

The Municipal Government Channel of Monetary Policy

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Abstract

Monetary policy in the U.S. 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, risk, and liquidity. In my baseline estimate, muni yields move 26bp after a 100bp monetary shock. To study implications for local fiscal policy, I model U.S. 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 codes: E52, E62, E63, F41, F45, G12, H72, H74

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1 Introduction

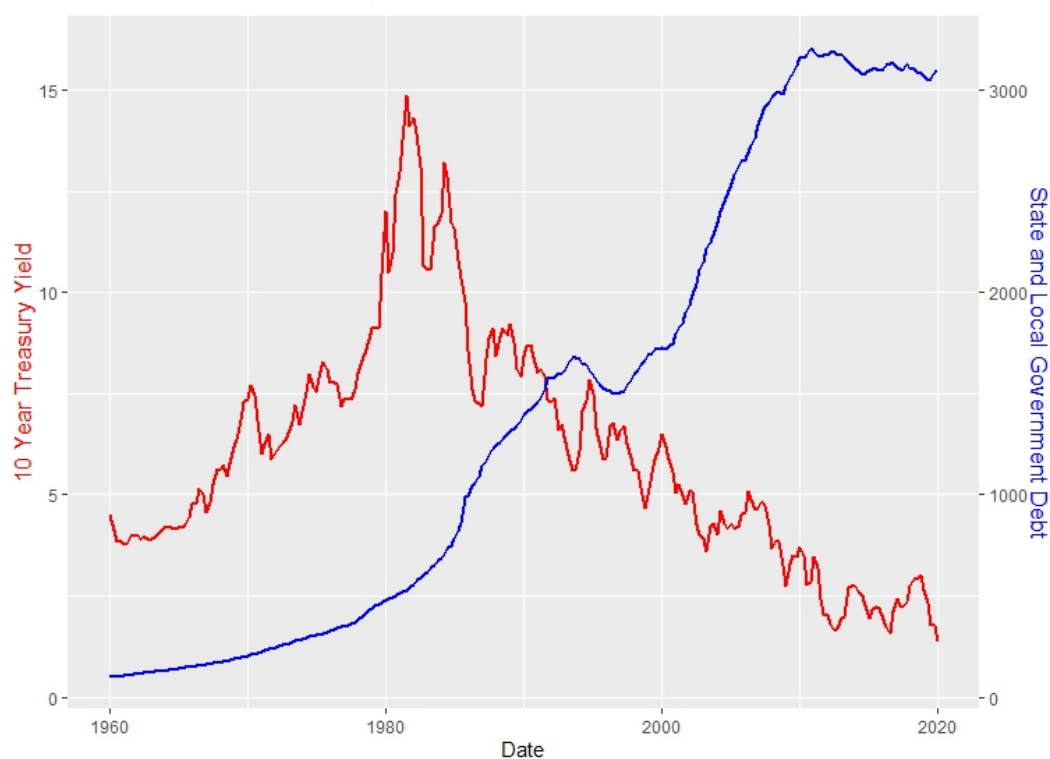
State and local government debt is a significant sector in the U.S. economy, with important implications for monetary policy. In 2019, the market for state and local government (municipal) bonds was valued at \$3.9 trillion, over 1/3 the size of the corporate bond market and greater than 3% of the valuation of the global bond market. Additionally, while most state and local governments in the U.S. 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, especially as interest rates have fallen (Figure 1). 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 fall¹, 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 26bp in response to a 100bp decrease (increase)

¹Appendix 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.

Figure 1: Municipal Debt and Treasury Rates, 1960-2020



Note: Treasury yields are reported in percentage points, quarterly, and obtained from the OECD via FRED. State and local government debt is reported in nominal USD (billions), quarterly, and obtained from Federal Reserve Table Z.1 via FRED.

in treasury yields, though there is sizeable heterogeneity across U.S. states, driven in part by liquidity and default risk factors. I then outline a framework for modeling U.S. 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-free 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 U.S. 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 bonds in the United States increase 26bp in response to a 100bp 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 22bp to 44bp 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.

To investigate the role of illiquidity in municipal bond responses to monetary shocks, I use transaction-level MSRB data of municipal bonds. An exercise as in Gilchrist, Yue, and Zakrajšek (2019), who are concerned with sovereign bonds, suggest liquidity factors play a role in determining municipal yield responses. This is consistent with literature documenting search frictions, bargaining power, and transaction costs in the municipal bond market. I

²Adelino, Cunha, and Ferreira (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.

also connect the bond microdata 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 U.S. 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 non-zero portion of observed dispersion of monetary transmission across U.S. 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 U.S. 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.

Given that I have constructed a model of state and local governments that links financial markets and business cycles, it is natural to use the model to lend insight into other macroeconomic questions. I use the model to provide an explanation for why state and local government spending decreased in the wake of the 2008 recession, the first time it has ever done so. In my model, a real recession induces fiscal stimulus, but the same recession combined with a lockup of financial markets causes a fiscal contraction; this result suggests the financial nature of the 2008 recession placed heavy constraints on the ability of municipal governments to respond.

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), Farhi and Werning (2017b), 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, Gertler, and Gilchrist (1999), McKay, Nakamura, and Steinsson

(2016), and Kaplan, Moll, and Violante (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, Thwaites, and Vicendoa (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 U.S., 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. (2019) and Beraja, Hurst, and Ospina (2019). 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 cyclicity of subnational spending and computes some associated multipliers. Finally, the over-the-counter markets version of the model in Appendix B builds on the work of Duffie, Garleanu, and Pedersen (2005), who model OTC markets for financial assets, and Bethune, Sultanum, and Trachter (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 U.S. 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, Hyman, and Shachar (2021) 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, Yue, and Zakrajšek (2019) studies the response of international sovereign yields to U.S. monetary shocks; I perform similar exercises to their paper, but in the U.S. 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 U.S. monetary policy, I also add to a robust literature on municipal bond pricing, especially as it relates to risk and liquidity; mine is the first paper to explore explicitly the roles of these channels in determining monetary policy responses. Two important papers, Schwert (2017) and Ang, Bhansali, and Xing (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, Hollifield, and Schürhoff, 2007a; Green, Hollifield, and Schürhoff, 2007b; Brancaccio, Li, and Schürhoff, 2020; Garrett et al., 2018; Moldogaziev, 2018) 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, Lee, and Murphy (2019), Grigoris (2019), Adelino, Cunha, and Ferreira (2017), and a host of others.

2 The Effect of U.S. 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 liquidity or risk in

the muni market. I find evidence for both possibilities; a transaction-level dataset suggests illiquidity as a key factor, while high-yield (lower rated) indices respond twice as strongly to monetary shocks than the most highly rated indices.

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, Yue, and Zakrajšek (2019), who study foreign bond responses to U.S. interest rate shocks. I find that an index of General Obligation (GO) municipal bonds responds to a 100bp monetary shock by an average of 26bp; furthermore, I find evidence of substantial heterogeneity by state, as responses vary from 22bp to 44bp 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 liquidity and risk can be explored further as possible drivers of monetary transmission (or lack thereof). First, I perform an exercise from Gilchrist, Yue, and Zakrajšek (2019), finding joint significance for indicators of illiquidity, but not risk. I then 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. In any case, my overall results suggest dampened (relative to, say, corporate bonds) but heterogeneous responses of municipal borrowing costs to U.S. interest rate shocks, with which I can use a municipal open economy model introduced in Section 3

³The 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.

to evaluate the characteristics of monetary passthrough via state and local governments.

2.1 The Municipal Bond Market

State and local governments in the U.S. 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, 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 Over-the-Counter (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, Hollifield, and Schürhoff (2007b) 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 an 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 also vary substantially over the business cycle. Table 1 presents basic summary statistics on transaction-level municipal yields⁴ from 2005-2019, as well as during the zero lower bound period of 2008-2014. The mean municipal bond spread from 2008-2014 is more than double its value over the entire sample period, indicating that treasuries decreased by far more than municipals did during this period. There are three main avenues by which yields on municipal bonds might differ from yields on U.S. treasuries of similar maturities, as well as yields of other municipal bonds: taxes, risk, and liquidity. Some differences in marginal tax rates across locations in the U.S. may be driving a small portion of these differences, but Figure 2 suggests that taxes

⁴The transaction-level municipal bond data from MSRB. Appendix C.1 describes the data selection procedure.

are not the whole story.

Factors other than taxes influence municipal bond spreads. Figure 2 highlights that the variance of muni spreads moves at a higher frequency than changes in tax rates, and increased markedly in the wake of the recent financial crisis⁵. Furthermore, note the systematic difference in spread behavior in the aftermath of the financial crisis. In addition to the increase in the variance of spreads, note that spreads move from negative to positive on average. Despite the tax advantage of municipals, yields were higher during and after the crisis than comparable treasuries; in other words, yields on municipals did not decrease as rapidly as yields on treasuries during a time of unprecedented monetary expansion. The changing variance of municipal bond yields over time suggests that macroeconomic shocks likely have heterogeneous effects on municipal borrowing costs.

Table 1: Summary Statistics, Daily Municipal Bond Yields

	Mean	Variance	25th	50th	75th
Yield, 2005-2019	2.760	2.077	1.630	2.743	3.758
Yield, 2008-2014	2.712	2.494	1.452	2.600	3.754
Spread, 2005-2019	0.4216	1.856	-0.535	0.155	1.147
Spread, 2008-2014	0.9137	2.171	-0.076	0.767	1.774

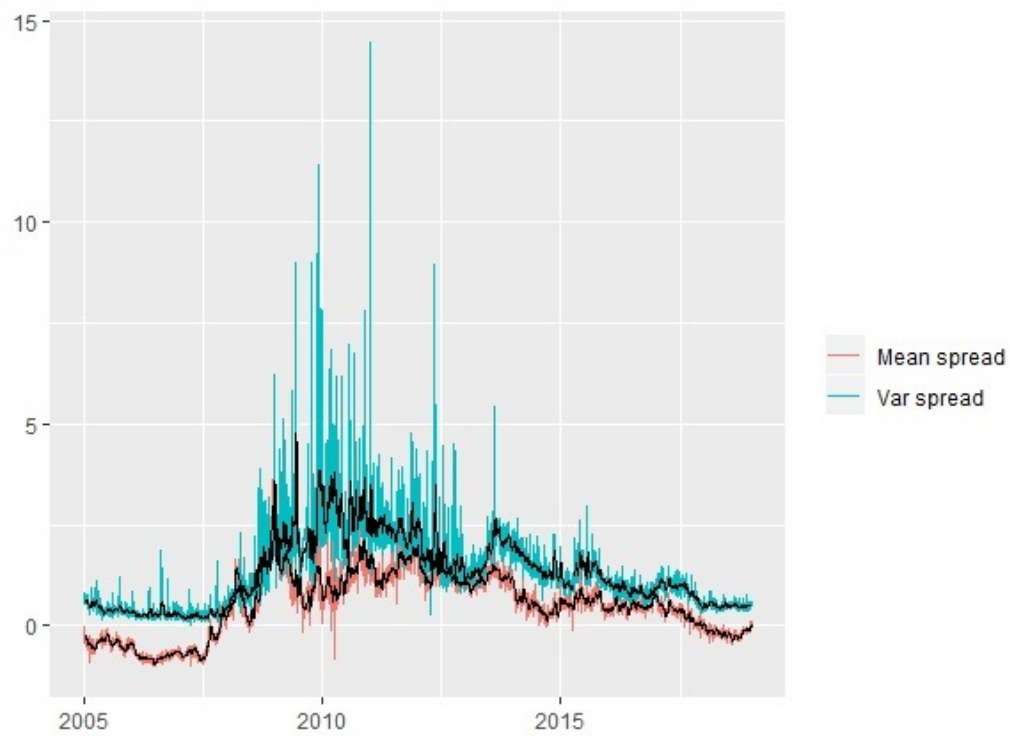
Note: Each variable is the median of daily municipal bond trades in the MSRB dataset. The sample does not include a bond on days in which it is not traded. Spreads are calculated as the difference between a bond's yield and an interpolated hypothetical U.S. treasury bond of the same length to maturity in days.

Heterogeneity in yields will be important for the upcoming framework, as I will 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

⁵The yields plotted here are simply the raw trade-level yields in the MSRB data, described in Appendix C.1.

Figure 2: Muni Spreads Over Time



Note: Municipal bond spread mean and variance is reported in percentage points. Colored lines plot daily moments for all MSRB municipal bond trades in my cleaned sample; black lines are rolling averages of daily moments.

count is found in Adelino, Cunha, and Ferreira (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 Monetary Shocks

For the monetary shocks used in the exercise of this section, I use the strategy of Bu, Rogers, and Wu (2021) to identify monetary shocks on FOMC announcement dates. I give a brief overview of the identification strategy here, with a full presentation in Appendix C.2. The BRW method uses the movements of prices of zero-coupon U.S. Treasury bonds with maturities $i \in \{1, 2, \dots, 30\}$ 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 ten-year Treasury yield:

$$\Delta R_t^{10} = \alpha + m_t + \eta_t. \quad (1)$$

Here ΔR_t^{10} is the one-day movement in the ten-year treasury yield, α is a constant, m_t is the monetary shock at date t , and η_t catches all other factors affecting the yield. Armed with this equation, we can use the change in the ten-year Treasury yield on FOMC dates as a proxy to back out the monetary shocks m_t .⁶

First, we need to estimate the sequence of 30 time series equations

$$\Delta R_{it} = \alpha_i + \beta_i \Delta R_t^{10} + \varepsilon_{it} \quad (2)$$

⁶While the original method uses the five-year yield, I use the ten-year, which corresponds to the average maturity of municipal bonds in the S&P muni indices.

for each zero-coupon bond $i \in \{1, 2, \dots, 30\}$.⁷ Armed with estimates $\hat{\beta}_1, \hat{\beta}_2, \dots, \hat{\beta}_{30}$, shocks can be backed out by regressing the daily yield changes on the set of estimated $\hat{\beta}_i$ on each FOMC announcement date. This requires estimating the following equation for each $t \in \{1, 2, \dots, T\}$:

$$\Delta R_{it} = \alpha_t + \hat{m}_t \hat{\beta}_i + \varepsilon_{it}. \quad (3)$$

The set of estimated \hat{m}_t from each of these estimations is taken to be the monetary shock series.

The Bu, Rogers, and Wu (2021) 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, Sack, and Wright (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 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.

2.3 Time Series Evidence

The main set of results I use for the calibration of the model are time series estimates of the response of municipal yields to monetary shocks based on the yields of muni indices constructed by S&P.⁸ 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

⁷In practice, these are estimated with a heteroskedasticity-based IV approach a la Rigobon and Sack (2004). Details are found in Appendix C.2.

⁸All of these indices are available for download at <https://www.spglobal.com/spdji/en/index-family/fixed-income/>.

sectoral indices, reminiscent of Gilchrist, Yue, and Zakrajšek (2019), who study the effects of U.S. 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.

S&P constructs these indices using a broad selection of bonds issued by state, local, and regional government entities in the U.S., 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 U.S. dollars par value on the market. The indices are constructed as value weighted averages of the constituent bonds.⁹

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

$$\Delta y_t = \beta_0 + \beta_1 m_t + X_t \varepsilon_t, \quad (4)$$

where m_t is the Bu, Rogers, and Wu (2021) monetary shock series and $\Delta y_t = y_{t+1} - y_{t-1}$ is the two-day change in the yield to maturity of the asset around the FOMC meeting date.¹⁰¹¹ The coefficient $\hat{\beta}_1$ reflects the number of basis points the muni index yield should increase for every 1bp monetary shock, and is estimated with heteroskedasticity-robust standard errors.

2.3.1 Baseline Results

This section summarizes the average response of municipal bond yields to monetary shocks. Table 2 gives the estimated coefficients of monetary shocks on yields for three indices of general obligation municipal bonds. These indices group all municipals, state governments, and local governments, respectively, with an index for bonds from S&P 500 firms for comparison¹². I choose to focus on general obligation bonds, which are backed by the full taxing

⁹More 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>.

¹⁰I follow GYZ in choosing a 2 day window; their alternative window of 6 days produces similar results.

¹¹As in GYZ, if the monetary shock is properly identified, it is appropriate to include it as the only regressor.

¹²Suppose 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

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.

Table 2: 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 (0.08)	0.28 (0.08)	0.27 (0.08)	0.57 (0.14)	0.31 (0.14)	0.35 (0.16)	0.35 (0.13)	0.76 (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 one 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.

