Econometrica Supplementary Material

SUPPLEMENT TO "FISCAL FORESIGHT AND INFORMATION FLOWS"

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BY ERIC M. LEEPER, TODD B. WALKER, AND SHU-CHUN SUSAN YANG

S.1. SIMULATIONS DETAILS

S.1.1. *Specifications of Models*

FOR THE QUANTITATIVE RESULTS reported in Section 3, we augment a prototype RBC model (similar to the one in Chari, Kehoe, and McGrattan (2008)) and a standard New Keynesian model (similar to those in Smets and Wouters (2003), Smets and Wouters (2007)) with distorting taxes levied on capital and labor income. Agents in the models have foresight over tax policy changes. This supplement describes the models and the calibration/estimation strategy. Except for the parameters that characterize the information flow processes in the tax rules, the parameters in the RBC model are calibrated to the values commonly used in the literature, and the NK model is calibrated to the posterior mode of an estimated New Keynesian model, fit to U.S. quarterly data from 1984 to 2007.

S.1.1.1. *RBC Model*

The representative agent maximizes utility

$$E_t \sum_{t=0}^{\infty} \beta^t \bigl[\log c_t + \phi \log(1 - l_t)\bigr]$$

over consumption c_t and labor l_t, where β is the discount factor and ϕ is the preference weight on leisure. The agent's budget constraint is $c_t + k_t - (1 - \delta)k_{t-1} = (1 - \tau_t^L)w_t l_t + (1 - \tau_t^K)r_t^K k_{t-1} + z_t$, where k_t is capital, w_t is the wage rate, r_t^K is the real rate of return on capital, z_t is government transfers, and δ is the capital depreciation rate.

The representative firm produces output using the technology $y_t = u_t^a k_{t-1}^{\alpha} \times l_t^{1-\alpha}$, where y_t is output and u_t^a is total factor productivity, which follows the exogenous process $\ln u_t^a = \rho_a \ln u_{t-1}^a + \sigma_a \varepsilon_t^a$ and $\varepsilon_t^a \sim N(0, 1)$. The firm chooses capital and labor to maximize profit: $y_t - r_t^K k_{t-1} - w_t l_t$.

Let capital letters denote aggregate quantities. Each period, the government chooses a set of fiscal variables to satisfy its budget constraint, $G_t + Z_t = \tau_t^L w_t L_t + \tau_t^K r_t^K K_{t-1}$, where G_t is government consumption. The goods market clearing condition is $Y_t = C_t + I_t + G_t$, where $I_t = K_t - (1 - \delta)K_{t-1}$ is investment.

Capital and labor tax rates follow the policy rules described by (22) and its capital tax analog.

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S.1.1.2. *New Keynesian Model*

The NK model expands the RBC model to incorporate a variety of real and nominal frictions. The economy is populated by a continuum of households, indexed by $j \in [0, 1]$. Each household maximizes expected utility,

$$E_t \sum_{t=0}^{\infty} \beta^t u_t^b \left[\frac{(c_t(j) - hC_{t-1})^{1-\gamma} - 1}{1-\gamma} - \frac{l_t(j)^{1+\kappa}}{1+\kappa} \right],$$

where u_t^b is a general preference shock that follows the process $\ln(u_t^b) = \rho_b \ln(u_{t-1}^b) + \sigma_b \varepsilon_t^b$. We assume external habits that depend on aggregate consumption last period, C_{t-1}. As in Erceg, Henderson, and Levin (2000), each household supplies unique labor inputs. A state-contingent claim x_t sold at a price of q_t exists to eliminate the income differentials due to differentiated labor. The household's flow budget constraint (dropping index j) in units of goods is

$$\begin{aligned}
&\left(1 - \tau_t^L\right) \frac{W_t}{P_t} l_t + \left(1 - \tau_t^K\right) \frac{R_t^K v_t k_{t-1}}{P_t} + \frac{R_{t-1} b_{t-1} + x_{t-1}}{\pi_t} + z_t + d_t \\
&\quad = c_t + i_t + b_t + q_t x_t + \Psi(v_t) k_{t-1},
\end{aligned}$$

where W_t is the nominal wage rate, P_t is the general price level, and $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the inflation rate. The model has variable capital utilization with the utilization rate v_t; in the steady state, $v = 1$. Varying the utilization rate involves a cost $\Psi(v_t)k_{t-1}$, where Ψ is an increasing, convex function with $\Psi(1) = 0$. We define the utilization cost parameter ψ such that $\frac{1-\psi}{\psi} = \frac{\Psi''(1)}{\Psi'(1)}$. The nominal rental rate for effective capital, $v_t k_{t-1}$, is R_t^K. i_t is investment inclusive of adjustment costs. Capital evolves as $k_t = (1 - \delta)k_{t-1} + [1 - s(\frac{u_t^i i_t}{i_{t-1}})] \times i_t$, where $s(\cdot)$ is the adjustment cost function for investment; in the steady state, $s(1) = s'(1) = 0$, and $s''(1) \equiv s > 0$. Adjustment costs are subject to an investment shock, u_t^i, which follows the process $\ln(u_t^i) = \rho_i \ln(u_{t-1}^i) + \sigma_i \varepsilon_t^i$. Finally, each household owns an equal share of all intermediate goods producing firms and receives dividends, d_t.

Wages are rigid. A perfectly competitive labor packer purchases the differentiated labor inputs and assembles them to form composite labor service, L_t, using the technology $L_t = [\int_0^1 l_t(j)^{1/(1+\eta_t^w)}\, dj]^{1+\eta_t^w}$, where η_t^w denotes wage markups and is assumed to follow the process $\ln(\eta_t^w) = \rho_w \ln(\eta_{t-1}^w) + \sigma_w \varepsilon_t^w$. The aggregate wage is $W_t = [\int_0^1 W_t(j)^{1/\eta_t^w}\, dj]^{\eta_t^w}$. Each period, household j receives a signal to reset its nominal wage with a probability $1 - \omega_w$. Those who cannot reoptimize instead index their wages to past inflation according to $W_t(j) = W_{t-1}(j)\pi_{t-1}^{\chi^w}$.

Prices are rigid. A perfectly competitive final goods producer uses a continuum of intermediate goods ($y_t(i), i \in [0, 1]$) to produce the final good, Y_t, using the technology $[\int_0^1 y_t(i)^{1/(1+\eta_t^p)}\, di]^{1+\eta_t^p} \geq Y_t$. η_t^p is the price markup for intermediate goods and follows the process $\ln(\eta_t^p) = \rho_p \ln(\eta_{t-1}^p) + \sigma_p \varepsilon_t^p$. Intermediate goods producers are monopolistic competitors in the product market. Firm i produces with the technology $y_t = u_t^a (v_t k_{t-1})^\alpha (l_t)^{1-\alpha}$, where u_t^a is the total factor productivity, following the process $\ln(u_t^a) = \rho_a \ln(u_{t-1}^a) + \sigma_a \varepsilon_t^a$. Analogously to households' wage decisions, a monopolistically competitive intermediate firm faces a probability $1 - \omega_p$ that it will be able to reset its optimal price. Firms that cannot reoptimize index their prices to past inflation according to $p_t(i) = p_{t-1}(i)\pi_{t-1}^{\chi^p}$. The goods market clearing condition is $Y_t = C_t + I_t + G_t + \Psi(v_t)K_{t-1}$.

The monetary authority obeys a rule that sets the nominal interest rate

$$\hat{R}_t = \rho_r \hat{R}_{t-1} + (1 - \rho_r)(\phi_\pi \hat{\pi}_t + \phi_y \hat{Y}_t) + \phi_{dy}(\hat{Y}_t - \hat{Y}_{t-1}) + \sigma^m \varepsilon_t^m.$$

Fiscal policy evolves according to the rules in (22). The flow budget constraint of the government is $B_t + \tau_t^K \frac{R_t^K}{P_t} v_t K_{t-1} + \tau_t^L \frac{W_t}{P_t} L_t = \frac{R_{t-1} B_{t-1}}{\pi_t} + G_t + Z_t$.

S.1.2. *Calibration and Estimation*

The RBC model is calibrated to values in the literature (largely following those in Chari, Kehoe, and McGrattan (2008)): $\beta = 0.99$, $\phi = 1.6$ implying a steady-state labor share of 0.32, $\alpha = 0.36$, $\frac{G}{Y} = 0.2$, and $\delta = 0.025$. The steady-state capital and labor tax rates are set at their sample means in the U.S. data from 1984 to 2007. The standard deviations of the technology, transfer, and capital and labor tax shocks are calibrated to the estimated posterior modes for the same shocks in the NK model to be described next (see Table S.I).

We estimate most of the parameters in the NK model using Bayesian methods, assuming agents have no foresight over taxes. In the exercises, the model parameters are fixed at the posterior modes that Table S.I reports.

The NK model is log-linearized and solved by Sims's (2002) method. Models have no growth; data are detrended with a linear trend, as in Smets and Wouters (2003). The sample period, 1984–2007, is selected because monetary policy is widely believed to follow a Taylor rule (Taylor (1993)). The estimation uses ten observables: real consumption, investment, labor, wage rate, the nominal interest rate, inflation, capital tax revenues, labor tax revenues, the sum of real government consumption and investment, and government transfers. Government data include all federal, state, and local levels. Section S.1.3 below describes the data.

