# Appendices for "The Municipal Government Channel of Monetary Policy"

## 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, recall that the profit for an individual intermediate goods firm is given by $P^N_{it} y^N_{it} - (1 - \frac{1}{\mu}) W_t h_{it}$. 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 $P^N_{it}$:

$$P^N_{it}((1-\kappa)c^N_t + \kappa c^{N,H}_t + g_t)\left(\frac{P^N_{it}}{P^N_t}\right)^{-\mu} - (1 - \frac{1}{\mu})W_t((1-\kappa)c^N_t + \kappa c^{N,H}_t + g_t)^{\frac{1}{\alpha}}\left(\frac{P^N_{it}}{P^N_t}\right)^{-\frac{\mu}{\alpha}},$$

where $P^N_{it}$ is the firm's price and $y^N_{t+s} = ((1-\kappa)c^N_{t+s} + \kappa c^{N,H}_{t+s} + g_{t+s})$. 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 $\theta$ that its chosen price will continue on to the next period:

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

Here $\tilde{P}^N_{it}$ 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 $\beta$ and $\lambda_t$. 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 (22) and (23) 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 (24) in the text.

Similarly, to obtain (25), 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 (25).

# 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 $\nu$. Governments buy and sell from risk-neutral financial firms at competitive prices. A mass $\alpha$ 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.[33]

The value of the bond for the financial firm, $v^F$, then, is the present value of the bond

[33] In 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.

at time $t$, discounted by the expected path of aggregate interest rates $r_t$:

$$v_t^F = E_t \sum_s^{\infty} \left[ c(1-\nu)(1-p_{t+s}^{sell}) + (1-\nu)P_{t+s}p_{t+s}^{sell} + \nu \right] \prod_{k=1}^{s} \frac{1}{1+r_k}(1-p_{t+k})(1-\nu)). \quad (31)$$

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:

$$P_t = \theta v_t^F + (1-\theta)v^H. \quad (32)$$

$\theta$ 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 system

$$p_t^{sell} = \max\left\{ \frac{\alpha - (1-\nu)B_t^H}{(1-\nu)B_t^F}, 1 \right\}$$

$$B_{t+1}^F = (1-p_t^{sell})(1-\nu)B_t^F + x_t$$

$$B_{t+1}^H = (1-\nu)B_t^H + p_t^{sell}(1-\nu)B_t^F,$$

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

$$r_t^G = \frac{d_{t+1}^G}{v_t^F d_{t+1}^G + (1-\nu)(1-c-v_t^F)d_t^G} - 1, \tag{33}$$

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: $A = 10$, $B = 11$, ... $Z = 35$

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.[34]

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

## 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 yield[35]:

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

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 $\beta_i$. Since $m_t$ is 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: $\varepsilon_{it}$ is correlated with $R_t^{10}$ through $\eta_t$, resulting in a biased OLS estimate. To deal with this issue, the BRW method estimates each $\beta_i$ using a Rigobon and Sack (2004) instrumental variables method. In short, an estimate

[35] The 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.

for $\beta_i$ 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 $\psi_{it}$, I standardize three measures of illiquidity used by Schwert, and construct $\psi_{it}$ 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:

$$IRC_{its} = \frac{P_{its}^{max} - P_{its}^{min}}{P_{its}^{min}}, \tag{34}$$

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 occurence 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:

$$DISP_{it} = \sqrt{\frac{1}{\sum_j Q_j} \sum_j (P_{ij} - M_{it})^2 Q_j}, \tag{35}$$

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

$$DEPTH_{it} = \frac{1}{N_{it}} \sum_{j=2}^{N_{it}} \frac{\left| \frac{P_{ij} - P_{i,j-1}}{P_{i,j-1}} \right|}{Q_j}, \tag{36}$$

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 repsonse 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

$$Y_t = A + B_1 Y_{t-1} + ... + B_4 Y_{t-4} + \varepsilon_t, \tag{37}$$

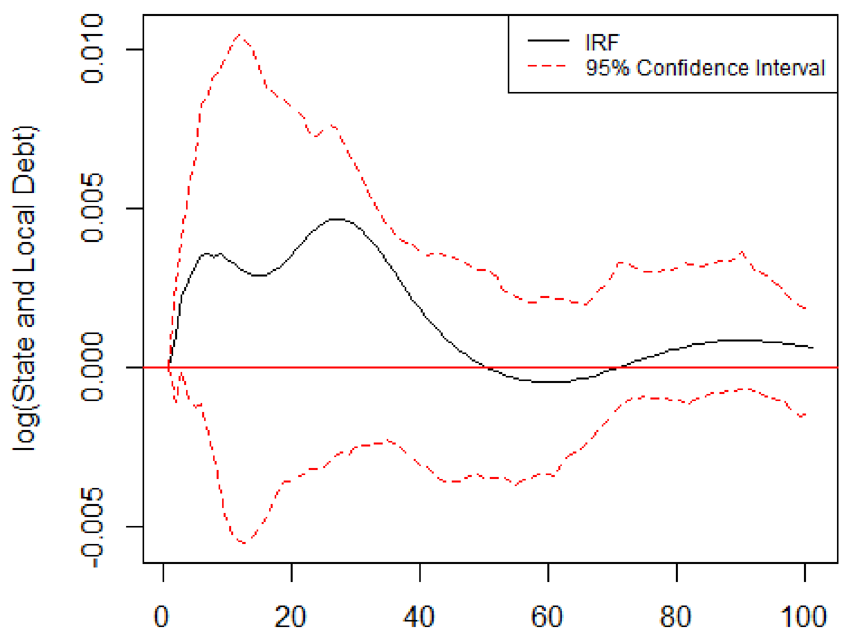
where $t$ corresponds to one quarter. The vector $Y$ includes variables in the following order:

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

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, $\Pi$ is profits, and $\Delta M$ 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 7, 8, 9, and 10 here show the effect of an expansionary shock to the federal funds rate on the variables of interest. Furthermore, Figure 11 gives the estimated response of output in the VAR with debt.