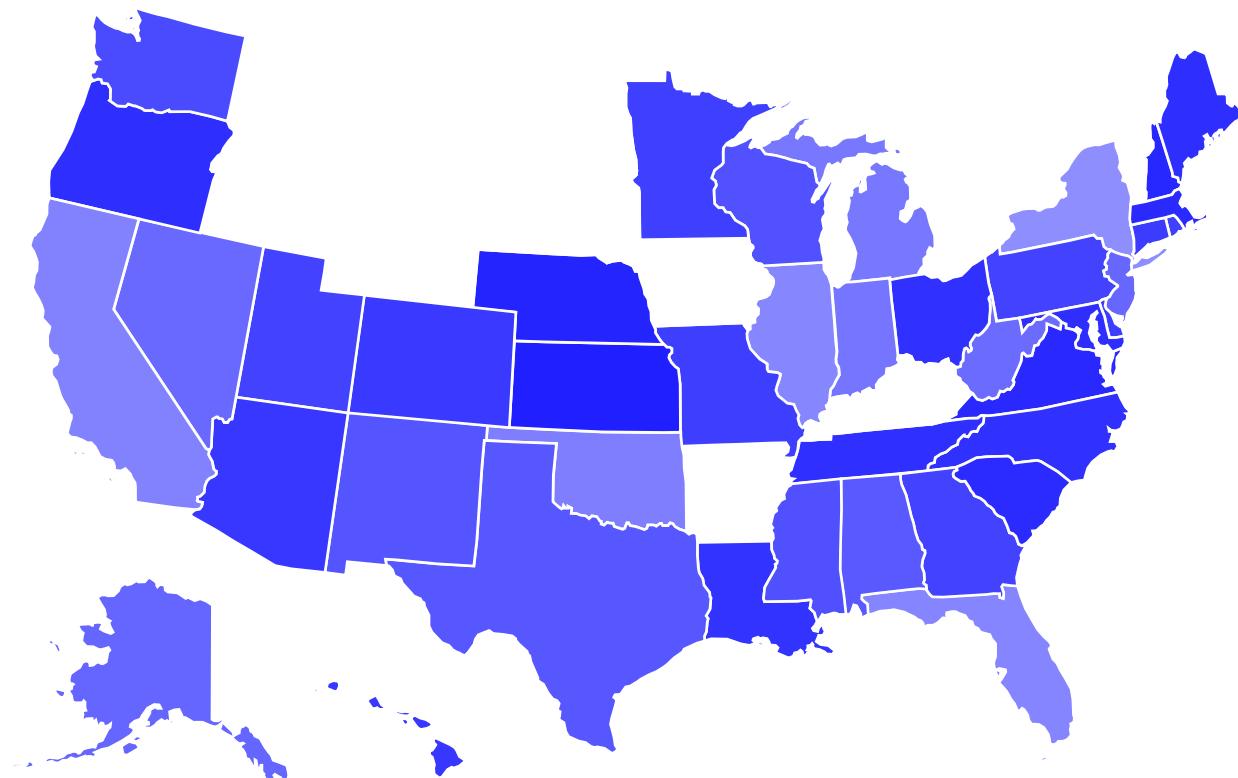
This exercise closely mirrors that of Rosa (2014), though my results exhibit slightly higher responses to monetary shocks than his due to the inclusion of a wider set of bonds and the shock corresponding to the 10-year rate. Nevertheless, the coefficients are quite dampened relative to models in which 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.¹³ 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.

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.

¹³Additionally, 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.

Figure 3: 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).

2.3.2 Heterogeneity by State

A natural place to look for heterogeneity across localities is in the presence of *geographic* variation. For this section, I estimate Equation 4 separately for indices of GO bonds originating in U.S. states, for which these indices exist.¹⁴ Figure 3 summarizes the estimates, highlighting visually the heterogeneity of responses across the U.S.

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.¹⁵ Second, no immediately obvious patterns emerge, save the apparent tendency for high-population areas to have muni bonds which response *more weakly* to monetary shocks; this result appears again in Section 2.4.3. In any

¹⁴A number of states prohibit or limit the use of GO bonds.

¹⁵We 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.

case, the results suggest that heterogeneity exists across space in the U.S. in the response of municipal bond yields to monetary shocks, and monetary policy may affect different areas of the U.S. differently.

2.3.3 Heterogeneity by Risk and Sector

In this section, I investigate heterogeneity in yield responses for muni indices broken out by rating and sector. 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 3: Time Series Results by S&P Rating

	AAA	AA	A	BBB Band	BB Band	NR
Monetary shock	0.15 (0.15)	0.13 (0.14)	0.08 (0.13)	0.23 (0.08)	0.24 (0.12)	0.40 (0.24)

Note: An observation corresponds to one 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.

Table 3 shows the coefficient estimates of Equation 4 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, i.e., 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.¹⁶ 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.

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

¹⁶It is worth noting that the majority of munis fall in the investment-grade category.

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.

Ultimately, this section has documented the presence of heterogeneity in municipal bond responses to monetary shocks, which are dampened on average relative to U.S. treasuries and corporate bonds. The type of government does not seem to make much difference, though smaller and riskier governments have greater responses to monetary shocks. 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, including illiquidity, which is suggested by the consistently low values of these coefficients.

2.4 Panel Evidence: MSRB Data

Monetary shocks have a dampened effect on municipal bonds, with a fair amount of heterogeneity across different types of bonds. There is evidence that risk drives a portion of this, but time series evidence cannot say whether liquidity and transaction costs may also be a contributing factor. Additionally, there may be information about specific local governments that influence the responses of munis to monetary shocks. Knowing that there is heterogeneity in these responses is sufficient 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 sources of 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 general obligation (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

$$\Delta y_{it} = \beta_0 + \beta_1 m_t + \Gamma_0 X_{it} + \Gamma_1 X_{it} m_t + \varepsilon_{it}, \quad (5)$$

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 weeks¹⁷; 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 .

2.4.1 Average Results

Before moving on to other dimensions of heterogeneity, it may be helpful to benchmark baseline estimates in the panel data. In Table 4, I present coefficient estimates of β_1 from Equation 5. These estimates represent four regressions of monetary shocks on muni yields and spreads, and varying the inclusion of controls for time to maturity.

Table 4: Baseline Panel Estimates

	Yield	Yield	Spread	Spread
Monetary shock	0.50 (0.25)	0.68 (0.26)	-0.07 (0.16)	0.11 (0.22)
N	22758	22758	22699	22699
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.

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. In any case, these estimates, should be kept in mind as a baseline as we move through the rest of the section.

¹⁷Anderson and Cesa-Bianchi (2020) use one week for corporate bonds, and I double this window to allow for more trading to occur.

2.4.2 Liquidity and Risk

In addition to time series evidence on the effect of monetary policy on sovereign bond yields, Gilchrist, Yue, and Zakrajšek (2019) also perform an experiment to evaluate the effects of risk and liquidity on these responses.¹⁸ Specifically, in the context of Equation 5, X_{it} includes an indicator for whether a bond is investment grade or not (S&P rating BBB- or above), as well as a series of basic characteristics that the authors argue may *influence* liquidity: par value $\log PAR_i$, age $\log(1 + AGE_{it})$, time to maturity $\log T2M_{it}$, and coupon $\log(1 + COUP_{it})$. Furthermore, the response variable is the change in the muni spread rather than the yield.

Table 5 reports results from this estimation exercise, along with a joint test for the significance of the liquidity variables together. While none of the individual interactions are significant, the interactions of the four liquidity variables are significant for determining yields—and are close to significant for determining spreads—suggesting a role for bond characteristics in the responses of borrowing costs. Finally, while the coefficient on risk is noisy—in contrast to the GYZ results for sovereign bonds—the sign is consistent with theory and time series evidence, in which less risky bonds exhibit lower responses to monetary shocks.

¹⁸Appendix D.3 provides another examination of risk and liquidity, using a method based on Schwert (2017) to extract the risk and liquidity components of municipal spreads, finding mixed evidence on the extent to which these components respond to monetary shocks.

Table 5: Heterogeneous Responses: GYZ Method

	Yield	Spread
Monetary Shock	1.56 (0.96)	1.19 (1.00)
Investment Grade = 1	0.01 (0.02)	0.01 (0.02)
$\log PAR_i$	0.03 (0.00)	0.03 (0.00)
$\log(1 + AGE_{it})$	-0.00 (0.00)	0.00 (0.00)
$\log T2M_{it}$	-0.00 (0.01)	-0.02 (0.01)
$\log(1 + COUP_{it})$	-0.00 (0.03)	0.00 (0.03)
Monetary Shock * Investment Grade = 1	-0.19 (0.20)	-0.21 (0.16)
Monetary Shock * $\log PAR_i$	-0.02 (0.04)	-0.02 (0.04)
Monetary Shock * $\log(1 + AGE_{it})$	-0.01 (0.03)	-0.01 (0.02)
Monetary Shock * $\log T2M_{it}$	-0.15 (0.10)	-0.14 (0.12)
Monetary Shock * $\log(1 + COUP_{it})$	0.21 (0.29)	0.06 (0.29)
P-value, liquidity interactions	0.051	0.103
N	22758	22699

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. Risk and liquidity factors are defined as in Gilchrist, Yue, and Zakrajšek (2019).

2.4.3 Public Finance Variables

The last 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 U.S. Census. This survey obtains hundreds of balance sheet variables for state and local governments in the U.S., taking a representative sample annually and a full population sample every five years. Following Schwert (2017), I select the local governments in the U.S. 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 Equation 5 using numerous different public finance indicators as independent variables in separate regressions to explain municipal yield responses. Results are given in Table 6, 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 and liquidity; 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.

2.5 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 general obligation 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 U.S. 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 or liquidity considerations,

Table 6: 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 (0.044)	Total	-0.125 (0.052)	Population	-0.136 (0.061)
Current	-0.123 (0.043)	General	-0.123 (0.045)	Total Long Term Debt	-0.104 (0.046)
Capital	-0.102 (0.047)	Total Tax	-0.105 (0.042)	Total LTD Issued	-0.112 (0.048)
Construction	-0.077 (0.038)	Property Tax	-0.002 (0.013)	Total Cash and Securities	-0.095 (0.039)
Interest	-0.102 (0.044)	Sales Tax	-0.044 (0.023)	Total Cash and Securities (non-insurance)	-0.122 (0.042)
Benefits	-0.048 (0.018)	Income Tax	-0.025 (0.008)		
Wage	-0.094 (0.044)	Intergovernmental	-0.138 (0.046)		
General	-0.121 (0.045)	Miscellaneous	-0.115 (0.042)		
Education	-0.030 (0.022)	Interest	-0.078 (0.044)		
Health	-0.040 (0.020)	Utilities	-0.009 (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 Equation 5. 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.

which map to a model of over-the-counter debt pricing. 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,¹⁹ reflecting the tens of thousands of distinct municipal governments in the United States. In this model, households choose labor and purchases of local municipal bonds, financial

¹⁹The model builds on the canonical Calvo model found in Schmitt-Grohe and Uribe (2016), adding the municipal government sector and hand-to-mouth consumers.

markets buy and sell bonds, local governments choose spending 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 modelled 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^H . 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 U.S. 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

$$\max_{\{c_t^T, c_t^N, h_t, d_{t+1}\}} E_0 \beta^t [U(c_t) - V(h_t) + W(g_t)], \quad (6)$$

where

$$c_t = A(c_t^T, c_t^N) \quad (7)$$

$$c_t^T + p_t c_t^N + d_t = y_t^T (1 - \tau^G) + w_t h_t + \frac{d_{t+1}}{1 + r_t^H} + T_t. \quad (8)$$

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:

$$\lambda_t = U'(c_t) A_1(c_t^T, c_t^N) \quad (9)$$

$$\frac{A_2(c_t^T, c_t^N)}{A_1(c_t^T, c_t^N)} = p_t \quad (10)$$

$$\frac{\lambda_t}{1 + r_t^H} = \beta E_t \lambda_{t+1} \quad (11)$$

$$V'(h_t) = \lambda_t w_t. \quad (12)$$

Equation 9 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 Equation 9, yields 10, which allocates consumption according to the relative price of the two goods. Equation 11 trades off the benefits of borrowing today with the costs of paying it back tomorrow, and Equation 12 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:

$$c_t^{T,H} + p_t c_t^{N,H} = w_t h_t^H. \quad (13)$$

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

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

$$\lambda_t^H = U'(c_t^H) A_1(c_t^{T,H}, c_t^{N,H}) \quad (14)$$

$$\frac{A_2(c_t^{T,H}, c_t^{N,H})}{A_1(c_t^{T,H}, c_t^{N,H})} = p_t \quad (15)$$

$$V'(h_t^H) = \lambda_t^H w_t. \quad (16)$$

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 calculated.

3.3 Local Government

The representative local government uses local fiscal policy to solve the problem 6²⁰ by choosing a borrowing level d_{t+1}^G subject to

$$g_t = \tau^G y_t^T + \frac{d_{t+1}^G}{1 + r_t^G} - d_t, \quad (17)$$

Other than its choice variables, another key difference emerges for the local government: it exerts full market power over its debt. In other words, while the representative household is a price taker with respect to the interest rate, the local government can only 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

$$W'(g_t) \frac{1 + r_t^G - d_{t+1}^G \frac{\partial r_t^G}{\partial d_{t+1}^G}}{(1 + r_t^G)^2} = \beta E W'(g_{t+1}) \left(-1 + \frac{-d_{t+2}^G \frac{\partial r_{t+1}^G}{\partial d_{t+1}^G}}{(1 + r_{t+1}^G)^2} \right). \quad (18)$$

In an analog to the household's debt decision, the government uses debt issues to balance government increased spending now with decreased spending from debt obligations later. 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

²⁰Note 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 stimulative effects on the economy. 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 U.S. states have the tools to achieve stabilization policy through deficit spending. However, it is reasonable to think of small local economies in the U.S. 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 optimizing according to a fiscal rule, or if fiscal policy was coordinated at the union level, its borrowing costs would not matter for fiscal adjustments. Additionally, these adjustments would “lean against” monetary policy, which is contrary to the data on local government responses.

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 New Keynesian Production

3.4.1 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

$$y_t^N = \left(\int_0^1 (y_{it}^N)^{1-\frac{1}{\mu}} di \right)^{\frac{1}{1-\frac{1}{\mu}}}, \quad (19)$$

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,

$$y_t^N = (1 - \kappa)c_t^N + \kappa c_t^{N,H} + g_t, \quad (20)$$

so the relevant demand equations become

$$y_{it}^N = ((1 - \kappa)c_t^N + \kappa c_t^{N,H} + g_t) \left(\frac{P_{it}^N}{P_t^N} \right)^{-\mu}. \quad (21)$$

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

3.4.2 Intermediate Goods Producers

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

$$y_{it}^N = h_{it}^\alpha, \quad \alpha \in (0, 1]. \quad (22)$$

The choice variable for these firms is the price for good i , P_{it}^N , which determines demand for the intermediate good as in Equation 21. 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.

Plugging in the demand equations and production functions, period t profits for the intermediate goods firm are given as a function of the chosen price P_{it}^N :

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

Prices are sticky according to a Calvo mechanism, i.e., 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

$$mr_t = \frac{\mu - 1}{\mu} y_t^N p_t (\tilde{p}_t^N)^{1-\mu} + \beta \theta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\tilde{p}_t^N}{\tilde{p}_{t+1}^N} \frac{1}{\pi_{t+1}^N} \right)^{1-\mu} mr_{t+1} \quad (23)$$

and

$$mc_t = \frac{1 - \frac{1}{\mu}}{\alpha} (y_t^N)^{\frac{1}{\alpha}} w_t (\tilde{p}_t^N)^{-\frac{\mu}{\alpha}} + \beta \theta E_t \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{\tilde{p}_t^N}{\tilde{p}_{t+1}^N} \frac{1}{\pi_{t+1}^N} \right)^{-\frac{\mu}{\alpha}} mc_{t+1}. \quad (24)$$

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

$$1 = \theta(\pi_t^N)^{\mu-1} + (1 - \theta)(\tilde{p}_t^N)^{1-\mu}, \quad (25)$$

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

$$1 = \theta s_{t-1} (\pi_t^N)^{\mu/\alpha} + (1 - \theta) (\tilde{p}_t^N)^{-\mu/\alpha}, \quad (26)$$

3.5 Financial Sector

As mentioned before, 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

$$r_t^H = f^H(d_t, d_{t+1}, r_t^*, m_t) \quad (27)$$

and

$$r_t^G = f^G(d_t^G, d_{t+1}^G, r_t^*, m_t). \quad (28)$$

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 over-the-counter 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.