Several parameters, which are known to be difficult to estimate from the data, are calibrated. The discount factor β is set to 0.99, implying an annual steady-state real interest rate of 4 percent. The capital income share in output is $\alpha = 0.36$. The quarterly depreciation rate $\delta = 0.025$. The steady-state elasticities of substitution in the goods and labor markets $(\frac{1+\eta^p}{\eta^p}, \frac{1+\eta^w}{\eta^w})$ are assumed to

TABLE S.I

PRIOR AND POSTERIOR DISTRIBUTIONS OF THE ESTIMATED PARAMETERS FOR THE NEW KEYNESIAN MODEL[a]

	Prior			Posterior Mode	
Parameters	Func.	Mean	Std.	Our Estimation	Smets and Wouters (2007)
Structural					
γ, risk aversion	G	1.75	0.5	1.54	1.47
θ, inverse Frisch labor elasticity	G	2	0.5	2.19	2.30
h, habit formation	B	0.5	0.15	0.31	0.68
ψ, capital utilization	B	0.5	0.15	0.45	0.69
s, investment adjustment cost	N	4	1.5	4.61	6.23
ω^w, wage stickiness	B	0.5	0.1	0.69	0.74
ω^p, price stickiness	B	0.5	0.1	0.79	0.73
χ^w, wage indexation	B	0.5	0.15	0.45	0.46
χ^p, price indexation	B	0.5	0.15	0.23	0.21
Monetary and fiscal policy					
ϕ_π, interest rate response to inflation	N	1.5	0.25	2.22	1.73
ϕ_y, interest rate response to output	N	0.12	0.05	0.04	0.08
ϕ_{yd}, interest rate response to output	N	0.12	0.05	0.17	0.16
γ_g, government spending response to debt	N	0.15	0.05	0.20	N.A.
γ_z, transfers response to debt	N	0.15	0.05	0.13	N.A.
AR(1) coefficients					
ρ_a, technology	B	0.5	0.2	0.93	0.94
ρ_b, preference	B	0.5	0.2	0.89	N.A.
ρ_i, investment	B	0.5	0.2	0.56	0.64
ρ_w, wage markup	B	0.5	0.2	0.31	0.82
ρ_p, price markup	B	0.5	0.2	0.49	0.74
ρ_r, interest rate	B	0.5	0.2	0.86	0.29
ρ_g, government spending	B	0.5	0.2	0.94	0.96
$\rho_{\tau,k}$, capital tax	B	0.5	0.2	0.92	N.A.
$\rho_{\tau,l}$, labor tax	B	0.5	0.2	0.88	N.A.
ρ_z, transfers	B	0.5	0.2	0.86	N.A.
Std. of shocks					
σ_a, technology	IG	0.1	2	0.55	0.35
σ_b, preference	IG	0.1	2	1.29	N.A.
σ_i, investment	IG	0.1	2	2.06	0.39
σ_w, wage markup	IG	0.1	2	0.27	0.21
σ_p, price markup	IG	0.1	2	0.16	0.11
σ_r, interest rate	IG	0.1	2	0.15	0.12
σ_g, government spending	IG	0.1	2	1.04	0.41
$\sigma_{\tau,k}$, capital tax	IG	0.1	2	2.65	N.A.
$\sigma_{\tau,l}$, labor tax	IG	0.1	2	2.46	N.A.
σ_z, transfers	IG	0.1	2	3.66	N.A.

[a]Functions G, B, N, IG denote Gamma, Beta, normal, and inverse Gamma distributions.

be 8, which implies the steady-state markups in the product and labor markets are approximately 14 percent, consistent with evidence that the average price markup of U.S. firms is between 5 and 15 percent (Basu and Fernald (1995)). Steady-state (gross) inflation is assumed to be 1. Other calibrated parameters are steady-state fiscal variables, which are set to their sample means. Steady-state ratios of government spending and debt to output come from their sample means: $\frac{G}{Y} = 0.17$ and $s^b = 1.58$ (debt to quarterly output), where output is the sum of consumption, investment, and government spending. The steady-state capital and labor income tax rates are computed based on Jones's (2002) definition: $\tau^K = 0.36$ and $\tau^L = 0.24$. When estimating the model, the correlation parameter of capital and labor tax shocks ξ is assumed to be zero. The simulation results in Table A-II assume $\xi = 0.26$, implying a correlation of 0.5 between capital and labor tax shocks as estimated by Yang (2005).

We assume that parameters are drawn independently and restrict the parameter space to deliver a unique rational expectations equilibrium. Our priors follow closely the priors used in Smets and Wouters (2007) for most of the shared parameters (see Table S.I). Priors for the debt financing parameters (γ_g and γ_z) are guided by their implied dynamics. When γ_g and γ_z are too high, macro variables oscillate because the government overreacts to stabilize debt. On the other hand, when the parameters are too small, a solution does not exist when monetary policy is active (in the sense of Leeper (1991)). Priors for γ_g and γ_z have independent normal distributions with means of 0.15 and standard deviations of 0.05.

To search for the posterior mode, the log-posterior function is minimized by Christopher Sims's minimization routine, `csminwel`. We initiate the mode search from different points, and multiple modes do not appear to be a concern. Table S.I summarizes our estimation results and compares them with the estimates by Smets and Wouters (2007) over a similar sample period. For structural and monetary policy parameters, most of our estimates are comparable to theirs.

S.1.3. *Data Description*

This section describes the data for estimating the NK model and the municipal and treasury bonds data used in Section A.3.

S.1.3.1. *Data for Estimating the New Keynesian Model*

Unless otherwise noted, data are from the National Income and Product Accounts Tables released by the Bureau of Economic Analysis.[1] All data in levels are nominal values. To convert nominal values to real per capita values, we deflate by the deflator for personal consumption expenditures (Table 1.1.9, line 2) and a population index (described below).

[1]Further information on data construction appears in Traum and Yang (2010).

Consumption. Consumption, C, is defined as total personal consumption expenditures (Table 1.1.5, line 2).

Investment. Investment, I, is defined as gross private domestic investment (Table 1.1.5, line 7).

Capital and Labor Tax Revenues. Following Jones (2002), the average personal income tax rate is

$$\tau^p = \frac{IT}{W + PRI/2 + CI},$$

where IT is personal current tax revenues (Table 3.1, line 3), W is wage and salary accruals (Table 1.12 line 3), PRI is proprietors' income (Table 1.12, line 9), and CI is capital income. Capital income is defined as rental income (Table 1.12, line 12), corporate profits (Table 1.12, line 13), interest income (Table 1.12 line 18), and $PRI/2$.

Labor income tax revenue, T^l, is

$$\tau^p(W + PRI/2) + CSI,$$

where CSI is contributions for government social insurance (Table 3.1, line 7). Capital income tax revenue, T^k, is

$$\tau^p CI + CT,$$

where CT is taxes on corporate income (Table 3.1, line 5) and PT is property taxes (Table 3.3, line 8).

Government Consumption and Investment. Government consumption is defined as government consumption expenditure (Table 3.1, line 16), government investment for defense (Table 3.9.5, line 13), and government net purchases of non-produced assets (Table 3.1, line 37), minus government consumption of fixed capital (Table 3.1, line 38). Government investment is defined as government investment for non-defense (Table 3.9.5, line 18).

Transfers. Transfers, Z, are defined as net current transfers, net capital transfers, and subsidies (Table 3.1, line 25), minus the tax residual. Net current transfers are defined as current transfer payments (Table 3.1, line 17) minus current transfer receipts (Table 3.1, line 11). Net capital transfers are defined as capital transfer payments (Table 3.1, line 36) minus capital transfer receipts (Table 3.1, line 32). The tax residual is defined as current tax receipts (Table 3.1, line 2), contributions for government social insurance (Table 3.1, line 7), income receipts on assets (Table 3.1, line 8), and the current surplus of government enterprises (Table 3.1, line 14), minus total tax revenues (the sum of labor, capital, and consumption tax revenues, where consumption tax revenues are taxes on production and imports (Table 3.1, line 4) less property taxes (Table 3.3, line 8).

Hours Worked. Hours worked are constructed from the following variables:
H: the index for nonfarm business, all persons, average weekly hours duration, 1992 = 100, seasonally adjusted (from the Department of Labor);
Emp: civilian employment for 16 years and over, measured in thousands, seasonally adjusted (from the Department of Labor, Bureau of Labor Statistics, CE16OV). The series is transformed into an index where 1992Q3 = 100.
Hours worked are defined as

$$N = \frac{H * Emp}{100}.$$

Wage Rate. The wage rate is defined as the index for hourly compensation for nonfarm business, all persons, 1992 = 100, seasonally adjusted (from the U.S. Department of Labor).

Inflation. The gross inflation rate is defined using the GDP deflator for personal consumption expenditures (Table 1.1.4, line 2).

Interest Rate. The nominal interest rate is defined as the average of daily figures of the Federal Funds Rate (from the Board of Governors of the Federal Reserve System).

Definitions of Observable Variables. The observable per capita variable X is defined from the real level data x

$$X = \ln\left(\frac{x}{Popindex}\right) * 100,$$

where
Popindex: index of *Pop*, constructed such that 1992Q3 = 1;
Pop: Civilian noninstitutional population in thousands, ages 16 years and over, seasonally adjusted (from the Bureau of Labor Statistics).
x = consumption, investment, hours worked, the sum of government consumption and investment, capital tax revenues, labor tax revenues, and transfers. The real wage rate is defined in the same way, except that it is not divided by the total population.

S.1.3.2. *Municipal and Treasury Bonds Data*

Yields to maturity from 1954M1 to 1994M12 on tax-exempt prime-grade general obligation municipal bonds come from Salomon Brothers, Analytical

Record of Yields and Yield Spreads. Salomon Brothers' municipal data are collected on bonds of various maturity lengths on the first of each month and based on estimates of the yields of new issues sold at face value. Yields on similarly rated (AAA) municipal bonds from 1994 to 2006 are obtained from Bloomberg's Municipal Fair Market Bond Index. Market yields on constant-maturity-adjusted, non-inflation-indexed U.S. Treasury securities from 1955 to 2006 come from the Federal Reserve's Statistical Release on Selected Interest Rates. These yields reflect the average of the weekly values within each month, which are interpolated from the daily yield curve.

S.2. TESTING ECONOMIC THEORY

S.2.1. *Testing Present-Value Constraints*

An extension of the econometric implications is that tests of economic theory will also be misspecified. One important example pertaining to fiscal policy is the testing of the government's present-value constraint, which links the value of government debt to the expected discounted value of future primary surpluses. A widely used approach to test present-value restrictions estimates a VAR with debt and surpluses and then tests for the cross-equation restrictions that the present-value condition imposes on the model (Campbell and Shiller (1987)). As we have shown, fiscal foresight implies that the VAR obtained by the econometrician will not yield the true dynamics and hence will not impose the correct cross-equation restrictions in testing the present-value condition.