Figure 7: CEE Impulse Response to Fed Funds Shock



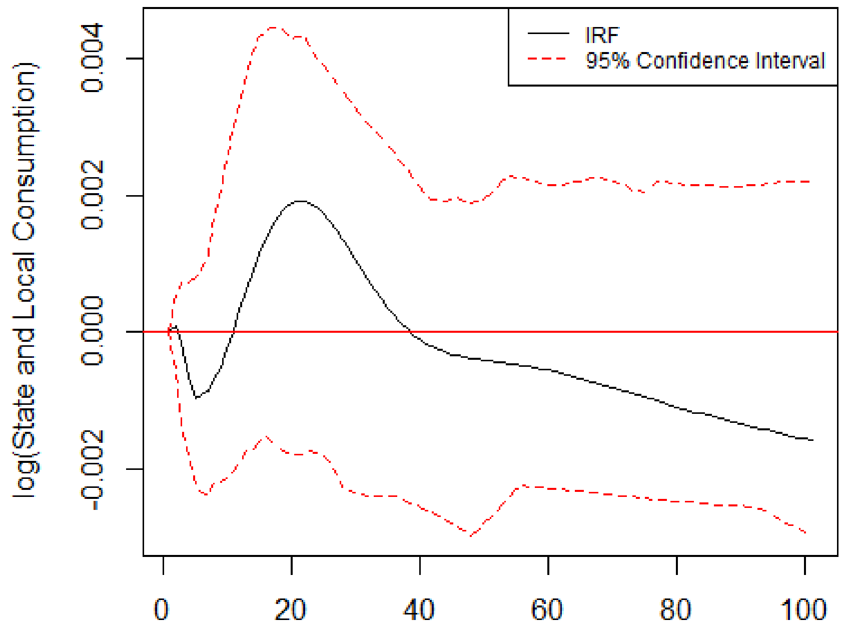

***Note:*** *Time period corresponds to one quarter. IRF depicts the response of the specified variable to a one standard deviation downward shock to the federal funds rate in the estimated VAR described in Section D.1.*

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.

## 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

Figure 8: 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.*

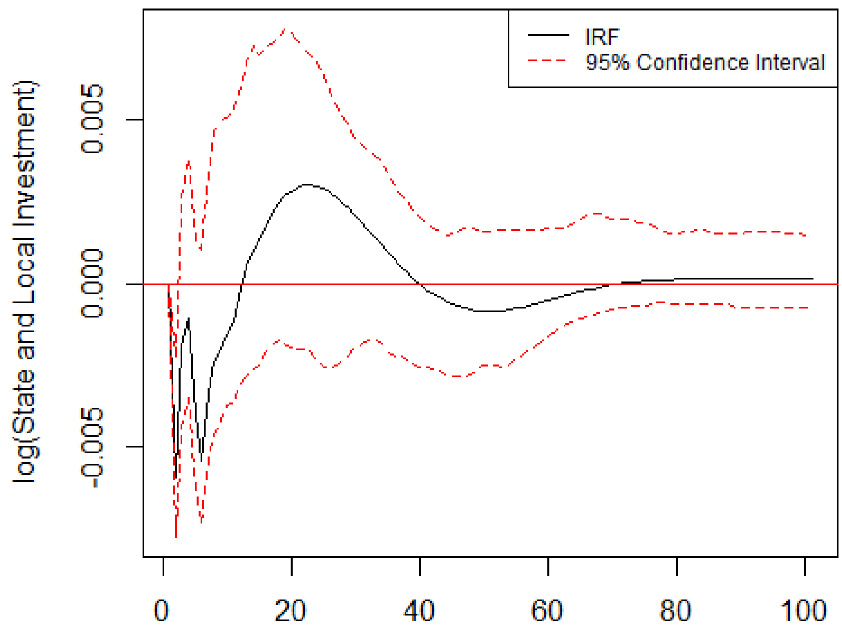
issuer codes in the MSRB data. I use this dataset to estimate the regression equation

$$\log G_{it} = 1 + \beta R_{it} + \Gamma X_{it} + \varepsilon_{it}, \tag{38}$$

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 version of the monetary shocks used later in the paper. Results are summarized in Table 7.

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

Figure 9: 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.*

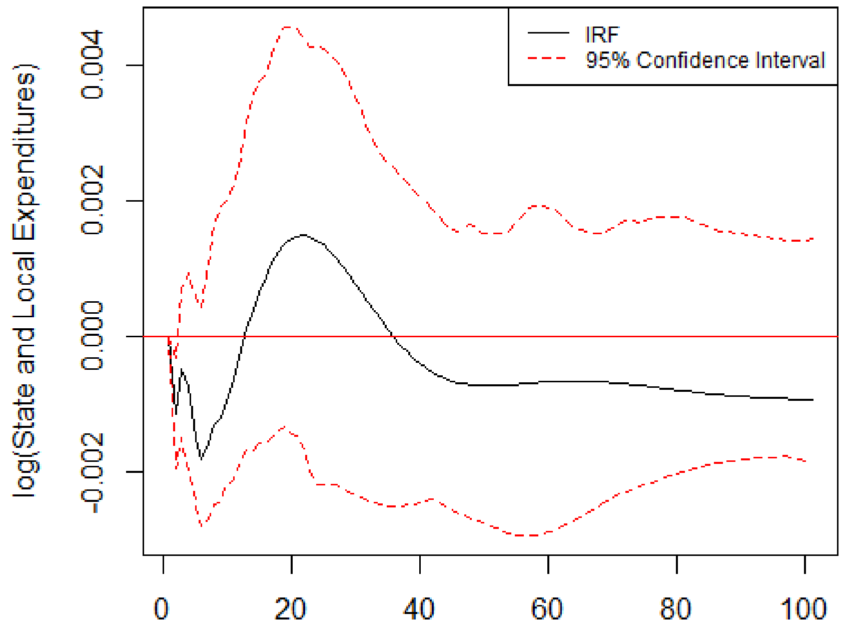
new debt issues.[36] Municipalities seem to respond in powerful ways to borrowing costs. Additionally, note that higher borrowing costs seem to shift the *composition* of municipal spending away from debt-financed capital projects to current expenditures. The secondary market for municipal debt clearly 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