3.6 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 $s \in \{1, \dots, S\}$. These economies exchange tradable goods and debt with each other, as well as with the rest of the world.²¹ 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:

$$r_t^* = R(\{y_{st}^T\}_s, \{y_{st}^T\}_s, \{\pi_{st}\}_s). \quad (29)$$

3.7 Equilibrium

A competitive equilibrium is a set of quantities $y_t^N, c_t^T, c_t^N, h_t, g_t, d_t, d_t^G, \lambda_t, \pi_t^N, s_t, mr_t, mc_t$ 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 (9), (10), (12), and (11)
- (ii) Hand-to-mouth quantities satisfy Equations (16), (14), and (15)
- (iii) The government's problem is solved by Equation (18)
- (iv) Marginal revenue and marginal cost are given by Equations (23) and (24), 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 (25) and (26)
- (vii) Inflation is defined by $\pi_t^N = \frac{p_t}{p_{t-1}}$
- (viii) Market clearing in tradable goods implies $(1 - \kappa)c_t^T + \kappa c_t^{T,H} + d_t = y_t^T + \frac{d_{t+1}}{1+r_t^H}$

²¹The 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).

(ix) Interest rates satisfy Equations (27) and (28)

(x) The risk free rate is set by the monetary authority according to Equation 29

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 literature²² 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 26bp in response to a 100bp 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

²²The main result is in Adelino, Cunha, and Ferreira (2017), which I discuss in Section 2.1. Table 10 in the Appendix presents additional suggestive evidence that public finances do indeed respond to borrowing costs.

10th to 90th percentile of U.S. state estimates implies an increase of up to 25 percent 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 U.S. 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 exogenous 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 U.S. 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

In the body of the paper, 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

$$z_t = Bz_{t-1} + \varepsilon_t^z, \quad (30)$$

where $z_t = \left[\log \frac{y_t^T}{y^{T*}} \log \frac{1+r_t^*}{1+r^*} \right]'$, and y^{T*} , 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,

$$r_t^H = r_t^* + \phi^H(\exp(d_t^H - \bar{d}^H) - 1). \quad (31)$$

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*, i.e., $\bar{d}^H < 0$.²³ I set the government's borrowing costs in a similar fashion, but with a friction on the adjustment to the treasury rate:

$$r_t^G = r^* + \theta^G(r_t^* - r^*) + \phi^G(\exp(d_t^G - \bar{d}^G) - 1). \quad (32)$$

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. These pricing functions will be used in the main results of this paper, and similar results for the OTC model can be found in Appendix E.1.

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

$$U(c) = \frac{c^{1-\sigma} - 1}{1 - \sigma} \quad (33)$$

$$V(h) = \Phi \log(\bar{h} - h) \quad (34)$$

²³This 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.

$$W(g) = \gamma \log(g). \quad (35)$$

Furthermore, the consumption aggregator is CES:

$$A(c^T, c^N) = \left(A(c^T)^{1-\frac{1}{\xi}} + (1-A)(c^N)^{1-\frac{1}{\xi}} \right)^{\frac{1}{1-\frac{1}{\xi}}}, \quad (36)$$

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—more on this below.

4.1.2 Parameters

The parameters in the model are set using a combination of data and literature. Table 7 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 U.S.

Table 7: 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	Discount rate	Literature, imply s.s. interest rate of 0.03	0.9694
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	Normalize to log utility	1
ξ	Elasticity of substitution	Literature, set to $1/\sigma$	1/2

The exogenous 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 simply estimate the matrix B as a 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 U.S. 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 general obligation bonds in the empirical section, $\theta^G = 0.26$. In the section studying the effects of heterogeneity in this elasticity, I use the distribution of the state-level estimates as plausible *lower bounds* on the heterogeneity, since they themselves represent averages to some extent. 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 U.S. 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 8. At this

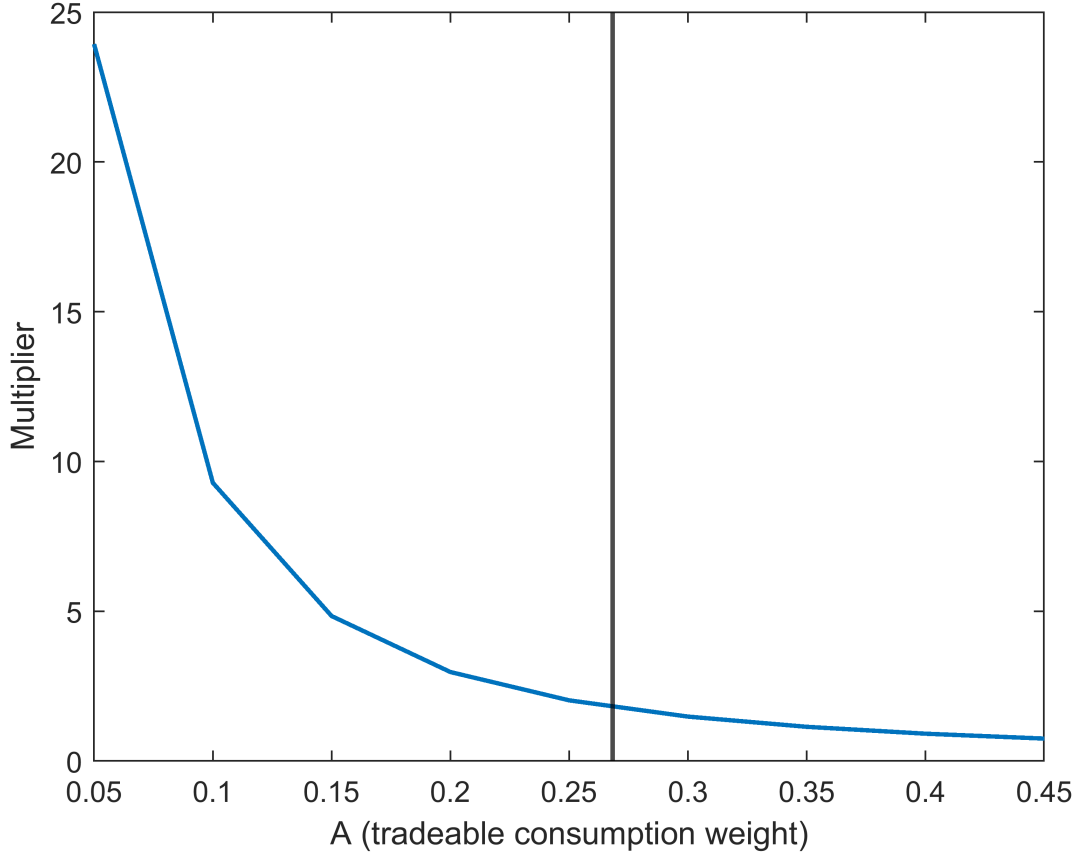
Table 8: Calibration Targets

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	2.75
Local government spending multiplier (Chodorow-Reich)	1.8

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 U.S. 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. Suffice it to say, for now, 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

²⁴I also set $\phi^H = 1$. This matches fairly well the persistence of the household debt response to a monetary shock in the Christiano, Eichenbaum, and Evans (1996) style procedure mentioned previously, as well as the magnitude of the economy’s output response.

Figure 4: Local Government Multiplier and Openness



Note: Blue line indicates the local fiscal multiplier generated by a given tradeable consumption weight. Local fiscal multipliers computed as the unit change in output generated by a unit change in local government spending in a simple version of the baseline model with exogenous government spending.

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.” To see how the choice of openness affects the multiplier, Figure 4 plots the on-impact government spending multiplier as a function of A , holding the rest of the calibration constant.²⁵

In this figure, the vertical line represents the baseline calibration, which is chosen to match

²⁵ ϕ is dependent on the choice of A , for market clearing.

the preferred local government spending multiplier from the literature survey in Chodorow-Reich (2019), which puts forward 1.8 as a good value. Clearly, the impact multiplier 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 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

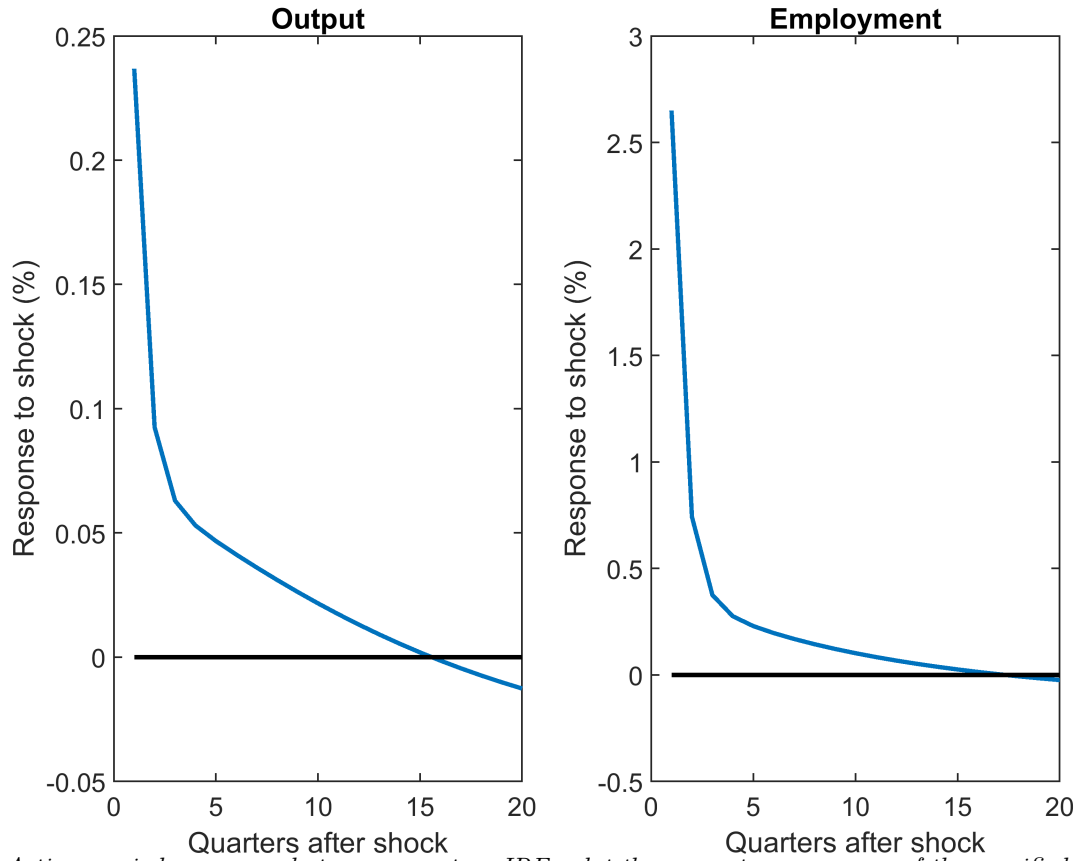
For the results in this paper, I solve for the impulse response functions of the model by simulating the model’s response to a one-time, unexpected shock to the exogenous portion of the interest rate. I assume that the economy is in steady state before the shock, and returns to steady state after 300 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.²⁶ 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 perturbation²⁷.

²⁶In Appendix E.4 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.

²⁷I 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.

Figure 5: IRFs, 25bp Expansionary Shock



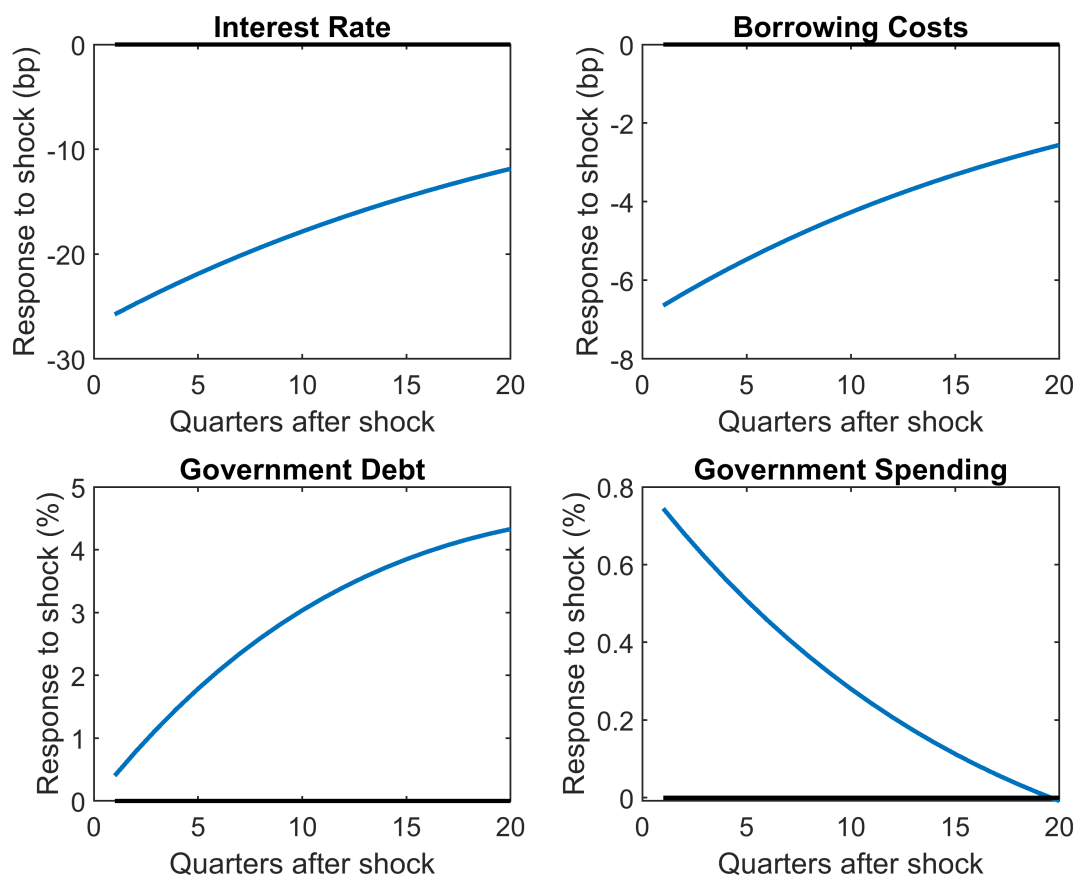
Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate.

4.2 Results of an Interest Rate Shock

The response of this calibrated economy to a 25bp expansionary monetary shock is shown in Figures 5 and 6. 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 25bp decrease in the risk-free rate results in about a quarter percent increase in output on impact.

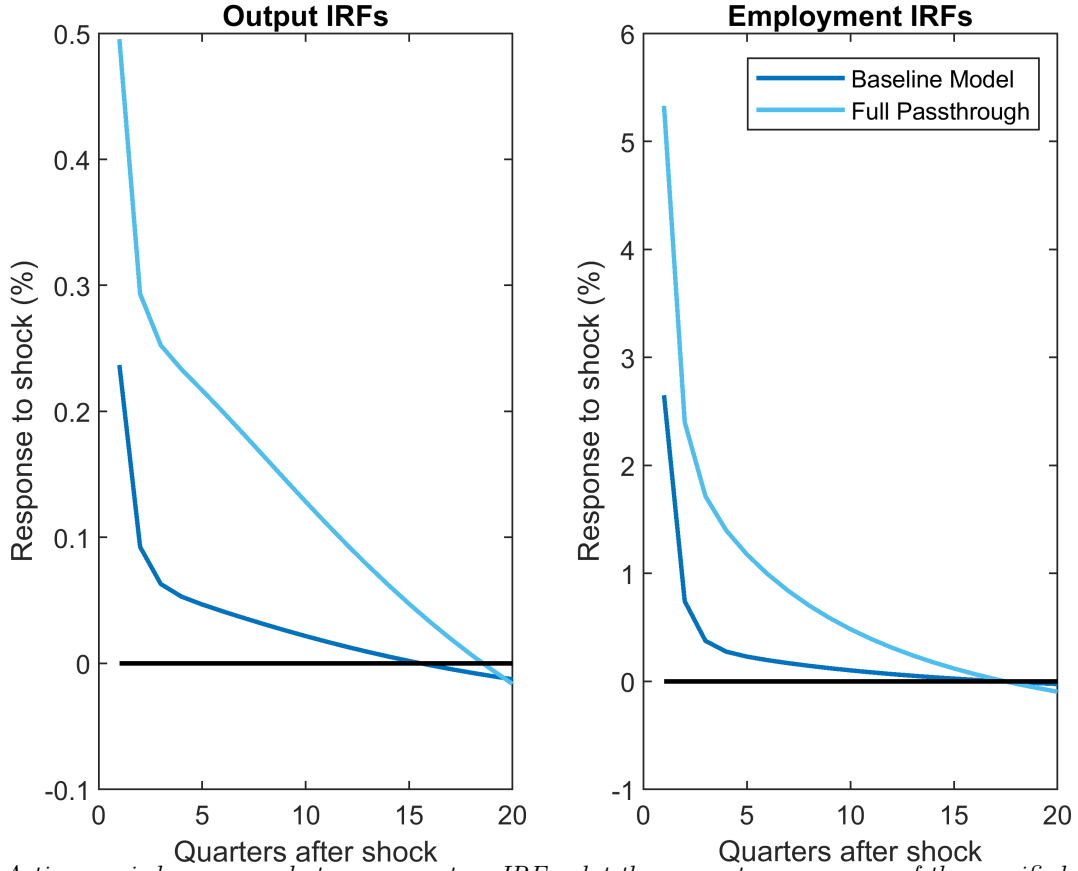
Note, however, there is a long-run effect of the government debt buildup. Because the only margins of fiscal adjustment for the government are debt and spending—revenues are exogenous—the government will have to reverse its debt accumulation through costly decreases in government spending later on. One immediate consequence of this result is the importance of thinking about the long-term consequences of stimulating debt-financed spend-

Figure 6: IRFs, 25bp Expansionary Shock



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

Figure 7: 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 25bp downward shock in the national risk-free interest rate.

ing. 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, even after interest rates have returned to steady state.