To see how foresight will lead to Type I error in present-value tests, consider an endowment economy with lump sum taxes, a constant equilibrium real interest rate, and one-quarter foresight with respect to innovations in surpluses (receipts less expenditures net of interest payments on the government's debt). Taking expectations conditional on information at time $t-1$ of the government's flow budget constraint yields

$$E(b_t|\Omega_{t-1}) = \beta^{-1}b_{t-1} - E(s_t|\Omega_{t-1}), \tag{A.1}$$

where s_t is the primary surplus, b_t is one-period debt outstanding, and $\beta^{-1} = (1+r)$ is the constant gross rate of return between time t and $t+1$. Fiscal sustainability is ensured by a policy rule that makes future surpluses rise with debt. Two exogenous disturbances—for revenues and spending—drive surpluses, and agents have one period of foresight over both components of the surpluses. The policy rule is

$$s_t = \gamma b_{t-1} + \frac{\varepsilon_{1,t-1}}{1-\rho_1 L} + \frac{\varepsilon_{2,t-1}}{1-\rho_2 L}, \tag{A.2}$$

where γ is set to ensure that the agent's transversality condition for debt is satisfied and $0 < \rho_1, \rho_2 < 1$ determine the serial correlation properties of the driving processes. The expectations are taken with respect to the agents' information set, which is assumed to be $\Omega_{t-1} = \{\varepsilon_{1,t-j}, \varepsilon_{2,t-j}\}_{j=1}^{\infty}$. If this process holds for $t = 0, 1, \dots, T$, then imposing the transversality condition on government debt,

$$\lim_{N\to\infty} \beta^N E(b_{t+N}|\Omega_{t-1}) = 0,$$

implies the present-value restriction that the current value of outstanding debt equals future discounted surpluses,

$$b_t = \sum_{j=1}^{\infty} \beta^j E(s_{t+j}|\Omega_{t-1}). \tag{A.3}$$

Following Hansen, Roberds, and Sargent (1991) and Roberds (1991), the cross-equation restrictions that satisfy (A.3) are given by

$$\begin{aligned} \begin{bmatrix} s_t \\ b_t \end{bmatrix} &= \begin{bmatrix} LA(L) & LC(L) \\ \dfrac{\beta[L^2 A(L) - \beta^2 A(\beta)]}{L-\beta} & \dfrac{\beta[L^2 C(L) - \beta^2 C(\beta)]}{L-\beta} \end{bmatrix} \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}, \\ \mathbf{y}_t &= \mathcal{P}(L)\mathbf{v}_t, \end{aligned} \tag{A.4}$$

where $A(L) = \frac{\beta^{-1}-\gamma}{(1-\rho_1 L)(1-\gamma L)}$, and $C(L) = \frac{\beta^{-1}-\gamma}{(1-\rho_2 L)(1-\gamma L)}$. Two observations spring from (A.4). First, foresight implies that (A.4) is not an invertible representation (due to the zero at $L = 0$). Second, the cross-equation restrictions imposed on the moving average representation are nonlinear.

In light of the second observation, Campbell and Shiller (1987) derived the present-value restrictions on the VAR representation instead of the moving average representation. This simplification makes the present-value constraint easy to test, as it amounts to restrictions on the coefficients of the VAR. Denote the invertible representation of (A.4) by $\mathcal{P}^*(L)$ and write the corresponding VAR of (A.4) as

$$\begin{aligned} \begin{bmatrix} s_t \\ b_t \end{bmatrix} &= \mathcal{A}_0^{*-1}\mathcal{A}_1^*(L) \begin{bmatrix} s_{t-1} \\ b_{t-1} \end{bmatrix} + \mathcal{A}_0^{*-1} \begin{bmatrix} \varepsilon_{1t}^* \\ \varepsilon_{2t}^* \end{bmatrix} \\ &= \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} s_{t-1} \\ b_{t-1} \end{bmatrix} + \begin{bmatrix} w_{1t} \\ w_{2t} \end{bmatrix}, \\ \mathbf{y}_t &= A^* \mathbf{y}_{t-1} + \mathbf{w}_t. \end{aligned} \tag{A.5}$$

Note that $\mathcal{A}^*(L) = \mathcal{P}(L)^{*-1}$, implying that the coefficients of the VAR will *not* yield the correct cross-equation restrictions implied by (A.4) when there is foresight. Campbell and Shiller (1987) showed that the restrictions on the

VAR coefficients implied by the present-value constraint are given by

$$a_{11} + a_{21} = 0, \quad a_{22} + a_{12} = \beta^{-1}. \tag{A.6}$$

With foresight, however, the restrictions given by (A.6) will not hold even though the present-value constraint is satisfied. The VAR estimates give

$$a_{11} + a_{21} = \frac{\eta\rho_1\rho_2\beta A(\beta)C(\beta)}{\rho_2 C(\beta) - \rho_1 A(\beta)},$$
$$a_{22} + a_{12} = \frac{A(\beta)\eta\rho_2\rho_1(C(\beta) - A(\beta))}{\beta(\rho_2 C(\beta) - \rho_1 A(\beta))},$$

where $\eta = (1 + [A(\beta)C(\beta)]^2)^{-1/2}$. Therefore, the econometrician will incorrectly reject the null hypothesis that the present-value constraint holds.

S.2.2. *Tests of Granger Causality*

Sargent (1981) called for Granger (1969)–Sims (1972) causality tests to play a key role in helping the econometrician determine which variables properly belong in agents' information sets. For example, causality tests are commonly used to justify treating variables as exogenous for purposes of inference. Causality tests, however, are misspecified if agents have fiscal foresight.[2] To see this more clearly, return to the analytical model of Section A.2 with one quarter of foresight and an i.i.d. tax rule. The (true) moving average representation, on the left, and the (econometrician's) fundamental representation, on the right, in the variables $(\hat{\tau}_t, k_t)'$, are given by

$$\begin{bmatrix} \hat{\tau}_t \\ k_t \end{bmatrix} = \begin{bmatrix} L & 0 \\ -\dfrac{\kappa}{1-\alpha L} & \dfrac{1}{1-\alpha L} \end{bmatrix} \begin{bmatrix} \varepsilon_{\tau,t} \\ \varepsilon_{A,t} \end{bmatrix} \tag{A.7}$$
$$= \begin{bmatrix} \delta & -\kappa\delta L \\ 0 & \left[\delta(1-\alpha L)\right]^{-1} \end{bmatrix} \begin{bmatrix} \delta(\varepsilon_{\tau,t-1} + \kappa\varepsilon_{A,t-1}) \\ \delta(-\varepsilon_{\tau,t} + \kappa\varepsilon_{A,t}) \end{bmatrix},$$
$$\mathbf{x}_t = \mathcal{D}(L)\boldsymbol{\epsilon}_t = \mathcal{D}^*(L)\boldsymbol{\epsilon}_t^*,$$

where $\delta = (1+\kappa^2)^{-1/2}$. Note that the zero appearing in the true MA will appear in the opposite off-diagonal in the econometrician's representation. By Theorem 1 of Sims (1972), the econometrician's representation implies that $\hat{\tau}$ fails to Granger-cause k; in fact, $\hat{\tau}$ lies in a proper subspace of k, and hence k fails to Granger-cause $\hat{\tau}$. By not modeling foresight, the econometrician effectively reverses the Granger-causal ordering of the true dynamics.

[2]Leeper (1990) showed that fiscal foresight can imply that money growth Granger-causes deficits in an equilibrium in which deficits are systematically monetized.

S.3. MUNICIPAL BONDS AND FISCAL FORESIGHT: ADDITIONAL RESULTS

We now offer a new method to capture the information flows associated with news about future tax changes in an estimated VAR that builds on Poterba (1989). Identification takes two steps. First, we condition on the spread between municipal and treasury bonds. Then we apply two well-known identification schemes.

In the United States, municipal bonds are exempt from federal taxes.[3] If $\mathcal{Y}_T^M$ is the yield on a municipal bond with maturity T and $\mathcal{Y}_T$ is the yield on a taxable bond with the same maturity, then if the bonds have the same callability, market risk, credit risk, and so forth, an implicit tax rate is given by $\tau_T^I = 1 - \mathcal{Y}_T^M/\mathcal{Y}_T$. This is the tax rate at which the investor is indifferent between the tax-exempt and taxable bond. If participants in the municipal bond market are forward looking, the implicit tax rate should predict subsequent movements in individual tax rates. This tactic follows the advice of Sims (1977), who showed that durable goods prices that are determined in spot markets, and financial prices in particular, should be nearly Granger-causally prior to any time series that market participants observe. This observation motivates and restricts the kinds of information that might be useful for capturing foresight in VARs, and explains why merely augmenting VARs with "forward-looking" variables, especially slow-moving ones, is unlikely to be helpful.

Several papers document that municipal bonds respond to changes in tax policy (Poterba (1989), Fortune (1996), Park (1997), and Ang, Bhansali, and Xing (2010)). Leeper, Richter, and Walker (2012) updated Poterba (1989) and found that municipal bonds are reliable predictors of future tax changes. Many of these papers conclude that the short end of the municipal bond yield curve predicts pending fiscal policy changes much more accurately than the long end of the yield curve—the municipal bond puzzle (Chalmers (1998)). In light of this puzzle, our analysis uses municipal and treasury bond data with maturity lengths of one and five years only.

A newly issued tax-exempt bond with maturity T, a par value of \$1, and per-period coupon payments C_M, will sell at par if

$$1 = \frac{C^M}{\sum_{t=1}^{T}(1+R_t^\tau)^t} + \frac{1}{(1+R_T^\tau)^T}, \tag{S.1}$$

where R_t^τ is the *after-tax* nominal interest rate for payments made in period t. No-arbitrage conditions imply that an identical taxable bond paying coupon C

[3]Depending on the type of bond, municipal bonds can also be exempt from the Alternative Minimum Tax, state, and local taxes.

and selling at par satisfies

$$1 = \frac{\sum_{t=1}^{T} C(1-\tau_t^e)}{\sum_{t=1}^{T}(1+R_t^\tau)^t} + \frac{1}{(1+R_T^\tau)^T}, \tag{S.2}$$

where τ_t^e is the future tax rate expected to hold in period t.

Bonds that sell at par have a yield-to-maturity that equals the coupon payments, so the implicit tax rate is $\tau_T^I = 1 - C_M/C$. Subtracting (S.2) from (S.1) and solving for C_M/C gives

$$\tau_T^I = \sum_{t=1}^{T} \omega_t \tau_t^e, \tag{S.3}$$

where $\omega_t = \delta_t / \sum_{t=1}^{T} \delta_t$ and $\delta_t = (1+R_t^\tau)^{-t}$. The current implicit tax rate is a weighted average of discounted expected future tax rates from $t = 1$ to T and should respond immediately to news about anticipated *future* tax changes.

