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Fiscal Foresight and Information Flows

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Abstract

News—or foresight—about future economic fundamentals can create rational expectations equilibria with non-fundamental representations that pose substantial challenges to econometric efforts to recover the structural shocks to which economic agents react. Using tax policies as a leading example of foresight, simple theory makes transparent the economic behavior and information structures that generate non-fundamental equilibria. Econometric analyses that fail to model foresight will obtain biased estimates of output multipliers for taxes; biases are quantitatively important when two canonical theoretical models are taken as data generating processes. Both the nature of equilibria and the inferences about the effects of anticipated tax changes hinge critically on hypothesized information flows. Different methods for extracting or hypothesizing the information flows are discussed and shown to be alternative techniques for resolving a non-uniqueness problem endemic to moving average representations.

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I. Introduction

A venerable tradition, often traced to Pigou (1927), ascribes a significant role in aggregate fluctuations to economic decision makers' responses to expectations about not-yet-realized economic fundamentals. That tradition finds voice in a recent surge of interest in the economic consequences of *news*—or *foresight*. Recent work explores how news affects the predictions of standard theories, seeks evidence of the impacts of news in time series data, and estimates dynamic stochastic general equilibrium models to quantify the relative importance of anticipated and unanticipated "shocks" to fundamentals.

Existing work typically posits a particular stochastic process for news, grounded in neither theory nor empirics. That process determines the economy's information flows and, in a rational expectations equilibrium, agents' expectations. Given the prominent role of expectations in the news literature, it is remarkable that existing work does not systematically examine how the specification of information flows affects the nature of equilibrium and the connection of theory to data. This paper addresses that gap.

For several reasons we focus on how to identify and quantify the impacts of foreseen "shocks" to taxes. First, few economic phenomena provide economic agents with such clear signals about how important margins will change in the future: foresight is intrinsic to tax policy. Second, an institutional structure governs information flows about taxes: the process of changing taxes entails two kinds of lags—the inside lag, between when new tax law is initially proposed and when it is passed, and the outside lag, between when the legislation is signed into law and when it is implemented. That institutional structure informs the nature of tax information flows. Third, differential U.S. tax treatment of municipal and treasury bonds leads to a direct measure of tax news that offers a potential solution to modeling tax foresight. Such measures are scarce for news about nonpolicy fundamentals like total factor productivity. Despite the paper's focus on taxes, one of its key messages—that hypothesized information flows are critical to determining the impacts of news—extends immediately to other contexts.[1]

Fiscal foresight poses a challenge to econometric analyses of fiscal policy because it generates an equilibrium with a non-fundamental moving average representation. Information sets of economic agents and the econometrician can be misaligned, with agents basing their choices on more information than the econometrician possesses. Structural shocks to tax policy, then, cannot be recovered from current and past fiscal data, a central assumption of conventional econometric methods. Instead, conventional methods can lead

[1] In addition to taxes, studies have examined news about a wide range of fundamentals, including total factor and investment-specific productivity [Beaudry and Portier (2006), Christiano, Ilut, Motto, and Rostagno (2008), Jaimovich and Rebelo (2009), Schmitt-Grohé and Uribe (2008), Fujiwara, Hirose, and Shintani (2011)]; government military spending run ups [Fisher and Peters (2010), Ramey (2011)]; phased-in government infrastructure spending [Leeper, Walker, and Yang (2010)]; announcements of interest-rate paths by inflation-targeting central banks [Blattner, Catenaro, Ehrmann, Strauch, and Turunen (2008), Laséen and Svensson (2011)]. All of these applications lend themselves to the analysis that we conduct.

the econometrician to label as “tax shocks” objects that are linear combinations of all the exogenous disturbances at various leads and lags.[2]

This paper builds on and extends Hansen and Sargent’s (1991b) general characterization of the implications of environments in which the history of innovations in a vector autoregression does not equal the history of information that agents observe. We go beyond treating invertibility as a 0–1 proposition by assessing the quantitative importance of failing to model foresight in two workhorse macroeconomic models. We offer a compelling economic example—tax foresight—that makes clear that non-fundamentalness and its consequences affect answers to substantive macroeconomic questions. Most importantly, we ground non-fundamentalness in economic theory, which points towards empirical lines of attack. Both Hansen and Sargent (1991b) and Fernández-Villaverde, Rubio-Ramírez, Sargent, and Watson (2007) have been read primarily as cautionary notes, in large part because they point to a serious problem, but not to a way forward.

No consensus exists on how to handle tax foresight, a fact that is underscored by the diverse empirical findings in the literature. Research concludes that an anticipated cut in taxes may have little or no effect [Poterba (1988), Blanchard and Perotti (2002), Romer and Romer (2010)], may be mildly expansionary in the short run [Mountford and Uhlig (2009)], or may be strongly contractionary in the short run [House and Shapiro (2006), Mertens and Ravn (2011)]. By using different measures of tax news and different methodologies, these studies implicitly posit different tax information flows, which, as we show, can produce strikingly different inferences about the effects of anticipated tax changes.

The paper has three parts:

1. A simple analytical example makes precise how foresight and optimizing behavior create equilibria with non-fundamental moving average representations. The example makes the source of non-fundamentalness transparent: it arises as a natural by-product of the fact that agents’ optimal intertemporal decisions discount future tax obligations. Although private agents discount tax *rates* in the usual way, they discount recent tax *news* more heavily than past news because with foresight the recent news informs about taxes in the more distant future. The econometrician, in contrast, discounts in the usual way, down weighting older news relative to recent news. Agents and the econometrician employ different discounting patterns because the econometrician’s information set lags the agents’.

2. Simple analytics reveal the source of non-fundamentalness, but do not shed light on whether it matters in practice. Using two canonical dynamic stochastic general equilibrium models—Chari, Kehoe and McGrattan’s (2008) real business cycle model and Smets and Wouters’ (2003; 2007) new Keynesian model—as data generating

[2]Issues associated with non-fundamentalness were pointed out in the rational expectations econometrics literature by Hansen and Sargent (1980, 1991b) and Lippi and Reichlin (1993, 1994) and recently emphasized by Fernández-Villaverde, Rubio-Ramírez, Sargent, and Watson (2007). Leeper (1989) and Yang (2005) examine the issues in the context of tax foresight.

processes, we quantify the inference errors an econometrician might make by failing to model foresight. We tie those errors to alternative, empirically motivated specifications of tax news processes—information flows that distinguish between the "inside" and "outside" lags associated with tax policies. Estimates of tax multipliers can be off by hundreds of percent and even be of the wrong sign. Biases can be positive or negative, but the econometrician tends to underestimate the effects of foresight over longer horizons.

3. We discuss several lines of attack that offer a way forward in dealing with non-fundamental equilibria. We show that seemingly unrelated approaches—the narrative approaches of Ramey (2011) and Romer and Romer (2010) and the dynamic stochastic general equilibrium approach of Schmitt-Grohé and Uribe (2008)—are solving the problems associated with foresight in a similar fashion: by expanding the information set of the econometrician in order to resolve a non-uniqueness problem endemic to moving average representations.

II. ANALYTICAL EXAMPLE

This section introduces fiscal foresight into a simple economic environment where the econometric issues can be exposited analytically. Results and conclusions reached in the simple exposition extend to more general setups, as section B discusses.

Consider a standard growth model with a representative household that maximizes expected log utility, $E_0 \sum_{t=0}^{\infty} \beta^t \log(C_t)$, subject to $C_t + K_t + T_t \leq (1-\tau_t)A_t K_{t-1}^{\alpha}$, where C_t, K_t, Y_t, T_t, and τ_t denote time-t consumption, capital, output, lump-sum taxes, and the income tax rate respectively, and A_t is an exogenous technology shock. As usual, $0 < \alpha < 1$ and $0 < \beta < 1$. The government sets the tax rate according to a time-invariant rule and adjusts lump-sum transfers to satisfy the constraint, $T_t = \tau_t Y_t$. Government spending is identically zero. We assume complete depreciation of capital. Labor is supplied inelastically which, as section C shows, understates the problems that foresight creates.

The equilibrium conditions are well known and given by

$$\frac{1}{C_t} = \alpha\beta E_t\left[(1-\tau_{t+1})\frac{1}{C_{t+1}}\frac{Y_{t+1}}{K_t}\right] \tag{1}$$

$$C_t + K_t = Y_t = A_t K_{t-1}^{\alpha} \tag{2}$$

Let A and τ denote the steady state values of technology and the tax rate. The steady state capital stock is $K = [\alpha\beta(1-\tau)A]^{1/(1-\alpha)}$. Let lower case letters denote percentage deviations from steady state values, $k_t = \log(K_t) - \log(K)$, $a_t = \log(A_t) - \log(A)$, and $\hat{\tau}_t = \log(\tau_t) - \log(\tau)$. Log linearizing (1)–(2) yields an equilibrium that is characterized by a second-order difference equation in capital

$$E_t k_{t+1} - (\theta^{-1} + \alpha)k_t + \alpha\theta^{-1}k_{t-1} = E_t[a_{t+1} - \theta^{-1}a_t] + \left\{\theta^{-1}(1-\theta)\left(\frac{\tau}{1-\tau}\right)\right\}E_t\hat{\tau}_{t+1} \tag{3}$$

where $\theta = \alpha\beta(1-\tau)$ is a particularly important constant in the analysis. Assuming an *i.i.d.* technology shock, the solution to (3) is

$$k_t = \alpha k_{t-1} + a_t - (1-\theta)\left(\frac{\tau}{1-\tau}\right)\sum_{i=0}^{\infty}\theta^i E_t\hat{\tau}_{t+i+1} \tag{4}$$

Equilibrium investment depends negatively on the expected discounted present value of future tax rates, a well-known result [Lucas (1976), Abel (1982), Judd (1985), Auerbach (1989)]. Of course, more distant tax rates receive heavier discount than more recent rates.

To model foresight, we must specify how news about taxes signals future tax rates. For many of the points we wish to make, it suffices to assume that tax information flows take a particularly simple form: agents at t receive a signal that tells them exactly what tax rate they will face in period $t+q$. In later sections we will relax this assumption and posit more sophisticated rules for tax rates. The tax rule is $\tau_t = \bar{\tau}e^{\varepsilon_{\tau,t-q}}$ where $\bar{\tau}$ is the steady-state tax rate, or in log-linearized form

$$\hat{\tau}_t = \varepsilon_{\tau,t-q} \tag{5}$$

Assume the technology and tax shocks—$\varepsilon_{A,t}$ and $\varepsilon_{\tau,t}$—are $i.i.d.$ and the representative agent's information set at date t consists of variables dated t and earlier, including the shocks, $\{\varepsilon_{A,t}, \varepsilon_{\tau,t}\}$. Given the tax news process in (5), this implies that at t the agent has (perfect) knowledge of $\{\hat{\tau}_{t+q}, \hat{\tau}_{t+q-1}, \ldots\}$.

Using the information flows in (5) to solve for expected tax rates in (4) for various degrees of fiscal foresight yields the following equilibrium dynamics:

$q = 0$ implies:

$$k_t = \alpha k_{t-1} + \varepsilon_{A,t} \tag{6}$$

$q = 1$ implies:

$$k_t = \alpha k_{t-1} + \varepsilon_{A,t} - \kappa\varepsilon_{\tau,t} \tag{7}$$

$q = 2$ implies:

$$k_t = \alpha k_{t-1} + \varepsilon_{A,t} - \kappa\left\{\varepsilon_{\tau,t-1} + \theta\varepsilon_{\tau,t}\right\} \tag{8}$$

$q = 3$ implies:

$$k_t = \alpha k_{t-1} + \varepsilon_{A,t} - \kappa \left\{ \varepsilon_{\tau,t-2} + \theta \varepsilon_{\tau,t-1} + \theta^2 \varepsilon_{\tau,t} \right\} \tag{9}$$

where $\kappa = (1 - \theta)(\tau/(1 - \tau))$.