In the empirical section, I noted that the responses of municipal yields to monetary shocks were muted relative to what one might expect. 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 and a model with borrowing costs at the risk-free rate, see Figure 7.

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 model with realistic borrowing costs. 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.

In Figure 15, I plot an estimated response of output to a monetary shock according to the Christiano, Eichenbaum, and Evans (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.

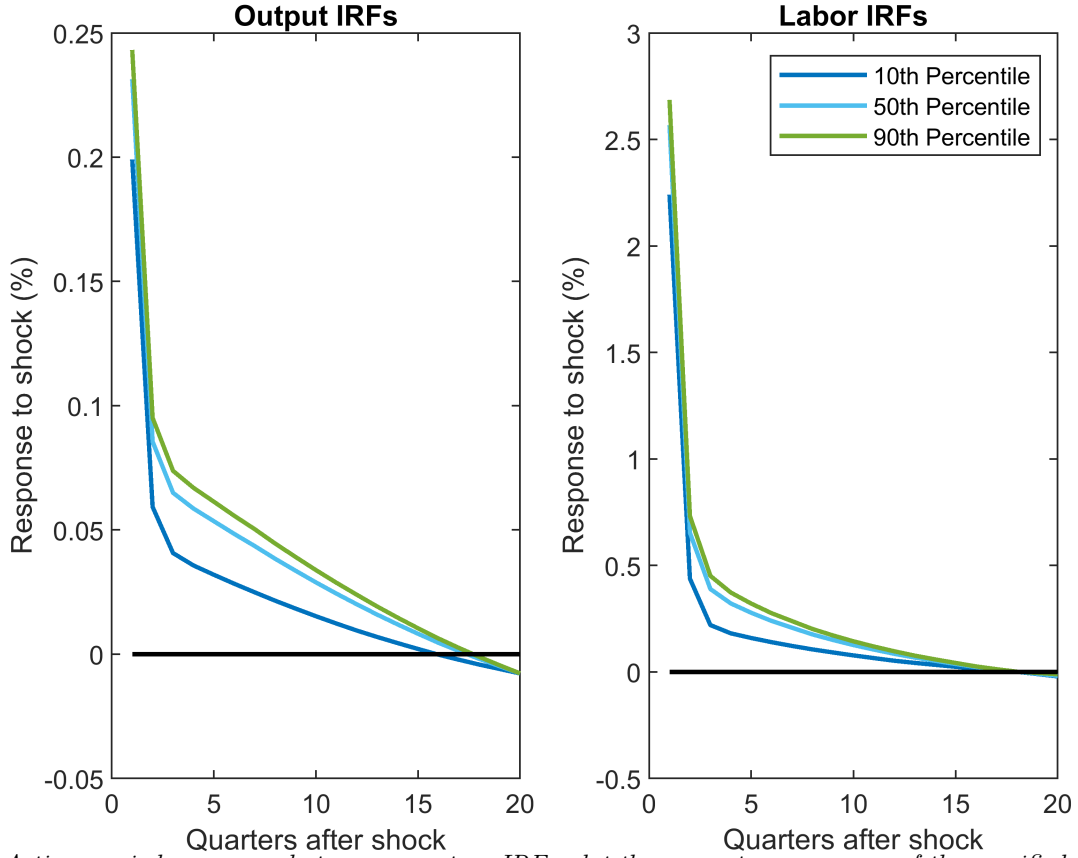
4.3 Heterogeneity Over Monetary Responses

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 U.S. 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 U.S. 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

²⁸In Appendix E.2, I show that the inclusion of an explicit limit on debt issuance dampens the effect even further, resulting in another potential source of heterogeneity, depending on the distribution of such limits in practice.

Figure 8: IRFs Under Muni Heterogeneity



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

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.

In Figure 8, I plot the same impulse response functions to a 25bp risk-free rate shock as in the previous section, for the 10th, 50th, and 90th percentiles of θ^G in the large economy²⁹. 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

²⁹The 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.

increases on impact; the impact effects on output and labor are almost 25 percent 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.

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, Owyang, and Sekhposyan (2012) estimate the responses of several U.S. 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 percent 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. To investigate this in the data, I use the peak employment responses at the MSA level estimated by Francis, Owyang, and Sekhposyan (2012).³⁰ I take the Census of Governments subsample mentioned in Section 2.4.3 and Appendix C.1, assign governments to MSAs where possible, and merge to the CUSIP-6 muni issuer codes where possible. After estimating Equation 5 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 :

$$\log Peak_{ij} = 1 + \beta_1 \theta_i + \beta_2 \%Gov_j + \beta_3 \%Gov_j * \theta_i + \beta_4 \log Density_j + \beta_5 \log Income_j + \varepsilon_{ij} \quad (37)$$

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, Owyang, and Sekhposyan (2012) corresponding to percent employed in the government sector, popula-

³⁰Many thanks are due the authors for graciously providing data and code to reproduce these estimates.

tion density, and median income; $\%Gov_j$ and $Density_j$ especially emerge in their paper as significant determinants of local monetary policy transmission.

Table 9: Determinants of Monetary Policy Transmission

Variable	Coefficient (s.e.)
Intercept	3.75 (2.84)
θ_i	3.40 (1.94)
$\%Gov_j$	7.52 (4.97)
$\%Gov_j * \theta_i$	-20.29 (12.72)
$\log Density_j$	-0.66 (0.09)
$\log Income_j$	-0.32 (0.30)

Note: Results from a regression of $\log Peak_{ij}$ on explanatory variables as in Equation 37. i represents a CUSIP-6 issuer and j represents an MSA. Heteroskedasticity-robust standard errors given in parentheses. N = 125.

Table 9 displays the results from this regression. Encouragingly for the model, higher muni yield responses are associated with more monetary transmission to employment, though standard errors are large ($p = 0.08$). One reason for this is the scarcity of data: only 125 large CUSIP-6 issuers for which I can obtain an estimate of θ are able to match an MSA from the Francis, Owyang, and Sekhposyan (2012) sample. Additionally, the size of the government sector may be associated with stronger monetary transmission (though decreasingly so for higher θ); I show in Appendix E.3 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 U.S. when it is considering a policy³¹. Additionally, to the

³¹In 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.

extent that a given policy 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. Finally, 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 the past. I now turn to an example of such an analysis.

4.4 Application: State and Local Governments During the Financial Crisis

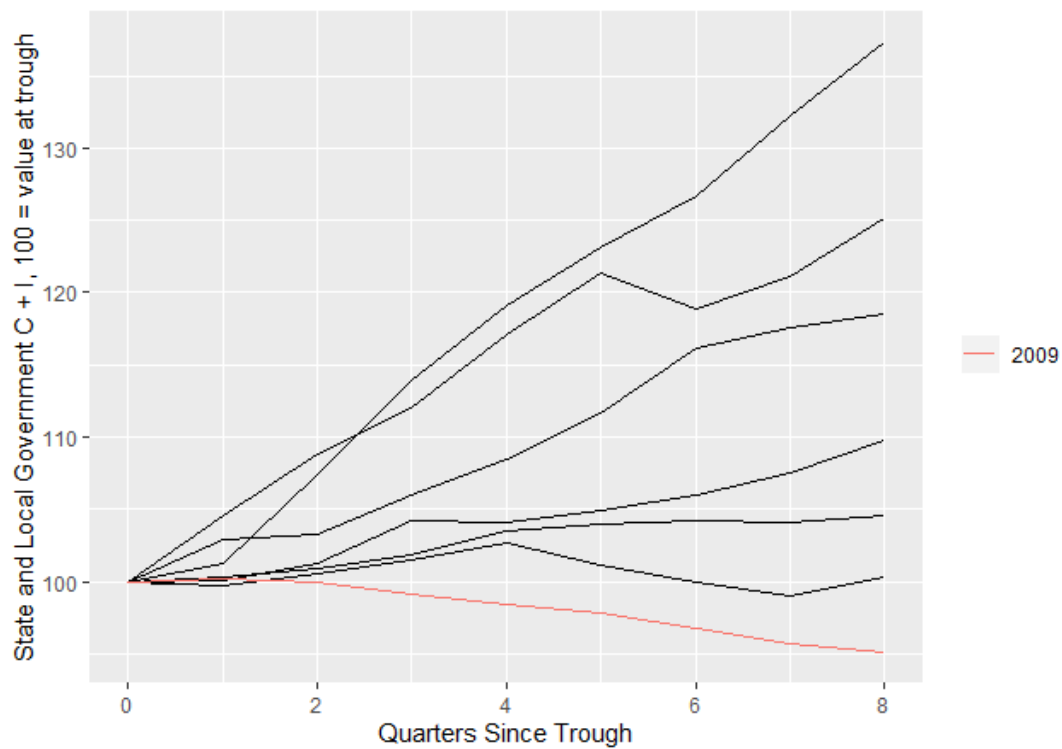
The Great Recession and its subsequent recovery were unique in myriad ways, and the behavior of state and local governments is no exception. For the three recessions leading up to 2008, state and local government expenditures increased during the immediate recovery. In 2009, however, state and local governments *decreased* their spending, representing a break from previous recoveries. Figure 9 shows these recoveries.

One key difference in 2008, aside from the severity of the recession, was the associated crisis in financial markets. The model outlined in this paper allows us to examine the interaction between financial markets and state and local fiscal policy during recessions. Table 1 shows that, while U.S. treasury yields decreased quite dramatically during 2008-2014, municipal bond yields did not move much at all, especially at the high end of yields. This suggests either a decrease in liquidity in muni markets, or an increased perception of risk due to financial conditions.

Figure 10 plots the response of government spending in the open-economy model to two types of models. The first is a simple decrease in the tradable endowment y^T ; in other words, an external crisis. The second combines an external crisis with a *financial* crisis; following the muni market during and after the Great Recession, I define this as a negative shock to θ^G , i.e., a dampening of the ability of municipal bond yields to decrease during the recession, and an increase in ϕ^G , meaning that increasing debt becomes costlier.

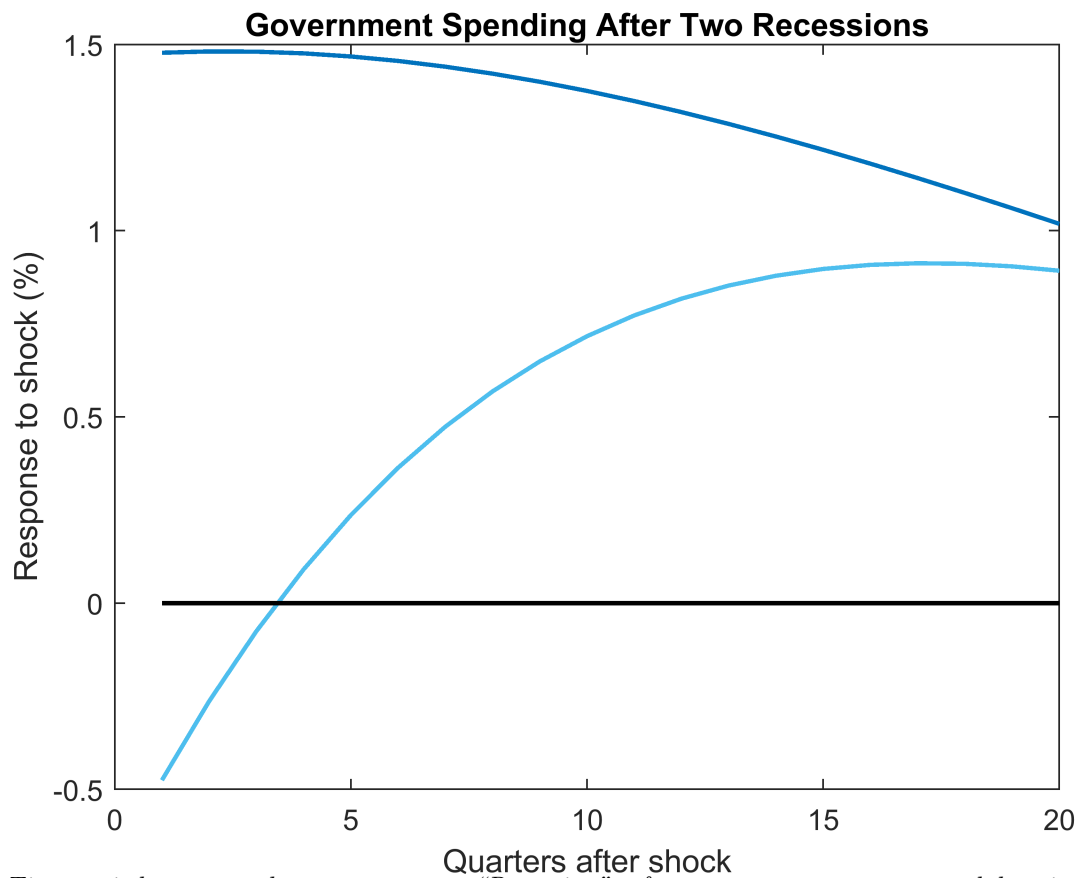
Clearly, the financial crisis dampens the fiscal response of state and local governments to an external crisis. While a *decrease* is not induced for long, the financial crisis does cut out much of the government's fiscal response. A number of factors go in to the fiscal decisions of

Figure 9: State and Local Government Spending After Recessions



Note: Lines represent the paths of real state and local government spending in the aftermath of the 2008-2009 recession (red line) and the previous six recessions (black lines). Spending at the trough is indexed to 100 in each case. Spending is defined as consumption plus investment. Data are obtained from BEA via FRED.

Figure 10: Government Spending After Two Recessions



Note: Time period corresponds to one quarter. “Recession” refers to an exogenous external drop in tradable output; “Financial crisis” refers to a lockup of the municipal market in the form of an inability to respond to lower national interest rates.

these governments in response to crises, including political considerations and budget rules, the non-response of borrowing costs during the Great Recession is likely an important factor in the lack of fiscal response by state and local governments.

5 Conclusion

This paper has provided a framework for understanding the passthrough of monetary policy to localities in the U.S. 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 over-the-counter municipal market, default risk perceptions, or some combination of the two. In an open economy model of a small U.S. 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 percent 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.

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Appendices

A New Keynesian Model Details

This appendix section provides further details on some of the equations in the New Keynesian portion of the model. First, consider again the period t profits of an intermediate goods producer,

$$P_{it}^N (c_t^N + g_t) \left(\frac{P_{it}^N}{P_t^N} \right)^{-\mu} - (1 - \frac{1}{\mu}) W_t (c_t^N + g_t)^{\frac{1}{\alpha}} \left(\frac{P_{it}^N}{P_t^N} \right)^{-\frac{\mu}{\alpha}},$$

where P_{it}^N is the firm's price. When a firm is given the opportunity to set its price, it maximizes the present value of these per-period profits, taking into account the probability θ that its chosen price will continue on to the next period:

$$E_t \sum_{s=0}^{\infty} Q_{t,t+s} \theta^s \left[\tilde{P}_{it}^N y_{t+s}^N \left(\frac{\tilde{P}_{it}^N}{P_{t+s}^N} \right)^{-\mu} - (1 - \frac{1}{\mu}) W_{t+s} (y_{t+s}^N)^{\frac{1}{\alpha}} \left(\frac{\tilde{P}_{it}^N}{P_{t+s}^N} \right)^{-\frac{\mu}{\alpha}} \right].$$

Here \tilde{P}_{it}^N is the chosen price of the firm, W_t is the raw wage in time t , and $Q_{t,t+s}$ is the nominal discount factor that converts income in $t+s$ to payments t ; this discount factor is based on β and λ_t . The first order condition associated with this problem is given by

$$E_t \sum_{s=0}^{\infty} Q_{t,t+s} \theta^s \left(\frac{\tilde{P}_{it}^N}{P_{t+s}^N} \right)^{-\mu} \left\{ \frac{\mu-1}{\mu} \tilde{P}_{it}^N - \frac{1}{\alpha} (1 - \frac{1}{\mu}) W_{t+s} \left[y_{t+s}^N \left(\frac{\tilde{P}_{it}^N}{P_{t+s}^N} \right)^{-\mu} \right]^{\frac{1-\alpha}{\alpha}} \right\} = 0.$$

The first term of the bracketed piece is the marginal revenue in each period, while the second term is the marginal cost. Separating the two terms results in a present value marginal revenue and a present value marginal cost, and recognizing that all adjusting firms will choose the same price \tilde{P}_t^N , marginal costs and revenues can be written recursively as

$$mr_t = \frac{\mu-1}{\mu} y_t^N \tilde{P}_t^N \left(\frac{\tilde{P}_t^N}{P_t^N} \right)^{-\mu} + \theta E_t Q_{t,t+1} mr_{t+1}$$

and

$$mc_t = -\frac{1}{\mu} (1 - \frac{1}{\mu}) (y_t^N)^{\frac{1}{\mu}} W_t \left(\frac{\tilde{P}_t^N}{P_t^N} \right)^{-\frac{\mu}{\alpha}} + \theta E_t Q_{t,t+1} mc_{t+1}.$$

Converting to relative variables $w_t = \frac{W_t}{P_t^N}$, $\tilde{p}_t^N = \frac{\tilde{P}_t^N}{P_t^N}$, and using $\pi_t^N = \frac{P_t^N}{P_{t-1}^N}$ and $Q_{t,t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t}$ results in Equations 23 and 24 from the text.

