly rated bonds are similar to what Rosa finds, my other results provide a fuller picture of the effect of monetary shocks on the municipal bond market, especially with regard to potential heterogeneity.

Estimation equation. For each of the indices in question, I am interested in estimating the equation

$$\Delta y_t = \beta_0 + \beta_1 m_t + X_t \varepsilon_t, \tag{1}$$

where m_t is the Bu et al. (2021) monetary shock series and $\Delta y_t = y_{t+1} - y_{t-1}$ is the 2-day change in the yield to maturity of the asset around the FOMC meeting date.[5,6] The coefficient $\hat{\beta_1}$ reflects the number of basis points the muni index yield should increase for every 1 bp monetary shock and is estimated with heteroskedasticity-robust standard errors.

Municipal bond indices. The dependent variable in all specifications of (1) is a yield on one of several muni indices constructed by S&P.[7] S&P constructs these indices using a broad selection of bonds issued by state, local, and regional government entities in the USA, which are not subject to income taxes. The bonds must have been issued in 2010 or later and must have a minimum of 2 million US dollars par value on the market. The indices are constructed as value weighted averages of the constituent bonds.[8]

Monetary Shocks. In this analysis, I use the strategy of Bu et al. (2021) to identify monetary shocks on FOMC announcement dates, the full details of which are in Appendix C.2. The BRW method uses the movements of prices of zero-coupon US treasury bonds with maturities $i \in \{1, 2, \ldots, 30\}$ on FOMC announcement dates to back out the implied monetary shocks on each date. This is accomplished in a Fama-Macbeth-style (Fama and MacBeth (1973)) procedure, which starts by making a standardizing assumption that defines the monetary shock as having a one-to-one effect on the 10-year treasury yield. The procedure then estimates the time series relationship between each of the zero-coupon bonds and the 10-year treasury yield. To back out the implied shock m_t on each FOMC date, it then regresses the yields of the zero-coupon bonds on the "loadings" estimated in the first step on each FOMC date.

This monetary shock series has a number of desirable characteristics. First, it relies completely on publicly available data; the treasury yield is taken from the Federal Reserve website, and the estimated zero-coupon yields as estimated by Gürkaynak et al. (2006) are found at https://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html. The publicly available nature of the data allows the shocks to be constructed at no cost, and the series is quite easy to

Table 1. Baseline time series results

	All GO	State GO	Local GO	S&P 500	All GO	State GO	Local GO	S&P 500
Monetary shock	0.26	0.28	0.27	0.57	0.31	0.35	0.35	0.76
	(0.08)	(0.08)	(0.08)	(0.14)	(0.14)	(0.16)	(0.13)	(0.22)
Horizon	2 days	2 days	2 days	2 days	6 days	6 days	6 days	6 days
N	2147	2147	2147	2147	2139	2139	2139	2139

Note: An observation corresponds to 1 day, around which a window is constructed from the previous day's price and the price at a given horizon. Each column refers to a time series regression of a municipal bond index on monetary shocks. Heteroskedasticity-robust standard errors are reported in parentheses.

update through the current date. Furthermore, the authors argue in the paper that this series is robust to the information critique of Nakamura and Steinsson (2018), but is nevertheless highly correlated with existing estimates of monetary policy shocks. Finally, these shocks are able to incorporate well the unconventional nature of monetary policy in the aftermath of the financial crisis; this is an especially important feature for this paper, as my sample only begins in 2005.

2.2.2 Baseline results

This section summarizes the average response of municipal bond yields to monetary shocks. Table 1 gives the estimated coefficients of monetary shocks on yields for three indices of GO municipal bonds. These indices group all municipals, state governments, and local governments, respectively, with an index for bonds from S&P 500 firms for comparison.[9] I choose to focus on GO bonds, which are backed by the full taxing power of the issuer rather than a specific revenue source, in order to more closely match the budget situation of the government in the model. These bonds can be reasonably thought of as representing the borrowing cost situations of their local governments.

This exercise closely mirrors that of Rosa (2014), though my results exhibit slightly higher responses to monetary shocks than his due to the inclusion of a wider set of bonds and the shock corresponding to the 10-year rate. Nevertheless, the coefficients are quite dampened relative to models in which governments can borrow at the risk-free rate: municipal bond yields only increase (decrease) by 26 basis points in response to a 100 point change in the risk free rate, which is less than half of the response of corporate bonds, and far less than treasuries. This dampened response cannot be fully explained by the tax-free nature of municipals, and therefore must be composed of illiquidity and/or risk effects. Models that do not take this dampened response into account will tend to overestimate the effects of monetary policy on local fiscal policy.

Interestingly, there does not seem to be much difference, on average, between the responses of state bonds and local bonds to monetary shocks.[10] This result is somewhat surprising, given the quite different tax and spending obligations between these two types of governments. Instead, it seems heterogeneity shows up in other ways, which I show in the next sections.

2.2.3 Heterogeneous responses

By state. A natural place to look for heterogeneity across localities is in the presence of *geographic* variation. For this section, I estimate (1) separately for indices of GO bonds originating in US states, for which these indices exist.[11] Fig. 2 summarizes the estimates, highlighting visually the heterogeneity of responses across the USA.

A few notes on these results are worth highlighting. First, the range of coefficients runs from 22.19 for New York to 43.85 for Kansas.[12] Second, no immediately obvious patterns emerge, save the apparent tendency for high-population areas to have muni bonds which response *more weakly*

Table 2. Time series results by S&P rating

	AAA	AA	A	BBB band	BB band	NR
Monetary shock	0.15	0.13	0.08	0.23	0.24	0.40
	(0.15)	(0.14)	(0.13)	(0.08)	(0.12)	(0.24)
N	2505	2505	2505	2088	2088	2088

Note: An observation corresponds to 1 day, around which a window is constructed from the previous day's price and the price at a given horizon. Each column refers to a time series regression of a municipal bond index on monetary shocks. Heteroskedasticity-robust standard errors are reported in parentheses.

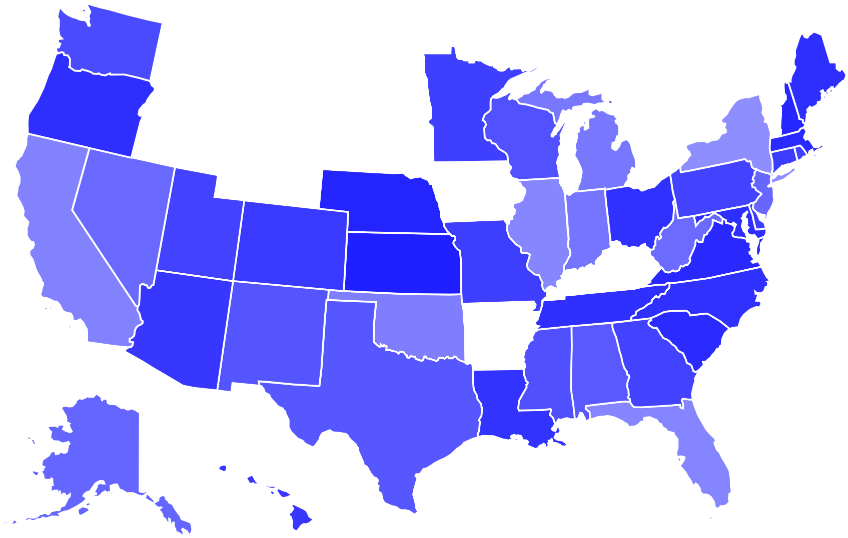

Figure 2. Responses of muni yields to monetary shocks.
Note: Darker color indicates a stronger response of municipal yields issued in the state to monetary shocks. Missing states are those for which an index of GO bonds is not available. Maximum value: 43.85 (KS); minimum value: 22.19 (NY).

to monetary shocks; this result appears again in Section 2.3.2. In any case, the results suggest that heterogeneity exists across space in the USA in the response of municipal bond yields to monetary shocks, and monetary policy may affect different areas of the USA differently.