[36] Combined with the relationship between municipal and treasury rates estimated below, this result implies 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 10: 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.*

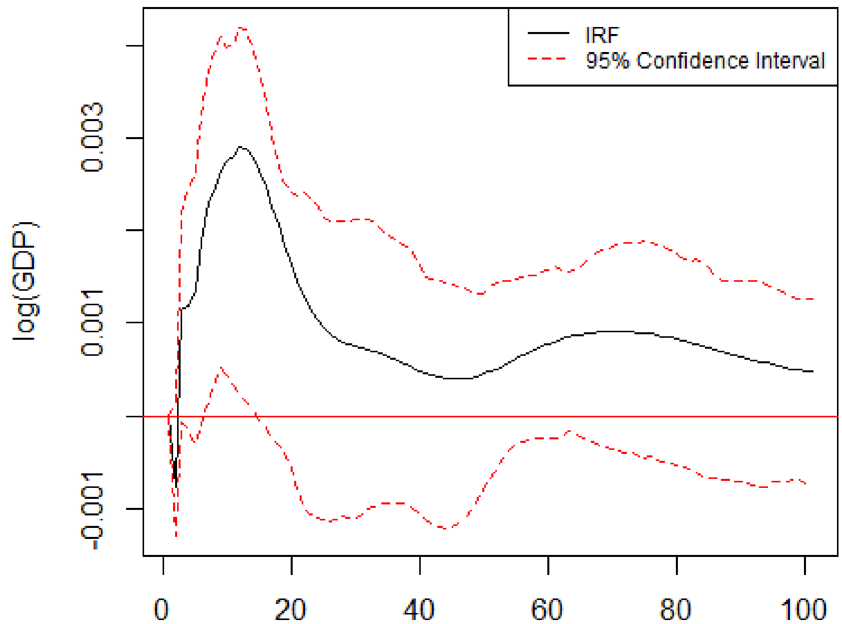
bonds, Schwert (2017) is a paper at the frontier of the municipal bond pricing literature. The main exercise in the paper exploits the microstructure of the MSRB data to examine the portions of tax adjusted muni spreads that are accounted for by risk and illiquidity concerns. The basic procedure assumes that yields on municipal bond trades are determined according to

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

where $\tau$ is the marginal tax rate, $r_t$ is the risk-free rate, $\gamma_{it}$ is the risk premium, and $\psi_{it}$ reflects illiquidity, perhaps in the form of trading costs or asymmetric information.

To estimate the liquidity component $\psi_{it}$, the method first constructs $\lambda_{it}$, an average of several (standardized) illiquidity measurements from the literature. I describe these illiquid-

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.*

ity 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 each time $t$:

$$\frac{y_{it}}{1-\tau_{it}} - r_t = \beta_0 + \beta_t \lambda_{it} + \beta_t^R Rating_{it} + \varepsilon_{it}. \tag{39}$$

Here, $y_{it}$ is the daily yield of a bond, $\tau_{it}$ is an imputed tax rate,[37] $r_t$ 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

[37]In 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.

Table 7: 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.

components is computed according to

$$\psi_{it} = \beta_t(\lambda_{it} - \lambda_{1t}), \tag{40}$$

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

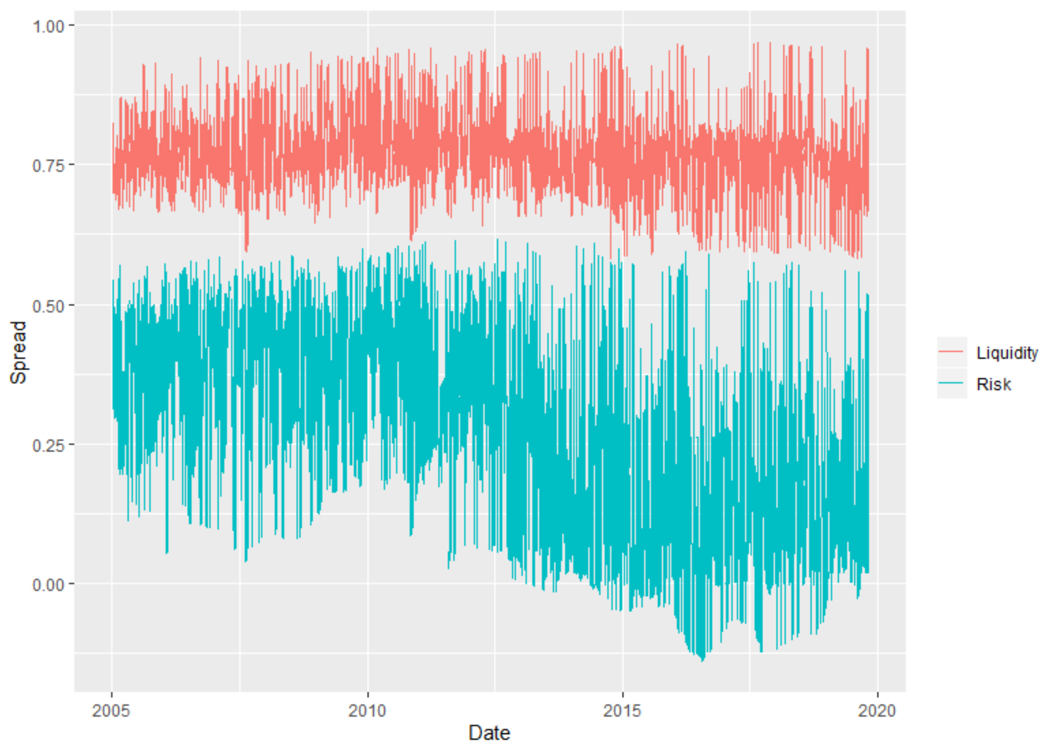
Because the individual measures of these components are noisy, Schwert aggregates them into time series variables, using the four-month rolling average of daily cross-sectional mean spread components. This results in the time series $\gamma_t$ and $\psi_t$, which are plotted in Figure 12. Note that my 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 8: Effect of Monetary Shocks on Spread Components

| | Default spread | Default spread | Liquidity spread | Liquidity spread |
|---|---|---|---|---|
| Monetary shock | 0.08 | -0.17 | 0.12 | -0.06 |
| | (0.25) | (0.17) | (0.07) | (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.