If there is no foresight, $q = 0$, we get the usual result that $i.i.d.$ shocks to tax rates have no effect on capital accumulation. When there is some degree of tax foresight ($q > 0$), rational agents will adjust capital contemporaneously to yield the unusual result that even serially uncorrelated tax hikes reduce capital accumulation. Fiscal foresight manifests in the additional moving average terms present in the equilibrium representation, with the number of moving average terms increasing in the foresight horizon.

A striking, though seemingly perverse, implication of (8) and (9) is that more *recent* news is discounted (by $\theta = \alpha\beta(1 - \tau) < 1$) relative to older news. This is because with two-quarter foresight, $\varepsilon_{\tau,t-1}$ affects $\hat{\tau}_{t+1}$, while $\varepsilon_{\tau,t}$ affects $\hat{\tau}_{t+2}$, so the news that affects tax rates farther into the future receives the heaviest discount. While tax *rates* are discounted in the usual way, tax *news* is discounted in reverse order. This difference in discounting between tax rates and tax news stems from optimizing behavior and underlies the econometric problems that foresight creates.

A. The Econometrics of Foresight

The moving average terms that foresight produces pose challenges for econometric inference. Conventional econometric analyses, such as those using identified vector autoregressions (VARs), can draw erroneous conclusions. Errors arise because models with foresight may imply that the information set of private agents is larger than the econometrician's.

An econometrician who estimates an identified VAR seeks to condition on the same information set as the economic agents in order to recover the structural shocks $\{\varepsilon_{\tau,t-j}\}_{j=0}^{\infty}$. Typically, this is achieved by conditioning the VAR estimates on current and past observables. Consider the univariate case of conditioning on current and past capital, $\{k_{t-j}\}_{j=0}^{\infty}$, and suppose that agents have two quarters of foresight. Using lag operators (i.e., $L^s x_t = x_{t-s}$), (8) may be written as

$$(1 - \alpha L)k_t = -\kappa(L + \theta)\varepsilon_{\tau,t} \tag{10}$$

Will the econometrician's conditioning set, current and past capital, span the same space as the agents' current and past structural shocks?[3] The answer depends on whether $\{\varepsilon_{\tau,t-j}\}_{j=0}^{\infty}$

[3]More specifically, the information sets are equivalent if the the Hilbert space generated by $\{k_{t-j}\}_{j=0}^{\infty}$ is equivalent (in mean-square norm) to the Hilbert space generated by $\{\varepsilon_{\tau,t-j}\}_{j=0}^{\infty}$.

is *fundamental* for $\{k_{t-j}\}_{j=0}^{\infty}$, using the terminology of Rozanov (1967). Fundamentalness requires the equilibrium process to be invertible in current and past k_t, so that

$$\left[\frac{1-\alpha L}{1+\theta^{-1}L}\right]k_t$$

is a convergent sequence. If $|\theta| > 1$, this condition holds and $\{k_{t-j}\}_{j=0}^{\infty}$ spans the same space as $\{\varepsilon_{\tau,t-j}\}_{j=0}^{\infty}$. But a unique saddlepath solution requires $|\theta| < 1$. Therefore, $\{\varepsilon_{\tau,t-j}\}_{j=0}^{\infty}$ is *not fundamental* for $\{k_{t-j}\}_{j=0}^{\infty}$.

To determine the econometrician's information set, we derive the Wold representation for k_t from the one-step-ahead forecast errors associated with predicting k_t conditional only on its past values.

This representation emerges from flipping the root of the moving average representation from inside the unit circle to outside the unit circle using the Blaschke factor, $[(L+\theta)/(1+\theta L)]$ [see Hansen and Sargent (1991b) or Lippi and Reichlin (1994)]. The Wold representation for capital is

$$\begin{aligned}(1-\alpha L)k_t &= \underbrace{-\kappa(L+\theta)\left[\frac{1+\theta L}{L+\theta}\right]}_{-\kappa(1+\theta L)}\underbrace{\left[\frac{L+\theta}{1+\theta L}\right]\varepsilon_{\tau,t}}_{\varepsilon^*_{\tau,t}} \\ &= -\kappa\left\{\theta\varepsilon^*_{\tau,t-1}+\varepsilon^*_{\tau,t}\right\} \qquad (11)\end{aligned}$$

By observing current and past capital, the econometrician recovers current and past ε^*_{τ}, rather than the news that private agents observe, current and past ε_{τ}. The econometrician's innovations are the statistical shocks associated with estimating the autoregressive representation; those shocks represent information that is mostly "old news" to the agents of the economy. Fundamental shocks map into the econometrician's shocks as

$$\begin{aligned}\varepsilon^*_{\tau,t} &= \left[\frac{L+\theta}{1+\theta L}\right]\varepsilon_{\tau,t} = (L+\theta)\sum_{j=0}^{\infty}-\theta^j\varepsilon_{\tau,t-j} \\ &= \theta\varepsilon_{\tau,t}+(1-\theta^2)\varepsilon_{\tau,t-1}-\theta(1-\theta^2)\varepsilon_{\tau,t-2}+\theta^2(1-\theta^2)\varepsilon_{\tau,t-3}+\cdots \qquad (12)\end{aligned}$$

This mapping shows that what the econometrician recovers as the tax innovation at time t, $\varepsilon^*_{\tau,t}$, is actually a discounted sum of the tax news observed by the agents at date t and earlier.

An econometrician who ignores foresight will discount the innovations incorrectly. In the econometrician's representation, yesterday's innovation has less effect than today's innovation, as the terms $\theta\varepsilon^*_{\tau,t-1}+\varepsilon^*_{\tau,t}$ in (11) show. Agents with foresight, in contrast, discount news according to $\varepsilon_{\tau,t-1}+\theta\varepsilon_{\tau,t}$, as in (8), because yesterday's news has a larger effect on capital accumulation than today's news. Differences in discounting patterns applied by the econometrician and the agents lead to a variety of econometric problems.

By not modeling foresight, the econometrician has conditioned on a smaller information set. The extent to which private agents condition on information that is not captured by current and past variables in the econometrician's information set determines the error associated with the VAR. This error can be mapped directly into the θ parameter that governs the non-invertibility of the equilibrium moving-average representation. The variance of the one-step-ahead forecast error for the agent is

$$\begin{aligned} E[(k_{t+1} - E[k_{t+1}|\varepsilon^t])^2] &= E\left[\left(\frac{-\kappa(L+\theta)}{1-\alpha L}\varepsilon_{\tau,t+1} - L^{-1}[-\frac{\kappa(L+\theta)}{1-\alpha L} + \kappa\theta]\varepsilon_{\tau,t}\right)^2\right] \\ &= (\kappa\theta)^2\sigma_\tau^2 \end{aligned} \tag{13}$$

where ε^t denotes current and past ε. For the econometrician's information set, the variance of the forecast error is

$$\begin{aligned} E[(k_{t+1} - E[k_{t+1}|k^t])^2] &= E\left[\left(\frac{-\kappa(L+\theta)}{1-\alpha L}\varepsilon_{\tau,t+1} - L^{-1}[-\frac{\kappa(1+\theta L)}{1-\alpha L} + \kappa]\left[\frac{L+\theta}{1+\theta L}\right]\varepsilon_{\tau,t}\right)^2\right] \\ &= \kappa^2\sigma_\tau^2 \end{aligned} \tag{14}$$

The ratio of (13) to (14) is θ^2. As θ^2 approaches unity (zero), the difference between the agent's and econometrician's information sets gets smaller (larger). If θ is greater than or equal to 1, the representation for capital becomes fundamental with respect to $\varepsilon_{\tau,t}$ and the variances of the forecast errors in (13) and (14) coincide.

To examine the importance of the information discrepancies in this model, we plot impulse response functions conditioning on the agents' and econometrician's information sets. Impulse response functions are widely used to convey how *agents* respond to innovations, but response functions based on the econometrician's information set will not capture these responses. Consider the impulse response functions generated by (8) and (11). Figure 1a plots the responses of capital assuming two quarters of foresight (with $\alpha = 0.36, \beta = 0.99, \tau = 0.25, \sigma_\tau^2 = 1$). With foresight, agents know exactly when the innovation in fiscal policy translates into changes in the tax rate. This creates the sharp decline in capital one quarter after the news arrives and before the tax rate changes, as the dotted-dashed line indicates. The econometrician's VAR, though, discounts the innovations incorrectly and reports that the biggest decline in capital occurs on impact, suggesting that foresight does not exist (solid line). The difference between the response functions can be quite dramatic, especially at short horizons.

Figure 1a shows that the econometrician will infer that the tax shock is *unanticipated*. Of course, not all shocks that affect fiscal policy are known several quarters in advance. Consider a tax rate process, $\hat{\tau}_t = e^u_{\tau,t} + \varepsilon_{\tau,t-q}$, that allows for both anticipated (ε_τ) and unanticipated (e^u_τ) shocks at time t. If these shocks are orthogonal at all leads and lags, then the equilibrium dynamics of (3) will not change because *i.i.d.* tax shocks will not alter the dynamics of capital. An econometrician who does not account for foresight will attribute *all* of the dynamics associated with the anticipated component of the tax rate to the unanticipated component. This suggests that researchers interested in the dynamic effects of

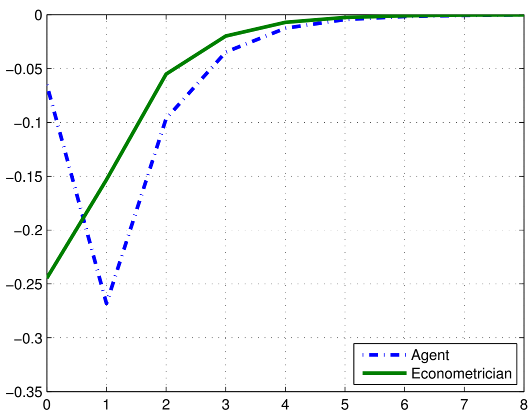

Figure 1a: Response of K with $q = 2$

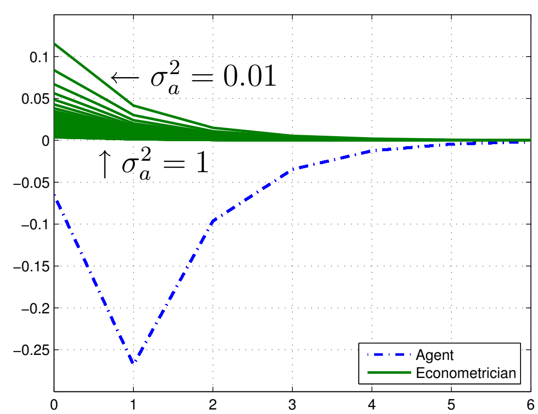

Figure 1b: Response of K for VAR $(\tau_t, k_t)'$

Figure 1. Responses of Capital to Tax Increase with $\alpha = 0.36, \beta = 0.99, \tau = 0.25$. Figure 1a plots the response of (13) and (14). Figure 1b plots the response to the VAR $(\tau_t, k_t)'$. Both figures assume two quarters of foresight.

fiscal policy—whether the interest is in anticipated or unanticipated changes in policy—must explicitly account for foresight to avoid spurious conclusions.