By credit rating. I also investigate heterogeneity in yield responses for muni indices broken out by credit rating. Lower rated and unrated bonds seem to respond more strongly to monetary shocks than highly rated bonds, providing an explanation for why the magnitudes in this paper might differ somewhat from Rosa (2014). There does not seem to be much explanatory power in examining differences in municipal bonds broken out by sector.

Table 2 shows the coefficient estimates of (1) run separately for indices of bonds in various S&P rating categories, at the 2-day horizon. Although some of the coefficient estimates are not statistically significant, there is a clear upward trajectory, that is, the coefficients on riskier bonds are higher. This is consistent with a world in which expansionary monetary policy–for example–lowers default risk for risky bonds.[13] Furthermore, the coefficients on AAA and AA bonds are more consistent with the findings of Rosa (2014), who only looks at low-risk indices. My baseline estimates, therefore, are higher than his in part because the GO index is not made up entirely of AAA and AA bonds.

This section documented the presence of heterogeneity in municipal bond responses to monetary shocks, which are dampened on average relative to US treasuries and corporate bonds. The

Table 3. Baseline panel estimates

	Yield	Yield	Spread	Spread
Monetary shock	0.50	0.68	−0.07	0.11
	(0.25)	(0.26)	(0.16)	(0.22)
N	22,758	22,758	22,699	22,699
Time to Maturity Controls?	N	Y	N	Y

Note: An observation corresponds to an FOMC date-bond pair from the cleaned MSRB municipal bond sample. Each column refers to a separate regression. Standard errors are reported in parentheses, and are clustered at the date level.

type of government does not seem to make much difference, though smaller and riskier governments have greater responses to monetary shocks.[14] In the next section, I move from time series to panel data in order to obtain more evidence on the potential sources of this heterogeneity.

2.3 Panel evidence: MSRB data

Monetary shocks have a dampened effect on municipal bonds, with heterogeneity across different types of bonds. There is evidence that risk drives a portion of this, but other contributing factors may also be at play. Namely, information about the public finances of specific local governments may influence the responses of munis to monetary shocks. Knowing that there is heterogeneity in these responses is important for the quantitative exercise below, but knowing the *reasons* for this heterogeneity may be necessary to begin drawing out policy implications from the model.

To investigate more fully the effects of public finances in heterogeneity in monetary passthrough, I use a transaction-level dataset of municipal bond trades from the Municipal Securities Rulemaking Board, hereafter MSRB. These data are available through Wharton Research Data Services and are available from 2005 onward. I end the sample on December 31, 2019 to avoid entanglements with the tumultuous nature of the muni market in early 2020. I restrict the sample to GO bonds issued by general governments (as defined by Bloomberg). Appendix C.1 provides more details on the dataset construction.

In this section I estimate the equation

$$\Delta y_{it} = \beta_0 + \beta_1 m_t + \Gamma_0 X_{it} + \Gamma_1 X_{it} m_t + \varepsilon_{it}, \tag{2}$$

where m_t is the same monetary shock as before and X_{it} reflect bond-specific characteristics that might influence a bond's response to monetary shocks. Here, I allow a longer adjustment period for yields (and spreads) y_{it}, owing to the sparse nature of municipal bond trades. My baseline time period of adjustment is two weeks;[15] furthermore, I assign a bond's yield as its most recent daily yield, provided the trade happened within the last week. Standard errors are clustered at the time level, owing to the grouped nature of the shock m_t.

2.3.1 Average results

Before investigating the drivers of heterogeneity, it may be helpful to benchmark baseline estimates in the panel data. In Table 3, I present coefficient estimates of β_1 from (2). These estimates represent four regressions of monetary shocks on muni yields and spreads, and varying the inclusion of controls for time to maturity.

Of particular note here is the coefficients on the response of muni yields to monetary shocks. Why are these estimates higher than the baseline estimate in the time series section? The main reason is the selection inherent in this exercise: in order to properly impute a price to bonds in this data, I only assign prices for trades within the last week. Trading rates of municipal bonds are quite low, so *conditional on trade*, we should expect individual-level responses to be higher. If we include those bonds which trade before the shock but not after, coding them as $\Delta y_{it} = 0$, the estimates (on yields) are quite close to the baseline 0.26 from the time series section. These estimates should be kept in mind as a baseline for the next exercise.

2.3.2 Public finance variables

The key margin of heterogeneity I investigate involves a series of finance variables for municipalities. To obtain these data, I use the Census/Survey of Governments data from the US Census. This survey obtains hundreds of balance sheet variables for state and local governments in the USA, taking a representative sample annually and a full population sample every 5 years. Following Schwert (2017), I select the local governments in the USA with annual revenues of over $50 million. I then obtain the 6-digit CUSIP codes for these government issuers from the Bloomberg Terminal and connect them to my panel dataset.

I estimate a series of regressions for (2) using numerous different public finance indicators as independent variables in separate regressions to explain municipal yield responses. Results are given in Table 4, from which a consistent theme emerges: larger governments are associated with less responsive municipal bond yields. Whether on the margin of revenues, expenditures, or debt, the estimated coefficients are negative across the board, and many are statistically significant. It is unclear why government size correlates with risk; one possibility is that larger governments are seen as having a more reliable tax base, resulting in better credit ratings and lower responses to monetary shocks. In any event, the association with size does seem to correspond with the state-level time series heterogeneity.

2.4 Empirical takeaways

This empirical section has studied, from a number of angles, the effect of monetary shocks on municipal bond markets. On average, the yields on an index of GO municipal bonds respond by 26 basis points to a 100 basis point shock to the risk-free rate. This dampened effect is consistent with the lower volatility of municipal yields in general relative to treasuries. Furthermore, while the "level" of the issuer does not seem to matter, the location of the issuer does. In other words, I document heterogeneity across the USA in the response of municipal yields to monetary shocks. This heterogeneity maps to the model from Section 3.

I then investigate potential sources of this heterogeneity. There is some limited evidence that the heterogeneity may arise from differences in bond ratings.[16] There may be an association as well between the size of a locality and its borrowing costs' response to monetary shocks, but the data on government finances is limited, especially for smaller governments. In the main quantitative results below, I do not take a stance on the source of heterogeneous responses, but the various options may carry different policy implications.

3. A model of a municipal government

In order to examine the effects of the financial market for municipal bonds on government behavior and household welfare, I propose a quantitative heterogeneous agents DSGE model of municipalities in a monetary union, with municipal government debt sold on outside markets, subject to financial frictions. The economies in question are small open economies,[17] reflecting the tens of thousands of distinct municipal governments in the USA. In this model, households choose labor and purchases of local municipal bonds, financial markets buy and sell bonds, local

Table 4. Panel estimates: interactions with public finance variables

Expenditure variables		Revenue variables		Other variables	
Interaction variable (log)	Interaction coefficient (s.e.)	Interaction variable (log)	Interaction coefficient (s.e.)	Interaction variable (log)	Interaction coefficient (s.e.)
Total	−0.123	Total	−0.125	Population	−0.136
	(0.044)		(0.052)		(0.061)
Current	−0.123	General	−0.123	Total Long-Term Debt	−0.104
	(0.043)		(0.045)		(0.046)
Capital	−0.102	Total Tax	−0.105	Total LTD Issued	−0.112
	(0.047)		(0.042)		(0.048)
Construction	−0.077	Property Tax	−0.002	Total Cash and Securities	−0.095
	(0.038)		(0.013)		(0.039)
Interest	−0.102	Sales Tax	−0.044	Total Cash and Securities (non-insurance)	−0.122
	(0.044)		(0.023)		(0.042)
Benefits	−0.048	Income Tax	−0.025		
	(0.018)		(0.008)		
Wage	−0.094	Intergovernmental	−0.138		
	(0.044)		(0.046)		
General	−0.121	Miscellaneous	−0.115		
	(0.045)		(0.042)		
Education	−0.030	Interest	−0.078		
	(0.022)		(0.044)		
Health	−0.040	Utilities	−0.009		
	(0.020)		(0.010)		
Highway	−0.075				
	(0.038)				
Housing	−0.069				
	(0.030)				
Public Welfare	−0.030				
	(0.018)				
Utility	−0.016				
	(0.012)				
Retirement	−0.048				
	(0.018)				

Note: An observation corresponds to an FOMC date-bond pair from the cleaned MSRB municipal bond sample, merged with Census of Governments public finance data. Each *row* corresponds to a regression with the specified variable interacted with monetary shocks, as in (2). The reported coefficient is the coefficient on the interaction term. Standard errors are reported in parentheses, and are clustered at the date level. $N = 9225$ for all regressions.

governments choose spending and debt issuance, and the central government chooses the risk-free interest rate. Local output is produced by monopolistically competitive firms using labor from households, resulting in standard New Keynesian features for prices.