Figure 12: 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.*

I estimate the effects of monetary shocks on these series, as in the time series results above, and present results in Table 8. 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 1. In Table 9, 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 10 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 9 indicate the upward shocks might have larger effects, the standard errors are large; additionally, the coefficients in Table 10 are virtually indistinguishable to those in Table 1.

Table 9: 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 | 0.23 | 0.22 | 0.62 | 0.26 | 0.21 | 0.34 | 0.88 |
| | (0.10) | (0.10) | (0.10) | (0.16) | (0.17) | (0.21) | (0.14) | (0.23) |
| Monetary shock * $I[Shock > 0]$ | 0.28 | 0.25 | 0.28 | 0.19 | 0.35 | 0.48 | 0.26 | -0.13 |
| | (0.19) | (0.19) | (0.20) | (0.35) | (0.35) | (0.36) | (0.34) | (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 10: 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 | 0.28 | 0.27 | 0.57 | 0.32 | 0.32 | 0.35 | 0.76 |
| | (0.08) | (0.08) | (0.08) | (0.14) | (0.14) | (0.16) | (0.13) | (0.22) |
| Horizon | 2 days | 2 days | 2 days | 2 days | 6 days | 6 days | 6 days | 6 days |
| N | 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 11, I summarize estimates of (1), computed separately for sector-level indices.

Table 11: 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 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.[38] Specifically, in the context of (2), $X_{it}$ 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 12 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 signficant 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.

## D.7 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

[38] Appendix 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 12: Heterogeneous Responses: GYZ Method

| | Yield | Spread |
|---|---|---|
| Monetary Shock | 1.56 | 1.19 |
| | (0.96) | (1.00) |
| Investment Grade = 1 | 0.01 | 0.01 |
| | (0.02) | (0.02) |
| $\log PAR_i$ | 0.03 | 0.03 |
| | (0.00) | (0.00) |
| $\log(1 + AGE_{it})$ | -0.00 | 0.00 |
| | (0.00) | (0.00) |
| $\log T2M_{it}$ | -0.00 | -0.02 |
| | (0.01) | (0.01) |
| $\log(1 + COUP_{it})$ | -0.00 | 0.00 |
| | (0.03) | (0.03) |
| Monetary Shock * Investment Grade = 1 | -0.19 | -0.21 |
| | (0.20) | (0.16) |
| Monetary Shock * $\log PAR_i$ | -0.02 | -0.02 |
| | (0.04) | (0.04) |
| Monetary Shock * $\log(1 + AGE_{it})$ | -0.01 | -0.01 |
| | (0.03) | (0.02) |
| Monetary Shock * $\log T2M_{it}$ | -0.15 | -0.14 |
| | (0.10) | (0.12) |
| Monetary Shock * $\log(1 + COUP_{it})$ | 0.21 | 0.06 |
| | (0.29) | (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).

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.[39] 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 13 repeats the estimation of (2), reporting the interaction between the estimated shock and government type.

Table 13: 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 | 0.06 | 0.01 | 0.05 |
| | (0.00) | (0.01) | (0.00) | (0.01) |
| Monetary shock | 0.22 | 0.56 | -0.05 | -0.10 |
| | (0.07) | (0.16) | (0.06) | (0.14) |
| Monetary shock * Big government | -0.00 | -0.21 | -0.14 | -0.20 |
| | (0.09) | (0.12) | (0.07) | (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 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

[39] I 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.

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 14: 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 14 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 15.

Table 15: 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 | 0.06 | 0.00 | 0.05 |
| | (0.01) | (0.01) | (0.01) | (0.01) |
| Low spread | 0.02 | 0.05 | 0.02 | 0.04 |
| | (0.00) | (0.01) | (0.00) | (0.01) |
| Monetary shock | 0.27 | 0.67 | -0.01 | 0.00 |
| | (0.08) | (0.19) | (0.07) | (0.16) |
| Monetary shock * Big government | -0.21 | -0.58 | -0.32 | -0.52 |
| | (0.13) | (0.22) | (0.12) | (0.19) |
| Monetary shock * Low spread | -0.07 | -0.17 | -0.05 | -0.13 |
| | (0.06) | (0.14) | (0.07) | (0.16) |
| Big government * Low spread | 0.01 | -0.00 | 0.01 | -0.01 |
| | (0.01) | (0.01) | (0.01) | (0.01) |
| Monetary shock * Big government * Low spread | 0.31 | 0.55 | 0.25 | 0.45 |
| | (0.12) | (0.21) | (0.12) | (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.

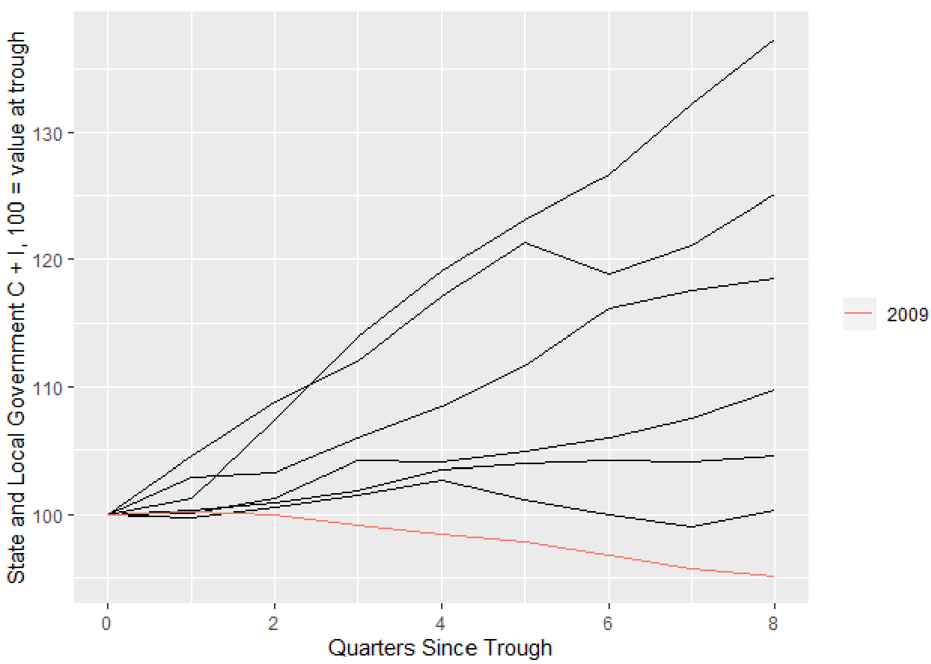
The results of this section, to the extent they say anything systematic about heterogeneity in the response of municipal bond yields to monetary shocks, may be summarized as follows. Bonds issued from state governments ("big" governments) are traded more often, and therefore are more likely to experience 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 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 13 shows these recoveries.