Conditioning on more variables will not always lead to better inference. In the case of two-quarter foresight, suppose the econometrician estimates a VAR that includes the tax rate and the capital stock as observables

$$\begin{bmatrix} \hat{\tau}_t \\ k_t \end{bmatrix} = \begin{bmatrix} L^2 & 0 \\ \frac{-\kappa(L+\theta)}{1-\alpha L} & \frac{1}{1-\alpha L} \end{bmatrix} \begin{bmatrix} \varepsilon_{\tau,t} \\ \varepsilon_{A,t} \end{bmatrix}$$
$$\mathbf{x}_t = \mathcal{H}(L)\boldsymbol{\epsilon}_t \tag{15}$$

A necessary condition for $\boldsymbol{\epsilon}_t$ to be a fundamental for $\mathbf{x}_t$ is that the determinant of $\mathcal{H}(z)$ be analytic with no zeros inside the unit circle. Foresight creates a zero inside the unit circle (at $z = 0$), implying that the information set generated by $\{\mathbf{x}_t, \mathbf{x}_{t-1}, \mathbf{x}_{t-2}, ...\}$ is smaller than the information set generated by $\{\boldsymbol{\epsilon}_t, \boldsymbol{\epsilon}_{t-1}, \boldsymbol{\epsilon}_{t-2}, ...\}$.

The Wold representation for (15) is obtained by finding Blaschke matrices $\mathcal{B}(L)$ and orthonormal matrices W, $\tilde{W}$ that do not alter the covariance generating function of $\mathbf{x}_t$, but "flip" the zeros outside of the unit circle. To do this we seek a $B(L)$, W, and $\tilde{W}$ that satisfy $\mathcal{B}(L)\mathcal{B}(L^{-1})' = I$ and $WW' = I$, $\tilde{W}\tilde{W}' = I$, and produce innovations that span the space generated by $\{\mathbf{x}_t, \mathbf{x}_{t-1}, \mathbf{x}_{t-2}, ...\}$. The first step in the algorithm is to evaluate $\mathcal{H}(L)$ at $L = 0$, and postmultiply by W so as to put the zeros in the first column of the product matrix [Townsend (1983, appendix A)]. Remaining columns of W can be constructed from a Gram-Schmidt orthogonalization procedure. The orthonormal W matrix ensures that the representation remains causal, preserving the assumption that the econometrician does not observe future values of the variables. Postmultiplying by $B(L)$ flips the zero outside of the unit circle. With two zeros inside the unit circle for (15), repeat this algorithm (find an orthonormal matrix $\tilde{W}$ that aligns the zeros in the first column, etc.). Proceeding in this fashion delivers the representation

$$\underbrace{\begin{bmatrix} \hat{\tau}_t \\ k_t \end{bmatrix}}_{\mathbf{x}_t} = \underbrace{\begin{bmatrix} L^2 & 0 \\ \frac{-k(L+\theta)}{1-\alpha L} & \frac{1}{1-\alpha L} \end{bmatrix} W\mathcal{B}(L)\tilde{W}\mathcal{B}(L)}_{\mathcal{H}^*(L)} \underbrace{\mathcal{B}(L^{-1})\tilde{W}'\mathcal{B}(L^{-1})W' \begin{bmatrix} \varepsilon_{\tau,t} \\ \varepsilon_{A,t} \end{bmatrix}}_{\boldsymbol{\epsilon}_t^*} \tag{16}$$

where

$$W = \begin{bmatrix} \frac{1}{\sqrt{1+(\theta\kappa)^2}} & \frac{-\kappa\theta}{\sqrt{1+(\theta\kappa)^2}} \\ \frac{\kappa\theta}{\sqrt{1+(\theta\kappa)^2}} & \frac{1}{\sqrt{1+(\theta\kappa)^2}} \end{bmatrix}, \tilde{W} = \begin{bmatrix} \Delta(1+\kappa^2\theta^2) & -\Delta\kappa \\ \Delta\kappa & \Delta(1+\kappa^2\theta^2) \end{bmatrix}, \mathcal{B}(L) = \begin{bmatrix} L^{-1} & 0 \\ 0 & 1 \end{bmatrix}$$

and $\Delta = [(1+\kappa^2\theta^2)^2 + \kappa^2]^{-1/2}$.

Now the econometric problems are more severe. First, the econometrician who proceeds with VAR analysis using (16) will likely obtain an impulse response function in which foresight does not appear to exist in the data. Figure 1b depicts the response of capital to a tax increase for the agent (dotted-dashed line) and econometrician as the variance of the technology shock decreases from 1 to 0.01. Conditioning on the econometrician's information set, the path of capital is flat when $\sigma_a^2 = \sigma_\tau^2 = 1$. In theory, unanticipated *i.i.d.* capital tax shocks have no effect on the economy, so based on the flat response of capital, an econometrician will infer that the effects of fiscal policy are limited to unanticipated components only. By not modeling foresight, the econometrician achieves a "self-fulfilling prophesy" and wrongly concludes that foresight is not an issue.[4]

Second, as the variance of the tax shock increases relative to the technology shock, the errors associated with foresight become more pronounced. Figure 1b shows that the initial response of capital to a one-standard-deviation increase in the tax shock *increases* from 0 to 0.12 as σ_a^2 decreases from 1 to 0.01, so that an anticipated tax increase could be estimated to have no effect or a positive effect on capital and output.

Existing empirical work reports a diverse set of inferences about the effects of an anticipated tax increase on output. Figures 1a and 1b demonstrate that even this simple model can deliver diverse results that depend on the underlying information flows.

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[4] With this simple form of foresight, an econometrician who estimates a VAR in $(\hat{\tau}_{t+q}, k_t)$ will recover the true shocks. But more sophisticated information flows, as in later sections, or empirically plausible tax rules, as in Leeper, Plante, and Traum (2010), preclude that easy fix.

Finally, *all* conditional statistics reported by the econometrician will be misspecified. Consider the variance decompositions that Hansen and Sargent (1991b) emphasize. Let

$$E(\mathbf{x}_t - E^*_{t-j}\mathbf{x}_t)(\mathbf{x}_t - E^*_{t-j}\mathbf{x}_t)' = \sum_{k=0}^{j-1} \mathcal{H}^*_k \, \Sigma^* \, \mathcal{H}'^*_k$$

denote the j-step ahead prediction error variance associated with the econometrician's information set, where Σ^* is the variance-covariance matrix associated with $(\varepsilon^*_{\tau,t}, \varepsilon^*_{A,t})'$. Like impulse response functions, variance decompositions are derived using *conditional* expectations, so the discrepancy in the information sets implies that the coefficients generated by $\mathcal{H}^*(L)$ will misallocate the variance across the structural shocks.[5] Figure 1b suggests that the econometrician will treat the tax shock as nearly *i.i.d.* and infer that none of the variation in capital (and hence output) can be attributed to tax innovations; all of the variation will be attributed to the technology shock. This inference holds even if, in fact, the tax shock explained nearly all of the variation in capital (for example, when the variance of the technology shock, σ^2_A, is arbitrarily small).

Further implications of foresight appear in the appendix, where we show that Granger causality tests and tests of economic theory, such as tests of present value restrictions, will be misspecified in the presence of foresight. Errors associated with ignoring foresight can be quite large.

B. Generalizations

The previous example assumes an *i.i.d.* tax shock, but the difficulties associated with foresight extend to more general setups. Suppose the stationary tax rate follows $\hat{\tau}_t = C(L)L^q\varepsilon_{\tau,t}$, where $C(L)$ is a polynomial in the lag operator L and q is the degree of foresight. The only restriction placed on $C(L)$ is that the corresponding coefficients are square summable, which allows for *any* serial correlation pattern. Agents guess that the law of motion for capital is given by a square summable linear combination of tax and technology shocks, $k_t = F(L)\varepsilon_{\tau,t} + G(L)\varepsilon_{a,t}$, as Whiteman (1983) shows. Focusing on tax shocks only and substituting this guess into the difference equation for capital in (3) yields

$$\theta L^{-1}[F(L) - F_0]\varepsilon_{\tau,t} - (1+\alpha\theta)F(L)\varepsilon_{\tau,t} + \alpha L F(L)\varepsilon_{\tau,t} = \left\{(1-\theta)\left(\frac{\tau}{1-\tau}\right)\right\}E_{t+1}\hat{\tau}_{t+1}$$

where the Wiener-Kolmogorov formula is used to take expectations (i.e., $E_t x_{t+1} = L^{-1}[D(L) - D_0]\varepsilon_{x,t}$), and $\theta = \alpha\beta(1-\tau)$. Uniqueness of the rational expectations equilibrium requires $|\theta| < 1$, where the equilibrium $F(L)\varepsilon_{\tau,t}$ for q degrees of foresight is

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[5] This result holds even though the statistical shocks of the VAR remain uncorrelated. Orthogonality of the Blaschke and W matrices ($\mathcal{B}(L)\mathcal{B}(L^{-1}) = I$ and $WW' = \tilde{W}\tilde{W}' = I$) implies that the unconditional second moments of the VAR system remain the same, but the conditional moments will be different.

given by

$$F(L)\varepsilon_{\tau,t} = -\left[\frac{\kappa[L^q C(L) - \theta^q C(\theta)]}{(1-\alpha L)(L-\theta)}\right]\varepsilon_{\tau,t} \tag{17}$$

This equation makes plain how foresight impinges on optimal capital accumulation for any choice of $C(L)$. Whenever $q \geq 2$, the equilibrium contains moving average components even when $C(L)$ is purely autoregressive. This representation suggests that it is straightforward to construct impulse response functions that take a wide range of shapes (including hump-shaped), for which the dynamic equation for capital continues to be non-invertible in current and past k_t. For example, setting $C(L) = (1 - \rho_1 L - \rho_2 L^2)^{-1}$ and assuming two quarters of foresight ($q = 2$) implies that the tax shocks $\varepsilon_{\tau t}$ are non-fundamental for k_t if $\theta < (1+\rho_1)^{-1}$. Because the condition for a non-fundamental moving average representation is independent of ρ_2, impulse response functions of non-fundamental moving average representations can adopt many forms.

The logic that leads foresight to produce equilibria with non-fundamental moving-average representations extends to a large class of models. Consider the generic multivariate rational expectations model

$$\Gamma_0 y_t = \Gamma_1 y_{t-1} + \Psi z_t + \Pi \eta_t \tag{18}$$

where y_t is an $n \times 1$ vector of endogenous variables, z_t is an $m \times 1$ vector of exogenous random shocks, η is a $k \times 1$ vector of expectation errors, which satisfy $E_t \eta_{t+1} = 0$ for all t. Γ_0 and Γ_1 are $n \times n$ coefficient matrices, along with Ψ ($n \times m$) and Π ($n \times k$). Klein (2000) and Sims (2002) use a generalized Schur decomposition of Γ_0 and Γ_1 to show that there exist matrices such that $Q'\Lambda Z' = \Gamma_0$, $Q'\Omega Z' = \Gamma_1$, $Q'Q = Z'Z = I_{n\times n}$, where Λ and Ω are upper-triangular. The ratios of the diagonal elements of Ω and Λ, ω_{ii}/λ_{ii}, are the generalized eigenvalues. Defining $w_t = Z'y_t$ and pre-multiplying (18) by Q, yields the decomposition

$$\begin{bmatrix} \Lambda_{11} & \Lambda_{12} \\ 0 & \Lambda_{22} \end{bmatrix} \begin{bmatrix} w_{1,t} \\ w_{2,t} \end{bmatrix} = \begin{bmatrix} \Omega_{11} & \Omega_{12} \\ 0 & \Omega_{22} \end{bmatrix} \begin{bmatrix} w_{1,t-1} \\ w_{2,t-1} \end{bmatrix} + \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} (\Psi z_t + \Pi \eta_t) \tag{19}$$

The system is partitioned so that the generalized eigenvalues imply an explosive path for $w_{2,t}$. Analogous to (4), $w_{2,t}$ must be solved forward to ensure stability of the system. Sims shows that the forward solution of (18) is

$$y_t = \Theta_1 y_{t-1} + \Theta_0 z_t + \Theta_y \Theta_z \sum_{s=1}^{\infty} \Theta_f^{s-1} E_t z_{t+s} \tag{20}$$

where $\Theta_f = \Omega_{22}^{-1}\Lambda_{22}$ is the inverse of the unstable eigenvalues, and $\Theta_z = \Omega_{22}^{-1} Q_2 \Psi$. Θ_f is the multivariate analog to θ in the simple analytical example and satisfies $\sum_{j=0}^{\infty} \text{tr}\, \Theta_f \Theta_f' < \infty$.[6]

[6] Mertens and Ravn (2010) derive this restriction in a real business cycle model with one unstable eigenvalue and refer to Θ^f as the "anticipation rate" because it is the rate at which news or foresight is discounted. In line with our findings, they argue that this relationship between the anticipation rate and unstable eigenvalues is a robust feature of models with foresight.