This model is able to quantify the effects of financial frictions, which appear here as a wedge between the risk-free rate and municipal borrowing costs and may potentially arise from an OTC framework, on local fiscal policy in response to macroeconomic shocks. As such, it serves as a contribution to the macro literature on passthrough of shocks, the fiscal policy literature, monetary unions models, models of the regional effects of macroeconomic shocks, and (in one possible application) models on OTC asset pricing. Note that in this section I focus on the problem of a single locality for simplicity.

3.1 Environment

The locality is modeled as a small open economy with a representative household and representative government, each of which maximizes the utility of the representative consumer. The household is made up of $1-\kappa$ traditional consumers and κ "hand to mouth," or HTM, consumers. The traditional, or "Ricardian," optimizers in the household choose a consumption bundle comprised of two types of final goods, tradable (c^T) and non-tradable (c^N), as well as labor supply h and debt d. The government chooses government purchases of non-tradable goods g and municipal debt d^G, given a tax rate τ^G on the exogenous stream of tradable goods for the economy, y^T. HTM consumers simply choose labor h^H and consume exactly their labor income in every period.

Tradable goods and bonds of both agents are traded with the rest of the world, where the locality is endowed with an exogenous income of the tradable good in every period. Non-tradable goods are produced using domestically supplied labor by monopolistically competitive firms within the region to satisfy demand for non-tradable consumption and government purchases of public goods. Inflation is induced by Calvo-style price setting on the part of these monopolistic competitors, who maximize expected future profits subject to household and government demand, as well as the expected constraints on price changes.

The aggregate risk-free interest rate in the economy is determined by a central authority and is exogenous with respect to local variables. Additionally, both the household and the government are subject to their own "proprietary" interest rates, r^H and r^G, which depend on the aggregate rate, deviation of debt from steady state, and parameters determining the relationship between monetary shocks and the actual interest rate paid by either the household or the government. Of particular interest in this project is the response of the *government's* borrowing costs to monetary shocks. The strength of this response will affect passthrough of interest rate shocks to households and presents a potential source of heterogeneity of monetary passthrough in the US economy.

3.2 Household

3.2.1 Basic problem

The household in the small economy is made up of $1-\kappa$ "Ricardian" agents and κ "hand-to-mouth" agents. The representative Ricardian optimizer solves

$$\max_{\{c_t^T, c_t^N, h_t, d_{t+1}\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[U(c_t) - V(h_t) + W(g_t) \right], \tag{3}$$

where

$$c_t = A\left(c_t^T, c_t^N\right) \tag{4}$$

$$c_t^T + p_t c_t^N + d_t = y_t^T \left(1 - \tau^G\right) + w_t h_t + \frac{d_{t+1}}{1 + r_t^H} + T_t. \tag{5}$$

Here, tradable consumption and debt are denominated in terms of the "national" price, which is normalized to unity. Prices p_t and w_t are prices—of non-tradables and labor, respectively—relative to the price of the tradable good. τ^G is the tax on exogenous tradable good allocation, and T_t is the lump-sum transfers to households from firm profits. Quantities are in per-person terms, such that total labor supply from optimizers is given by $(1-\kappa)h_t$.

3.2.2 Optimality conditions

Accordingly, the household's first-order conditions are given as follows:

$$\lambda_t = U'(c_t)A_1\left(c_t^T, c_t^N\right) \tag{6}$$

$$\frac{A_2\left(c_t^T, c_t^N\right)}{A_1\left(c_t^T, c_t^N\right)} = p_t \tag{7}$$

$$\frac{\lambda_t}{1+r_t^H} = \beta\mathbb{E}_t\lambda_{t+1} \tag{8}$$

$$V'(h_t) = \lambda_t w_t. \tag{9}$$

The equation in (6) is the first-order condition for tradable goods consumption, defining the shadow value of income denominated in the tradable goods price. The condition for non-tradable consumption, when plugged into (6), yields (7), which allocates consumption according to the relative price of the two goods. (8) trades off the benefits of borrowing today with the costs of paying it back tomorrow, and (9) equates marginal costs and benefits of labor supply.

3.2.3 Hand-to-mouth agents

The remaining κ agents in the economy behave in a hand-to-mouth manner. These agents supply per-capita labor h_t^H and use labor income to consume tradable and non-tradable goods:

$$c_t^{T,H} + p_t c_t^{N,H} = w_t h_t^H. \tag{10}$$

Here, as above, consumption is aggregated according to $c_t^H = A\left(c_t^{T,H}, c_t^{N,H}\right)$.

The first-order conditions for these consumers mirror those of the traditional agents, without the intertemporal condition:

$$\lambda_t^H = U'\left(c_t^H\right)A_1\left(c_t^{T,H}, c_t^{N,H}\right) \tag{11}$$

$$\frac{A_2\left(c_t^{T,H}, c_t^{N,H}\right)}{A_1\left(c_t^{T,H}, c_t^{N,H}\right)} = p_t \tag{12}$$

$$V'\left(h_t^H\right) = \lambda_t^H w_t. \tag{13}$$

The total amount of non-tradable consumption in the economy, then, is the sum $(1-\kappa)c_t^N + \kappa c_t^{N,H}$, and likewise with tradable consumption $(1-\kappa)c_t^T + \kappa c_t^{T,H}$ and total labor $(1-\kappa)h_t + \kappa h_t^H$. This departure from Ricardian equivalence in the model allows a realistic local government spending multiplier to be obtained.

3.3 Local government

The representative local government uses local fiscal policy to solve the problem (3)[18] by choosing a borrowing level d_{t+1}^G subject to

$$p_t g_t = \tau^G y_t^T + \frac{d_{t+1}^G}{1+r_t^G} - d_t^G, \tag{14}$$

Other than its choice variables,[19] another key difference emerges for the local government: it exerts full market power over its own debt when it issues in the financial market. In other words, while the representative household is a price taker with respect to borrowing costs because it is subject to the aggregate interest rate, the local government can be thought of as a singular agent and the only issuer of its asset. The government, therefore, must take into account the effect of its debt issues on its borrowing costs, both in the current period and in the future. The first-order condition with respect to debt purchases, then, is given by:

$$W'\left(g_t\right)\frac{1+r_t^G-d_{t+1}^G\frac{\partial r_t^G}{\partial d_{t+1}^G}}{\left(1+r_t^G\right)^2}=\beta\mathbb{E}W'(g_{t+1})\left(-1+\frac{-d_{t+2}^G\frac{\partial r_{t+1}^G}{\partial d_{t+1}^G}}{\left(1+r_{t+1}^G\right)^2}\right). \tag{15}$$

(15) is analogous to the household Euler equation for consumption and debt but uses public goods and local government debt. It captures the utility trade-off of public goods in period t for public goods in period $t+1$, taking into account the microeconomic effect of local government debt on prices. When the yields on municipal bonds move strongly with interest rate shocks, these fiscal policy responses will tend to be greater, while the opposite is true when responses of yields to monetary shocks are weak.

The condition that the government take into account its effect on interest rates is not an inconsequential one. It affects the response of debt to transitory shocks, but it also has an effect on the steady state of the model. If the government's debt level did not affect its borrowing costs, it would run up unrealistic levels of debt at normal interest rates. Failing to account for the effects of debt on borrowing costs unrealistically understates the market's response to high municipal debt levels.