Figure 13: 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.*

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. Figure 1 shows that the financial crisis included a runup of municipal spreads over treasuries. This suggests either a decrease in liquidity in muni markets, or an increased perception of risk due to financial conditions.

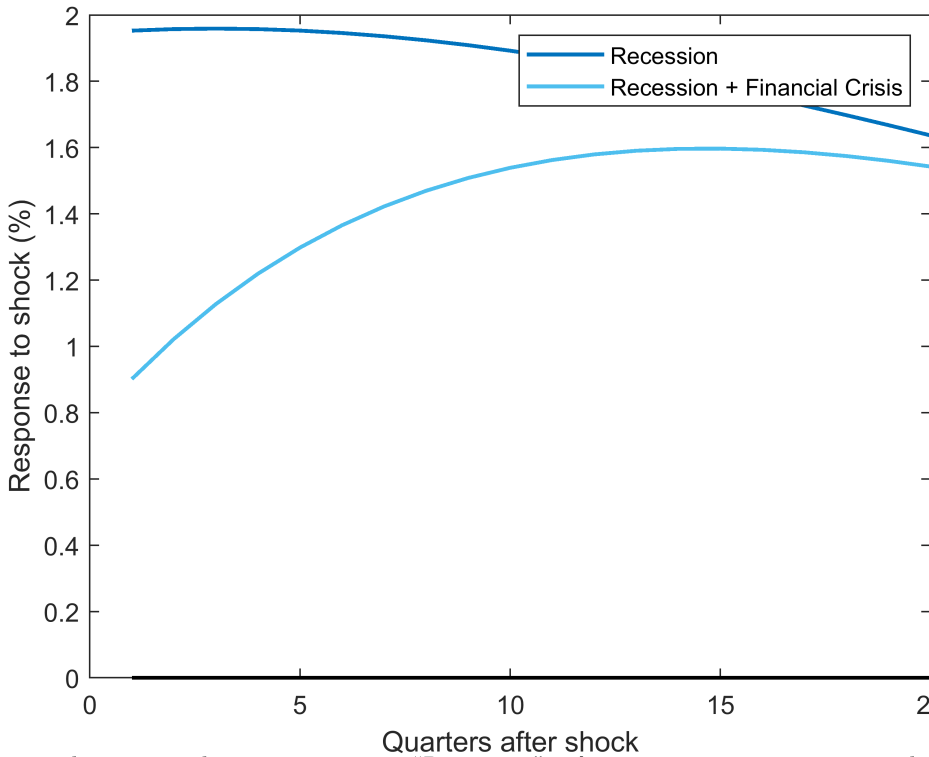
Figure 14 plots the response of government spending in the open-economy model to two types of models. The first is a simple decrease in the tradable endowment $y^T$; in other words, an external crisis which induces a decrease in output, employment, and prices. The second combines an external crisis with a *financial* crisis; following the muni market during and after the Great Recession, I define this as a negative shock to $\theta^G$, i.e., a dampening of the ability of municipal bond yields to decrease during the recession, and an increase in $\phi^G$, meaning that increasing debt becomes costlier.

The financial crisis dampens the fiscal response of state and local governments to an external crisis by dampening the decrease in borrowing costs. While an outright *decrease* is not induced, the financial crisis does cut out much of the government's fiscal response. A number of factors go in to the fiscal decisions of 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.