If the structural shocks, z_t, are *i.i.d.* and agents do not have foresight, then the last term in (20) drops out of the solution and the equilibrium has a VAR representation. In this case, conditioning on the control and state variables, y_t, allows a VAR to recover the structural shocks. But when agents have foresight, the equilibrium representation becomes a VARMA with the MA coefficients Θ_f. Suppose the structural shocks are given by $z_t = \epsilon_{t-q}$, and agents have foresight—at date t they observe ϵ's dated t and earlier, then the equilibrium is

$$y_t = \Theta_1 y_{t-1} + \Theta_0 \epsilon_{t-q} + \Theta_y \Theta_z [\epsilon_{t-q+1} + \Theta_f \epsilon_{t-q+2} + \cdots + \Theta_f^{q-1} \epsilon_t]. \tag{21}$$

As in the univariate case, the fiscal variables in (20), z_{t+s}, are discounted in the usual way, but the news innovations in (21), ϵ_{t-q}, are discounted perversely, with more recent news discounted the heaviest. This is why models with foresight are more likely to deliver non-fundamental equilibrium representations.

The y_t vector contains endogenous variables, which, like capital in the simple analytical model of section II, are typically forward looking. We established in the Wold representation (15) that simply adding forward-looking variables to the VAR does not always resolve the noninvertibility. In rational expectations models, variables like capital and consumption respond contemporaneously to news about future tax rates, but (21) shows that the contemporaneous response of these variables will be muted by the discount factor Θ_f^{q-1}. Most of the adjustment in variables to news occurs at future dates (in periods $t + q$), rather than contemporaneously (at t). To derive a fundamental VARMA representation, we need to augment (21) with a variable whose representation does not suffer from the perverse discounting. That variable's largest response to news will occur contemporaneously and news will be discounted in the usual way, as in (20). This makes the moving average part of (21) invertible, ensuring the econometrician's information set is consistent with the agents'.

The extent to which foresight leads to econometric errors depends on the underlying structure of the economy and the nature of information flows. The next section examines this issue in two canonical macro models.

III. Quantitative Importance of Foresight

The information flows specification in (5) was chosen for its analytical convenience, not for its plausibility. To assess the quantitative importance of foresight, this section generalizes those flows to capture actual news processes and embeds the generalized specification in two empirically motivated DSGE models. We show how the nature of information flows affects the inference errors an econometrician can make by not modeling foresight. Quantitative importance is summarized by dynamic tax multipliers, comparing those estimated by an econometrician who fits an identified VAR to the true tax multipliers.

A. Modeling Information Flows

Rich information flows characterize the arrival and accumulation of news about tax changes, but generally fall into two periods: between initial proposal and final enactment—or rejection—of a new tax law ("inside lag") and between enactment and when the law takes effect ("outside lag").[7] During the inside lag, information and expectations evolve about the likelihood and the precise form of proposed legislation. Sources of information that mark the beginning of the inside lag can be formal—a president's State of the Union speech—or informal—a politician's campaign pledges. And this early information may be confirmed or contravened by subsequent actions.[8] Outside lags arise whenever there is a delay between the legislation's passage and its implementation, as when tax changes are phased in. The two types of lags differ in important ways. During the inside lag, anticipated taxes are uncertain; news arrives regularly and induces agents to update their expectations. Agents are solving a dynamic signal extraction problem in an attempt to decipher noise from news. During the outside lag, the tax law has been adopted, no more news arrives, and agents have perfect foresight about future tax rates.

Examples clarify the nature of information flows. The Economic Recovery Tax Act of 1981, enacted in August 1981, phased in tax reductions through the beginning of 1984 to yield an outside lag of 10 quarters. In announcing his candidacy for president in November 1979, Ronald Reagan made clear that he intended to substantially lower taxes: "The key to restoring the health of the economy lies in cutting taxes" [Reagan (1979)]. News about future taxes then arrived throughout 1980, evolving with Reagan's prospects of winning office. An additional six months passed between President Reagan's formal call for tax relief in February 1981 and the legislation's enactment. The inside lag associated with this tax change is, arguably, five or more quarters, with the weights agents place on the bits of news changing over time. Taken together, the two lags imply a foresight period of about four years.

Adjustments to Social Security taxes can entail extraordinarily long lags. The National Commission on Social Security Reform was established in December 1981 to recommend solutions to the System's short- and long-term solvency problems. Its recommendations, reported in January 1983, formed the basis for the Social Security Amendments of 1983, which were enacted in April 1983. The Amendments phased in payroll tax increases beginning in 1984 and extending to 1990. Although their inside lag may have been only a few quarters, the Amendments' outside lag is over six years. Other changes in Social Security taxes had comparably long lags.

To model these intricacies, we generalize (5) with a specification of information flows about tax rates that is flexible enough to capture both inside and outside lags. For labor taxes, we

[7] These labels date back to Friedman (1948), where we combine the "recognition" and "decision" lags to form inside lags and our outside lags refer to how long it takes legislation to change tax rates.

[8] Announcing their candidacies, both Ronald Reagan and George W. Bush made clear their intentions to cut taxes, well over a year before they took office and formally proposed tax cuts. George H. W. Bush, in contrast, pledged in his announcement speech, "I am not going to raise your taxes—period." That was two-and-a-half years before he called for a tax increase. See http://www.4president.org for these speeches.

posit

$$\hat{\tau}_t^L = \rho\hat{\tau}_{t-1}^L + \sum_{j=0}^{J} \phi_j \left[\sigma^L \varepsilon_{\tau,t-j}^L + \xi\sigma^K \varepsilon_{\tau,t-j}^K\right] \tag{22}$$

where $\hat{\tau}_t^L$ is the labor tax rate, ξ permits labor and capital tax rates to be correlated, and the ε's are serially uncorrelated. We posit the best-case scenario for econometricians in that the tax processes are exogenous: in this case, identification is straightforward in the absence of foresight, ensuring that all errors arise solely from foresight.

As before, the sequence of innovations, $\{\varepsilon_{\tau,t-j}^L, \varepsilon_{\tau,t-j}^K\}_{j=0}^{\infty}$, enter the agent's information set directly. We interpret the moving-average coefficients as weights, imposing that $\sum_j \phi_j = 1$. Modeling information flows as moving average processes captures the idea that from quarter to quarter news about taxes evolves randomly, and generalizes the "perfect foresight" information structure. To see this more clearly, set $J = 2$, $\xi = 0$, $\rho = 0$, and $\sigma^L = 1$, so the tax rule becomes

$$\hat{\tau}_t^L = \theta\varepsilon_t + (1-\theta)\varepsilon_{t-1}$$

where $\theta \in (0,1)$. If $\theta = 0$, then agents have perfect foresight because they observe $\hat{\tau}_{t+1}^L$ perfectly. If $\theta = 1$, then agents have no foresight and receive news only about the contemporaneous tax rate. As θ moves smoothly from 1 to 0, agents receive more news about next period's tax rate.

Specification (22) embeds many of the information flows that appear in theoretical studies of foresight, including Christiano, Ilut, Motto, and Rostagno (2008), Jaimovich and Rebelo (2009), and Fujiwara, Hirose, and Shintani (2011) in the context of technology news; Ramey (2011) for government spending news; Yang (2005) and Mertens and Ravn (2011) with regard to tax news, and Schmitt-Grohé and Uribe (2008) for news about a variety of variables. These studies set $\phi_j = 0$ for all j except for $\phi_q = 1$, where q is the period of foresight.[9] These specifications imply that once the news arrives, agents have q periods of *perfect foresight* about the object being modeled. This may be an adequate assumption about information flows that stem from outside lags, but they miss altogether the inside lags. Inside lags are periods when agents are learning about how the future may play out. Tax policies develop over time, from initial informal proposals to formal proposals, all the way through the legislative process. The ϕ_j coefficients in (22) reflect how agents update their views about taxes during the inside lags. Values of the ϕ_j's describe how information flows differ from period to period.

[9] Some studies allow the news shocks, ε_{t-j}, to be drawn from distinct distributions for each j, and set $\phi_j = 1$ for each relevant j [Schmitt-Grohé and Uribe (2008), Fujiwara, Hirose, and Shintani (2011), and Mertens and Ravn (2011)]. The $j = 0$ shock is unanticipated, while the $j > 0$ shocks are anticipated given information at time t.

B. Model Descriptions

We study a real business cycle model—closely related to Chari, Kehoe, and McGrattan (2008)—and a new Keynesian model—similar to those in Smets and Wouters (2003, 2007)—but add distorting tax rates on capital and labor income. These models are workhorses in the macroeconomics literature so we provide only brief descriptions here. The appendix describes the models and estimation strategies thoroughly.

In the real business cycle (RBC) model, a representative agent maximizes time-separable discounted utility over consumption and leisure. The agent supplies labor and capital to a representative firm, which produces output according to a Cobb-Douglas technology. The government chooses a set of fiscal variables to satisfy the flow 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, and Z_t is transfers. Log-linearized government consumption policy follows an AR(1) process and lump-sum transfers adjust to balance the government budget constraint each period.

Tax legislation adjusts labor and capital taxes following (22) and its analog for capital tax rates. Yang (2005) estimates the correlation between tax rates at 0.5, implying the value of ξ. Since changes in individual income tax rates affect both labor income taxes and part of capital income taxes, the two tax shocks are often correlated.

The new Keynesian (NK) model extends the RBC model to incorporate real and nominal rigidities that have been shown to help fit macroeconomic data. It also models fiscal financing by allowing spending to adjust to stabilize government debt. The NK model adds external habit formation, differentiated labor types, a monopolistically competitive intermediate goods sector, variable capital utilization, wage and price rigidities, and a monetary authority that follows a Taylor-type rule for setting nominal interest rates. Tax policies obey (22) and government spending policies follow the process

$$\hat{X}_t = \rho_X \hat{X}_{t-1} + \gamma_X \hat{s}^B_{t-1} + \sigma_X \varepsilon^X_t, \ \hat{X} \in \{\hat{G}, \hat{Z}\} \tag{23}$$

where $\hat{s}^B_{t-1} \equiv \frac{B_{t-1}}{Y_{t-1}}$ is the debt-output ratio and $\gamma_X < 0$.