The nontradable price index is defined by

$$P_t^N = \int_0^1 (P_{it}^N)^{1-\mu} di^{\frac{1}{1-\mu}}.$$

Again using the fact that all prices set in period t will be the same, we see that

$$(P_t^N)^{1-\mu} = \theta (P_{t-1}^N)^{1-\mu} + (1-\theta) (\tilde{P}_t^N)^{1-\mu}.$$

Dividing both sides by $(P_t^N)^{1-\mu}$ gives rise to Equation 25 in the text.

Similarly, to obtain Equation 26, consider the aggregation of total hours worked, along with the definition of production and demand equations:

$$h_t = \int_0^1 h_{it} di = \int_0^1 (y_{it}^N)^{\frac{1}{\alpha}} di = \int_0^1 \left(y_t^N \left(\frac{P_{it}^N}{P_t^N} \right)^{-\mu} \right)^{\frac{1}{\alpha}} di = y_t^{N \frac{1}{\alpha}} \int_0^1 \left(\frac{P_{it}^N}{P_t^N} \right)^{-\frac{\mu}{\alpha}} di.$$

Define price dispersion

$$s_t = \int_0^1 \left(\frac{P_{it}^N}{P_t^N} \right)^{-\frac{\mu}{\alpha}} di,$$

such that now $y_t^N = s_t^{-\alpha} h_t^\alpha$. Again making use of the symmetry of price decisions, we get

$$s_t = \theta \left(\frac{P_{t-1}^N}{P_t^N} \right)^{-\frac{\mu}{\alpha}} + (1-\theta) \left(\frac{\tilde{P}_t^N}{P_t^N} \right)^{-\frac{\mu}{\alpha}},$$

which simplifying gives Equation 26.

B An Over-the-Counter Markets Model for Debt Pricing

While the borrowing cost functions in the model of the main text are presented in a reduced form way, the finance literature provides a path to a microfounded relationship between monetary shocks and municipal yields. Specifically, I consider the class of models for which

Duffie, Garleanu, and Pedersen (2005) was the seminal work, in which the trading of assets on secondary OTC markets is modeled carefully. In summary, municipal bonds are bought and sold to risk-neutral financial firms on primary markets, then sold on secondary markets to buyers who value the bonds highly but are subject to trading costs or incomplete market power. This friction in the secondary market dampens the response of the present value of the asset for financial firms to changes in the aggregate interest rate, thereby muting the primary market price response to monetary policy.

Every period, the municipal government makes debt issues x_t . Municipal bonds pay coupon rate c and mature with probability ν . Governments buy and sell from risk-neutral financial firms at competitive prices. A mass α of municipal buyers purchase bonds from financial firms; these buyers value the asset above its present value, at value v^H . This high valuation can be thought of as reflecting the tax advantage in municipals or warm-glow utility from supporting projects in one's community.³²

The value of the bond for the financial firm, v^F , then, is the present value of the bond at time t , discounted by the expected path of aggregate interest rates r_t :

$$v_t^F = E_t \sum_s^{\infty} \left[c(1 - \nu)(1 - p_{t+s}^{sell}) + (1 - \nu)P_{t+s}p_{t+s}^{sell} + \nu \right] \prod_{k=1}^s \frac{1}{1 + r_k} (1 - p_{t+k})(1 - \nu). \quad (38)$$

The price P_t is the price of the bond on the secondary market, which is determined by Nash bargaining, as in the OTC literature:

$$P_t = \theta v_t^F + (1 - \theta)v^H. \quad (39)$$

θ is a key parameter in the OTC model: it captures the financial frictions in the market resulting from trading costs or asymmetric information, which can broadly be described as contributing to illiquidity in munis. Additionally, p_t is the probability that a given muni held by the financial firm—that does not mature—is sold in period t , which is given by the

³²In support of both of these motivations, Pirinsky and Wang (2011) shows a great deal of market segmentation in the muni market, wherein household buyers tend to buy munis primarily from their own geographic areas.

system

$$\begin{aligned}
p_t^{sell} &= \max \left\{ \frac{\alpha - (1 - \nu)B_t^H}{(1 - \nu)B_t^F}, 1 \right\} \\
B_{t+1}^F &= (1 - p_t^{sell})(1 - \nu)B_t^F + x_t \\
B_{t+1}^H &= (1 - \nu)B_t^H + p_t^{sell}(1 - \nu)B_t^F,
\end{aligned}$$

where B_t^F and B_t^H are the bond holdings of financial firms and buyers, respectively. At any time t , we have $D_t = B_t^F + B_t^H$.

For simplicity, assume municipal governments face the competitive price—the financial firm’s valuation of the bonds—for their issuances and purchases of municipal bonds, v^F . We can now transform this model into the structure of the full model, where $r_t^G = f^H(d_t, d_{t+1}, r_t^*, m_t)$. In the model, the government’s net income from debt purchases is given by $y_t^G = \frac{d_{t+1}^G}{1+r_t^G} - d_t^G$. In the context of an OTC model, this income is given by $y_t^G = v_t^F x_t - (\nu + (1 - \nu)c)d_t^G$. By setting these terms equal to each other, we get that the *effective* interest rate at time t for the municipal government is given by

$$r_t^G = \frac{d_{t+1}^G}{v_t^F d_{t+1}^G + (1 - \nu)(1 - c - v_t^F)d_t^G} - 1, \quad (40)$$

where v_t^F is defined as above. Here, monetary shocks work through the term v_t^F , as they affect the future path of aggregate interest rates r_t .

For this formulation of debt pricing to make sense, we need both that $\frac{\partial r_t^G}{\partial d_{t+1}^G} > 0$ and $\frac{\partial r_t^G}{\partial r_t^*} > 0$.

C Empirical Methodology Appendix

C.1 Sample Selection and Data Cleaning

This appendix describes the process for selecting and cleaning the trade-level municipal bond data for use in the paper. First, I use the Bloomberg terminal to obtain CUSIP codes for all General Obligation (GO) bonds issued by general governments at any time up to present day. Depending on download limits, it may be necessary to break up the downloads into blocks of 5000 bonds or fewer.

Bloomberg provides CUSIP codes for each bond at the 8-digit level, consisting of a 6-digit issuer code followed by a 2-digit issue-specific code. MSRB, however, reports CUSIPs at the 9-digit level. The 9th digit in any CUSIP code is an automatically generated character according to the following algorithm:

1. Assign each character of the 8-digit code a numeric value x_i , with numeric characters being assigned their own value 0–9, and alphabetic characters assigned numeric values beginning with 10: $A = 10, B = 11, \dots Z = 35$
2. Construct a sum $S = \sum_{i=1}^8 (1 + I(i))x_i$, where $I(i) = 1$ if i is even, and $I(i) = 0$ if i is odd. In short, every other x_i is multiplied by 2.
3. Let s be the last (ones) digit of the sum S
4. Assign the 9th digit of the CUSIP code to be the *complement* of s , i.e., $10 - s$, or simply s if $s = 0$.

With the full 9-digit CUSIP codes in hand, I then request the full trade-level MSRB dataset from WRDS, which includes info on every brokered trade of a muni bond included in the list of CUSIPs I provide. This data begins in 2005, when brokers in the municipal bond market were required to provide real-time transaction information to the MSRB, and continues to the present day. The MSRB data includes bond characteristics such as coupon, dated date, and maturity date, and trade characteristics like par value, price, yield, time and date, and whether the trade was a purchase from or sale to a customer or if it was an inter-dealer trade.

I broadly follow Schwert’s conditions for cleaning this trade-level dataset to remove potential errors in the data. This includes all bonds with coupons greater than 20% and times to maturity over 100 years in the future. It also drops individual trades with a yield to maturity of 0, a price outside the range $[50, 150]$, or a recorded trade date after the maturity date. This results in a dataset of 1,587,426 trades from 2005 to 2019.

The dataset used in the main estimation procedure takes the monetary shocks series described below and merges with a dataset of daily yields and spreads. Daily yields and spreads are assumed to be the median value for a bond-day pair. An observation in the resulting data is an FOMC decision day-muni bond pair, with two sets of yields and spreads. The first is the most recent daily price as of the FOMC day, and the second is the most recent daily price as of the day two weeks after the FOMC day; for a bond that has not been traded in two weeks, these two values may be the same.³³

C.2 Identification of Monetary Shocks

As mentioned in the body of the paper, I employ the method of Bu, Rogers, and Wu, 2021 to identify monetary shocks at the FOMC date frequency. The BRW method uses a Fama-MacBeth two-step procedure to extract monetary shocks from a series of U.S. treasury yields. The procedure normalizes monetary shocks m_t such that they enter one-to-one into daily changes in the 10-year treasury yield³⁴:

$$\Delta R_t^{10} = \alpha + m_t + \eta_t.$$

The method then takes the zero-coupon treasury series, representing years to maturity i from $i = 1$ to $i = 30$. Each of these yields are assumed to respond to monetary shocks on FOMC dates according to

$$\Delta R_t^{10} = \tilde{\alpha}_i + \beta_i m_t + \eta_{it}.$$

The first step of the procedure seeks to estimate the series of 30 parameters β_i . Since m_t is

³³Though as I note in the body of the paper, such observations are ultimately dropped.

³⁴The choice of maturity is not crucial to the procedure, a 1-, 2-, or 5- year bond would work, as well. I choose the 10-year to correspond to the maturity structure of the S&P municipal bond indices.

unobserved, the method uses the normalization to R_t^{10} , allowing us to instead plug in and estimate the equation

$$\Delta R_{it} = \alpha_i + \beta_i \Delta R_t^{10} + \varepsilon_{it},$$

where $\alpha_i = \tilde{\alpha}_i + \beta_i \alpha$ and $\varepsilon_{it} = \eta_{it} + \beta_i \eta_t$.

An immediate problem arises in this estimation: ε_{it} is correlated with R_t^{10} through η_t , resulting in a biased OLS estimate. To deal with this issue, the BRW method estimates each β_i using a Rigobon and Sack (2004) instrumental variables method. In short, an estimate for β_i can be obtained from the equation

$$[\Delta R_{it}] = \alpha_i + \beta_i [\Delta R_t^{10}] + \mu_{it},$$

where $[\Delta R_t^{10}] = (\Delta R_t^{10}, \Delta R_t^{10*})'$ and $[\Delta R_{it}] = (\Delta R_{it}, \Delta R_{it}^*)'$. Variables with a * represent a one-day movement in the corresponding rate one week before the FOMC date. The instrumental variable for this estimation is $[\Delta R_t^{IV}] = (\Delta R_t^{10}, -\Delta R_t^{10*})'$. The procedure relies on the assumption that the variance of *non-monetary* news does not change from week to week.

The second step, armed with the IV estimates $\hat{\beta}_i$, then estimates the equation

$$\Delta R_{it} = \alpha_t + \hat{m}_t \hat{\beta}_i + \varepsilon_{it}$$

on each day t , recovering the estimated monetary shocks m_t as the resulting coefficients.

C.3 Schwert Illiquidity Measures

In Appendix D.3 I describe the method for decomposing municipal spreads into risk and illiquidity components, as in Schwert (2017). To construct the illiquidity measure ψ_{it} , I standardize three measures of illiquidity used by Schwert, and construct ψ_{it} as the monthly average of these three measures. The monthly average is used due to the paucity of munis with multiple trades on a given day, which is required for the daily measures.

The first measure originated in Feldhutter (2012), and is intended to explicitly capture the transaction costs introduced by the over-the-counter nature of bond markets, in which bonds might trade at multiple prices at the same time. This is the “Imputed Round-Trip

Cost” measure of illiquidity, and is measured as follows:

$$IRC_{its} = \frac{P_{its}^{max} - P_{its}^{min}}{P_{its}^{min}}, \quad (41)$$

where P is the price, i is a CUSIP code, t is a given day, and s is a trade size. The idea of this measure is to capture the common occurrence in which a dealer matches a buyer with a seller, with the difference in the prices representing the costs of finding and making the transaction. In the data, trades of the same bond on the same day of the same size are coded as round-trip trades, and the daily illiquidity measure is the average of round-trip trades on that day.

Another measure of the transaction costs element of liquidity is the “Price Dispersion” measure from Jankowitsch, Nashikkar, and Subrahmanyam (2011). This measure is similar to the first measure, but uses all prices on a given day. This measure of illiquidity represents the average dispersion around the “market consensus” price, or the average price on a given day:

$$DISP_{it} = \sqrt{\frac{1}{\sum_j Q_j} \sum_j (P_{ij} - M_{it})^2 Q_j}, \quad (42)$$

where j represents a trade of bond i on day t , P_{ij} is the price of trade j , Q_j is the par value of the trade, and $M_{it} = \frac{\sum_j P_{ij} Q_j}{\sum_j Q_j}$. If a bond’s prices are highly dispersed on a given day, it could reflect high transaction costs or inventory risks for dealers, among other sources of illiquidity in bond markets.

The third measure, from Amihud (2002), is meant to capture the price impact of trades for a municipal bond. This is related to the market depth component of liquidity, i.e., the ability of a bond to sustain large trades without large movements in price. If, on a day for which there are multiple price changes for a muni, the average price change relative to trade size is large, then trades are having an impact on prices, and market depth is low. The Amihud (2002) measure, then, is given by

$$DEPTH_{it} = \frac{1}{N_{it}} \sum_{j=2}^{N_{it}} \left| \frac{P_{ij} - P_{i,j-1}}{Q_j} \right|, \quad (43)$$

where notation is the same as above, and N_{it} is the number of trades of bond i on day t . Note that this measure begins with the second trade on a given day, since intraday price changes are the object of interest here.

D Additional Empirical Results

D.1 VAR Evidence of Government Behavior

This section provides aggregate time series evidence on the response of state and local government fiscal policy to monetary shocks. I follow closely the strategy of Christiano, Eichenbaum, and Evans (1996), by estimating the VAR equation

$$Y_t = A + B_1 Y_{t-1} + \dots + B_4 Y_{t-4} + \varepsilon_t, \quad (44)$$

where t corresponds to one quarter. The vector Y includes variables in the following order:

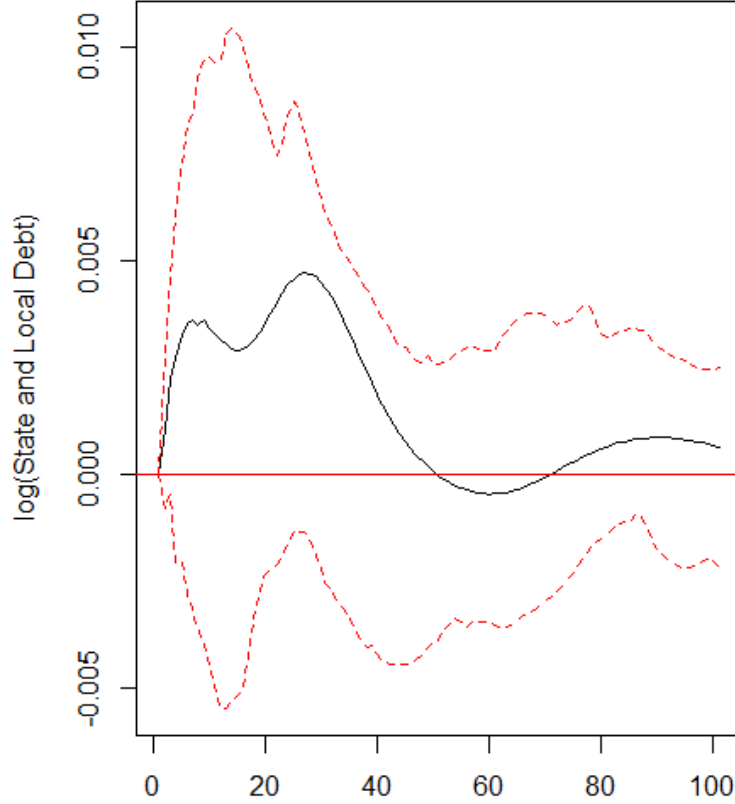
$$Y = [\log GDP \ \log C \ \log P \ \log I \ \log X \ \log WL \ R \ \log \Pi \ \Delta M],$$

where GDP is GDP, C is Personal Consumption Expenditures, P is the GDP deflator, I is private investment, WL is earnings, R is the federal funds rate, Π is profits, and ΔM is the change in M2 from the previous period. t represents a quarter in the U.S.; for monthly variables I use the first month of the quarter.