## E.2 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

Figure 14: Government Spending After Two Recessions



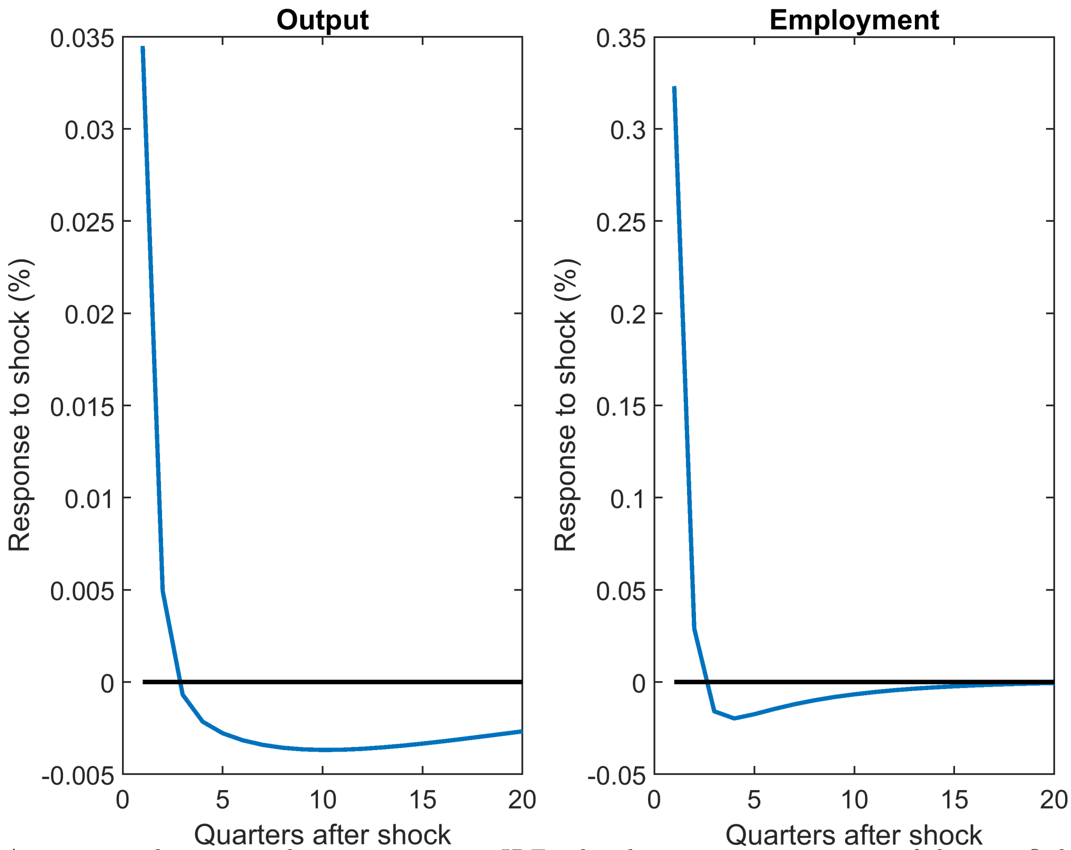

***Note:*** *Time period corresponds to one quarter. "Recession" refers to an exogeneous external drop in tradable output; "Financial crisis" refers to a lockup of the municipal market in the form of an inability to respond to lower national interest rates.*

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 $\nu$ to match the steady state $d^G$ and $r^G$ from the baseline model, and set $\theta = 0.5$ for simplicity.[40]

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

[40] Monetary responses do vary with $\theta$, but without variation in $\alpha$ cannot match the observed heterogeneity in the data.

Figure 15: IRFs, 25bp Expansionary Shock



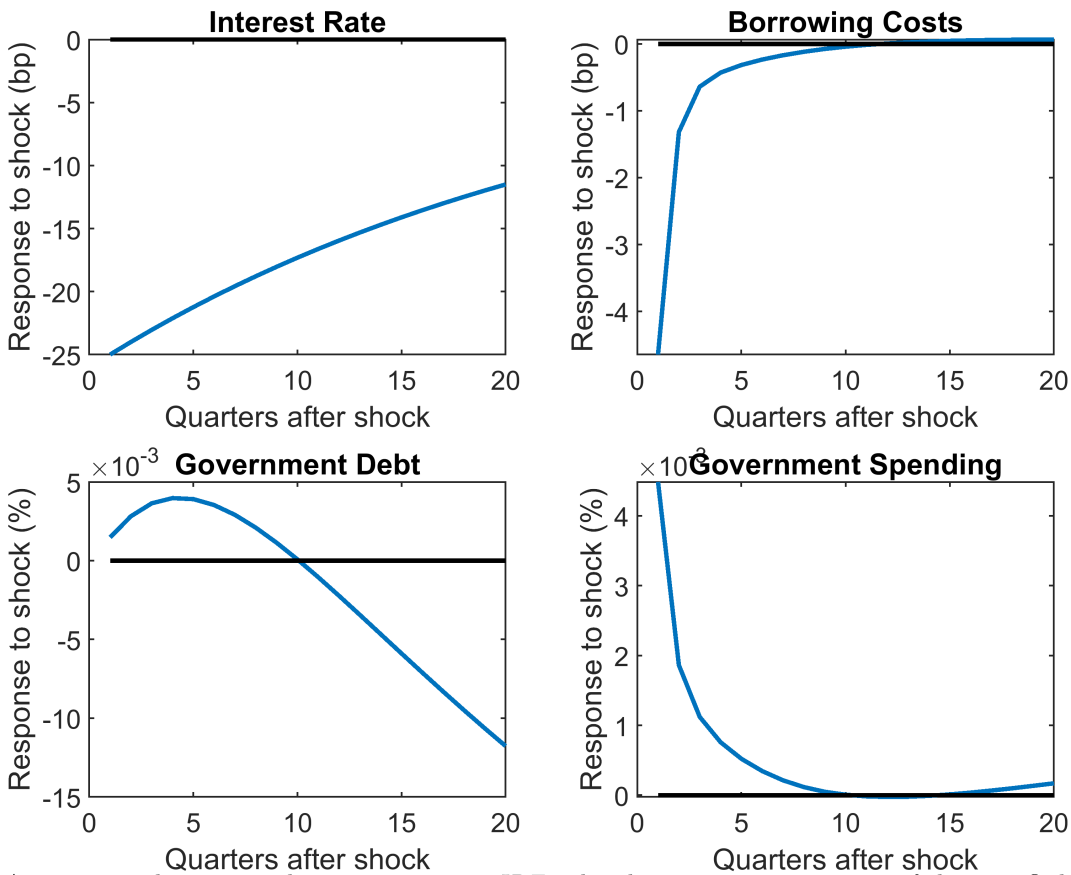

***Note:*** *A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate (annualized). Graph corresponds to the OTC model of muni pricing.*

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 $\phi^G$.