3.4 Financial sector

Household and government debt are traded on an external financial market, resulting in two interest rates r_t^H and r_t^G. These interest rates reflect the aggregate interest rate r_t^*, debt stock/purchases d_t, d_{t+1}, d_t^G, and d_{t+1}^G, and monetary shocks. The interest rates can be thought of as being determined by the functions

$$r_t^H=f^H\left(d_t,d_{t+1},r_t^*,m_t\right) \tag{16}$$

and

$$r_t^G=f^G\left(d_t^G,d_{t+1}^G,r_t^*,m_t\right). \tag{17}$$

The function $f^G(m_t)$ is of particular interest in this paper, as it will be a key determinant of the passthrough of monetary policy to local governments. The response of municipal government borrowing costs could vary based on a multitude of factors, including trading costs and illiquidity in the muni market, as I will show in the empirical section.

These pricing functions could arise from a number of financial market specifications. For example, a common formulation in the international literature is the debt-elastic interest rates of Schmitt-Grohe and Uribe (2003). In Appendix B, I show one alternative to this formulation, which incorporates a standard OTC asset market model. That feature serves as a microfoundation for the functions $f^H(m_t)$ and $f^G(m_t)$ and provides intuition into the mechanism working behind the empirical investigations. Given that a number of factors may give rise to heterogeneity over these functions, it is helpful to keep them general.

3.5 New Keynesian production

3.5.1 Final goods production

The non-tradable good y_t^N is produced by a final goods producer which buys intermediate goods y_{it}^N from a continuum of intermediate goods producers in the local economy. Production of the final good from intermediates is determined by the aggregating equation

$$y_t^N = \left(\int_0^1 \left(y_{it}^N\right)^{1-\frac{1}{\mu}} di \right)^{\frac{1}{1-\frac{1}{\mu}}}, \tag{18}$$

and final goods firm profits are given by $P_t^N y_t^N - \int_0^1 P_{it}^N y_{it}^N di$. Profit maximization on the part of the final goods producer implies the demand equations for the monopolistically competitive intermediate goods producers $y_{it}^N = y_t^N \left(\frac{P_{it}^N}{P_t^N} \right)^{-\mu}$. Here, the domestically produced good is used both for consumption—by both types of agents—and government spending,

$$y_t^N = (1-\kappa)c_t^N + \kappa c_t^{N,H} + g_t, \tag{19}$$

so the relevant demand equations become

$$y_{it}^N = ((1-\kappa)c_t^N + \kappa c_t^{N,H} + g_t) \left(\frac{P_{it}^N}{P_t^N} \right)^{-\mu}. \tag{20}$$

P_t^N here is the price of final non-tradable goods, which is given by the aggregator $P_t^N = \left(\int_0^1 (P_{it}^N)^{1-\mu} di \right)^{\frac{1}{1-\mu}}$.

3.5.2 Intermediate goods producers

Intermediate goods firms exist on the continuum $[0, 1]$ and produce differentiate inputs to the final non-tradable good using household labor:

$$y_{it}^N = h_{it}^\alpha, \quad \alpha \in (0, 1]. \tag{21}$$

The choice variable for these firms is the price for good i, P_{it}^N, which determines demand for the intermediate good as in (20). Profit for an individual intermediate goods firm is given by $P_{it}^N y_{it}^N - (1 - \frac{1}{\mu}) W_t h_{it}$, where W_t is the raw wage and $(1 - \frac{1}{\mu})$ is a labor subsidy meant to offset the distortions from monopolistic competition. Prices are sticky according to a Calvo mechanism, that is, intermediate goods firms may only change prices in each period with probability $(1-\theta)$. In Appendix A, I show that maximization of expected profits on the part of intermediate goods firms, since all price-adjusting firms choose the same price, result in choosing the flexible relative price $\tilde{p}_t^N$ to equate present value marginal costs and marginal revenues, $mr = mc$, where

$$mr_t = \frac{\mu - 1}{\mu} y_t^N p_t \left(\tilde{p}_t^N\right)^{1-\mu} + \beta\theta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\tilde{p}_t^N}{\tilde{p}_{t+1}^N} \frac{1}{\pi_{t+1}^N} \right)^{1-\mu} mr_{t+1} \tag{22}$$

and

$$mc_t = \frac{1 - \frac{1}{\mu}}{\alpha} \left(y_t^N\right)^{\frac{1}{\alpha}} w_t \left(\tilde{p}_t^N\right)^{-\frac{\mu}{\alpha}} + \beta\theta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\tilde{p}_t^N}{\tilde{p}_{t+1}^N} \frac{1}{\pi_{t+1}^N} \right)^{-\frac{\mu}{\alpha}} mc_{t+1}. \tag{23}$$

I also show in Appendix A that inflation dynamics are given by

$$1 = \theta \left(\pi_t^N\right)^{\mu-1} + (1-\theta) \left(\tilde{p}_t^N\right)^{1-\mu}, \tag{24}$$

where $\pi_t^N = \frac{P_t^N}{P_{t-1}^N}$, and aggregate production is given by $y_t^N = s_t^{-\alpha} h_t^\alpha$, where $s_t = \int_0^1 \left(\frac{P_{it}^N}{P_t^N}\right)^{-\frac{\mu}{\alpha}}$ represents the amount of price dispersion in the intermediate goods sector that has a dampening effect on aggregate output. Price dispersion evolves according to

$$1 = \theta s_{t-1} \left(\pi_t^N\right)^{\mu/\alpha} + (1-\theta)\left(\tilde{p}_t^N\right)^{-\mu/\alpha}, \tag{25}$$

3.6 Aggregation

Thus far I have focused on the problem of a single locality. In a full version of the model, there are a large number of localities subscripted by $s \in \{1, \ldots, S\}$. These economies exchange tradable goods and debt with each other, as well as with the rest of the world.[20] The nationwide interest rate r_t^* is set by the economy's monetary authority in response to aggregate output and inflation, which are made up of local values:

$$r_t^* = R\left(\left\{y_{st}^T\right\}_s, \left\{y_{st}^N\right\}_s, \{\pi_{st}\}_s\right). \tag{26}$$

3.7 Equilibrium

A competitive equilibrium is a set of quantities y_t^N, c_t^T, c_t^N, h_t, g_t, d_t, d_t^G, λ_T, π_t^N, s_t, mr_t, and mc_t and prices p_t, w_t, $\tilde{p}_t^N$, r_t^H, and r_t^G for each locality s satisfying:

(i) The optimizing household problem is solved by equations (6), (7), (9), and (8)
(ii) Hand-to-mouth quantities satisfy equations (13), (11), and (12)
(iii) The government's problem is solved by equation (15)
(iv) Marginal revenue and marginal cost are given by equations (22) and (23), where $mr = mc$
(v) Aggregate production satisfies $y_t^N = s_t^{-\alpha}((1-\kappa)h_t + \kappa h_t^H)^\alpha$
(vi) Inflation and price dispersion evolve according to equations (24) and (25)
(vii) Inflation is defined by $\pi_t^N = \frac{p_t}{p_{t-1}}$
(viii Market clearing in tradable goods implies $(1-\kappa)c_t^T + \kappa c_t^{T,H} + d_t = y_t^T + \frac{d_{t+1}}{1+r_t^H}$
(ix) Interest rates satisfy equations (16) and (17)
(x) The risk free rate is set by the monetary authority according to equation (26)

given the exogenous processes y_t^T and initial conditions s_{-1}, d_0, and d_0^G.

3.8 Elasticities of interest

A few key elasticities are important for understanding the passthrough of monetary policy through municipal public finance and its potential heterogeneity using this model. First, we need to know the effect of borrowing costs on government spending. Results from the literature[21] suggest these effects could be quite sizeable. Additionally, it is important to know the local government spending multiplier: a helpful review in Chodorow-Reich (2019) suggests a point estimate of 1.8, suggesting a meaningful role of fiscal policy at the local level.

The empirical section detailed in depth the effect of monetary shocks on municipal borrowing costs, which is the main component of this transmission channel. In the baseline, local government borrowing costs move by 26 bp in response to a 100 bp monetary movement. This dampened response will, in the context of this model, reduce the size of transmission relative to assuming local governments have access to the risk-free rate. Heterogeneity of this elasticity will also result in heterogeneity across localities. The following quantitative section confirms and quantifies these conclusions.