Equation (S.3) makes plain the advantages of using municipal bond spreads to capture information flows about pending tax changes. First, there is no need to specify a priori the period of foresight. Assuming market efficiency, the implicit tax rate reveals the extent to which agents do or do not have foresight. Second, there is no need to specify a functional form for information flows. In the previous section, we modeled information flows as coming from one of several possible information processes. We would have to conduct a similar sensitivity analysis if we were estimating a DSGE model. Using the implicit tax rate avoids taking an a priori stand on the nature of information flows.

We turn to two prominent identification strategies that have acknowledged foresight in the fiscal VAR literature—Blanchard and Perotti (2002) (BP) and Mountford and Uhlig (2009) (MU). We derive conditions under which these identification schemes capture the true information flows. We then augment each identification strategy by conditioning on implicit tax rates and argue that this additional step alleviates the problems associated with foresight.

S.3.1. *Blanchard and Perotti (2002)*

BP estimated a quarterly VAR in output, y, government revenues net of transfers (including interest payments), τ, and government spending (government consumption plus government investment), g. The data are logarithms of real, per capita variables. We allow for both a deterministic trend (quadratic in logs) and a stochastic trend (unit root with drift), as BP did.

Tests overwhelmingly support the causal priority of the implicit tax rate series in BP's VAR system. A test of whether lags of other variables help to predict spreads, given past information on spreads, yields χ^2 statistics with significance levels of 0.23 (deterministic detrending) and 0.34 (stochastic detrending).[4]

Write the reduced-form residuals from this VAR as

$$
\begin{aligned}
u_t^\tau &= a_{\tau y} u_t^y + b_{\tau g} e_t^{*g} + e_t^{*\tau}, \\
u_t^g &= a_{gy} u_t^y + b_{g\tau} e_t^{*\tau} + e_t^{*g}, \\
u_t^y &= c_{y\tau} u_t^\tau + c_{yg} u_t^g + e_t^{*y}.
\end{aligned}
\tag{S.4}
$$

If agents have sufficient foresight, as BP themselves noted and Section A.3 above documents, the BP VAR will be misspecified and will result in biased inference. To account for such bias, we let e_t^{*g}, $e_t^{*\tau}$, and e_t^{*y} denote the shocks associated with the VAR representation. We differentiate these shocks from the structural shocks available to the agents of the economy (which we denote e_t^g, e_t^τ, and e_t^y).[5]

Section VIII of BP derives a mapping from the e_t^* shocks to the shocks observed by the agents, e_t, that follows from augmenting the VAR as

$$\tau_t = a_1 y_t + A_{11}(L)\tau_{t-1} + A_{12}(L)y_{t-1} + e_t^{*\tau}, \tag{S.5}$$

$$y_t = c_0 E_t(\tau_{t+1}) + c_1 \tau_t + A_{21}(L)\tau_{t-1} + A_{22}(L)y_{t-1} + e_t^{*y}, \tag{S.6}$$

where now output at date t responds to *expected* taxes at $t+1$. When agents have foresight, it is likely that output will depend not only on current and lagged taxes but also on expected taxes. BP showed how the innovation in (S.5) led one quarter, $e_{t+1}^{*\tau}$, can be used to instrument for the expectational effects in (S.6). For this instrumental variables approach to be valid, two stringent assumptions must hold. First, agents must have *exactly* one quarter of foresight—no more, no less. Second, the innovation, $e_t^{*\tau}$, in (S.5) cannot be correlated with other shocks in the VAR.

Neither assumption is likely to hold in practice. As the previous section argues, the length of foresight is likely to be much longer than one quarter and

[4]Forni and Gambetti (2010) and its references contain detailed discussion of tests for "informational sufficiency" of a VAR. According to their criteria, our test satisfies a necessary but not sufficient condition for fundamentalness. Sufficiency requires testing the null of no Granger-causality against the principal components from a factor model that contains a large set of macroeconomic data. For reasons discussed in the conclusion, we avoid using a factor model framework.

[5]To confront the non-uniqueness described in Section A.4, BP identified the e_t shocks by arguing that legislative lags ensure that there can be no within-quarter adjustment of fiscal policy to unexpected changes in GDP, other than "automatic effects of activity on taxes and spending under existing fiscal policy rules." Automatic effects operate through parameters $a_{\tau y}$ and a_{gy}, which are elasticities of tax revenues and government purchases with respect to output. BP then showed that once $a_{\tau y}$ and a_{gy} are calibrated to 2.08 and 0, respectively, $u_t^\tau - a_{\tau y} u_t^y$ and $u_t^g - a_{gy} u_t^y$ can be used as instruments in estimating $c_{y\tau}$ and c_{yg}. The final two parameters are set to either $b_{\tau g} = 0$ and $b_{g\tau} \neq 0$ or vice versa to triangularize the fiscal sector.

it varies substantially over time. The BP identification scheme cannot handle more than one quarter of foresight because that would require an implausible lag in the discretionary response of fiscal policy. With one quarter of foresight, the BP identification requires no discretionary response of fiscal policy to output realizations both this quarter *and* last quarter. Amending (S.6) with $E_t\tau_{t+2}$, which allows for two quarters of foresight, requires that there is no discretionary response of fiscal policy to output for three quarters, and so on. If agents have more than one quarter of foresight, it is also very likely that the innovation $e_t^{*\tau}$ in (S.5) will be correlated with other shocks in the VAR. The innovation from the VAR in that example is a convolution of the tax and technology shocks. This suggests that the instrument used by BP to account for foresight will be only weakly correlated with the explanatory variable.

Now augment BP's VAR system with data on the spread, s, between municipal bonds and treasury bonds (the implicit tax rate):

$$\begin{aligned}
u_t^\tau &= a_{\tau y}u_t^y + a_{\tau s}u_t^s + b_{\tau g}e_t^g + e_t^\tau,\\
u_t^g &= a_{gy}u_t^y + a_{gs}u_t^s + b_{g\tau}e_t^\tau + e_t^g,\\
u_t^y &= c_{y\tau}u_t^\tau + c_{yg}u_t^g + e_t^y,\\
u_t^s &= c_{s\tau}u_t^\tau + c_{sg}u_t^g + c_{sy}u_t^y + e_t^s.
\end{aligned} \tag{S.7}$$

By conditioning on the implicit tax rate, the econometrician no longer needs to use the innovation $e_t^{*\tau}$ as an instrument for the expectation in (S.6). An efficient municipal bond market makes the implicit tax rate equivalent to the expectation in (S.6), as (S.3) makes clear. This relaxes the stringent assumptions that BP's identification of foresight requires; conditioning on the municipal bond spread posits that the innovations in (S.7) are the true structural shocks (i.e., that the observables augmented with the implicit tax rate span the space of the shocks observed by the agents), and all that is left to achieve identification is a rotation of the covariance matrix. We make the reasonable assumption that news contained in interest-rate spreads has no direct impact on current output, tax revenues, and spending. This assumption sets both $a_{\tau s}$ and a_{gs} to zero and implies that the relationship between the reduced-form and structural innovations for the tax and spending shocks of (S.7) are identical to those of (S.4). We can now apply BP's identification of these shocks. We also identify the "news" shock, e_t^s (again following the lead of BP), by using the reduced-form shocks and parameters as instruments to estimate $c_{s\tau}$, c_{sg}, and c_{sy}.[6] To facilitate comparison, we use the same data and follow the same detrending procedures as BP. We refer the reader to Section III of BP for a more detailed discussion of the data and empirical approach.

[6]More specifically, $u_t^\tau - a_{ty}u_t^y$, $u_t^g - a_{gy}u_t^y$, and $u_t^y - c_{y\tau}u_t^\tau - c_{yg}u_t^g$ are used as instruments for $c_{s\tau}$, c_{sg}, and c_{sy}, respectively.

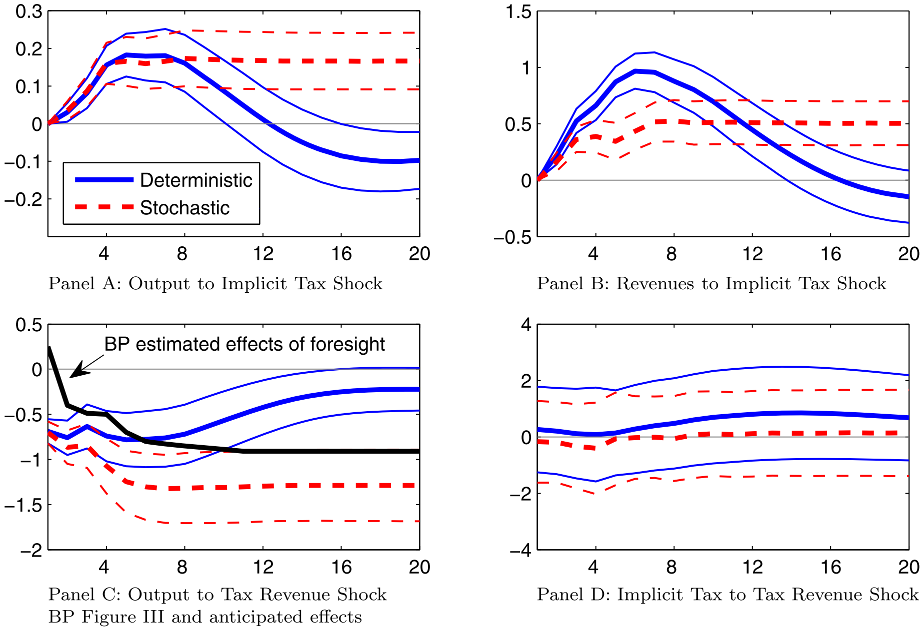

FIGURE S.1.—Estimated mean responses for deterministic trend (solid lines) and stochastic trend (dashed lines) to a positive tax revenue shock (panels C, D) and positive implicit tax rate shock (panels A, B) with one-standard-deviation bands.