We estimate the NK model using Bayesian methods and U.S. quarterly data from 1984 to 2007. To conduct simulations, we fix parameters at the mode of the posterior distributions (see table 1 in the appendix). For the RBC model, the structural parameters are calibrated to the values used in the literature and standard deviations of the shocks are set to the values estimated in the NK model. By calibrating one model to well known values and estimating the other model, we aim to demonstrate that our findings are not dependent on whether parameters are calibrated or estimated.

Process	Lags	Description	Coefficients
I	Inside	6 qtrs, smooth news	$\phi_j = \frac{1}{6}, j = 1, 2, \ldots, 6$ $\phi_0 = \phi_7 = \phi_8 = 0$
II	Inside	6 qtrs, concentrated news	$\phi_1 = \phi_2 = \phi_3 = 0.05, \phi_4 = 0.25$ $\phi_5 = \phi_6 = 0.3, \phi_0 = \phi_7 = \phi_8 = 0$
III	Outside	8-qtr phase-in	$\phi_j = 0\ j \neq 8$ $\phi_8 = 1$
IV	Outside	2-qtr phase-in	$\phi_j = 0, j \neq 2$ $\phi_2 = 1$

Table 1. Information Flow Processes. Coefficient settings in tax rule (22).

C. Information Flows and Estimation Bias

The Romers' (2007; 2010) narrative analysis and Yang's (2009) timeline of outside lags associated with federal tax changes reveal two critical features of information flows about taxes. First, the foresight horizon varies considerably from one piece of tax legislation to the next. Second, most tax changes entail substantial inside and outside lags. The generalized specification (22) can model these features of information flows; simple specifications like (5) cannot.

We examine the implications of four alternative information flows in the two DSGE models. The alternatives reflect the diversity of information flows that previous authors have documented. With a maximum length of tax foresight of eight quarters, the four information processes we employ appear in table 1.

Processes I and II model inside lags that differ in the intensity of information flows. In I, the flows are smooth, so news over the previous six quarters receives equal weight. Tax laws that make steady progress through the legislature and get implemented with little delay create flows like I. Process II concentrates the news on lags four through six, with small weight on recent news. Tax changes implemented with a lag of about one year, with only slight changes in details in the periods immediately before implementation, generate flows like II.

The outside lags in processes III and IV closely resemble the information flows that other authors posit [for example, Mertens and Ravn (2011), and Forni, Gambetti, and Sala (2011)]. These processes imply that agents have eight-quarter (III) or two-quarter (IV) perfect foresight about tax changes. Perfect foresight precludes any further changes in legislation, so these processes are exclusively about implementation delays or phased-in tax changes.[10]

Table 2 summarizes the actual and estimated output multipliers associated with a typical tax change in the RBC and NK models. In this exercise, the agent knows the information process and observes the actual ε_t's. The econometrician, on the other hand, bases inference on a set

[10]Ideally, information flows would encompass both inside and outside lags, but such flows would take us outside of a linear structure. For example, one could posit the flows for the inside lag and then, conditional on legislation having been enacted, switch to the outside lag specification, a process that is inherently nonlinear.

of observables. We construct the innovations representation based on the econometrician's conditioning set and use the Kalman filter to back out the econometrician's inferences about the responses of output and taxes to a shock to the tax rate. For the RBC model, the econometrician conditions on the labor tax rate, income tax revenue, output, and investment; the conditioning set for the NK model adds government consumption, private consumption, labor, government debt, inflation, and the nominal interest rate. Thus, the estimated VAR contains several "forward-looking" variables. As a robustness check, we examined many combinations of alternative conditioning variables and found results that are consistent with those in table 2. We report biases as estimated less actual multipliers and biases as a percentage of the actual multipliers. In the absence of foresight, the bias is always zero.

Several general findings emerge from the table. Biases can be very large—hundreds of percent—and can change sign over time across both models. In both models, the biggest errors arise from outside lags—information processes III and IV—which are the information flows most frequently posited in work on foresight. Inside lags with moving-average terms—processes I and II—produce smaller, though still sizeable errors. Information process III, in which agents have two years of perfect foresight about tax rates, generates the largest inference errors in both models. It also confounds dynamics: the econometrician estimates that the strongest effect is contemporaneous, while the largest impact actually occurs two or three years later, depending on the model.

In the RBC model, actual multipliers change *sign*—positive in the foresight period and negative later—but estimated multipliers are uniformly negative. Frictions in the NK model propagate errors, making short-/long-run distinctions less pronounced.[11] In the frictionless RBC model, biases dissipate over time.

A consistent finding across the two models is that for horizons of eight quarters and beyond, the econometrician *underestimates* the multiplier. The lone exception is the NK model under information process I. The discounting of the tax innovations that appears in (4) and (20) explains this result. An agent with q quarters of foresight discounts the innovations so that the $\varepsilon_{\tau,t-q}$ shock receives little discount relative to shocks dated t through $t-q-1$. As in the analytical model, this perverse discounting occurs because $\varepsilon_{\tau,t-q}$ informs about the contemporaneous tax rate, τ_t, while shocks dated t through $t-q-1$ inform about future tax rates. An econometrician, who does not observe the true innovations, applies the conventional discounting to the innovations in her information set, as in (11). This makes the econometrician's impulse response functions die out faster than the true impulse response functions to yield the underestimates.

These findings establish two key points. First, failure to model fiscal foresight can produce quantitatively important errors of inference in the canonical models used for macroeconomic policy analysis. Second, the precise nature of information flows about news matters for the pattern of inference errors. Getting the information flows "right" poses a substantial challenge to DSGE modelers. We turn now to empirical approaches designed to address the errors associated with foresight.

[11] This echoes Leeper and Walker's (2011) results for foresight about technology.

Real Business Cycle Model							
Info Process		0 qtr	4 qtrs	8 qtrs	12 qtrs	20 qtrs	peak (qtr)
I	actual	0.19	−1.14	−1.48	−1.11	−0.65	−1.71 (6)
	estimated	−0.31	−1.35	−1.27	−0.97	−0.59	−1.57 (5)
	bias	−0.50	−0.21	0.20	0.14	0.06	
	% bias	−263%	−19%	14%	12%	8%	
II	actual	0.15	−0.54	−1.40	−1.05	−0.61	−1.62 (6)
	estimated	−0.56	−1.46	−1.19	−0.91	−0.55	−1.48 (2)
	bias	−0.71	−0.92	0.21	0.14	0.06	
	% bias	−473%	−169%	15%	13%	9%	
III	actual	0.09	0.16	−1.51	−1.12	−0.64	−1.51 (8)
	estimated	−1.44	−1.09	−0.82	−0.64	−0.39	−1.44 (0)
	bias	−1.54	−1.24	0.69	0.49	0.25	
	% bias	−1641%	−784%	46%	43%	39%	
IV	actual	0.16	−1.34	−1.00	−0.76	−0.45	−1.56 (2)
	estimated	−1.41	−1.06	−0.81	−0.62	−0.38	−1.41 (0)
	bias	−1.57	0.28	0.20	0.14	0.07	
	% bias	−962%	21%	20%	18%	16%	
New Keynesian Model							
Info Process		0 qrt	4 qtrs	8 qtrs	12 qtrs	20 qtrs	peak (qtr)
I	actual	−0.08	−0.36	−0.48	−0.43	−0.24	−0.48 (8)
	estimated	−0.07	−0.44	−0.57	−0.51	−0.28	−0.57 (8)
	bias	0.01	−0.09	−0.09	−0.08	−0.04	
	% bias	11%	−24%	−20%	−18%	−18%	
II	actual	−0.06	−0.27	−0.43	−0.40	−0.23	−0.43 (9)
	estimated	−0.09	−0.37	−0.42	−0.37	−0.19	−0.42 (7)
	bias	−0.03	−0.10	0.00	0.04	0.04	
	% bias	−51%	−37%	1%	9%	19%	
III	actual	−0.03	−0.12	−0.32	−0.37	−0.26	−0.37 (12)
	estimated	−0.14	−0.10	−0.08	−0.06	−0.01	−0.14 (0)
	bias	−0.11	0.01	0.24	0.32	0.25	
	% bias	−340%	13%	76%	85%	95%	
IV	actual	−0.06	−0.30	−0.33	−0.28	−0.14	−0.33 (7)
	estimated	−0.15	−0.24	−0.26	−0.22	−0.11	−0.26 (7)
	bias	−0.08	0.07	0.07	0.06	0.04	
	% bias	−128%	22%	22%	22%	25%	

Table 2. Output Multipliers for a Labor Tax Change, Correlated with a Capital Tax Change. Multipliers are output responses scaled by the peak response of revenues, converted to dollars, as in Blanchard and Perotti (2002). Agent knows the information process and observes the actual ε_t's. Econometrician bases inference on a set of observable variables, as described in text. Biases equal estimated less actual multipliers.

IV. Solving the Problem

This section unifies the empirical lines of attack that appear in the literature to deal with the econometric problems associated with foresight. We show how seemingly diverse approaches—for example, the narrative methods of Romer and Romer (2010) and Ramey (2011) and the dynamic stochastic general equilibrium approaches of Fujiwara, Hirose, and Shintani (2011) and Schmitt-Grohé and Uribe (2008)—are closely related attempts to solve the problems caused by foresight. Each approach aims to resolve a non-uniqueness problem intrinsic to moving average representations. We briefly discuss three lines of attack.[12]

[12]Detailed calculations in support of the discussion in this section appear in the appendix.

A. An Organizing Principle

Moving average representations are not unique for two distinct reasons that Hansen and Sargent (1991a) emphasize. Understanding the reasons for non-uniqueness provides a useful way to characterization solutions to the problems that foresight creates. Consider the Wold representation for the $n \times 1$ vector stochastic process $\mathbf{x}_t$

$$\mathbf{x}_t = \sum_{j=0}^{\infty} H_j^* \boldsymbol{\epsilon}_{t-j}^* \tag{24}$$

where $\sum_{j=0}^{\infty} \text{tr } H_j^* H_j^{*'} < \infty$ and $\boldsymbol{\epsilon}_t^*$ is an n-dimensional white noise process defined as the innovation in predicting $\mathbf{x}_t$ linearly from its semi-infinite past ($\boldsymbol{\epsilon}_t^* \equiv \mathbf{x}_t - P[\mathbf{x}_t | \mathbf{x}^{t-1}]$).

Two transformations are observationally equivalent to (24). The first comes from multiplying by a nonsingular matrix U,

$$\mathbf{x}_t = \sum_{j=0}^{\infty} (H_j^* U^{-1})(U \boldsymbol{\epsilon}_{t-j}^*) \tag{25}$$

where the innovation is now defined as $U\boldsymbol{\epsilon}_t^*$ and $H_j^* U^{-1}$ represents the altered impulse responses. If U is nonsingular, then the new innovations process spans the same space as $\mathbf{x}^t$ and the information content of $U\boldsymbol{\epsilon}_t^*$ is identical to that of $\boldsymbol{\epsilon}_t^*$. This is the type of non-uniqueness that Sims (1980) describes. Researchers confront this non-uniqueness with different orthogonalization schemes that rotate the covariance matrix through recursive orderings [Sims (1980)], short-run restrictions [Bernanke (1986), Sims (1986)], long-run restrictions [Blanchard and Quah (1989)], a combination of short and long-run restrictions [Galí (1999)], or sign restrictions [Faust (1998), Canova (2002), Uhlig (2005)].