4. Quantitative results

This section shows quantitatively the importance of the municipal public finance channel of monetary transmission in the model introduced in Section 3. Significantly, the estimated heterogeneity in muni yield responses to monetary shocks implies heterogeneous effects of monetary policy on localities, depending on local financial frictions. This effect appears in data, as well. Increasing the response of local government borrowing costs from the 10th to 90th percentile of US state estimates implies an increase of up to 25% in the output and labor response to monetary shocks. Furthermore, the nature of municipal bonds and frictions in muni markets significantly dampen this channel: allowing a municipal government to borrow at the aggregate risk-free rate more than doubles the output response to a monetary shock. Finally, although expansionary monetary policy is stimulative in early periods, the increase in municipal debt finance becomes a drag on local economies far into the future.

I begin by focusing on the response of a single small open economy, abstracting from a full model of the USA to clearly illustrate the model's mechanisms. I then show how economies with realistically heterogeneous borrowing cost elasticities exhibit meaningful differences in response to monetary shocks. Moving from $S = 1$ to $S > 1$, the only difference from the perspective of the locality is the process of the risk-free rate; when I consider the "partial equilibrium" with only one locality, I take the vector $[y_t^T \ r_t^*]$ as an exogeneous process, as is common in the international literature. I specify its process below.

4.1 Calibration and solution

Before moving on to the quantitative results, it is necessary to discuss specifics on the calibration of the model for proper interpretation, which in this case is a US municipality as a small open economy. I first discuss functional form choices, then parameters which are taken from the literature or estimated. I also calibrate a set of parameters to match some average statistics on state and local spending, revenues, consumption, and debt, followed by an investigation into the effects of local openness on the local fiscal multiplier. Finally, I briefly discuss the solution method.

4.1.1 Functional forms

I use the model outlined above, opting for an *ad hoc* version of financial markets, in the vein of models with external debt-elastic interest rates in the open economy literature. I use a simpler formulation for simplicity and ease of mapping the empirical response coefficients. Furthermore, because multiple sources of heterogeneity in borrowing costs have been explored, this formulation allows an abstraction from which of these courses is most important. To begin, assume the exogenous tradable endowment y^T reflects shocks in the aggregate economy. Then let the aggregate risk-free r_t^* be determined by the system

$$z_t = Bz_{t-1} + \varepsilon_t^z, \tag{27}$$

where $z_t = \left[\log \frac{y_t^T}{y^{T*}} \ \log \frac{1+r_t^*}{1+r^*} \right]'$, and y^{T*} and r^* are parameters reflecting steady state values. $\varepsilon_t^z = [\varepsilon_t^y \ m_t]'$ reflect the exogenous shocks, with m_t being our shock of interest. Household interest rates are given by a standard debt-elastic interest rate formulation,

$$r_t^H = r_t^* + \phi^H \left(\exp\left(d_t^H - \bar{d}^H\right) - 1\right). \tag{28}$$

Table 5. Fixed parameters

Parameter	Description	Strategy	Value
σ	CRRA utility parameter	Literature	2
α	Labor share of production	Data/Literature	0.6
μ	Elasticity of substitution in production	Literature (Gali and Monacelli, markup target 20 percent)	6
β (quarterly)	Discount rate	Literature, imply s.s. interest rate of 0.03 (annualized)	0.9926
θ	Calvo parameter	Data/Literature (target average 10 mos between price changes)	0.7
$\bar{h}, h$	Labor endowment and steady state	Literature, labor supply $= 1/3$	3, 1
Φ	Leisure utility	Set to solve $mr = mc$ in steady state	
γ	Government utility	Set to solve government's problem in steady state	
ξ	Elasticity of substitution	Literature, set to $1/\sigma$	1/2

The benefit of this formulation is the ability to set any arbitrary steady state debt level; in the baseline calibration, I make the representative local household a *saver*, that is, $\bar{d^H} < 0$.[22] I set the government's borrowing costs in a similar fashion, but with a friction on the adjustment to the treasury rate:

$$r_t^G = r^* + \theta^G \left(r_t^* - r^*\right) + \phi^G \left(\exp\left(d_t^G - \bar{d^G}\right) - 1\right). \tag{29}$$

First, note the imperfect response of actual borrowing costs to the risk-free rate, governed by θ^G, which will be the key parameter of interest capturing the response of muni yields to aggregate interest rate shocks.[23]

Utility over consumption in this model is CRRA, with log utility over leisure and public goods consumption:

$$U(c) = \frac{c^{1-\sigma} - 1}{1-\sigma}; \quad V(h) = \Phi \log\left(\bar{h} - h\right); \quad W(g) = \gamma \log(g).$$

Furthermore, the consumption aggregator is CES, $A(c^T, c^N) = \left(A(c^T)^{1-\frac{1}{\xi}} + (1 - A)(c^N)^{1-\frac{1}{\xi}}\right)^{\frac{1}{1-\frac{1}{\xi}}}$, where ξ determines the substitution elasticity across tradable and non-tradable consumption, and A represents the "openness" of the economy, which will be a key factor in the size of the local fiscal multiplier.

4.1.2 Parameters

The parameters in the model are set using a combination of data and literature. Table 5 gives the basic parameters from the model which are standard in the literature. Nothing of extreme note is here, other than to note the decreasing returns to scale in intermediate production, which are consistent with the labor share of production in the USA.

The exogeneous process for y_t^T and r_t^* is defined by the coefficient matrix B, which amounts to a VAR process with a lag of one period. For the baseline results, I estimate the matrix B as a

Table 6. Calibration targets

Target	Value
State and local government consumption and investment/GDP	0.11
State and local government own revenues/GDP	0.09
State and local government debt/GDP	0.15
Household savings/GDP	0.05
Imports/total shipments, from CFS (> 50 miles)	0.66
Municipal bond yield (annualized)	2.75
Local government spending multiplier (Chodorow-Reich)	1.8

bivariate VAR on the series $[\log(Y_t)\log(r_t)]'$, where Y_t is real GDP and r_t is a treasury rate, in this case, the USA 10-year. This estimation results in the (quarterly) coefficient matrix

$$\hat{B} = \begin{bmatrix} 0.985 & -0.0004 \\ 0.012 & 0.96 \end{bmatrix}.$$

The baseline elasticity of municipal borrowing costs to the exogenous component of the aggregate interest rate is taken directly from the main time series result for all GO bonds in the empirical section, $\theta^G = 0.26$. In the section studying the effects of heterogeneity in this elasticity, I examine the 10th, 50th, and 90th percentiles for θ^G.

The remaining six parameters,[24] y^{T*}, A, τ^G, $\bar{d}^H$, $\bar{d}^G$, ϕ^G, and κ, are calibrated to a set of moments that represent averages for state and local governments in the US economy, in addition to a selected point estimate from the literature on local spending multipliers. These targets and their values—approximated for simplicity—are given in Table 6.

At this point, a discussion is necessary on the exact interpretation of this small open economy. Is it a state government or a local government, or something else? The issue, of course, is that households in the USA are under the jurisdiction of multiple tiers of governments, each of which exerts its own sphere of responsibility. Why are state *and* local expenditures being used for calibration? A robust literature exists describing the determination of public policy in federalist systems, but it is not the goal of this paper to enter in to that exciting discussion. For now, it suffices to say that the "government" imagined in this model is some sufficiently small combination of government roles that can be thought to be representative of its constituents' value functions. In the baseline calibration, I set a tradable consumption to total consumption ratio of 0.66, matching the proportion of shipments in the Commodity Flow Survey that travel further than 50 miles. This yields a value for A of 0.2683.

The degree of openness, given in this paper by the parameter A, can also be thought of as defining the "size" of the locality in question. As the locality's area increases, a higher proportion of household consumption is produced within the locality; for example, a good produced in San Francisco but consumed in Oakland is considered an import if the locality is defined by the Oakland city limits, but as a domestic good if we define the locality as the state of California or the more nebulous "Bay Area." The impact multiplier of fiscal policy depends crucially on the definition of a locality, or its openness. Alternative definitions of a locality, such as a state, in which tradable consumption is less important, will result in larger multipliers. As the economy becomes increasingly closed, the multiplier increases, as we approach the closed economy case.