Figure S.1 plots the estimated mean responses to an unanticipated tax revenue shock (panels C and D) and to a shock to the implicit tax rate (panels A and B), with one-standard-deviation bands computed by Monte Carlo simulations based on 500 replications. Solid lines represent the deterministic-trend model and dashed lines the stochastic-trend VAR. Following BP, we transform the original impulse responses to report the dollar response of each variable to a dollar shock in the fiscal variables. We use the tax revenue data to transform the implicit tax rate so that the impulse response is interpreted as a dollar shock to *anticipated* tax revenue. Panels B and D of the figure condition on a five-year implicit tax rate, implying that agents have a maximum of five years of foresight, but results are robust to implicit tax rates with maturity less than five years.

Panel C is identical to BP's Figure III and shows that the response of output to a surprise tax increase is negative and significant. The heavy solid line in panel C is BP's instrumental-variable estimate of the effect of foresight (Figure VI in BP). That solid line represents the "upper bound" on the anticipatory effects of foresight, according to BP. As the figure shows, identifying foresight using their approach generates a positive response on impact, in contrast to the negative response from the VAR that ignores foresight altogether. Beyond the impact period, BP's methodology does not, however, deliver responses that are statistically different from the VAR that ignores foresight. This result led BP to conclude, "there is not much evidence of an effect of anticipated tax changes on output (p. 1353)."

Panel A contrasts sharply with BP's findings: output rises substantially and significantly after an increase in the implicit tax rate. The anticipatory effects of fiscal foresight last well beyond the initial quarter and, in the short run, anticipated increases in tax rates are *expansionary*.

Our approach generates markedly different results from BP primarily because the implicit tax rate provides flexible information about the degree of foresight. BP's identification permits only one quarter of foresight, while ours allows a maximum of five years. This is an example of the kind of a priori restriction on information flows that can drive inferences about foresight. Panels B and D of the figure corroborate the plausibility of our identification by showing that tax revenues respond positively and significantly to a positive innovation in the implicit tax rate, as theory suggests. Further corroboration of the identification comes from the fact that the implicit tax rate does not respond significantly to innovations in taxes, which theory also predicts (panel D).

Panels A and B of Table S.II report estimated output multipliers for the estimated VAR. The table also records results from BP's Table III for comparison. The primary difference between the BP multipliers and ours is that we allow for the anticipatory effect that arises from foresight—the inside and outside lags. The row labeled GDP (A) is the multiplier associated with an innovation in the implicit tax rate arising from an anticipated increase in tax rates. The row labeled GDP (U) is the multiplier associated with an innovation in the tax revenue shock, identified as the effect of an unanticipated tax cut.

Several features stand out. First, for the majority of the horizon and both detrending methods, the output multiplier for the implicit tax rate is *positive*, so higher anticipated taxes *raise* output in the short run. With the lone exception of the 1- and 12-quarter multipliers, all multipliers in the anticipatory horizon have one-standard-deviation error bands that do not cross zero. The peak positive responses are 0.19 at 4 quarters (deterministic trend model) and 0.18 (stochastic trend model). Second, the multipliers associated with the implicit tax rate are much smaller in absolute value than those from the tax revenue shock. This suggests that agents probably do not have *perfect* foresight, on average. Perfect foresight would imply movements in macro aggregates that are about the same magnitude as for unanticipated shocks (assuming identical variances). The relatively muted response of output to a shock in the implicit tax rate suggests that more intricate information flows than perfect foresight (e.g., moving average processes for news) are probably at work. Implicit tax rates capture this kind of subtlety. Finally, unanticipated tax hikes have substantially larger effects in the VAR that includes the implicit tax rate than in the BP specification, particularly for the deterministic trend. For example, the one-standard-deviation error bands on the 4-quarter multiplier are -1.64 and -0.65, which nearly exclude the BP estimate of -0.74. This is consistent with

TABLE S.II

OUTPUT AND INVESTMENT MULTIPLIERS FOR AN IMPLICIT TAX SHOCK (A) AND TAX REVENUE SHOCK (U)[a]

	0 qtr	4 qtrs	8 qtrs	12 qtrs	20 qtrs
			Panel A: Blanchard–Perotti, Deterministic Trend		
GDP (BP)	−0.69*	−0.74*	−0.72*	−0.42*	−0.22
GDP (U)	−0.84*	−1.15*	−0.95*	−0.36	−0.06
GDP (A)	0.03	0.19*	0.13*	−0.02	−0.10*
			Panel B: Blanchard–Perotti, Stochastic Trend		
GDP (BP)	−0.70*	−1.07*	−1.32*	−1.30*	−1.29*
GDP (U)	−0.71*	−1.15*	−1.39*	−1.34*	−1.33*
GDP (A)	0.04	0.17*	0.18*	0.18*	0.17*
			Panel C: Mountford–Uhlig, Output Multipliers		
GDP (MU)	−0.29*	−0.79*	−1.23*	−1.61*	−0.60
GDP (U)	−0.27	−1.04*	−1.64*	−1.81*	−1.05
GDP (A)	−0.10*	0.04*	0.09	0.02	0.03
			Panel D: Mountford–Uhlig, Investment Multipliers		
INV (MU)	−0.19	−0.27*	−0.38	−0.46	−0.14
INV (U)	−0.23	−0.31*	−0.50*	−0.42	−0.27
INV (A)	0.03	0.12*	0.14*	0.10	0.09

[a] An asterisk (*) indicates zero is outside of the region between the two one-standard-deviation bands. BP denoted the numbers from the VAR without municipal bonds.

the numerical evidence presented in Section A.3, where the econometrician consistently underestimates the multiplier.

Our finding that news of higher taxes increases economic activity over much of the anticipation period, as Figure S.1 depicts, echoes results from two very different methodologies. In a case study, House and Shapiro (2006) argued that the phased-in tax reductions enacted by the 2001 Economic Growth and Tax Relief Reconciliation Act played a significant role in creating the unusually slow recovery from the 2001 recession. By feeding the legislated paths of marginal tax rates on labor and capital into an RBC model, the authors generated a path of equilibrium GDP that shares qualitative features with panel A of Figure S.1.

Mertens and Ravn (2011) augmented a VAR with Romer and Romer's (2010) anticipated tax liabilities series, which they treated as strictly exogenous in the VAR. Mertens and Ravn appended to each equation of the VAR a distributed lag of q periods in *future* tax liabilities. They estimated that an anticipated tax increase induces a boom in output whose amplitude and duration increase with the period of foresight q. In contrast to our approach with muni-treasury spreads, Mertens and Ravn must specify a priori the period of foresight and maintain that anticipated taxes are exogenous—assumptions that are critical to the quantitative effects they obtained. Nonetheless, the qualitative effects closely resemble those in panel A of our figure.

Despite their different methodologies, House–Shapiro and Mertens–Ravn share a common economic explanation for their findings, which also applies to the RBC model in Section A.3. Anticipated tax changes generate wealth effects that kick in immediately—upon arrival of the news—but the substitution effects, which operate on critical economic margins, do not affect behavior until the tax rates have changed. In a conventional model, expected tax increases reduce wealth, which induces agents to work harder, increasing employment and output immediately.

Anticipated tax changes have sharply different macroeconomic impacts in our model, which includes a direct measure of tax news and a flexible specification of foresight, than in the instrumental variables, tightly circumscribed approach that BP took. These differences underscore the importance of modeling information flows.

S.3.2. *Mountford and Uhlig (2009)*

Mountford and Uhlig (2009) imposed restrictions directly on the shape of the impulse responses of the VAR to identify economic shocks, following the work of Faust (1998), Canova and Pina (2000), Uhlig (2005), and Canova and Pappa (2007). Like BP, MU identified two fiscal policy shocks—a government spending shock and a government revenue shock. They defined a fiscal shock as a positive reaction of the respective fiscal variable for four consecutive periods, including the impact response. This is to ensure that only substantial movements in fiscal variables are counted as "shocks." Fiscal shocks are required to be orthogonal to business cycle shocks and monetary policy shocks. A business cycle shock is defined as a shock that jointly moves output, consumption, nonresidential investment, and government revenue in the same direction for four quarters following the shock.[7] A monetary policy shock is defined as a shock that moves interest rates up and reserves and prices down for four quarters after the shock.

Like with most identification schemes, this one intends to identify rotations of the covariance matrix. Caldara and Kamps (2010) and Caldara (2011) showed that the sign restriction approach of MU can be reinterpreted as pinning down the elasticities associated with the BP system (S.4). And like BP, MU acknowledged the importance of foresight and imposed *additional* restrictions to account for it. MU argued that anticipated fiscal policy changes can be identified by imposing zero restrictions on the responses of fiscal variables

[7]To select among the many rotations consistent with this definition of the business cycle shock, MU imposed the criterion that substantial movements in output, consumption, nonresidential investment, and government revenue must be attributed to business cycle shocks.

over the period of fiscal foresight, reflecting the idea that the isolated policy shock is news about a change in future, but not current, policy variables.

Under what conditions will the MU identification scheme deliver correct inference? As the analytical section shows, fiscal foresight does not imply a zero response of all fiscal variables over the foresight period. The various fiscal rules considered in the previous section suggest that this is an exceptional situation. In the special case where the tax rate is exogenous and follows the simple rule

$$\hat{\tau}_t = e^u_{\tau,t} + \varepsilon_{\tau,t-q} \tag{S.8}$$

when news arrives in period t, the tax rate does not change until period $t+q$. MU's zero restriction, if it were applied to the tax *rate*, would work in this case. But MU imposed the zero restriction on tax *revenues*. They found that higher anticipated revenues reduce output—and, therefore, the tax base—over the period of foresight. Lower output, coupled with the restriction that revenues are fixed, delivers the eccentric implication that a particular sequence of *unanticipated* tax rate increases, $\{e^u_{\tau,t}\}$, is imposed to identify an anticipated tax hike. Considering that, in most countries, automatic stabilizers in the tax code would lower rates when output falls, MU's identification scheme may have difficulty isolating the effects of fiscal foresight.