Foresight produces a second type of non-uniqueness. It is also observationally equivalent to (24), and is described by the non-fundamental representation

$$\mathbf{x}_t = \sum_{j=0}^{\infty} H_j \boldsymbol{\epsilon}_{t-j} \tag{26}$$

where now $\{\boldsymbol{\epsilon}_{t-j}\}_{j=0}^{\infty}$ spans a larger space than $\{\mathbf{x}_{t-j}\}_{j=0}^{\infty}$, and $H(L)$ satisfies

$$H^*(z) E\boldsymbol{\epsilon}_t^* \boldsymbol{\epsilon}_t^{*'} H^*(z^{-1})' = H(z) E\boldsymbol{\epsilon}_t \boldsymbol{\epsilon}_t' H(z^{-1})'.$$

where $H(z)$ denotes the z-transform [see, Sargent (1979)]. Under the typical assumption that agents observe the structural shocks $\boldsymbol{\epsilon}_t$ directly, while the econometrician observes only $\mathbf{x}_t$, models with sufficient foresight belong to this class of non-fundamental representations. The covariance generating functions of $H(L)\boldsymbol{\epsilon}_t$ and $H^*(L)\boldsymbol{\epsilon}_t^*$ are identical, but only $H^*(L)$ possesses an invertible representation in $\mathbf{x}_t$. Letting $A(L) = H^*(L)^{-1}$, the typical VAR methodology delivers

$$\mathbf{x}_t = A_0^{-1}[A_1\mathbf{x}_{t-1} + A_2\mathbf{x}_{t-2} + \cdots + \boldsymbol{\epsilon}_t^*]. \tag{27}$$

Identifying A_0^{-1} in the usual way recovers the shocks $\boldsymbol{\epsilon}_t^*$, but not the structural shocks, $\boldsymbol{\epsilon}_t$, that agents observe; the econometrician conditions on a smaller information set than do agents.

Hansen and Sargent's non-uniqueness point sends a clear message: to identify structural shocks in a vector autoregression, *both* types of non-uniqueness must be confronted. Confronting the non-uniqueness in (25) does *not* solve the non-uniqueness of representation (26), and vice versa. A large literature focuses on the non-uniqueness associated with (25). Identifying (26), though, receives less attention and requires the econometrician to condition on the same information set as the agents they are modeling.

B. Lines of Attack

Casting the problem as resolving the two distinct forms of non-uniqueness sheds light on three approaches that appear in the empirical macro literature. One line of attack estimates conventional VARs, identified in a variety of creative ways to isolate anticipated effects, and then examines the impacts of foresight [Sims (1988), Blanchard and Perotti (2002), Yang (2007), Mountford and Uhlig (2009), Beaudry and Portier (2006), Fisher and Peters (2010), Barsky and Sims (2011)]. For example, Beaudry and Portier (2006) and Fisher and Peters (2010) condition on stock prices to capture news about expected changes in technology and government spending, respectively. Barsky and Sims (2011) identify news about productivity as the shock that is orthogonal to current utilization-adjusted productivity that best explains future variations in adjusted productivity.

A second line of attack argues that conventional VARs cannot adequately measure the impacts of foreseen changes in fiscal policy and pursues a narrative approach that introduces new information to aid identification [Ramey and Shapiro (1998), Edelberg, Eichenbaum, and Fisher (1999), Burnside, Eichenbaum, and Fisher (2004), Ramey (2011), Romer and Romer (2010)]. A third approach uses standard methods to estimate a model with foresight. To execute these methods, Schmitt-Grohé and Uribe (2008) and Fujiwara, Hirose, and Shintani (2011) make very particular assumptions about the information flows that give rise to foresight about technology and government spending. The tradeoff is that the modeler must be explicit about the role of information in the economy. Each line of attack tries to align agents' and the econometrician's information sets to address the second type of non-uniqueness that (26) describes.

1. The Narrative Approach

Narrative approaches to fiscal policy—pioneered by Ramey and Shapiro (1998), Romer and Romer (2010), Ramey (2011), and Mertens and Ravn (2011)—expands the econometrician's information set by using fresh data sources to identify fiscal news. For example, Ramey

(2011) derives a direct measure of spending news by culling from *Business Week* dates when there were significant increases in the expected present value of military spending. To the extent that this fiscal news is triggered by non-economic factors, it may be treated as exogenous for inferring the impacts of news on macroeconomic time series. Ramey augments the econometrician's usual information set by adding this news to fiscal VARs and infers that anticipated expansions in federal government spending reduce most measures of consumption and real wages, a strikingly non-Keynesian finding.

Recognizing the intrinsic endogeneity of tax policy decisions, Romer and Romer (2010) compile a data series on the forecasted revenue consequences of federal tax changes since World War II. Romer and Romer identify as "exogenous" those revenue changes that were a response to concerns about long-run economic growth or about the state of government debt. Using this measure of tax news, Mertens and Ravn (2011) apply a timing convention to distinguish between unanticipated and anticipated news. They append tax news as exogenous regressors to a VAR with a time trend

$$X_t = A + Bt + C(L)X_{t-1} + D(L)T_t^u + F(L)T_{t,0}^a + \sum_{i=1}^{K} G_i T_{t,i}^a + e_t \tag{28}$$

where X is a vector of macro time series, $D(L)T_t^u + F(L)T_{t,0}^a$ reflects dependence on current past unanticipated and anticipated news, and $\sum_{i=1}^{K} G_i T_{t,i}^a$ yields the impacts of known, but not-yet-implemented tax changes. Mertens and Ravn obtain provocative results: anticipated tax cuts induce sharp economic slowdowns during the period of foresight, and may even produce recessions.

Narrative approaches face two criticisms. First, theoretical and empirical models often do not line up in their treatments of information flows. Romer and Romer (2007, 2010) base their tax-shock series on narrative sources that report both enacted and proposed tax changes, but Mertens and Ravn's (2011) theory treats all anticipated tax changes as stemming from outside lags. The Romers also limit themselves to actions that actually change tax liabilities, so their data series excludes proposals that do not reach fruition, while news specifications like those in section III allow for revisions in expectations when proposals fail. Ramey's (2009a; 2011) narrative analysis identifies a number of instances where the news about major military build ups arrived well before any explicit legislative actions were taken, which are clear examples of inside lags. But Ramey's (2009b) theoretical specification posits a military spending rule as an autoregressive process with a news shock lagged two periods, capturing only the outside lag. This misalignment of information flows loosens the connection between theory and empirics and muddies the interpretations of empirical findings.

Second, empirical implementations of narrative news variables typically treat news as exogenous. Stock and Watson (2012) observe that, more precisely, narrative measures are instruments for exogenous shocks. Their dynamic factor analysis uncovers some unsettling characteristics of the fiscal news series derived by Romer and Romer (2010), Fisher and Peters (2010), and Ramey (2011). First, the fiscal instruments are weak, suggesting they are only weakly correlated with the underlying fiscal news shocks.[13] Second, the Romer-Romer tax series is highly correlated (0.93) with the Fisher-Peters government spending series, making it difficult to interpret the two shocks as distinct fiscal actions. Finally, all three fiscal news measures are highly correlated with monetary policy shocks, raising doubts about the efficacy of identifying one type of macro policy independently of the other.[14]

2. Conditioning on Asset Prices

If asset markets are efficient, the information contained in asset prices should coincide with all available information to agents and adding asset prices to a VAR should help align the information sets of the econometrician and agent. With respect to fiscal foresight, there is an asset class that is particularly useful for isolating news about future tax shocks. In the United States, municipal bonds are exempt from federal taxes and the differential tax treatment of municipal and treasury bonds can help identify news about tax changes.[15] If $\mathcal{Y}_t^M$ is the yield on a municipal bond at t and $\mathcal{Y}_t$ is the yield on a taxable bond, and assuming the bonds have the same term to maturity, callability, market risk, credit risk, and so forth, then 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 investors are indifferent between tax-exempt and taxable bonds. With forward-looking bond traders, the implicit tax rate predicts subsequent movements in individual tax rates: if investors expect individual tax rates to rise (fall), they drive up (down) yields on taxable bonds until they are indifferent between taxable and nontaxable bonds.[16]

More precisely, 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

$$1 = \frac{C^M}{\sum_{t=1}^T (1 + R_t^\tau)^t} + \frac{1}{(1 + R_T^\tau)^T}, \tag{29}$$

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, and selling at par satisfies

$$1 = \frac{\sum_{t=1}^T C(1 - \tau_t^e)}{\sum_{t=1}^T (1 + R_t^\tau)^t} + \frac{1}{(1 + R_T^\tau)^T}, \tag{30}$$

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

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[13] Weak instrument may also be a sign of endogeneity problems.

[14] Of course, Stock and Watson's findings are conditional on the variables they include in their factor model and on the labels they choose to attach to the six factors they isolate.

[15] Depending on the type of bond, municipal bonds can also be exempt from the Alternative Minimum Tax, state, and local taxes. Ang, Bhansali, and Xing (2010) describe the municipal bond market.

[16] There is a large literature demonstrating the ability of the municipal bond market to forecast changes in fiscal policy [Poterba (1989), Fortune (1996), Park (1997a), Kueng (2011)].

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 (III.2) from (III.1) and solving for C_M/C gives

$$\tau_T^I = \sum_{t=1}^{T} \omega_t \tau_t^e, \tag{31}$$

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 (III.3) reveals 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. Under efficient markets, the implicit tax rate reflects 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 section III, we modeled information flows as 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. Finally, conditioning on the implicit tax rate resolves the non-uniqueness associated with moving-average representation (26). Like the capital accumulation equation in section II, the implicit tax rate depends on the discounted future path of taxes. Unlike the capital equation, the yield curve of municipal bonds isolates the about taxes at different horizons.[17]

Employing exactly the identification scheme and data set of Blanchard and Perotti (2002) (BP), we ask how augmenting the econometrician's information set with a direct measure of tax news affects inferences.[18] To conserve space, we report the data construction and estimation procedure in Leeper, Walker, and Yang (2011) and the appendix. We find that municipal bonds respond to news about tax policy and that implicit tax rates are Granger-causally prior relative to the information sets in the fiscal VAR system that Blanchard and Perotti (2002) estimate.

Adding implicit tax rates dramatically changes the VAR results of BP: anticipated tax increases *raise* output substantially for about three years before output begins to decline. This contrasts sharply to the anemic response of output to an anticipated tax shock in BP (Figure III, p. 1343), which led them to conclude, "there is not much evidence of an effect of anticipated tax changes on output [p. 1353]." The difference in the results can be attributed to how fiscal foresight is identified. By conditioning on one- and five-year municipal bond yield

[17]As an oversimplified example, suppose that agents have two quarters of foresight and the econometrician has access to the implicit tax rate with maturities of one and two quarters. The one-quarter implicit tax rate identifies one-quarter news, while the difference between the implicit tax rates identifies two-quarter news.

[18]We do the same exercise for Mountford and Uhlig (2009). While the results are not as striking as for BP, we do find that conditioning on implicit tax rates qualitatively alters the findings of Mountford-Uhlig. For example, investment multipliers, which Mountford-Uhlig estimated to be zero, become significantly positive. See Leeper, Walker, and Yang (2011) and the appendix for more details.

spreads, we allow for a much longer foresight horizon than the BP approach, which assumes agents have only one-quarter of foresight. These differences underscore the importance of modeling information flows.

Our finding that news of higher taxes increases economic activity over much of the anticipation period echoes results from two very different methodologies. In a case study, House and Shapiro (2006) argue 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 generate a path of equilibrium GDP that declines in response to an anticipated tax reduction. Our results are also consistent with Mertens and Ravn (2011) whose augmented VAR, (28), implies that an anticipated tax increase induces a boom in output whose amplitude and duration increase with the period of foresight. 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 obtain. Nonetheless, the qualitative effects closely resemble our results.