The multiplier, in addition to depending on openness, also depends crucially on the proportion of non-Ricardian agents in the household, κ. These two determinants stand in agreement with the papers of Chodorow-Reich (2019) and Farhi and Werning (2017a), which analyze fiscal multipliers in monetary unions. A resulting implication is that if openness A decreases, fewer non-Ricardian agents will be required to match the preferred multiplier. Finally, this impact multiplier does not take into account the dynamic effects of local fiscal policy; the next section presents these effects in fuller detail.

4.1.3 Solution method

For the results in this paper, I solve for the impulse response functions of the model by simulating the model's response to a one-time, unexpected shock to the exogenous portion of the interest rate. I assume that the economy is in steady state before the shock and returns to steady state after 300 periods. While more computationally intensive than a perturbation strategy, this method allows more flexibility. For example, I can extend the model by including explicit constraints on debt issuance by the local government.

For the calibration of the hand-to-mouth share κ to match the local government spending multiplier of 1.8, I iterate over solutions of a stripped-down version of the model with exogenous government spending.[25] Because this calibration procedure requires potentially many evaluations of the response of the economy to an exogenous government spending shock, I compute these responses with a second-order perturbation.[26]

4.2 Results of an interest rate shock

The response of this calibrated economy to a 25 bp expansionary monetary shock is shown in Figs. 3 and 4.[27] The figure shows the percent deviations from the steady state in response to the monetary shock. Notice the logic of the channel shown in the second figure: borrowing costs decrease, increasing government debt and spending, resulting in output stimulus. In the baseline calibration, a 25 bp decrease in the risk-free rate results in about a quarter percent increase in output on impact.

Note, however, there is a long-run effect of the government debt buildup. Because the only margins of fiscal adjustment for the government are debt and spending—the tax rate is exogenous—the government has to reverse its debt accumulation through costly decreases in government spending later on. One immediate consequence of this result is the importance of thinking about the long-term consequences of stimulating debt-financed spending. Expansionary monetary policy allows local governments to shift spending from far in the future to the present, stimulating output in the short run but depressing it in the long run.

In the empirical section, I noted that the responses of municipal yields to monetary shocks were muted relative to what one might expect. When conditioned on trading activity, responses are higher but remain weaker than one-for-one. As a result, the stimulative or depressive effects of monetary policy through local public finance are lower in a model which takes these features of muni markets into account, relative to a model which assumes local governments can borrow at the risk-free rate. To see the magnitude of the difference between the calibrated model, a model with an alternate level of passthrough based on Table 3, and a model with borrowing costs at the risk-free rate, see Fig. 5.

In the model that does not take the muted response of local borrowing costs to monetary shocks into account, the stimulative effects of monetary policy are more than double the baseline model and 40% higher than in the alternate data-based model. When local government borrowing costs are tied more closely to the risk-free rate, local government debt increases by almost five percent relative to the steady state, and the reaction of spending, output, and labor are much higher than before. This stark difference suggests that models which assume municipal governments have access to borrowing at the aggregate risk-free rate will significantly overstate the stimulative effects of monetary policy on local economies; such models will also *understate* the possibility for heterogeneity of stimulus across localities.[28] I take up the extent of the heterogeneity in the next section.

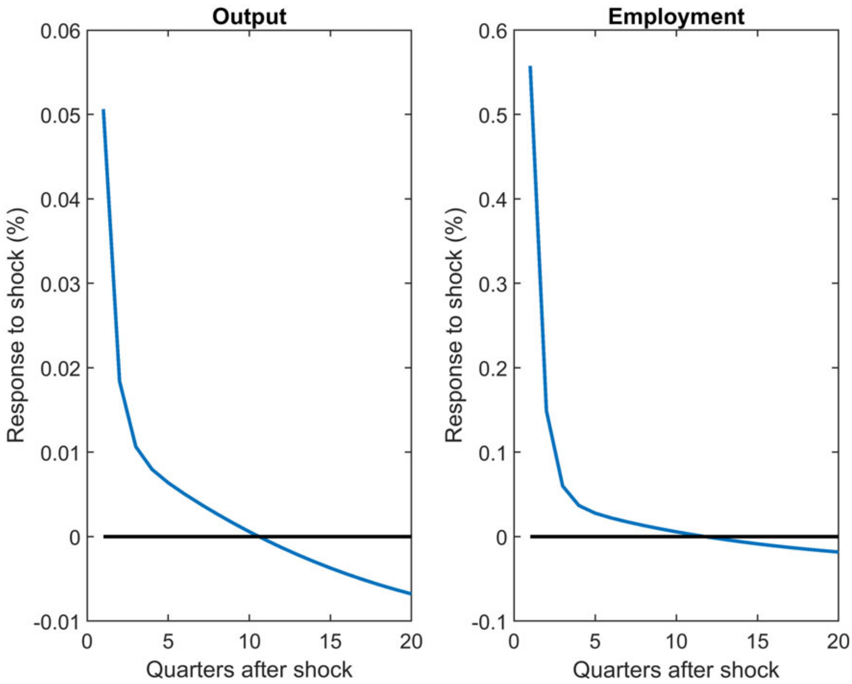

Figure 3. IRFs, 25 bp expansionary shock.
Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25 bp downward shock in the national risk-free interest rate (annualized).

In Appendix Figure 11, I plot an estimated response of output to a monetary shock according to the Christiano et al. (1996) methodology mentioned earlier. The peak response of output to a one standard deviation monetary shock matches very well the magnitude of the peak response in the calibrated model, suggesting that the magnitudes of response in this model are reflective of the real world. Across the board, this type of "canonical" open economy DSGE model fails to generate the hump-shaped responses of economic variables to monetary shocks observed in VARs. One could imagine a number of features to supplement the model which might better match these hump shapes, but these features are not the focus of this paper.

4.3 Heterogeneity over monetary responses

Model results. A model that assumes a one-for-one relationship between municipal borrowing costs and national interest rates eliminates the possibility that borrowing costs might respond differently to monetary shocks in different localities. As a result, such a model will eliminate an important source of heterogeneity in the passthrough of monetary shocks across regions and localities in the USA. Above, I focus on one locality for ease of exposition; here, I consider a full model with a large number of localities.

In the data, I identified the municipal yield responses to monetary shocks of 41 US states. In this specification, then, I set $S = 41$ and assign each state a θ^G corresponding to one of the empirical estimates, while all other parameters remain the same. Aggregate output is defined as total output, and aggregate inflation as average inflation of non-tradables across localities. The risk-free rate is set according to a Taylor rule which mimics the interest rate process above, replacing y^T with total output and adding in a response of inflation, where the risk-free rate responds to a basis point of lagged inflation with a 1.5 basis point rate increase.

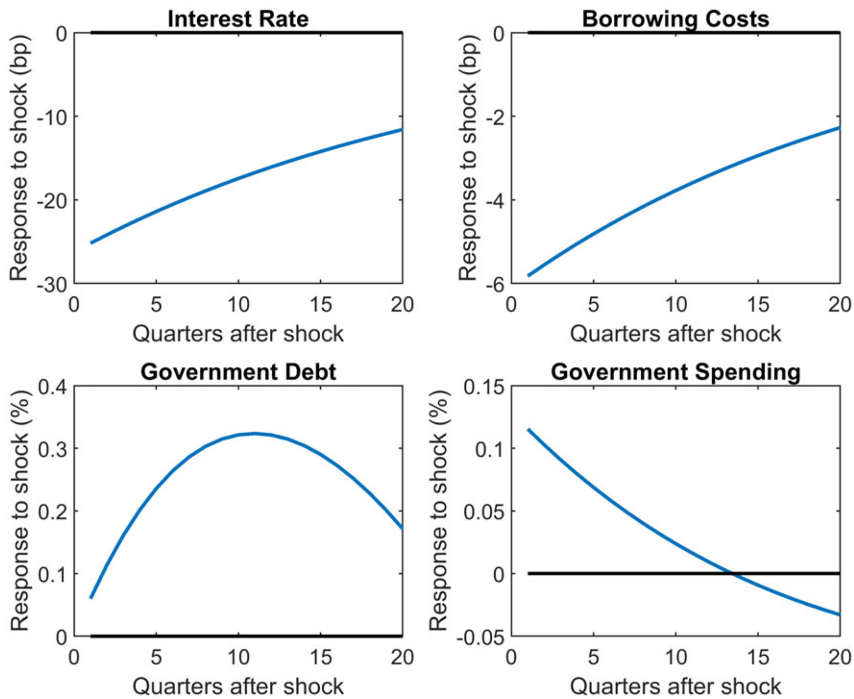

Figure 4. IRFs, 25 bp expansionary shock.
Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25 bp downward shock in the national risk-free interest rate (annualized).