We revisit the MU estimation, but, instead of zero restrictions on fiscal variables, we condition on the municipal bond spread to account for fiscal foresight. To facilitate direct comparisons, we use the same data and estimation procedure as MU. We estimate a VAR in GDP, private consumption, total government expenditure, total government revenue, real wages, private nonresidential investment, interest rate, adjusted reserves, the producer price index for crude materials, and the GDP deflator. Fiscal variables are defined as in MU, who followed BP; the remaining variables are quarterly observations from 1955 to 2000, and are logarithms, except the interest rate, which is in levels. The VAR has six lags and no deterministic terms. Detailed descriptions of the data and estimation can be found in Appendixes A and B of Mountford and Uhlig (2009). To the MU variables we add the municipal bond spread (implicit tax rate). We identify a shock to the implicit tax rate as a positive response to the municipal bond spread for four quarters, and impose that it is orthogonal to the other shocks in the system.[8]

Figure S.2 plots the median impulse response functions along with the 16th and 84th percentile bands for the MU zero restriction approach to foresight and the VAR specification conditioning on the implicit tax rate. The solid lines show the responses to a positive innovation in the implicit tax rate. The dashed lines show the response to a tax revenue shock imposing zero restrictions on the first four quarters (shaded area of panel D). Conditioning on the municipal

[8]MU's model expands BP's system of variables, but the test for Granger-causal priority of spreads still yields a χ^2 statistic with significance level of 0.74.

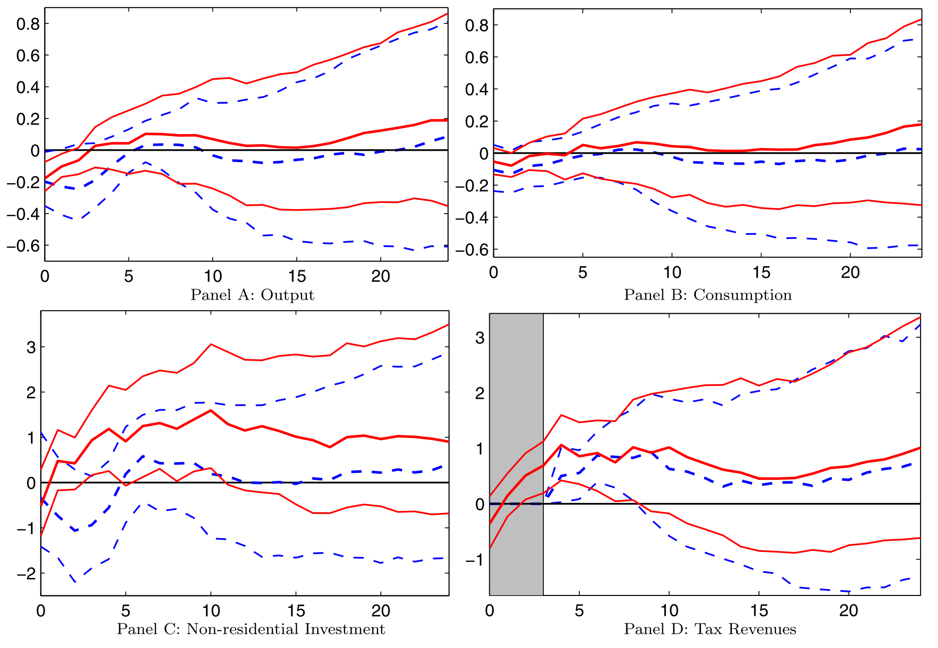

FIGURE S.2.—Estimated median responses with 16th and 84th percentile bands for MU VAR specification to a positive tax revenue shock (dashed lines) and MU VAR with muni spread to a positive implicit tax rate shock (solid lines).

bond spread suggests that tax revenues are not zero over the foresight horizon, contradicting the restriction imposed by MU. In response to a shock in the implicit tax rate, tax revenues are negative on impact and then follow a hump-shaped pattern similar to panel B of Figure S.1. We interpret the short-run response of tax revenues to an innovation in the implicit tax rate as evidence that automatic stabilizers lower rates as output falls. This, again, demonstrates the flexibility of the muni spread in capturing information flows. In lieu of imposing a rigid four-quarter foresight assumption, the shock to the implicit tax rate reports how agents respond to news about future tax changes.

Responses of many aggregate variables to a shock in the implicit tax rate are not very different from the responses when imposing MU's zero restrictions. The consumption path is nearly identical, with zero within the error bands for both identification approaches. This suggests that consumption does not respond significantly to anticipated changes in future tax rates, which is consistent with the evidence in the public finance literature (Poterba (1988), Parker (1999), Souleles (1999, 2002)). However, unlike the conclusions reached in those papers, we do not take this as evidence of the lack of foresight. Many of the aggregate variables respond in significant ways to the news in implicit tax rates. For example, the path of nonresidential fixed investment mimics the hump-shaped response of tax revenues. An anticipated increase in tax rates produces a positive and significant response of investment for several quarters, which contrasts to the negative or zero response generated by imposing MU's zero restrictions.

Effects of anticipated taxes in Figure S.2 are consistent with economic theory. Mertens and Ravn (2011) emphasized the distinction between consumption of durables and nondurables in understanding the impacts of anticipated tax changes. In their empirical and theoretical analyses, Mertens and Ravn found that, while foresight can have a significant effect on durable consumption, nondurables are less likely to move in response to anticipated changes in tax rates.[9] Auerbach (1989) emphasized the role of investment adjustment costs when examining the dynamic effects of anticipated taxes on investment. That investment responds positively and significantly over many quarters suggests that investment adjustment costs may be low: if adjustment costs were high, firms would begin to *decrease* investment immediately in response to an anticipated tax increase. Finally, counter to the results found in the BP specification, panel A shows that output responds negatively to an anticipated tax increase in both identification schemes. One explanation for the differences across BP and MU can be attributed to the particular rotation of the covariance matrix implemented by MU. Caldara and Kamps (2008) mapped the elasticities estimated by BP in (S.4) into the implied elasticities from imposing the MU sign restrictions. They found that MU imposed a much higher within-quarter elasticity of net taxes with respect to output. The higher elasticity will drive down the response of output to an implicit tax rate shock.

Panels C and D of Table S.II report estimates of the output and investment impact multipliers to an innovation in the tax revenue shock (U), the implicit tax rate (A), and the tax revenue shock in the original MU specification. As was the case with the BP identification, the estimated effects of an anticipated tax decline are smaller than the effects of unanticipated shocks. Also similar, the MU identification underestimates the size of the multipliers. For example, at the eight-quarter horizon, the MU estimate of the median output multiplier falls around the 20th percentile of the posterior for the tax revenue shock estimated from the expanded VAR. Table S.II makes clear that accounting for foresight changes the estimated output and investment multipliers associated with tax shocks.

S.4. ASSESSING THE EX ANTE APPROACH

We share the view of the ex ante approach that, in the presence of fiscal foresight, conventional fiscal VARs misalign the information sets of economic

[9]They reconciled this empirical finding with theory by assuming habit formation in consumption and complementarity in consumption goods, which smooth out the wealth effects during the period of foresight.

agents and the econometrician. In the context of the model in Section 2, conventional VARs estimate systems in current and past values of capital (or output) and revenues. Fiscal foresight implies that those systems are not invertible and do not adequately capture the fiscal news to which agents respond. When tax rates are exogenous, as in the simple example, information sets are correctly aligned by including *future* tax rates in the VAR. This results in a VAR system in $\{k_t, \tau_{t+q}\}$, and now the fundamental representation is invertible. The ex ante approach essentially applies this principle by seeking instruments for expected future tax obligations.

The discussion in Section 2 makes this interpretation more precise. Although non-invertibility of the moving average representation implies that there is no autoregressive representation in which the true fiscal news is a function of current and past endogenous variables, there is an autoregressive representation in the fiscal news and *future* endogenous variables. The ex ante approach uses forecasts of revenue changes associated with tax legislation to instrument for the information agents possess about future taxes. To infer the effects of anticipated taxes on output, the ex ante approach regresses output against forecasted revenue changes, among other variables, and interprets the estimated coefficients causally. To assess the ex ante approach, we examine the quality of instruments employed.

Of course, tax rates are not exogenous. They are the outgrowth of a complex set of economic and political decisions. Recognizing the intrinsic endogeneity of tax policy decisions, Romer and Romer (2007, 2010) used a narrative method to compile data series that decompose the forecasted revenue consequences of federal tax changes into "endogenous" and "exogenous" components. Mertens and Ravn (2010) used the Romers' compiled data series. They generalized the Romers' empirical work and laid out an intricate DSGE model to interpret their estimates of the impacts of anticipated and unanticipated changes in taxes. Whereas the Romers found only weak evidence that private agents react to anticipated tax changes, Mertens and Ravn obtained provocative and striking results reminiscient of Branson, Fraga, and Johnson's (1986) argument about the Reagan tax cuts: anticipated tax cuts induce sharp economic slowdowns during the period of fiscal foresight, and may even produce recessions.

In this section, we use a standard real business cycle model with proportional capital and labor tax rates to simulate equilibrium data, including forecasted revenue changes induced by anticipated and unanticipated tax disturbances. We then run regressions using simulated data and compare the estimated effects of foreseen changes in tax rates to the true effects of fiscal foresight. Because the simulated data and revenue forecasts are generated by a single coherent model, if the ex ante approach is efficacious, the regressions should recover the true effects almost exactly.

Before we can proceed with this test of the ex ante method, we first must embed the narrative identification scheme in a formal theoretical model.

S.4.1. *Formalizing the Narrative Identification*

The Romers distinguished between "endogenous" changes in taxes—ones induced by short-run countercyclical concerns and those undertaken because government spending was changing—and "exogenous" changes in taxes—those that are responses to the state of government debt or to concerns about long-run economic growth. To avoid confusion with other definitions, we shall refer to these as "RR endogenous" and "RR exogenous" components of tax policy behavior.

We specify a tax rule that includes the various motivations for tax changes that the Romers considered and embeds both anticipated and unanticipated shocks to taxes. Alternative parametric specifications of policy coincide with different formalizations of the narrative identification scheme. Our message is that the performance of the ex ante approach hinges critically on the precise formalization attributed to the narrative identification.