X here is the response variable of interest, corresponding to state and local government total debt, consumption expenditures, investment, or consumption + investment. The expenditures are reported at the quarterly level as a part of NIPA. Debt is included in the Federal Reserve's flow of funds data; due to a definitional change in 2004, I adjust pre-2004 values to match the post-2004 series, imputing the 2004Q1 growth rate to 2003Q4. Figures 11, 12, 13, and 14 here show the effect of an expansionary shock to the federal funds rate on the variables of interest. Furthermore, Figure 15 gives the estimated response of output in the VAR with debt.

While there is an initial decrease in expenditures in the short run, due to conventional leaning-against-the-wind factors, expenditures do seem to rise in the medium run. This increase corresponds with the peak of the debt buildup response. As such, it is consistent with the borrowing costs channel put forward in this paper.

Figure 11: CEE Impulse Response to Fed Funds Shock



***Note:** Time period corresponds to one quarter. IRF depicts the response of the specified variable to a one standard deviation downward shock to the federal funds rate in the estimated VAR described in Section D.1.*

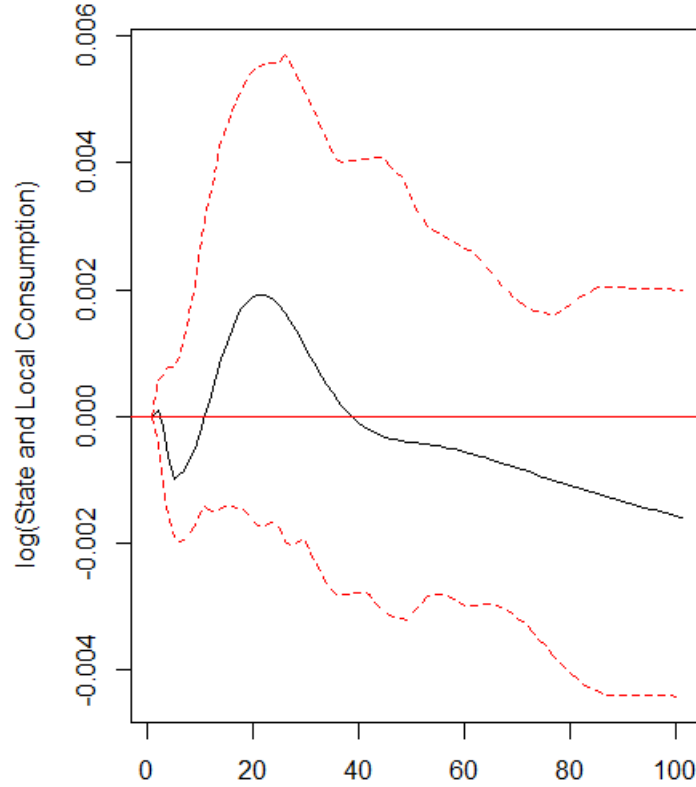
D.2 Borrowing Costs and Government Behavior

To further explore the effects of borrowing costs on local government spending highlighted in Adelino, Cunha, and Ferreira (2017), I connect governments with revenues more than \$50 million from the Census Bureau’s annual survey of state and local governments with CUSIP-6 issuer codes in the MSRB data. I use this dataset to estimate the regression equation

$$\log G_{it} = 1 + \beta R_{it} + \Gamma X_{it} + \varepsilon_{it}, \quad (45)$$

where G_{it} represents a few categories of government spending in a year, while R_{it} is the average yield of that government’s debt on the secondary market and X_{it} is a vector of controls, including the average treasury yield. These yields are instrumented with an annualized

Figure 12: CEE Impulse Response to Fed Funds Shock



Note: Time period corresponds to one quarter. IRF depicts the response of the specified variable to a one standard deviation downward shock to the federal funds rate in the estimated VAR described in Section D.1.

version of the monetary shocks used later in the paper. Results are summarized in Table 10.

Table 10: Government Responses to Secondary Market Muni Yields (IV)

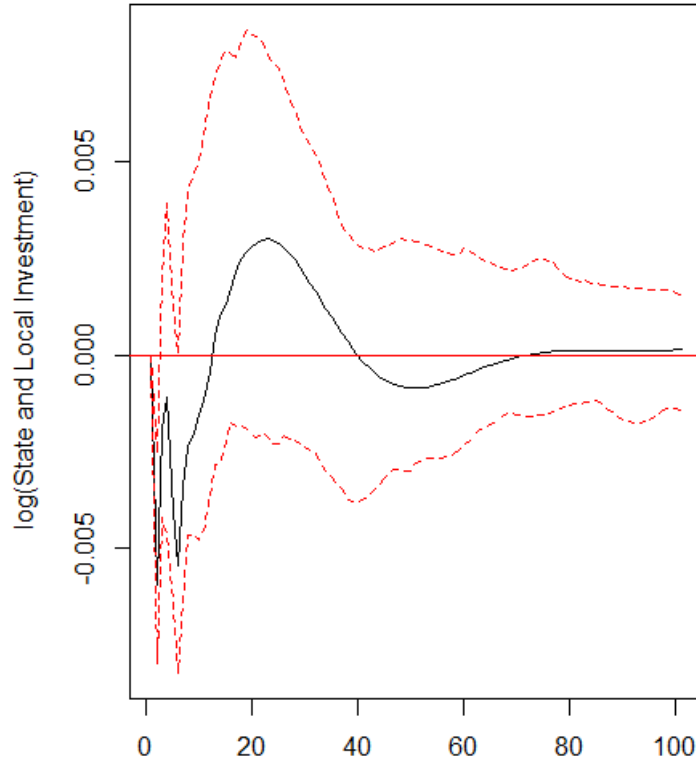
	log(Debt Issues)	log(Current Exp)	log(Capital Exp)
Yield (100bp = 1)	-8.68	1.692	-0.9555
	(5.366)	(1.036)	(0.7759)

Note: An observation is a municipality-year pair. The sample includes all municipalities in the Census Bureau's Annual Survey of State and Local Government Finances for which average revenues are greater than \$500,000 and bonds could be found on the Bloomberg database from 2005 to 2012. Control variables include GDP, municipal revenues, and treasury rates. The explanatory variable is instrumented using summed monetary shocks as described below.

A couple of key suggestive results emerge from this exercise. The first, and most striking, is the apparent massive effect of secondary yields on new debt issues. An decrease of average annual yields on a government's debt of 100 basis points results in a large increase in its new debt issues.³⁵ Municipalities seem to respond in powerful ways to borrowing costs.

³⁵Combined with the relationship between municipal and treasury rates estimated below, this result implies

Figure 13: CEE Impulse Response to Fed Funds Shock



Note: Time period corresponds to one quarter. IRF depicts the response of the specified variable to a one standard deviation downward shock to the federal funds rate in the estimated VAR described in Section D.1.

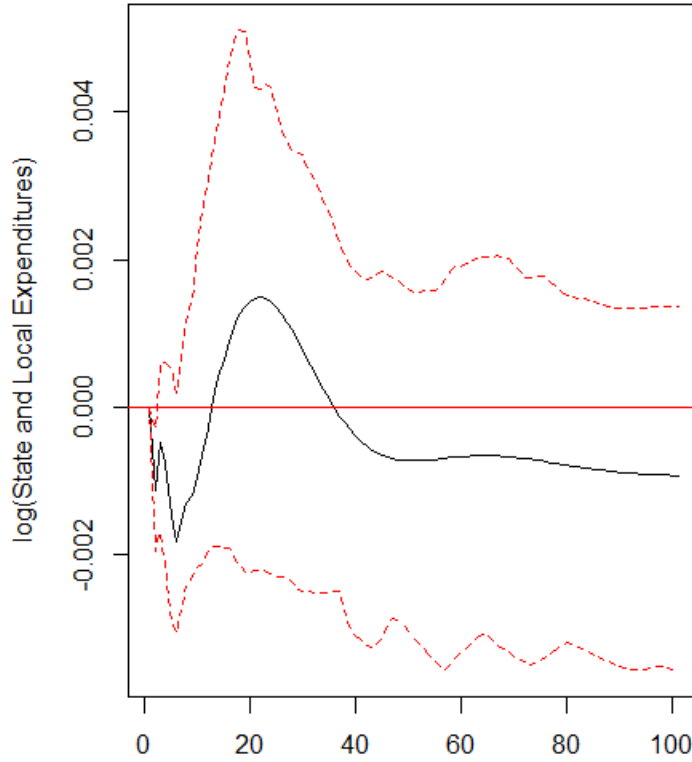
Additionally, note that higher borrowing costs seem to shift the *composition* of municipal spending away from debt-financed capital projects to current expenditures. The secondary market for municipal debt clearly influences states and localities, both in terms of debt issuance and spending composition.

D.3 Schwert Spread Components

This section provides another angle from which to examine the role of risk and liquidity in the response of municipal bonds to monetary shocks. While GYK deals with sovereign bonds, Schwert (2017) is a paper at the frontier of the municipal bond pricing literature. The main exercise in the paper exploits the microstructure of the MSRB data to examine the

that a 25bp expansionary monetary shock drives over a 30% increase in new debt issues for the average local government. This is a larger effect than is seen in aggregate time series evidence (Appendix D.1) or in our experiments below. Disparities arise from data imprecision and compositional effects.

Figure 14: CEE Impulse Response to Fed Funds Shock



Note: Time period corresponds to one quarter. IRF depicts the response of the specified variable to a one standard deviation downward shock to the federal funds rate in the estimated VAR described in Section D.1.

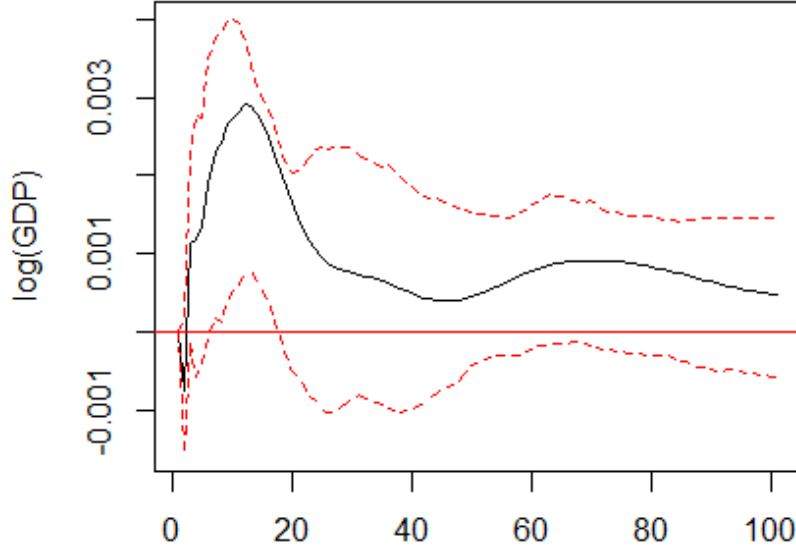
portions of tax adjusted muni spreads that are accounted for by risk and illiquidity concerns. The basic procedure assumes that yields on municipal bond trades are determined according to

$$y_{it} = (1 - \tau)(r_t + \gamma_{it} + \psi_{it}),$$

where τ is the marginal tax rate, r_t is the risk-free rate, γ_{it} is the risk premium, and ψ_{it} reflects illiquidity, perhaps in the form of trading costs or asymmetric information.

To estimate the liquidity component ψ_{it} , the method first constructs λ_{it} , an average of several (standardized) illiquidity measurements from the literature. I describe these illiquidity measures in more detail in Appendix C.3; I follow Schwert closely, dropping a measure that requires more observations in order to extend to a larger sample of municipal bonds from smaller governments. The following equation for (tax-adjusted) spreads is then estimated at

Figure 15: CEE Impulse Response to Fed Funds Shock



Note: Time period corresponds to one quarter. IRF depicts the response of the specified variable to a one standard deviation downward shock to the federal funds rate in the estimated VAR described in Section D.1.

each time t :

$$\frac{y_{it}}{1 - \tau_{it}} - r_t = \beta_0 + \beta_t \lambda_{it} + \beta_t^R \text{Rating}_{it} + \varepsilon_{it}. \quad (46)$$

Here, y_{it} is the daily yield of a bond, τ_{it} is an imputed tax rate,³⁶ r_t is the zero coupon U.S. treasury rate of similar maturity, and Rating_{it} is a factor variables describing the S&P bond rating, if one exists. Armed with a series of betas on each day, the series of liquidity spread components is computed according to

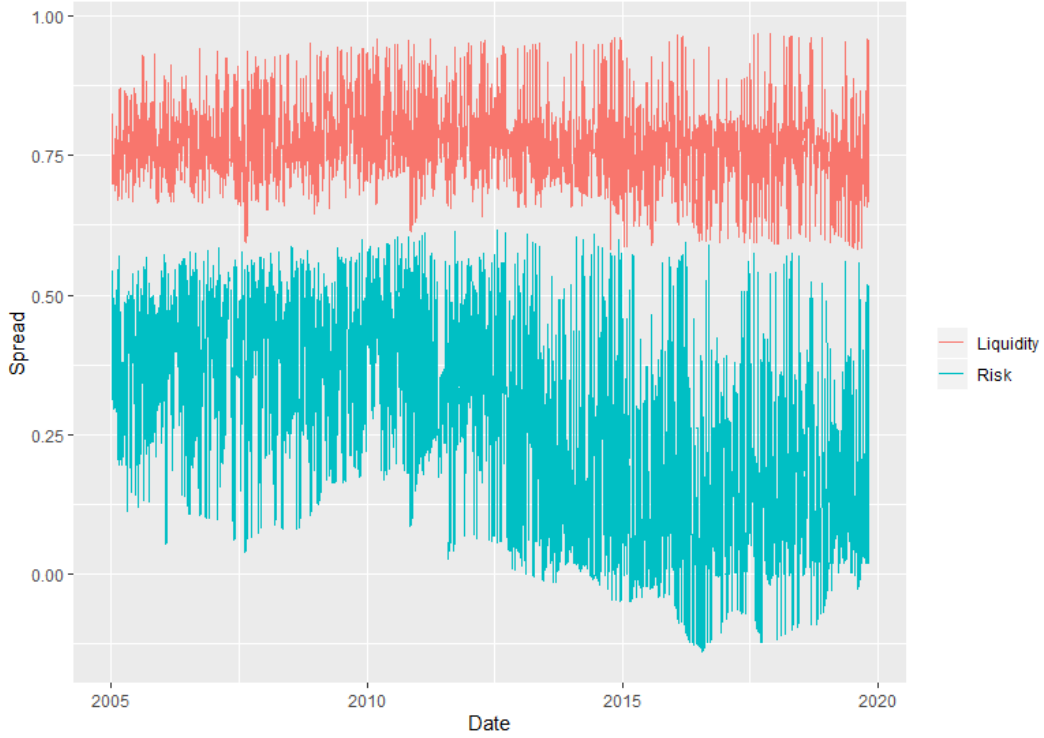
$$\psi_{it} = \beta_t(\lambda_{it} - \lambda_{1t}), \quad (47)$$

where λ_{1t} is the first percentile of the liquidity measure. The risk component, γ_{it} , is simply computed as the portion of the tax-adjusted spread unexplained by the liquidity component.

Because the individual measures of these components are noisy, Schwert aggregates them into time series variables, using the four-month rolling average of daily cross-sectional mean spread components. This results in the time series γ_t and ψ_t , which are plotted in Figure 16.

³⁶In my estimation, this is the same for all bonds, since I want to use this procedure on the full range of the data and cannot match all bonds to a geographic area.

Figure 16: Muni Spread Components



Note: Each line plots the daily measure of liquidity and risk muni spread components described in Section D.3. Data are the cleaned MSRB sample used in the paper.