There are obvious limitations to using municipal bonds as a measure of anticipated tax changes. First, fiscal news must be separated from other factors that influence municipal bonds (callability, liquidity risk, default risk, etc.), factors whose influence can be controlled for and limited by using high-quality municipal bond data. Leeper, Richter, and Walker (2011) show how to construct a risk-adjusted implicit tax rate based on the methodology of Fortune (1996). They argue that for AAA-rated municipal bonds, the risk adjustment is not substantial. Using state municipal bonds, Kueng (2011) shows that default risk and liquidity factors are nearly negligible for maturities of longer horizons and that municipal bonds contain substantial news about pending tax changes. Second, the marginal investor may be high-income households and not representative of the typical taxpayer. Kueng (2011) provides supporting evidence but argues that it does not invalidate using municipal bonds to back out news about pending tax changes for other tax brackets because the economic response to tax news depends on the path of expected taxes, not the level. If municipal bonds provide an accurate indication of this path, the levels are irrelevant. Third, municipal bonds respond to changes in individual income taxes only. While this is true, often changes to the tax code (personal, corporate, etc.) occur simultaneously, so municipal bonds may not accurate indicate *how* corporate taxes change, but they will can indicate *when* corporate taxes will change. Finally, municipal bonds are an asset that is unique to the United States, which limits the implementability of this approach.

3. Direct Estimation of DSGE Model

A third approach uses standard econometric methods, such as An and Schorfheide (2007), to estimate a DSGE model in which agents have foresight about shocks that hit the economy. Specifying the entire structure of the economy, including the information sets of the agents, yields a likelihood function that contains sufficient information to overcome the non-uniqueness of section A. In models with foresight, the likelihood will be an vector ARMA process similar to the equilibrium processes of section II. When estimating the model directly (via maximum likelihood or Bayesian techniques), one does not need to put the equilibrium into VAR form and therefore the invertibility of the moving average process is irrelevant. By defining the information sets explicitly, it is no longer critical whether the MA representation is fundamental or non-fundamental because the likelihood function can distinguish between the two.

This benefit comes at a cost. Modelers must make very particular assumptions about the information flows that give rise to foresight about technology, government spending, taxes, and so forth. Solutions are *conditional on the specified information flows*, aspects of the economic structure about which economists rarely have well developed prior beliefs or direct empirical evidence.[19] For example, in models with foresight, the length of foresight (the q in section III) and the strength of foresight (the MA coefficients, θ, in section III) must be specified prior to estimation. As shown in table 2, the dynamic properties of the equilibria can vary dramatically conditional on the news process.

Leeper and Walker (2011) argue that the information sets specified to achieve identification in this regard are chosen largely arbitrarily, grounded in neither theory nor empirics. Alternative, equally plausible processes for news, can deliver strikingly different equilibrium dynamics. Surprisingly, despite the centrality of information structures to the burgeoning news literature, there has been essentially no exploration of alternative, equally plausible, assumptions about how information about critical economic variables flows to agents.

V. Concluding Remarks

We have shown how foresight introduces econometric difficulties that complicate the interpretation of conventional econometric analyses. Foresight, of *any* type, can introduce non-fundamental moving average terms into the linear equilibrium process, changing the mapping between the true news that agents observe and the “shocks” that the econometrician identifies. Many of the econometric techniques in macroeconomists’ toolboxes can be distorted by empirical methods that do not adequately estimate the non-invertible moving average components of equilibrium time series. Section II uses simple analytics to describe the nature of the problem. Section III demonstrates that failing to model foresight can produce quantitatively important inference errors in data generated by models now in wide use for macro policy analysis. Section IV explains that existing empirical methods to handle foresight aim to resolve the same non-uniqueness, but in different ways.

This paper focuses on tax policy as a particularly relevant and tangible form of foresight. There is little doubt that agents know and react to tax changes before they are implemented. But the econometric difficulties that fiscal foresight creates are entirely general: they emerge

[19]That the assumptions about information flows matter to inferences from estimated DSGE models is shown in two versions of the same paper that differ in information flow specifications and yield different inferences about the relative importance of various shocks [Schmitt-Grohé and Uribe (2008, 2011)].

anytime agents respond to news about future realizations of fundamentals. Although the problem is general, we suspect the solution is not. A general solution, if one exists, lies in the future.

Foresight poses a challenging mix of structural and measurement problems. Hypothesized information flows that are uninformed by observations and information sets that are unrestricted by theory are unlikely to resolve the foresight problem. Answers lie in blending theory with measurement.

APPENDIX I. SIMULATIONS DETAILS

A. 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, 2007)) with distorting taxes levied on capital and labor income. Agents in the models have foresight over tax policy changes. This appendix 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.

1. RBC Model

The representative agent maximizes utility

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

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 $c_t + k_t - (1-\delta)\, k_{t-1} = \left(1 - \tau_t^L\right) w_t l_t + \left(1 - \tau_t^K\right) r_t^K k_{t-1} + z_t$, 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 $y_t = u_t^a k_{t-1}^{\alpha} l_t^{1-\alpha}$, 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.

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

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

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 $k_t = (1-\delta)k_{t-1} + \left[1 - s\left(\frac{u_t^i i_t}{i_{t-1}}\right)\right] \times i_t$, 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 $L_t = \left[\int_0^1 l_t(j)^{\frac{1}{1+\eta_t^w}} dj\right]^{1+\eta_t^w}$, 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 $W_t = \left[\int_0^1 W_t(j)^{\frac{1}{\eta_t^w}} dj\right]^{\eta_t^w}$. 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 $\left[\int_0^1 y_t(i)^{\frac{1}{1+\eta_t^p}} di\right]^{1+\eta_t^p} \geq Y_t$. 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 $\ln(u_t^a) = \rho_a \ln(u_{t-1}^a) + \sigma_a \varepsilon_t^a$. Analogous to households' wage decisions, a monopolistically competitive intermediate firm faces a probability $1-\omega_p$ that is 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

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

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

B. 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 3).

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 3 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 C 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 elasticity of substitution in the goods and labor markets ($\frac{1+\eta^p}{\eta^p}$, $\frac{1+\eta^w}{\eta^w}$) are assumed to 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 5-15 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 2 assumes $\xi = 0.26$, 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 3). 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 3 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.

C. Data Description

This section describes the data for estimating the NK model and the municipal and treasury bonds data used in section 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.[20] 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).

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

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

Parameters	Prior			Posterior mode	
	func.	mean	std.	our estimation	S&W (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.

Table 3. Prior and posterior distributions of the estimated parameters for the New Keynesian model. Functions G, B, N, IG denote Gamma, Beta, normal and inverse Gamma distributions.

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 sixteen 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.

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 1994-2006 are obtained from Bloomberg's Municipal Fair Market Bond Index. Market yields on constant-maturity-adjusted, non-inflation-indexed U.S. Treasury securities from 1955-2006 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.

APPENDIX II. TESTING ECONOMIC THEORY

A. 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 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 $t = 0, 1, ...T$, 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

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

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) derive 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

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

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) show that the restrictions on the VAR coefficients implied by the present-value constraint are given by

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

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

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

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.

B. Tests of Granger Causality

Sargent (1981) calls 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.[21] To see this more clearly, return to the analytical model of section 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

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

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.

Appendix III. 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

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

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.[22] 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 shows 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 (1997b), and Ang, Bhansali, and Xing (2010)]. Leeper, Richter, and Walker (2011) update Poterba (1989) and find 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

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

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, and selling at par satisfies

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

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 (III.2) from (III.1) and solving for C_M/C

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

gives

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

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 (III.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.

1. Blanchard and Perotti (2002)

BP estimate 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 do.

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).[23]

[23] 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.

Write the reduced-form residuals from this VAR as

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

If agents have sufficient foresight, as BP themselves note and section 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).[24]

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

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

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

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 show how the innovation in (III.5) led one quarter, $e_{t+1}^{*\tau}$, can be used to instrument for the expectational effects in (III.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 (III.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 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 (III.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 (III.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.

---

[24] To confront the non-uniqueness described in section 4, BP identify 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 show 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.

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

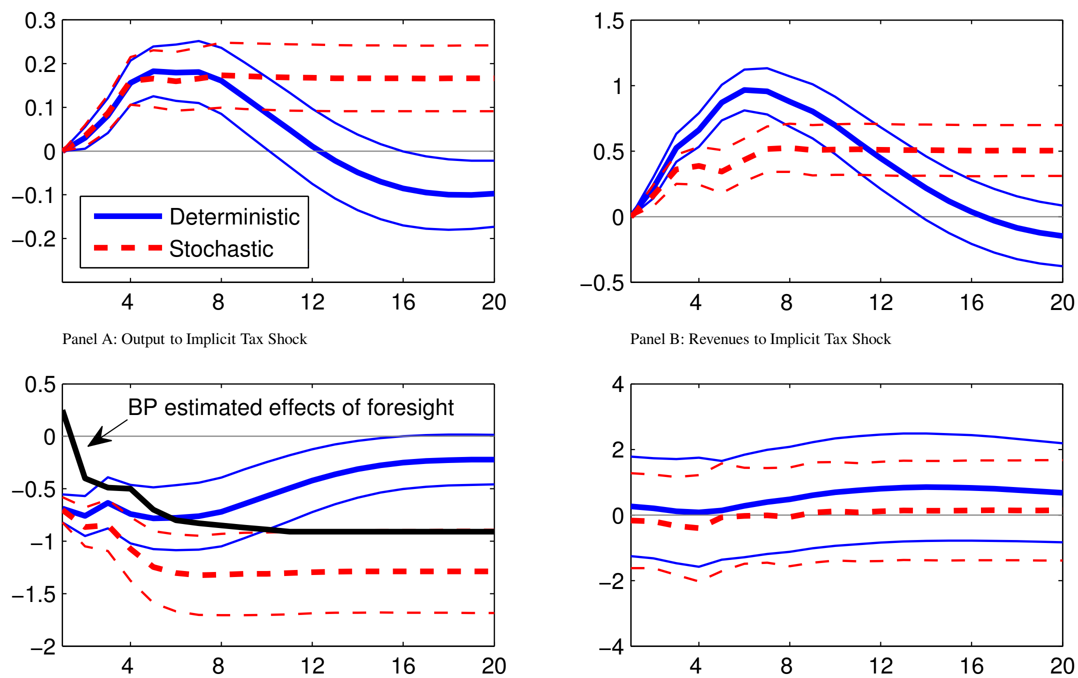
$$\begin{aligned} u_t^\tau &= a_{\tau y} u_t^y + a_{\tau s} u_t^s + b_{\tau g} e_t^g + e_t^\tau \\ u_t^g &= a_{gy} u_t^y + a_{gs} u_t^s + b_{g\tau} e_t^\tau + e_t^g \\ u_t^y &= c_{y\tau} u_t^\tau + c_{yg} u_t^g + e_t^y \\ u_t^s &= c_{s\tau} u_t^\tau + c_{sg} u_t^g + c_{sy} u_t^y + e_t^s \end{aligned}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

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 (III.6). An efficient municipal bond market makes the implicit tax rate equivalent to the expectation in (III.6), as (III.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 (III.7) are the true structural shocks (i.e., that the observables augmented with the implicit tax rate spans 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 (III.7) are identical to those of (III.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}.[25] 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.

Figure 2 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.

[25] 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.



Panel A: Output to Implicit Tax Shock

Panel B: Revenues to Implicit Tax Shock

Panel C: Output to Tax Revenue Shock
BP Figure III and anticipated effects

Panel D: Implicit Tax to Tax Revenue Shock

Figure 2. 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.