## E.3 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

Figure 16: IRFs, 25bp Expansionary Shock

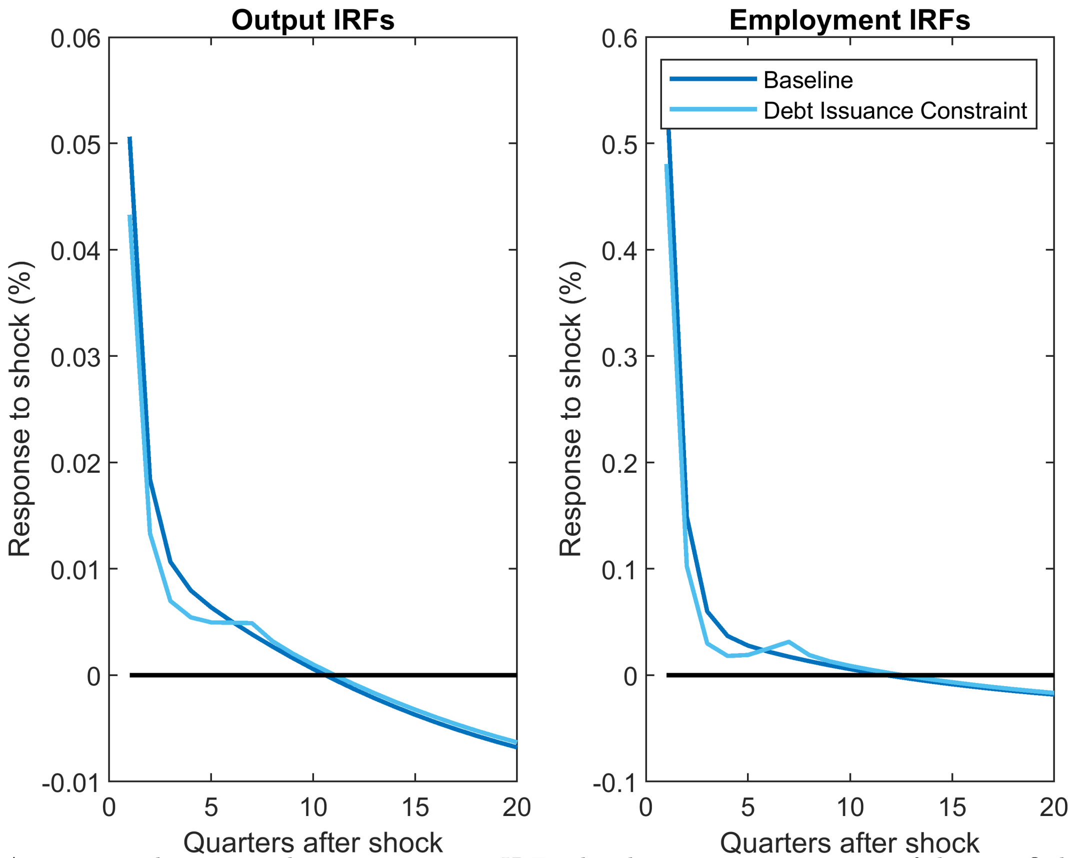



***Note:*** *A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate (annualized). Graph corresponds to the OTC model of muni pricing.*

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.

Figures 17 and 18 show how the results in the paper are affected by an additional constraint on debt issued by a local government: $d^G_{it} \leq 1.00025 d^G_{i,t-1}$. Figure 17 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 18 compares three economies which differ according to $\theta^G$, 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

Figure 17: The Effect of Debt Constraints



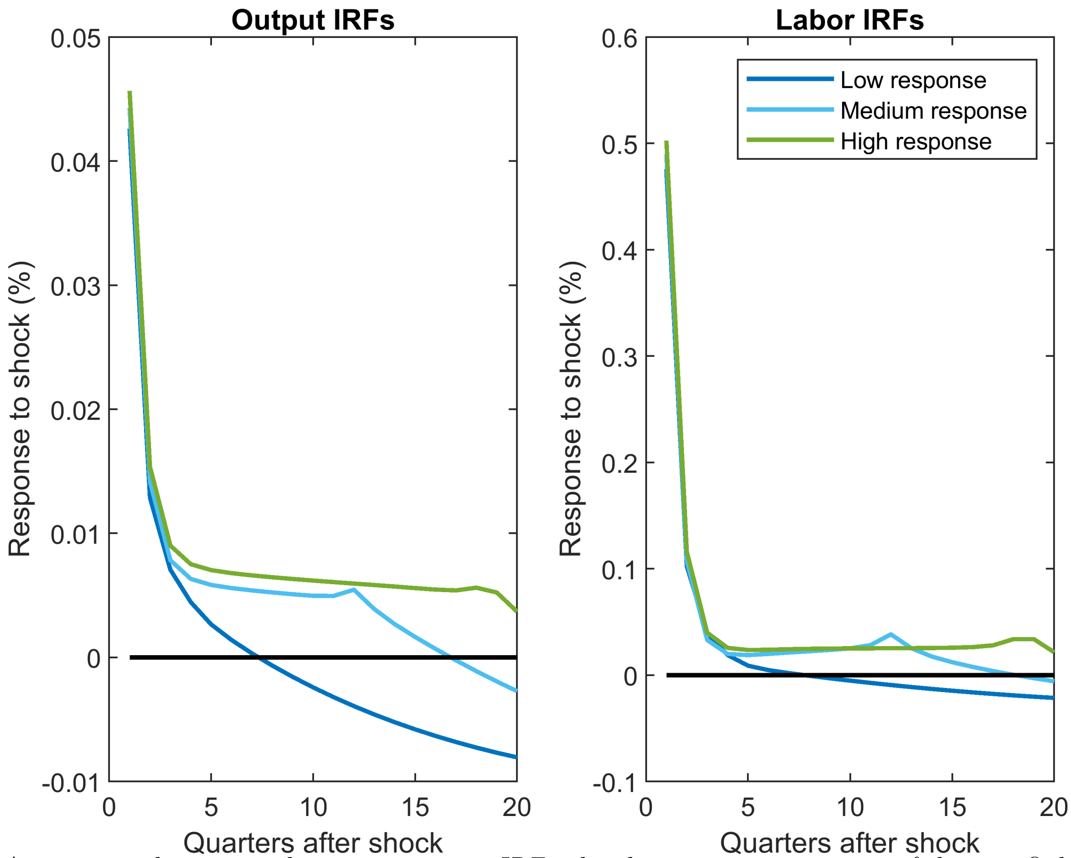

***Note:*** *A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate (annualized). "Debt Issuance Constraint" restricts debt growth in each period.*

quarters, before the medium response economy begins to go back to normal more quickly. 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.4 Steady State Government Debt