In Fig. 6, I plot the same impulse response functions to a 25 bp risk-free rate shock as in the previous section, for the 10th, 50th, and 90th percentiles of θ^G in the large economy.[29] The municipal bond market is the only difference between these states, yet monetary transmission is markedly different between them. A government whose borrowing costs fall more after an expansionary shock borrows more, spends more, and sees greater output and labor increases on impact; the impact effects on output and labor are almost 25% greater in the 90th percentile than the 10th percentile state. In the long run, of course, these effects will be flipped: the high-response governments have more debt to pay down, and thus a bigger future recession. The magnitude of response of municipal bond prices to monetary shocks is a key parameter, then, in determining both the *size* and *path* of local economic outcomes.

Empirical results. Realistic differences in the response of local government borrowing costs to monetary shocks have quantitatively important implications for heterogeneity in monetary transmission. For example, Francis et al. (2012) estimate the responses of several US cities to monetary shocks, grouping them according to region, and finding that the difference between the smallest regional peak employment response and the largest is about tenfold. While the differences in this experiment are smaller, a 25% difference in responses is an not inconsequential proportion of this estimate.

A key testable implication of this model is the positive effect of municipal bond elasticities (to monetary shocks) on monetary policy transmission. Specifically, the model predicts that an increased elasticity of municipal bond yields with respect to monetary shocks implies increased effects of monetary policy on employment. To investigate this in the data, I use the peak employment responses at the MSA level estimated by Francis et al. (2012).[30] I take the Census of Governments subsample mentioned in Section 2.3.2 and Appendix C.1, assign governments to

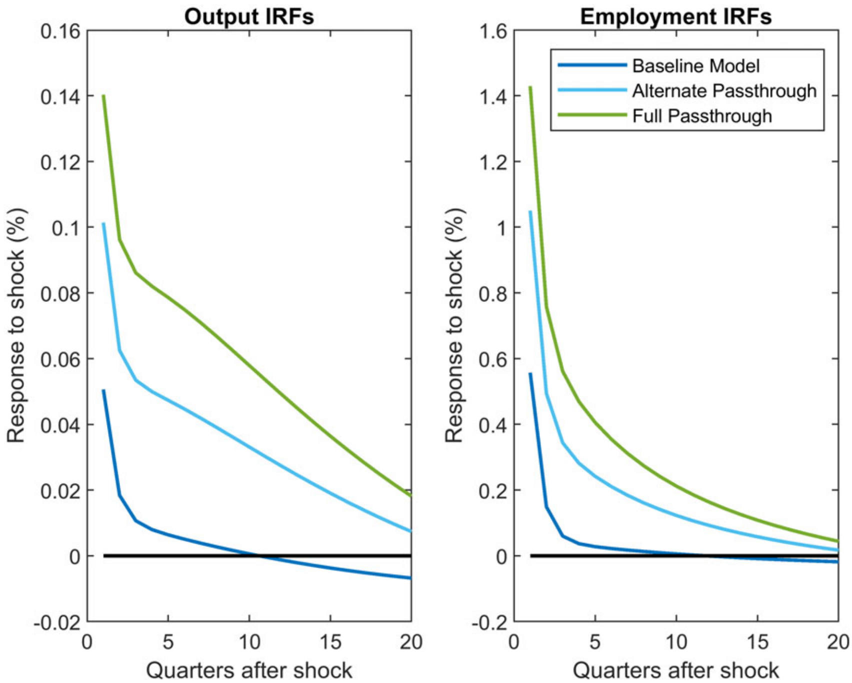

Figure 5. IRFs compared to standard case.
Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25 bp downward shock in the national risk-free interest rate (annualized). The alternate model sets the passthrough parameter equal to 0.68.

MSAs where possible, and merge to the CUSIP-6 muni issuer codes where possible. After estimating (2) to obtain coefficients θ on monetary shocks separately for each issuer code, I then estimate the following equation for each issuer i in MSA j:

$$\log Peak_{ij} = 1 + \beta_1\theta_i + \beta_2\%Gov_j + \beta_3\%Gov_j * \theta_i + \beta_4 \log Density_j + \beta_5 \log Income_j + \varepsilon_{ij} \quad (30)$$

Here, $Peak_{ij}$ is the peak employment response to an expansionary monetary shock and θ_i is the estimated CUSIP6-level response of municipal bonds to monetary shocks. $\%Gov_j$, $Density_j$, and $Income_j$ are MSA-level explanatory variables from Francis et al. (2012) corresponding to percent employed in the government sector, population density, and median income; $\%Gov_j$ and $Density_j$ especially emerge in their paper as significant determinants of local monetary policy transmission.

Encouragingly for the model, higher muni yield responses are associated with more monetary transmission to employment: the estimated effect $\hat{\beta}_1 = 3.40$ with p-value $p = 0.08$ indicate a positive effect of muni responses on monetary transmission. Additionally, the size of the government sector may be associated with stronger monetary transmission (though decreasingly so for higher θ, and not significantly); I show in Appendix E.4 that this is also a prediction of the model. While the data is limited, these simple results align with predictions of the quantitative model.

Why is this heterogeneity important? First, such differences in passthrough may affect the desirability of a given central bank policy in a monetary union. The results here suggest that, for example, the Federal Reserve should take into account heterogeneous effects on municipal governments across the USA when it is considering a policy.[31] To the extent that a given policy

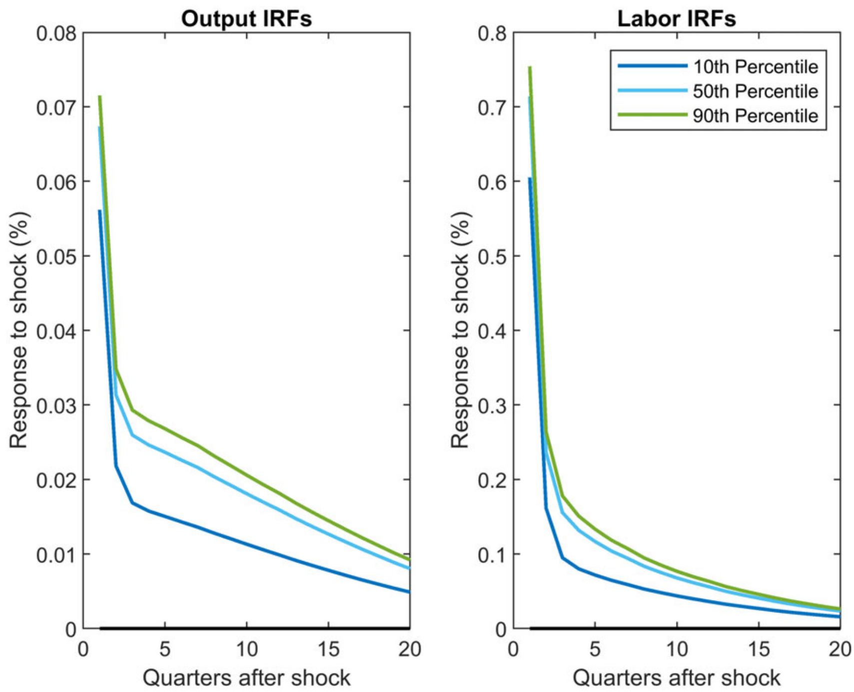

Figure 6. IRFs under muni heterogeneity.
Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25 bp downward shock in the national risk-free interest rate (annualized). Lines correspond to the 10th, 50th, and 90th percentiles of responsiveness to an interest rate shock in the full multi-region economy.

can strengthen the relationship between treasuries and munis, that policy can increase the short-term output effects of monetary policy on the economy as a whole. Additionally, since we have a calibrated model of a local government in a monetary union, in which the muni market plays an important role, we can explore how financial markets have affected local governments in past crises.[32]

5. Conclusion

This paper has provided a framework for understanding the passthrough of monetary policy to localities in the USA through state and local government spending. Municipal bond yields in the data exhibit dampened but heterogeneous responses to monetary shocks. These responses may be affected by liquidity in the OTC municipal market, default risk perceptions, or some combination of the two. In an open economy model of a small US region, the financial market underlying municipal borrowing costs affect the local government's ability to borrow and spend on fiscal policy in response to a change in the national risk-free rate.