Note that my estimates of the relative magnitudes of these components differ substantially from Schwert's, which put the majority of the weight on risk; this is because I am using a more extensive sample of municipal bonds, whereas he uses only the largest state and local governments. This suggests a difference in spread makeup between smaller and larger state governments, and merits investigation in future research.

Table 11: Effect of Monetary Shocks on Spread Components

	Default spread	Default spread	Liquidity spread	Liquidity spread
Monetary shock	0.08 (0.25)	-0.17 (0.17)	0.12 (0.07)	-0.06 (0.13)
N	2944	2941	3351	3347
Horizon	2 days	6 days	2 days	6 days

Note: An observation corresponds to one day. Each column refers to a separate regression. Heteroskedasticity-robust standard errors are reported in parentheses.

I estimate the effects of monetary shocks on these series, as in the time series results above, and present results in Table 11. Not much of significance stands out here, although there is

some weak evidence of a transitory effect of monetary shocks on the liquidity component of spreads. Overall, it does not seem, to the extent monetary policy affects borrowing costs in a heterogeneous way, that the effect is working through altering the components of risk and liquidity on spreads.

D.4 Additional Specifications

In this section, I investigate two additional specifications of the baseline results in Table 2. In Table 12, I allow the response of municipal yields to monetary shocks to differ based on whether or not the monetary shock is positive, i.e., in include the indicator $I[Shock > 0]$. Table 13 is the same as in the main body of the text, but controlling for the S&P 500 index. In each of these specifications, I find no significant differences from the baseline results reported in the paper. While the sign of the coefficients in Table 12 indicate the upward shocks might have larger effects, the standard errors are large; additionally, the coefficients in Table 13 are virtually indistinguishable to those in Table 2.

Table 12: Time Series Results, Shock Direction

	All GO	State GO	Local GO	SP 500	All GO	State GO	Local GO	SP 500
Monetary shock	0.22 (0.10)	0.23 (0.10)	0.22 (0.10)	0.62 (0.16)	0.26 (0.17)	0.21 (0.21)	0.34 (0.14)	0.88 (0.23)
Monetary shock * $I[Shock > 0]$	0.28 (0.19)	0.25 (0.19)	0.28 (0.20)	0.19 (0.35)	0.35 (0.35)	0.48 (0.36)	0.26 (0.34)	-0.13 (0.59)
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 one 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 separate time series regression of an index on monetary shocks. Heteroskedasticity-robust standard errors are reported in parentheses.

Table 13: Time Series Results, Controlling for S&P 500 Index

	All GO	State GO	Local GO	SP 500	All GO	State GO	Local GO	SP 500
Monetary shock	0.26 (0.08)	0.28 (0.08)	0.27 (0.08)	0.57 (0.14)	0.32 (0.14)	0.32 (0.16)	0.35 (0.13)	0.76 (0.22)
Horizon	2 days	2 days	2 days	2 days	6 days	6 days	6 days	6 days
N	2144	2144	2144	2144	2136	2136	2136	2136

Note: An observation corresponds to one 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 separate time series regression of an index on monetary shocks. Heteroskedasticity-robust standard errors are reported in parentheses.

D.5 Sector-Level Time Series

In Table 14, I summarize estimates of Equation 4, computed separately for sector-level indices.

Table 14: Sector-level Time Series Estimates

Sector	Coefficient (s.e.)
Airport	0.209 (0.070)
Education	0.240 (0.071)
Health Care	0.199 (0.066)
Higher Education	0.231 (0.073)
Infrastructure	0.243 (0.078)
Land Backed	1.311 (1.096)
Lifecare	0.187 (0.069)
Multifamily	0.172 (0.056)
Nursing	0.509 (0.389)
Port	0.216 (0.072)
Public Power	0.244 (0.093)
Single Family	0.105 (0.035)
Student Loan	0.248 (0.080)
Tobacco	0.289 (0.134)
Toll Road	0.230 (0.078)
Transportation	0.235 (0.074)
Utility	0.234 (0.081)
Water and Sewer	0.228 (0.078)

Note: An observation corresponds to one 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 separate time series regression of an index on monetary shocks. Heteroskedasticity-robust standard errors are reported in parentheses.

D.6 Government Type

In addition to the heterogeneity in the body of the paper, and in order to provide a more comprehensive view of heterogeneity in municipal bond spreads, I investigate the response of muni yields and spreads to monetary shocks on two important dimensions. The first is government type. Insofar as bonds issued by state governments are different in terms

of liquidity (or risk) than their city and county counterparts, these bonds might respond differently to monetary shocks. In particular, if these bonds are on average more liquid than bonds of smaller governments, we might expect their yields to respond more strongly to monetary shocks. One piece of suggestive evidence in this direction is the fact that state governments are disproportionately represented in the sample of bonds which actually record a trade in the window following a monetary shock.

To identify what type of government issued a particular bond, I first retrieve the bond issuer names from the Bloomberg Terminal. I then keep those issuers which include the words “state” or “commonwealth,” and label these the “big” government issuers.³⁷ The estimate of interest, then, is the differential magnitude of response to monetary shocks for these “big” governments *vis-à-vis* other types of governments. Table 15 repeats the estimation of Equation 5, reporting the interaction between the estimated shock and government type.

Table 15: 2-Week Response of Muni Yields to Monetary Shocks, by Issuer Type

	d yield	d yield ($\neq 0$)	d spread	d spread ($\neq 0$)
Big government	0.01 (0.00)	0.06 (0.01)	0.01 (0.00)	0.05 (0.01)
Monetary shock	0.22 (0.07)	0.56 (0.16)	-0.05 (0.06)	-0.10 (0.14)
Monetary shock * Big government	-0.00 (0.09)	-0.21 (0.12)	-0.14 (0.07)	-0.20 (0.11)
N	74648	36870	74584	37579

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

The results lend some further insight into the pattern observed earlier, in which the average response of muni yields to monetary shocks is made up of some bonds that adjust and some that do not. Interestingly, while there is weaker evidence of a differential response *on average* between bonds from big governments and smaller governments, there is a difference conditional on adjustment. Among the bonds which adjust price in response to a monetary shock, the bonds for state governments adjust 35 basis points in accordance with a 100 bp shock, whereas all other bonds adjust 56 basis points on average. Of course, the bonds for

³⁷I can also break out the smaller governments by the words “city,” “county,” “town,” “village,” etc., but the most important distinction seems to be the fifty states versus all other governments. Surely there is heterogeneity within cities and towns; this is a potential direction for future research.

these bigger governments are a larger proportion of the “responding” sample than the full sample; in other words, their yields are more likely to respond to a monetary shock than those of smaller governments. Because these bonds trade at a higher frequency, their price adjustments in response to a given shock, conditional on adjustment, are smaller than those bonds which trade at a lower frequency. The pattern for spreads exhibits a similar pattern, in which the coefficient on the interaction term is more negative and more precisely estimated in the reduced sample; the average response remains zero, as before.

The second additional margin of heterogeneity involves an attempt at a comprehensive measure of unexplained spreads, which is made up of liquidity, risk, and tax components. I residualize the implied spread on every transaction in the original data by regressing out time to maturity and fixed effects at the month level. For each bond, I take the average of its residualized (actual minus predicted) spread to compute a time-invariant measure of unexplained spreads for each muni. If average residuals are above zero, I code the bond as “high spread;” similarly, I code as “low spread” those bonds for which average residuals are below zero. Of course these unexplained spreads include liquidity, risk, and tax components, but they represent a simple and intuitive margin of heterogeneity that does not require dropping observations yet carries some important information about the desirability of certain types of bonds.

Table 16: 2-Week Response of Muni Yields to Monetary Shocks, by High/Low Spreads

	d yield	d yield ($\neq 0$)	d spread	d spread ($\neq 0$)
Low spread	0.02	0.05	0.02	0.05
	(0.00)	(0.01)	(0.00)	(0.01)
Monetary shock	0.21	0.44	-0.11	-0.21
	(0.10)	(0.20)	(0.07)	(0.15)
Monetary shock * Low spread	0.03	0.05	0.02	0.04
	(0.06)	(0.12)	(0.06)	(0.12)
N	74451	36774	74387	36711

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

Table 16 presents the results of analogous regressions, in which the more liquid (and less risky) bonds are expected to be in the “low unexplained spread” category. The “average unexplained spreads” dimension of heterogeneity seems not to have much of an effect on the response of muni yields to monetary shocks, in either the conditional or unconditional

specifications. Note that these measures are time invariant and the bond level; while a time-varying measure of excess spread would be helpful, many of these bonds simply aren't traded at a high enough frequency to obtain a meaningful measure.

While the average spread differential doesn't reveal a systematic response in the same way that government type does, it may be the case that a differential response is revealed *within* certain types of governments. To finish the investigation into heterogeneity of responses, I include both the government issuer's type and unexplained spreads in the regression specifications. Results are given in Table 17.

Table 17: 2-Week Response of Muni Yields to Monetary Shocks, by Issuer Type and High/Low Spreads

	d yield	d yield ($\neq 0$)	d spread	d spread ($\neq 0$)
Big Government	0.01 (0.01)	0.06 (0.01)	0.00 (0.01)	0.05 (0.01)
Low spread	0.02 (0.00)	0.05 (0.01)	0.02 (0.00)	0.04 (0.01)
Monetary shock	0.27 (0.08)	0.67 (0.19)	-0.01 (0.07)	0.00 (0.16)
Monetary shock * Big government	-0.21 (0.13)	-0.58 (0.22)	-0.32 (0.12)	-0.52 (0.19)
Monetary shock * Low spread	-0.07 (0.06)	-0.17 (0.14)	-0.05 (0.07)	-0.13 (0.16)
Big government * Low spread	0.01 (0.01)	-0.00 (0.01)	0.01 (0.01)	-0.01 (0.01)
Monetary shock * Big government * Low spread	0.31 (0.12)	0.55 (0.21)	0.25 (0.12)	0.45 (0.22)
N	74648	36870	74584	36807

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

As before, state governments respond less strongly to monetary shocks, especially conditional on adjustment, and low unexplained spreads have zero effect on the response of yields to a monetary shock. Note, however, the triple-difference coefficient in these specifications. Big governments with low excess spreads do not exhibit a lower response to monetary shocks, even conditional on adjustment; this coefficient almost completely negates the negative coefficient on being a state government. In these specifications, the bonds which exhibit a lower response to monetary shocks are only those which are issued by state governments with high excess spreads.

The results of this section, to the extent they say anything systematic about heterogene-

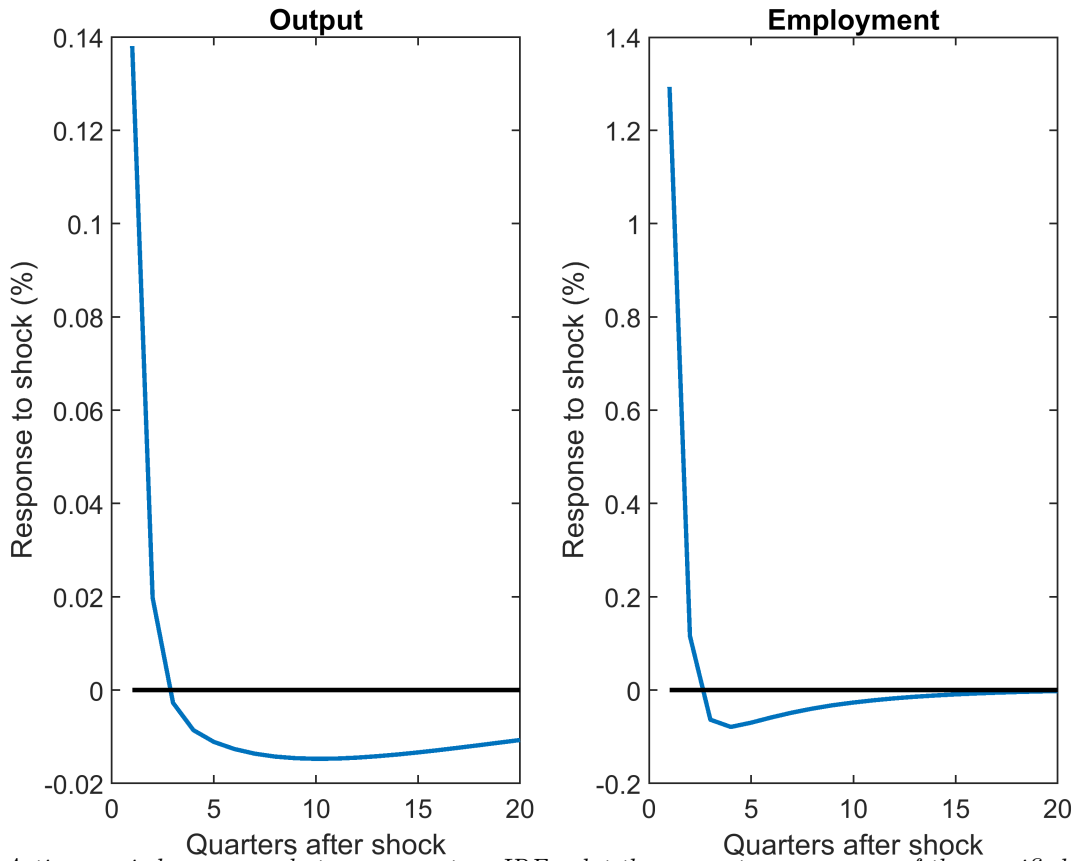
ity in the response of municipal bond yields to monetary shocks, may be summarized as follows. Bonds issued from state governments (“big” governments) are traded more often, and therefore are more likely to experience a price change as a result of a monetary shock. Unsurprisingly, the magnitude of their responses are smaller on average. This lower response is mainly driven by state bonds with high excess spreads, reflecting higher illiquidity or potentially higher risk premia than other bonds from similar issuers.

E Additional Quantitative Results

E.1 OTC Model Results

Here, I present some brief results from the OTC version of the model described in Section B of the main paper. Calibration moves forward similarly as in the baseline model, with a few additions. First, for simplicity I assume that financial firms are immediately able to sell bonds on the secondary market, i.e., $p^{sell} = 1$. A fuller examination of heterogeneity in muni pricing would require a more specific specification of the thickness of this secondary market, but in this section I will show simply the basic results. I calibrate v^H and ν to match the steady state d^G and r^G from the baseline model, and set $\theta = 0.5$ for simplicity.³⁸

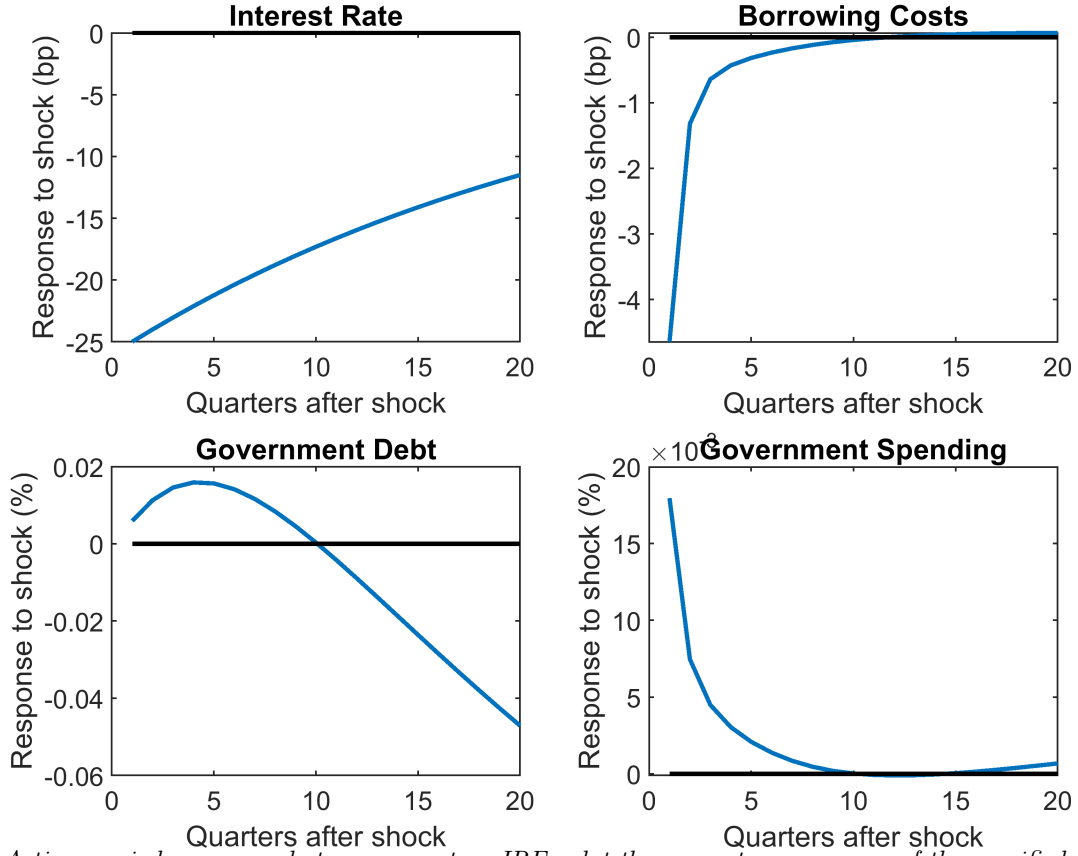
Figure 17: IRFs, 25bp Expansionary Shock



Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate. Graph corresponds to the OTC model of muni pricing.