Figure 19 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

Figure 18: IRFs by Response Elasticity, Debt Issue Constrained

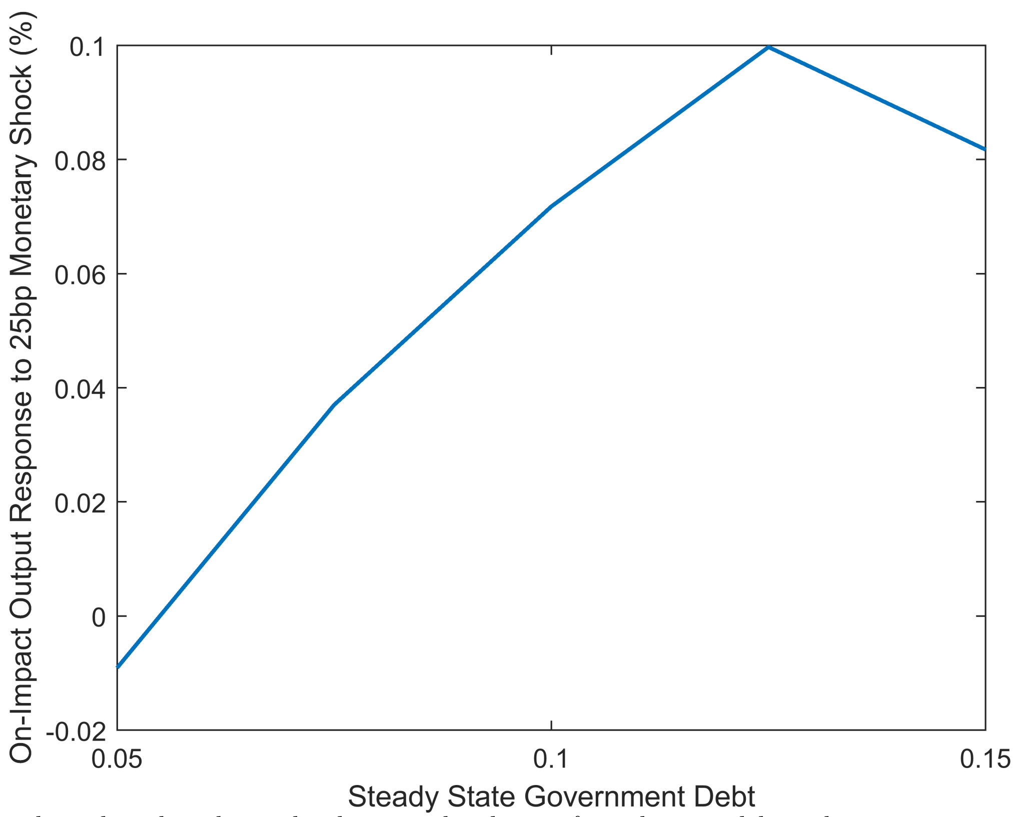



***Note:*** *A time period corresponds to one quarter. IRFs plot the percentage response of the specified variable to an unforeseen 25bp downward shock in the national risk-free interest rate (annualized).*

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.

There is generally a positive correlation between the steady state level of government debt and monetary transmission, though the relationship turns at the top end of debt. The same percentage increase in government spending will generally 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.

Figure 19: Monetary Transmission and Government Debt



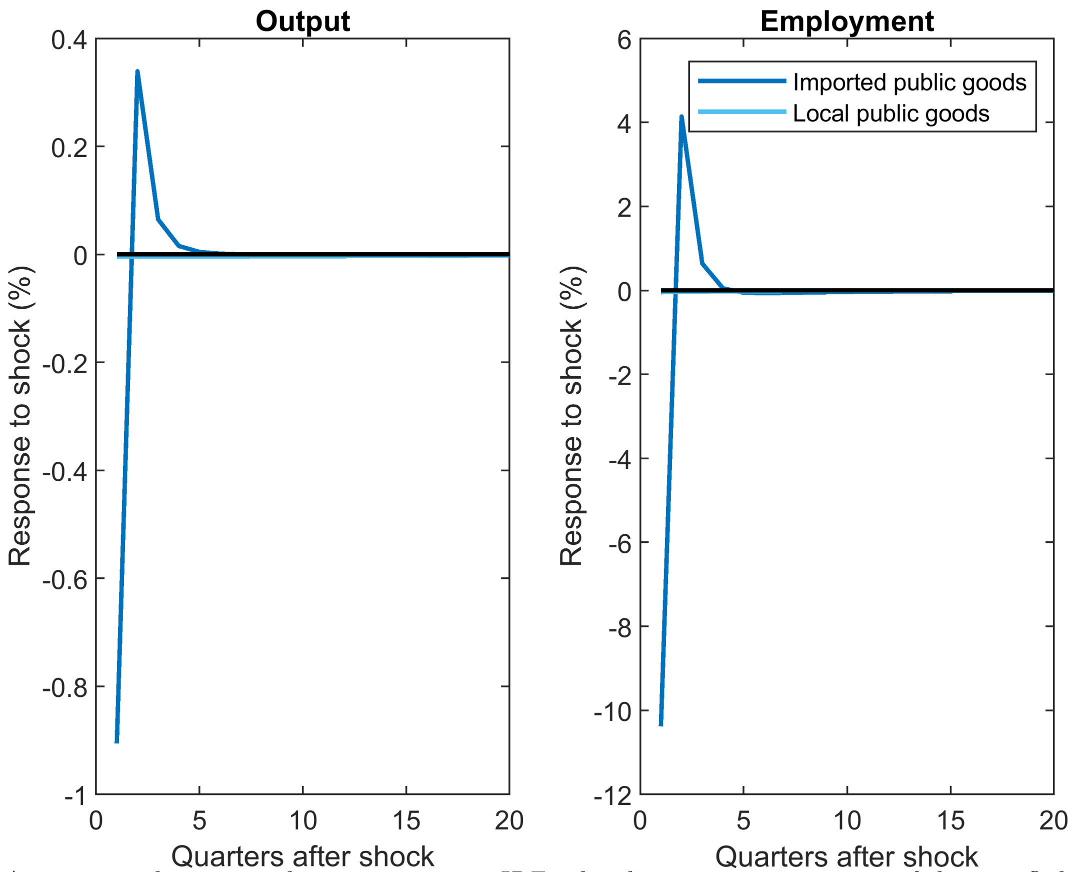

***Note:*** *Blue line plots the relationship between the choice of steady-state debt and monetary transmission in the baseline model of the paper.*

## E.5 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 20 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 enters aggregate demand on impact, as public goods are now being bought by the federal government. However, 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 20: 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 (annualized). "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.*