To reflect the distinction the Romers drew between "endogenous" countercyclical concerns and "exogenous" long-run concerns, it is convenient to decompose output into business cycle, y_t^C, and trend, y_t^T, components. A rule for tax rates that embeds this multiplicity of motivations for tax changes is given by

$$\tau_t = \rho(L)\tau_{t-1} + \underbrace{\sum_{j=-P}^{P} \mu_j^C E_t y_{t+j}^C + \sum_{j=-M}^{M} \beta_j E_t g_{t+j}}_{\text{“RR endogenous”}} + \underbrace{\sum_{j=-P}^{P} \mu_j^T E_t y_{t+j}^T + \sum_{j=-N}^{N} \gamma_j E_t s_{t+j-1}^B + \varepsilon_{\tau,t-q} + e_{\tau,t}^u}_{\text{“RR exogenous”}}. \quad \text{(S.9)}$$

The fiscal authority's choice of the current tax rate is permitted to respond systematically to current, past, and expected fluctuations in output at both business cycle and trend frequencies and to current, past, and expected changes in government spending (g_{t+j}) and government indebtedness as measured by the debt-to-output ratio (s_{t+j-1}^B). The rule also embeds an unanticipated shock, $e_{\tau,t}^u$, and "news" about the tax rate that arrived q periods in the past, $\varepsilon_{\tau,t-q}$. Both of these shocks are assumed to be unrelated to economic conditions.[10]

To study the Romers' identification, we simplify (S.9) by restricting the "RR endogenous" component and the feedback from trend output movements in the "RR exogenous" component. We also specialize the timing of the response

[10]Although, in their papers, the Romers did not explicitly interpret tax legislation as containing shock components, in private communication David Romer confirmed that this interpretation is not inconsistent with their views.

to the state of government debt to coincide with the period of foresight, q, and allow only one lag of the tax rate to enter, $\rho(L)=\rho$. This simplifies (S.9), written in terms of its anticipated and unanticipated parts, to

$$\tau_t = \rho\tau_{t-1} + \mu^C y_t + \xi_{t-q} + e^u_{\tau,t}, \tag{S.10}$$

where

$$\xi_{t-q} = \mu^T y_{t-q-1} + \gamma s^B_{t-q-1} + \varepsilon_{\tau,t-q} \tag{S.11}$$

is the fiscal foresight, which stems from both systematic responses of taxes to past economic and fiscal conditions and exogenous news about tax legislation. By simplifying the tax rule to restrict the sources of feedback from the economy to expected future tax rates, we are likely to bias our results in favor of the ex ante narrative approach.

It might seem like a stretch to model the response of tax policy to concerns about long-run economic growth as we do in the definition of ξ_{t-q}. But several large tax bills that Romer and Romer (2007) labeled as long-run, "exogenous" tax changes could easily be categorized as "endogenous" responses to short-term economic conditions. Stein (1996) documented that President Kennedy was prompted to change his position on a tax cut by the stalled recovery in 1962 and 1963 from the 1960–1961 recession.[11] The Economic Recovery Act of 1981 signed by President Reagan is widely regarded as driven by philosophical considerations. But the supply-side promise to stimulate growth without triggering inflation is arguably an endogenous reaction to the stagflation of the 1970s and early 1980s. The Romers classified two recent tax cut bills signed by President Bush—part of the Economic Growth and Tax Relief Reconciliation Act of 2001 and the Working Families Tax Relief Act of 2003—as long-run "exogenous" events. The Council of Economic Advisers (2002, p. 44) argued, "The President laid a strong foundation for growth in 2001 with the Economic Growth and Tax Relief Reconciliation Act. This package provides a powerful stimulus for future growth. . . ." But the tax cut bills enacted in 2001, 2002, and 2003 were also clearly linked to the recession in 2001 and its subsequent "jobless" recovery. Congressional Quarterly Inc. (2006) documented that in the case of the 2003 tax cut, President "Bush continued to insist that tax cuts were the best way to deal with both the budget deficit and the slow pace of job creation" (p. 42). Evidently there is no sharp distinction between tax cuts motivated by countercyclical considerations and those driven by a desire to boost economic growth in the long run.

[11]The unemployment rate fell from 6.7 percent in October, 1961 to 5.5 percent in March, 1962 and then leveled off for the remainder of 1962. Output growth was slower than in the previous year. Stein (1996) wrote that the proposal to cut taxes "was a delayed response to a chronic condition after hopes of a spontaneous recovery were dimmed" (p. 408).

We have specified a rule for future tax *rates*, but the Romers and Mertens and Ravn employed forecasts of tax *revenues.* We simulate the model to generate data and model-generated forecasts of revenue changes due to both the unanticipated, $e^u_{\tau,t}$, and anticipated, $\varepsilon_{\tau,t-q}$, exogenous disturbances to capital and labor tax rates. Although the Romers estimated single-equation regressions, we reproduce the slightly more general estimated VARs that Mertens and Ravn used to report the dynamic impacts of the two kinds of tax shock. Specifically, we estimate

$$X_t = A + CX_{t-1} + \sum_{i=0}^{24} D_i T^u_{t-i} + \sum_{i=0}^{24} F_i T^a_{t-i} + \sum_{i=1}^{6} G_i T^a_{t+i} + u_t, \tag{S.12}$$

where X_t is a data vector that includes output, consumption, investment, and hours worked, $X_t = [\ln y_t, \ln c_t, \ln i_t, \ln l_t]'$. T^u_t is revenue changes divided by output due to the unanticipated tax shock and T^a_{t+i} is the out-of-sample forecast of revenue changes for anticipated tax policy divided by output.[12] Forecasts are conditional on information at t, for each date in the simulated data. Since the DSGE model we use to generate data has separate exogenous shocks for capital and labor tax rates, estimation of (S.12) is done separately for the two taxes; therefore, to estimate the effects of an anticipated capital tax cut, T^u_t and T^a_t in (S.12) are associated with capital tax changes, and vice versa for labor taxes. [13]

Romer and Romer and Mertens and Ravn shared the critical maintained assumption that forecasted revenue changes *are* the exogenous news about taxes. This assumption explains why the system in (S.12) does not include an equation that describes the evolution of revenues or government debt over time. Implicitly in Romer and Romer and explicitly in Mertens and Ravn's theoretical model, lump-sum transfers are assumed to adjust to keep the government solvent. But this Ricardian assumption conflicts with the way that "RR exogenous" changes in taxes are constructed: as the rule in (S.9) makes clear, that constructed measure includes legislative actions that are a response to budget deficits or the state of government indebtedness.

[12]The Romers' data set scales revenues by *actual* future output, which treats a function of future shock realizations as a regressor in (S.12). We follow their procedure in the simulations.

[13]The Romers and Mertens and Ravn did not distinguish between capital and labor tax changes in their empirical work. Sorting revenue forecasts into those due to capital and labor tax policy changes is a difficult task, as a single provision in a tax bill often affects both capital and labor income taxes simultaneously. For example, an across-the-board individual income tax rate reduction would change both types of taxes. In addition, Yang (2005) showed that anticipated capital and labor taxes can have very different effects and that assuming a single tax rate on both sources of income can mask the impacts of fiscal foresight.

S.4.2. *Simulation Results*

Revenue forecasts provide an important input to fiscal decisions by policy makers at both the federal and the state levels. Large fluctuations in tax bases make revenues notoriously difficult to forecast accurately. One way to mimic the difficulties inherent in forecasting revenues is to add measurement error that is unrelated to economic fundamentals. An alternative, more economically grounded method, is simply to build into the theory multiple sources of uncertainty. In addition to unanticipated and anticipated shocks to capital and labor tax rates, the DSGE model used to simulate data includes several other sources of random variation—shocks to technology, preferences over leisure, government spending, and government transfers. Multiple sources of uncertainty imply that forecasted tax rates, $E_t\tau_{t+q}$, are a function of many different structural disturbances whose effects on taxes operate through the endogenous variables.

Figures S.3–S.6 depict the paths of consumption and output in response to six-period foresight about cuts in labor and capital tax rates. Shocks to tax rates are assumed to be correlated, though not perfectly, as they are in data. Panels (a)–(d) reflect alternative parametric formalizations of the narrative identification. These impulse response functions are derived from estimates of (S.12) using 1000 sample paths generated by the growth model. Heavy solid lines are the true theoretical impacts; thin solid lines are the means of the estimated

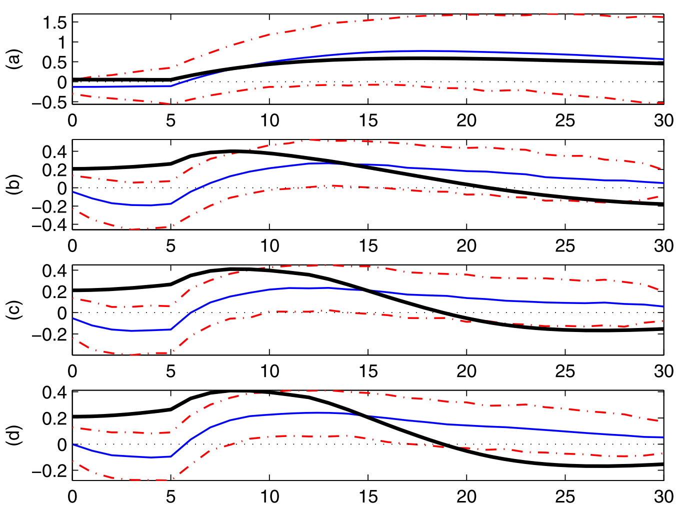

FIGURE S.3.—Responses of consumption to 6-period foresight of labor taxes. Panel (a): $\mu^C = 0$, $\mu^T = 0$, $\gamma_T = -0.1$, $\sigma_K = 0.025$, $\sigma_L = 0.02$. Panel (b): $\mu^C = 1$, $\mu^T = 0$, $\gamma_\tau = 0.05$, $\sigma_K = 0.025$, $\sigma_L = 0.02$. Panel (c): $\mu^C = 1$, $\mu^T = 0.5$, $\gamma_\tau = 0.05$, $\sigma_K = 0.025$, $\sigma_L = 0.02$. Panel (d): $\mu^C = 1$, $\mu^T = 0.5$, $\gamma_\tau = 0.05$, $\sigma_{Ka} = 0.0375$, $\sigma_{Ku} = 0.0125$, $\sigma_{La} = 0.03$, $\sigma_{Lu} = 0.01$.