Realistic heterogeneity in the response of municipal borrowing costs to monetary shocks implies differences of over 20% in output and employment responses to monetary shocks in the calibrated small open economy model. The financial market is important: failing to take into account the dampened response of municipal yields to monetary shocks would overstate the local stimulative effects of monetary policy by more than double. The importance of borrowing costs in determining local fiscal policy provides a playground which may give some insight into local fiscal policies in response to recent economic crises.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1365100524000385

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Competing interests. The author declares none.

Notes

1 Appendix D.1 present some time series evidence of the responses of some public finance variables to monetary shocks. A 1 s.d. expansionary monetary shock increases municipal government spending in the medium term by up to 0.25%, after an initial decrease which is possibly due to decreases in automatic stabilizers.
2 Adelino et al. (2017) find that local governments do in fact respond with spending to lower borrowing costs. I also provide evidence for such behavior in Appendix D.2.
3 The tax-free nature of municipal bonds, in the absence of risk or illiquidity, would imply coefficients of $1-\tau$, where τ is the relevant tax rate. Coefficients lower than this, as I find here, suggest the presence of illiquidity.
4 Those transaction-level municipal bond data are obtained from MSRB. Appendix C.1 describes the data selection procedure.
5 I follow GYZ in choosing a 2 day window; their alternative window of 6 days produces similar results.
6 As in GYZ, if the monetary shock is properly identified, it is appropriate to include it as the only regressor.
7 All of these indices are available for download at https://www.spglobal.com/spdji/en/index-family/fixed-income/.
8 More information is available from S&P for each index; for example, the methodology for the baseline index is found at https://www.spglobal.com/spdji/en/documents/methodologies/methodology-sp-municipal-bond.pdf.
9 Suppose that the tax-free nature of municipals were the only difference between munis and corporate bonds. In this case, the yield on municipal bonds y^m would simply be the after-tax return of corporate bonds, $(1-\tau)y^c$. The link between munis and treasuries, then, would be the coefficient on corporates discounted by the tax rate, $\frac{\partial y^m}{\partial r}=(1-\tau)\frac{\partial y^c}{\partial r}$. To the extent the coefficient on munis is lower than this, I say that the response of munis is *dampened* relative to corporates, for reasons other than their tax-free nature.
10 Additionally, in Appendix D.4 I investigate some alternative specifications. There is no significant difference between positive and negative monetary shocks, and including controls for the stock market does not affect the results.
11 A number of states prohibit or limit the use of GO bonds.
12 We can reject that New York's response is 43.85 or higher, though the standard error bands for the two estimates do overlap. Even though sample size reduces power in this exercise, I interpret these results as evidence of heterogeneity across location given the remarkable consistency of coefficients for most of the sector-level indices and for state vs. local bonds.
13 The majority of munis fall in the investment-grade category.
14 Another way in which municipal bonds may differ from each other is the sector for which the bond was issued, especially for revenue bonds. Many local government entities may issue debt: schools, utility authorities, etc. While not directly entering a local government's general fund, these bonds do contribute to the overall burden of debt for local governments in a given places. Perhaps surprisingly, there is not much evidence of heterogeneity in the responses of these indices by sector, whose results can be found in Appendix D.5. Most of the coefficients, with a small number of exceptions, are close to and slightly lower than the baseline estimate of around 0.26.
15 Anderson and Cesa-Bianchi (2020) use one week for corporate bonds, and I double this window to allow for more trading to occur.
16 Appendix D.6 presents panel evidence that both risk and liquidity factors influence the heterogeneity in responses.
17 The model builds on the canonical Calvo model found in Schmitt-Grohe and Uribe (2003), adding the municipal government sector and hand-to-mouth consumers.
18 Note that fiscal policy in this model is "passive" in the sense that policymakers are concerned primarily with the efficient provision of public goods. The local policymaker does not factor explicitly its general equilibrium effects on the economy via output, prices, or employment. The local policymaker is an agent of the model and can be considered as an extension of the household, in line with the literature on public goods provision. Beetsma and Jensen (2005) shows that such passive policies in a two-economy fiscal union result in welfare loss relative to centralized optimization or fiscal policy rules, and Carlino and Inman (2013) finds that indeed US states have the tools to achieve stabilization policy through deficit spending. However, it is reasonable to think of small local economies in the USA as being more concerned with public goods provision than stabilization at the level of a fiscal union. In a case in which the local government was a Ramsey optimizer, optimizing

according to a fiscal rule, or if fiscal policy was coordinated at the union level, its adjustments would "lean against" monetary policy, which is contrary to the data on local government responses to monetary policy (Appendix D.1).
19 The representative local government in this model takes the tax rate as a given. While state and local governments do have control over tax rates, these rates, especially for large distortionary taxes such as income and sales taxes, do not vary much at the quarterly or annual frequency. In the face of an acute shock, tax rates will tend to be fixed in the short run. This is a key friction in the model which motivates debt issuance.
20 The relaxation of market clearing at the union-wide level is essentially a preservation of the assumption of an external financial market with which households and governments trade. This allows the monetary authority to easily set r_t^*. Such an approach is consistent with the regional model found in Beraja et al. (2019).
21 The main result is in Adelino et al. (2017), which I discuss in Section 2.1. Table 7 in the Appendix presents additional suggestive evidence that public finances do indeed respond to borrowing costs.
22 This imposition captures two features of the real world. First, it is more reasonable to assume that a household saves at the risk-free rate than that it borrows at this rate, and I wish to abstract from the market for household debt in this project. Second, it provides a "demand side" for the external financial market; while not strictly necessary here, it may be helpful for the reader to be able to think of having borrowers and savers in the model.
23 Similar results for the OTC model of Appendix B can be found in Appendix E.2.
24 I also set $\phi^H = 1$. This matches fairly well the persistence of the household debt response to a monetary shock in the Christiano et al. (1996) style procedure mentioned previously, as well as the magnitude of the economy's output response.
25 In Appendix E.5 I further explore the effects of fiscal shocks in this model. I find that, for a shock to federal government spending, the effects on the local economy depend crucially on whether the federal government is purchasing local output or output from elsewhere. Federal spending on public goods crowds out local spending on public goods and is only stimulative when that spending occurs locally.
26 I perform the perturbations for this calibration using the `Dynare` package for `Matlab`. This produces similar IRFs as the "MIT Shock" method for the stripped-down model.
27 That shock corresponds to a 25 bp shock to the annualized interest rate.
28 In Appendix E.3, I show that the inclusion of an explicit limit on debt issuance can dampen the effect even further, resulting in another potential source of heterogeneity, depending on the distribution of such limits in practice.
29 The comparison here reflects cross-sectional heterogeneity, but time-varying relationships between munis and treasuries would generate similar time-varying differences in transmission. I find no significant evidence of time-varying coefficients; however, the time series sample is limited.
30 Many thanks are due the authors for graciously providing data and code to reproduce these estimates.
31 In addition to *cross-sectional* heterogeneity, the model also suggests implications for monetary policy in different states of the world. If interest rate responsiveness varies over time, so will the strength of this transmission channel.
32 Appendix E.1 shows that this model can explain the failure of state and local expenditures to expand in the aftermath of the 2008-2009 recession as they did following the previous six recessions.

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