³⁸Monetary responses do vary with θ , but without variation in α cannot match the observed heterogeneity in the data.

Figure 18: IRFs, 25bp Expansionary Shock



Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate. Graph corresponds to the OTC model of muni pricing.

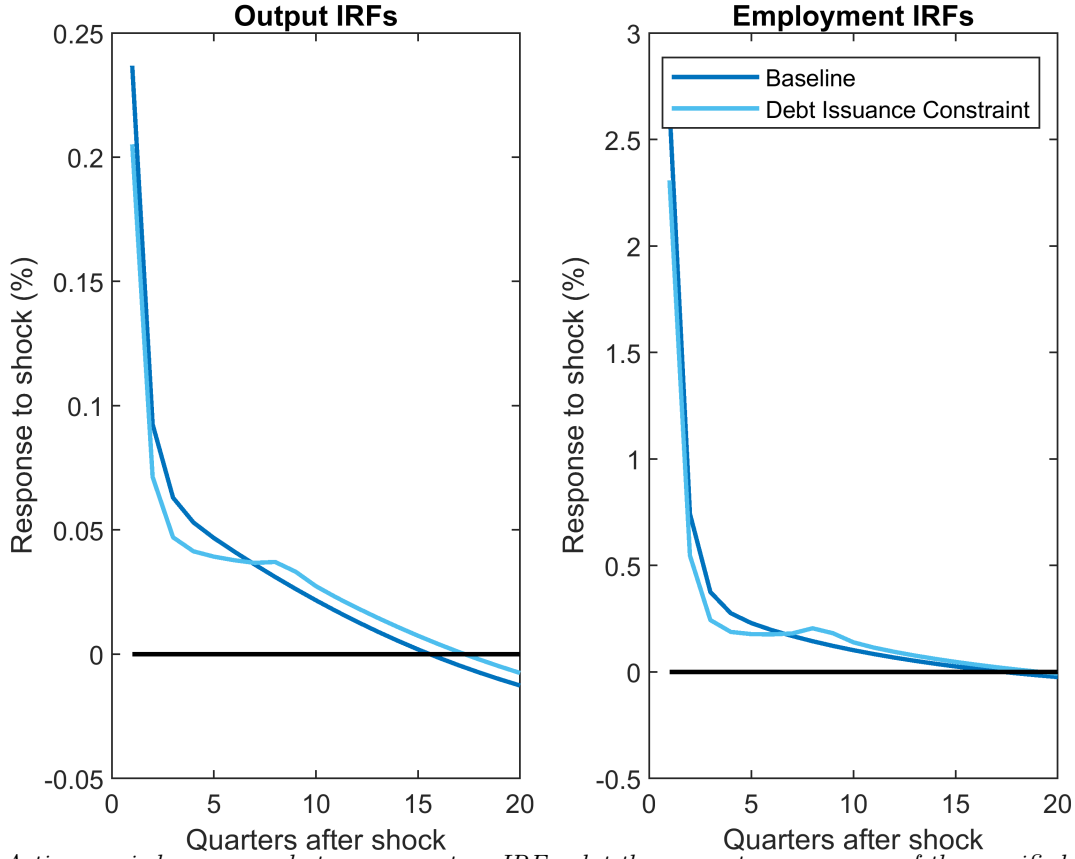
This model behaves similarly to the baseline model in terms of the directions of the IRFs. Note, however, in this special case of the model, the response of government debt and spending is much lower than the baseline model. The reason for this is the costs involved in issuing debt: the explicit inclusion of coupon payments and debt retirements puts upward pressure on their borrowing costs. As a result, $\frac{\partial r^G}{\partial d^G}$ is quite large, dampening significantly the responses to monetary shocks. In the baseline model, this translates to a larger value for ϕ^G .

E.2 Explicit Debt Constraints

This paper examines in detail the effect of municipal bond markets' response to monetary shocks on the size and potential heterogeneity in monetary policy transmission. Another

fiscal dimension on which state and local governments differ is the stringency of balanced-budget rules, which vary across governments. Most governments have some sort of balanced budget requirement on the books; the rules surrounding these requirements likely result in an effective *politically imposed* on the amount of debt a government can issue.

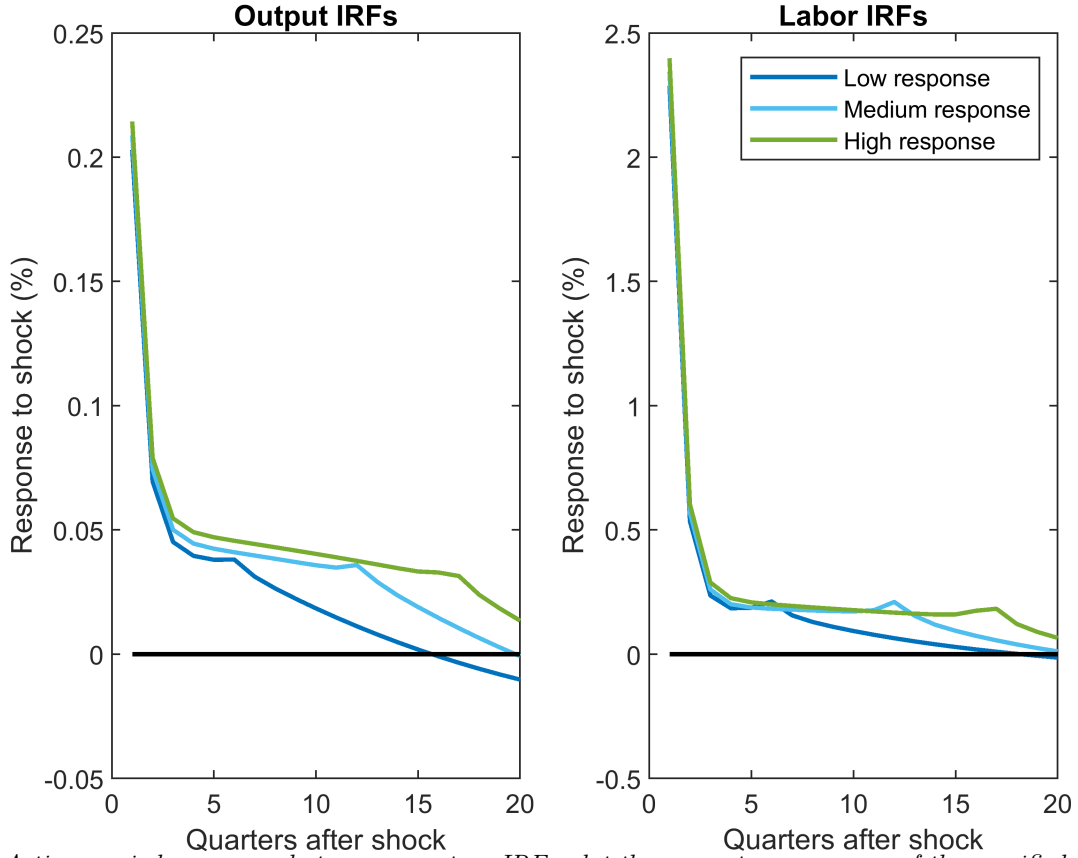
Figure 19: The Effect of Debt Constraints



Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate. “Debt Issuance Constraint” restricts debt growth to be less than 2.5 percent in each period.

Figures 19 and 20 show how the results in the paper are affected by an additional constraint on debt issued by a local government: $d_{it}^G \leq 1.025d_{i,t-1}^G$. Figure 19 shows that the debt constraint dampens the transmission of monetary policy, even relative to the already-dampened baseline case, on the order of about 10 percent in the baseline case. Figure 20 compares three economies which differ according to θ^G , where $\theta^G \in \{0.22, 0.33, 0.44\}$ corresponds to “low,” “medium,” and “high” response coefficients from the state estimates. Here, the medium- and high- response economies have almost equal IRFs for the first several quarters, before the medium response economy begins to go back to normal more quickly.

Figure 20: IRFs by Response Elasticity, Debt Issue Constrained



Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate. “Debt Issuance Constraint” restricts debt growth to be less than 2.5 percent in each period.

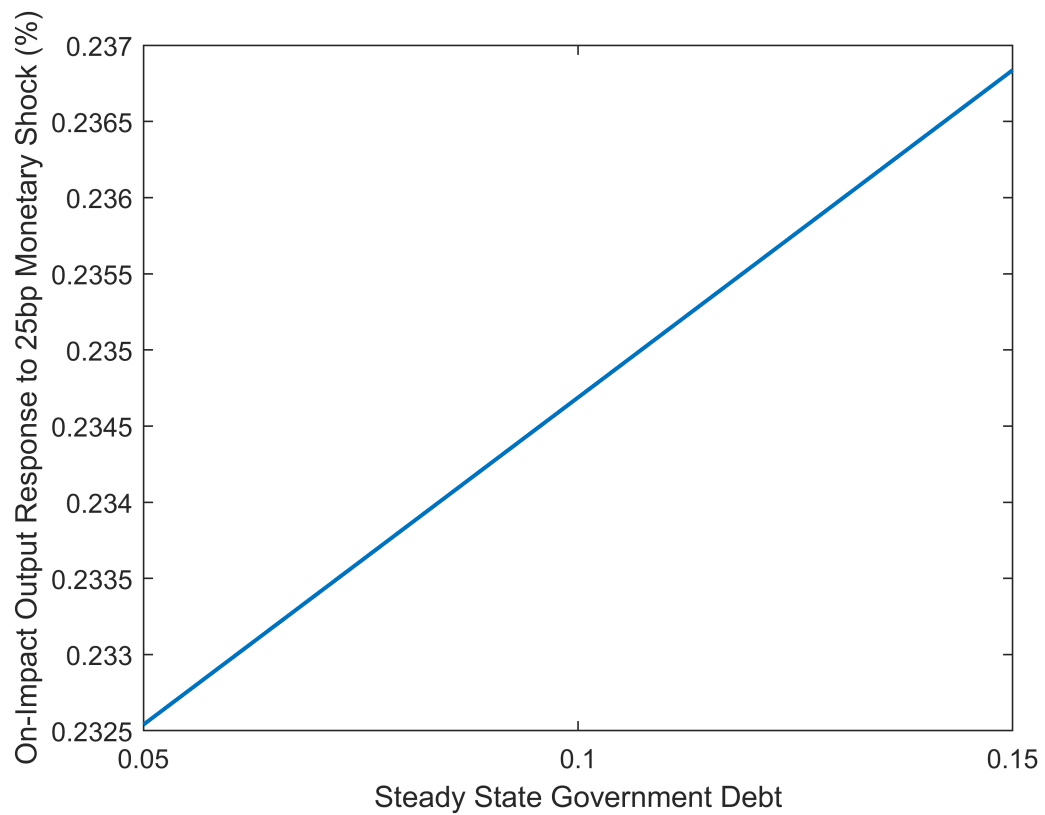
Just as the response of borrowing costs to monetary shocks affects monetary transmission through local fiscal policy, so too will the debt issuance constraints placed on these localities through various budgeting laws.

E.3 Steady State Government Debt

Figure 21 shows the positive relationship between steady state local government debt and the transmission of monetary policy in the baseline calibrated model. Here I recalibrate the parameters of the model in the same way as the body of the paper for a number of values for steady state local government debt as a fraction of output, from 0.05 to 0.15. I record the on-impact transmission of monetary policy for each of these economies in the figure.

Clearly, there is a positive correlation between the steady state level of government debt

Figure 21: Monetary Transmission and Government Debt



Note: Blue line plots the relationship between the choice of steady-state debt and monetary transmission in the baseline model of the paper.

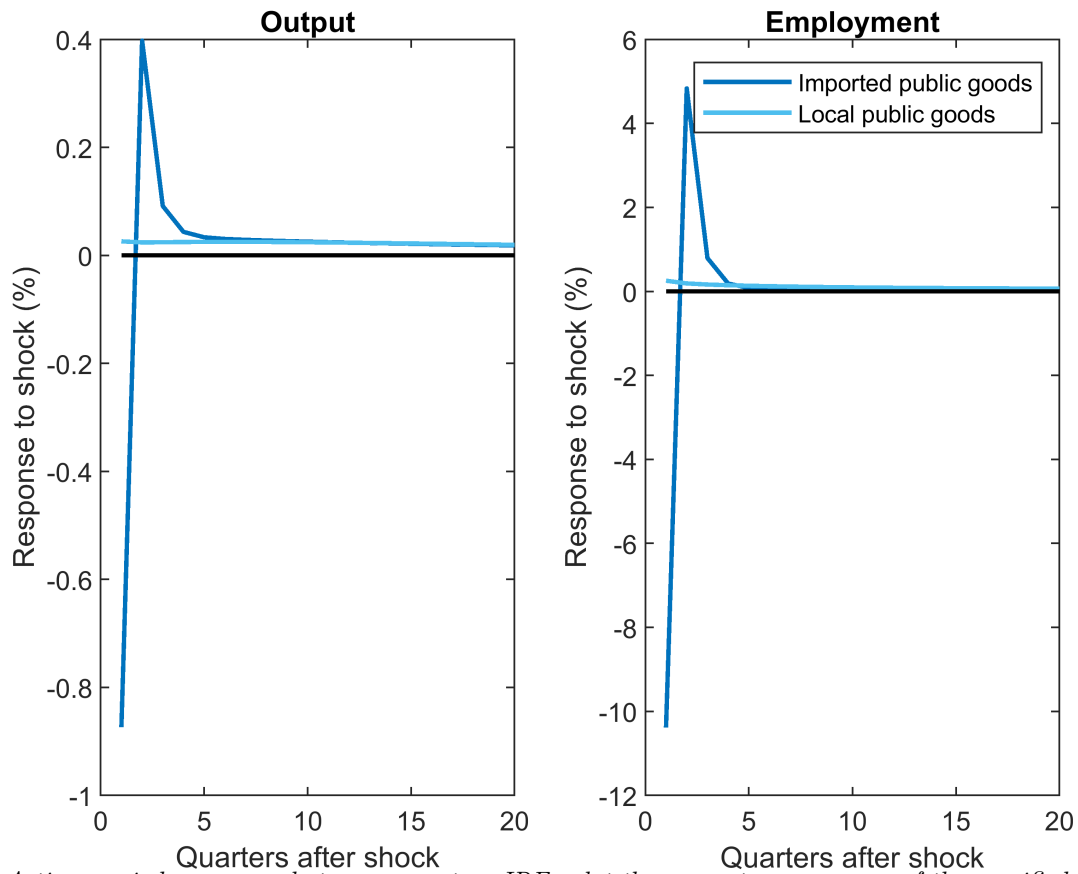
and monetary transmission. The same percentage increase in government spending will be more stimulative for a government which spends more in steady state. The steady state level of government spending is one of many possible dimensions on which these governments may differ, and which may contribute to the transmission of monetary policy.

E.4 Fiscal Policy Shocks

In the body of the paper, I explore the interactions between national monetary policy and local fiscal policy. A natural related question is how national fiscal policy might enter into the small open economy model, and what effects it might have given the problems faced by the local government. Figure 22 shows the response of the baseline economy to two different federal government spending shocks. In the first, public goods spending exogenously increases, but the public goods come from outside the local economy; i.e., the federal government does not purchase g from local goods producers. In the second case, the federal government purchases public goods from the local nontradable sector.

The fiscal shock in each case corresponds to a five percent (transitory) increase over the steady state level of government spending. In both cases, federal spending crowds out local spending as the local government simply wants to provide efficient levels of public goods given the household's preferences. When federal spending is imported from elsewhere in the economy, local output decreases markedly as the local government decreases its spending, lowering aggregate demand and employment. This lack of need to spend allows the local government to pay down debt, allowing for increased spending in the future, and an expansion of local aggregate demand. In the second case, the federal spending represents an increase in aggregate demand on impact, as public goods are now being bought by the federal government. Subsequently, local spending increases as before; the subsequent spending is muted in this case because of the inflationary effect of the initial federal shock, which is not present in the first case.

Figure 22: Federal Government Spending Shock (5 Percent Increase)



Note: A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate. “Imported Public Goods” represents a 5 percent exogenous increase in g purchased from outside the economy, leaving local demand unaffected. In the “Local Public Goods” scenario, the same fiscal shock increases local demand for local goods.