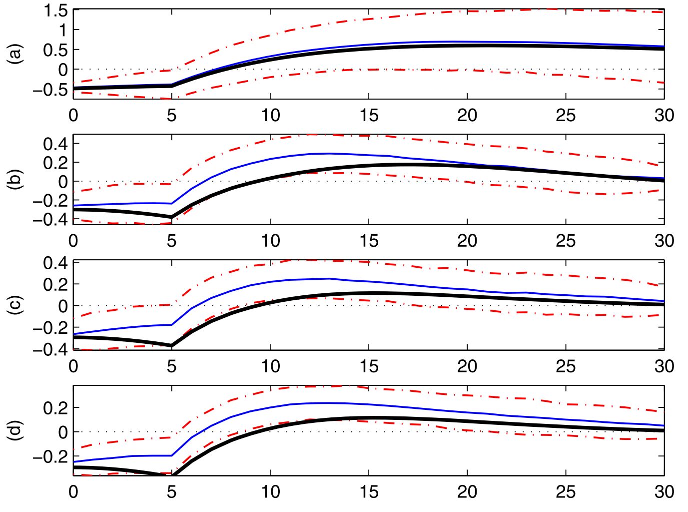

FIGURE S.4.—Responses of consumption to 6-period foresight of capital taxes. Panel (a): $\mu^C = 0, \mu^T = 0, \gamma_T = -0.1, \sigma_K = 0.025, \sigma_L = 0.02$. Panel (b): $\mu^C = 1, \mu^T = 0, \gamma_\tau = 0.05, \sigma_K = 0.025, \sigma_L = 0.02$. Panel (c): $\mu^C = 1, \mu^T = 0.5, \gamma_\tau = 0.05, \sigma_K = 0.025, \sigma_L = 0.02$. Panel (d): $\mu^C = 1, \mu^T = 0.5, \gamma_\tau = 0.05, \sigma_{Ka} = 0.0375, \sigma_{Ku} = 0.0125, \sigma_{La} = 0.03, \sigma_{Lu} = 0.01$.

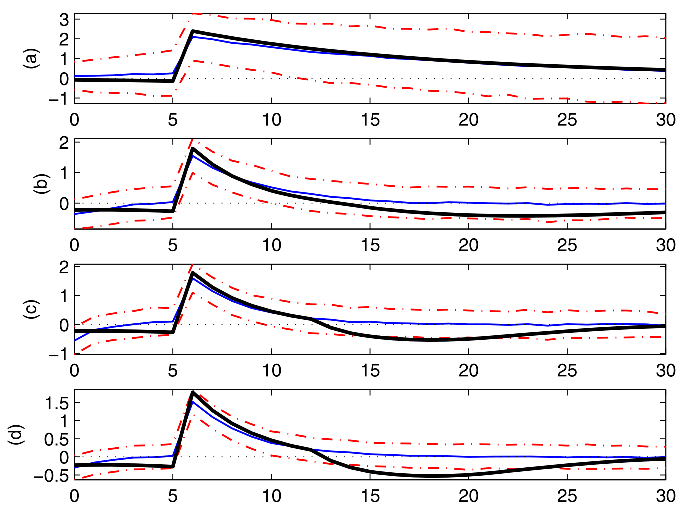

FIGURE S.5.—Responses of output to 6-period foresight of labor taxes. Panel (a): $\mu^C = 0, \mu^T = 0, \gamma_T = -0.1, \sigma_K = 0.025, \sigma_L = 0.02$. Panel (b): $\mu^C = 1, \mu^T = 0, \gamma_\tau = 0.05, \sigma_K = 0.025, \sigma_L = 0.02$. Panel (c): $\mu^C = 1, \mu^T = 0.5, \gamma_\tau = 0.05, \sigma_K = 0.025, \sigma_L = 0.02$. Panel (d): $\mu^C = 1, \mu^T = 0.5, \gamma_\tau = 0.05, \sigma_{Ka} = 0.0375, \sigma_{Ku} = 0.0125, \sigma_{La} = 0.03, \sigma_{Lu} = 0.01$.

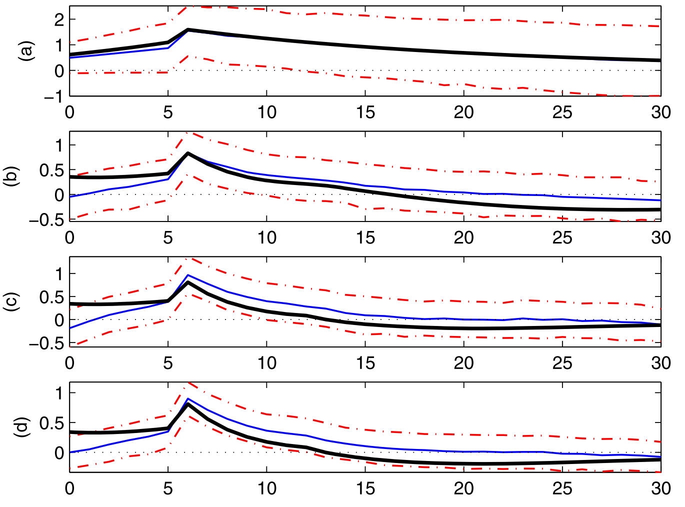

FIGURE S.6.—Responses of output to 6-period foresight of capital taxes. Panel (a): $\mu^C = 0$, $\mu^T = 0$, $\gamma_T = -0.1$, $\sigma_K = 0.025$, $\sigma_L = 0.02$. Panel (b): $\mu^C = 1$, $\mu^T = 0$, $\gamma_\tau = 0.05$, $\sigma_K = 0.025$, $\sigma_L = 0.02$. Panel (c): $\mu^C = 1$, $\mu^T = 0.5$, $\gamma_\tau = 0.05$, $\sigma_K = 0.025$, $\sigma_L = 0.02$. Panel (d): $\mu^C = 1$, $\mu^T = 0.5$, $\gamma_\tau = 0.05$, $\sigma_{Ka} = 0.0375$, $\sigma_{Ku} = 0.0125$, $\sigma_{La} = 0.03$, $\sigma_{Lu} = 0.01$.

impacts; dashed lines are 68 percent probability bands for the estimated responses.

Panel (a) is the best-case scenario for the narrative approach. It shuts down all responses of tax rates to economic conditions and has lump-sum transfers adjust to stabilize debt. The policy rule becomes $\tau_t = \rho\tau_{t-1} + \varepsilon_{\tau,t-q} + e^u_{\tau,t}$; transfers evolve according to $T_t = \gamma_T s^B_{t-1}$, with $\gamma_T > 0$. Across all four figures, estimates of (S.12) do a very good job of recovering the theoretically correct responses.[14]

Once tax rates respond to debt, estimates based on the VAR in (S.12) can go badly astray over both the period of foresight and longer horizons. Panels (b)–(d) each impose that labor and capital tax rates adjust to stabilize debt ($\gamma_\tau > 0$); they differ in the degree to which tax policy choices react to output and in the relative variability of anticipated and unanticipated exogenous disturbances to taxes. Panel (b) comes from a model that allows for automatic stabilizers in the tax code ($\mu^C > 0$); panel (c) includes both automatic stabilizers and fiscal foresight that includes a systematic response to past output ($\mu^T > 0$); panel (d) includes both of these components, but raises the variance of anticipated tax shocks relative to unanticipated tax shocks, reflecting the fact that because most tax changes are implemented with a lag, anticipated

[14]Discrepancies between the thin and the thick solid lines arise from the fact that the Romers and Mertens and Ravn scaled forecasted revenue changes by actual future GDP, a procedure that we mimic, whereas the true theoretical responses do not include this scaling.

changes are more prevalent and more important. Modeling "RR exogenous" tax changes as including a systematic response of tax rates—as opposed to lump-sum transfers—to the state of government debt is fully consistent with the Romers' narrative, so panels (b)–(d) of the figures provide more appropriate assessments of the ex ante approach.

The ex ante approach may perform quite well over the period of foresight, as it does in estimating the response of consumption to foresight about a capital tax rate cut in Figure S.4 (see also Figure S.5). But it can also perform very poorly. Figure S.3 shows that an anticipated cut in labor taxes creates a boom in consumption in the foresight period, while estimates of (S.12) find that a substantial recession is quite likely. A less pronounced slump in consumption is estimated for the response of output to a foreseen capital tax cut, when the correct theoretical response is a mild expansion (Figure S.6). The inference that a recession occurs before an anticipated cut in taxes coincides closely with Merten and Ravn's results from estimating (S.12) based on the Romers' data on changes in tax liabilities.

Difficulties with the ex ante approach are not limited to inferences about the effects of foresight over the short run. Figure S.3 shows that, over horizons of five or more years, it is very unlikely that estimates of (S.12), which die out rather quickly, will recover the medium-run decline in consumption following a reduction in labor tax rates. The source of the mispredictions is that the VAR system in (S.12) treats the changes in revenues forecasts, the T^a_{t+i} terms, as exogenous "shocks" that are not systematically related to the state of the economy. This treatment fails to provide agents with the structural information that debt-financed tax cuts will ultimately bring forth higher tax rates still farther in the future. In other words, given how the revenue forecasts are constructed, treating them as evolving autonomously amounts to misspecifying the tax rule. Panels (b)–(d) of Figure S.3 make clear that misspecification of the tax rule is the source of the medium-run mispredictions: when lump-sum transfers adjust to stabilize debt, as in panel (a), the estimated system in (S.12) nails the responses at longer horizons.

Our simulation exercise dramatically understates the uncertainty inherent in revenue forecasts because our model forecaster knows the true structure of the economy. If the ex ante approach cannot consistently work in our idealized laboratory, the noise associated with actual revenue forecasts is likely to hinder severely the method's ability to recover anticipated tax effects.

This assessment of the ex ante approach employs a barebones real business cycle model and a relatively crude specification of tax policy behavior. A model with many more parameters and internal propagation mechanisms or a more sophisticated characterization of policy can generate far more exotic dynamics. But greater complexity does not alter the basic message: success of the ex ante approach hinges on how the narrative method of identifying tax news is formalized. Even simple theory can produce a wide range of conclusions about the efficacy of the approach. Two factors emerge as critical to the success of the ex ante approach: the degree to which forecasted revenue changes reflect exogenous changes in taxes and the relative volatility of the random components of tax decisions.

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Dept. of Economics, Indiana University, Bloomington, IN 47405, U.S.A., Monash University, and NBER; eleeper@indiana.edu,

Dept. of Economics, Indiana University, Bloomington, IN 47405, U.S.A.; walkertb@indiana.edu,

and

International Monetary Fund, Washington, DC 20431, U.S.A.; SYang@imf.org.

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