Beyond the impact period, BP's methodology does not, however, deliver responses that are statistically different from the VAR that ignores foresight. This result leads 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).

	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

Table 4. Output and Investment Multipliers for an Implicit Tax Shock (A) and Tax Revenue Shock (U). An asterisk indicates zero is outside of the region between the two one-standard deviation bands. BP denotes the numbers from the VAR without municipal bonds.

Panels A and B of table 4 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 the numerical evidence presented in section 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 2 depicts, echoes results from two very different methodologies. In a case study, House and Shapiro (2006) argue 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 generate a path of equilibrium GDP that shares qualitative features with panel A of figure 2.

Mertens and Ravn (2011) augment a VAR with Romer and Romer's (2010) anticipated tax liabilities series, which they treat as strictly exogenous in the VAR. Mertens and Ravn append to each equation of the VAR a distributed lag of q periods in *future* tax liabilities. They estimate 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 obtain. 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 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 take. These differences underscore the importance of modeling information flows.

2. Mountford and Uhlig (2009)

Mountford and Uhlig (2009) impose 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 identify two fiscal policy shocks—a government spending shock and a government revenue shock. They define 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. Business cycle shocks are defined as a shock which jointly moves output, consumption, nonresidential investment and government revenue in the same direction for four quarters following the shock.[26] 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) show that the sign restriction approach of MU can be reinterpreted as pinning down the elasticities associated with the BP system (III.4). And like BP, MU acknowledge the importance of foresight and impose *additional* restrictions to account for it. MU argue that anticipated fiscal policy changes can be identified by imposing zero restrictions on the responses of fiscal variables 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

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

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

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 impose the zero restriction on tax *revenues*. They find 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 non-residential investment, interest rate, adjusted reserves, the producer price index for crude materials, and the GDP deflator. Fiscal variables are defined as in MU, who follow 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.[27]

Figure 3 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 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 2. 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),

[27]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.

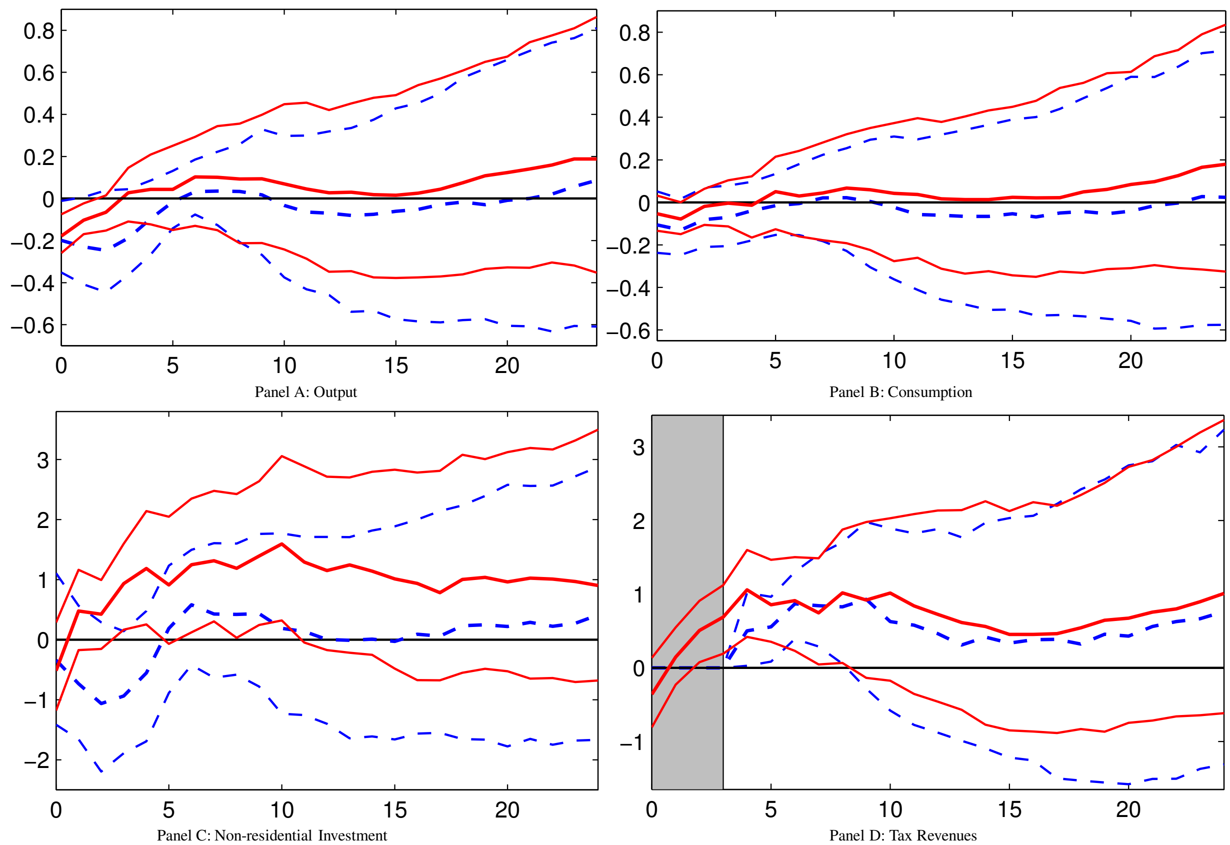


Figure 3. Estimated median responses with 16th and 84th percentile bands for MU VAR specification to a positive tax revenue shock (dashed lines) and MU VAR with muni spread to a positive implicit tax rate shock (solid lines).

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 non-residential 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 3 are consistent with economic theory. Mertens and Ravn (2011) emphasize 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 find 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.[28] Auerbach (1989) emphasizes 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) map the elasticities estimated by BP in (III.4) into the implied elasticities from imposing the MU sign restrictions. They find that MU impose 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 4 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 4 makes clear that accounting for foresight changes the estimated output and investment multipliers associated with tax shocks.

APPENDIX IV. 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 agents and the econometrician. In the context of the model in section 2, conventional VARs estimate

[28]They reconcile 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.

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 make this interpretation more precise. Although non-invertibility of the moving average representation implies 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 (2010, 2007) use 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) use the Romers' compiled data series. They generalize the Romers' empirical work and lay out an intricate DSGE model to interpret their estimates of the impacts of anticipated and unanticipated changes in taxes. Whereas the Romers find only weak evidence that private agents react to anticipated tax changes, Mertens and Ravn obtain 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.

A. Formalizing the Narrative Identification

The Romers distinguish 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 consider 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 draw 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

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

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.[29]

To study the Romers' identification, we simplify (IV.1) 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 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 (IV.1), written in terms of its anticipated and unanticipated parts, to

$$\tau_t = \rho\tau_{t-1} + \mu^C y_t + \xi_{t-q} + e_{\tau,t}^u \tag{IV.2}$$

where

$$\xi_{t-q} = \mu^T y_{t-q-1} + \gamma s_{t-q-1}^B + \varepsilon_{\tau,t-q} \tag{IV.3}$$

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

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

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) label as long-run, "exogenous" tax changes could easily be categorized as "endogenous" responses to short-term economic conditions. Stein (1996) documents 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.[30] 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 classify 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 Economic Report of the President (2002, p. 44) argues, "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 Press (2006) documents 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.

We have specified a rule for future tax *rates*, but the Romers and Mertens and Ravn employ 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 estimate single-equation regressions, we reproduce the slightly more general estimated VARs that Mertens and Ravn use to report the dynamic impacts of the two kinds of tax shock. Specifically, we estimate

$$X_t = A + CX_{t-1} + \sum_{i=0}^{24} D_i T^u_{t-i} + \sum_{i=0}^{24} F_i T^a_{t-i} + \sum_{i=1}^{6} G_i T^a_{t+i} + u_t, \tag{IV.4}$$

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.[31] Forecasts are conditional on information at t, for

[30] 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) writes that the proposal to cut taxes "was a delayed response to a chronic condition after hopes of a spontaneous recovery were dimmed" [p. 408].

[31] The Romers' data set scales revenues by *actual* future output, which treats a function of future shock realizations as a regressor in (IV.4). We follow their procedure in the simulations.

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 (IV.4) is done separately for the two taxes; therefore, to estimate the effects of an anticipated capital tax cut, T_t^u and T_t^a in (IV.4) are associated with capital tax changes, and vice versa for labor taxes.[32]

Romer and Romer and Mertens and Ravn share the critical maintained assumption that forecasted revenue changes *are* the exogenous news about taxes. This assumption explains why the system in (IV.4) 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 (IV.1) makes clear, that constructed measure includes legislative actions that are a response to budget deficits or the state of government indebtedness.

B. 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 4-7 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 (IV.4) 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 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

[32]The Romers and Mertens and Ravn do 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) shows 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.

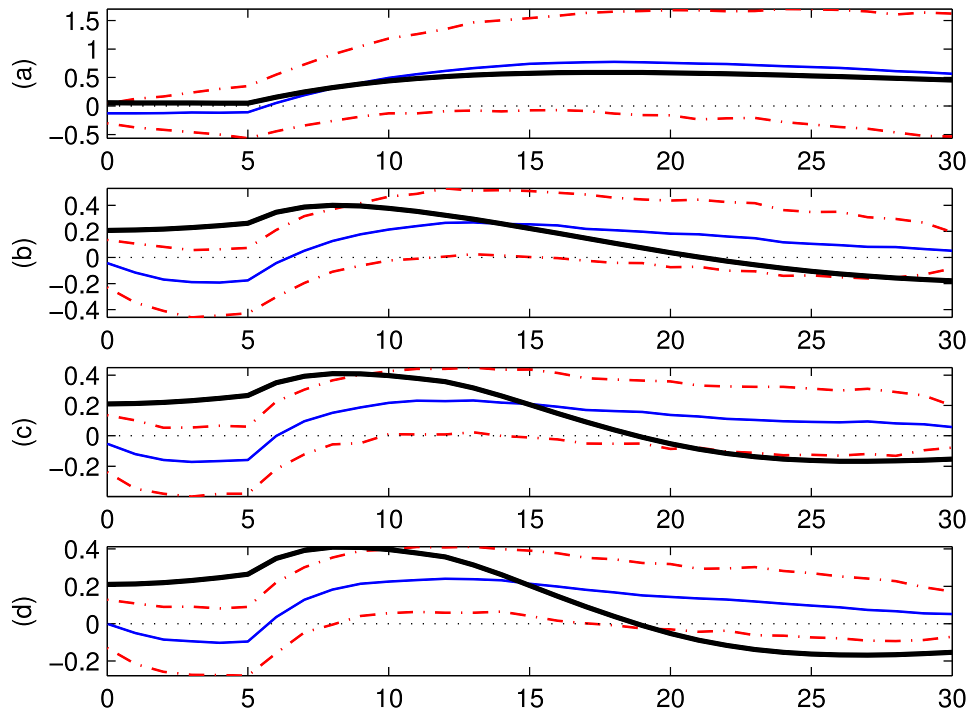


Figure 4. Responses of Consumption to 6-Period Foresight of Labor Taxes.
Panel (a) $\mu^C = 0, \mu^T = 0, \gamma_T = -.1, \sigma_K = .025, \sigma_L = .02$
Panel (b) $\mu^C = 1, \mu^T = 0, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (c) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (d) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_{Ka} = .0375, \sigma_{Ku} = .0125, \sigma_{La} = .03, \sigma_{Lu} = .01$

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 (IV.4) do a very good job of recovering the theoretically correct responses.[33]

Once tax rates respond to debt, estimates based on the VAR in (IV.4) 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 changes are more prevalent and more important. Modeling "RR exogenous" tax

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

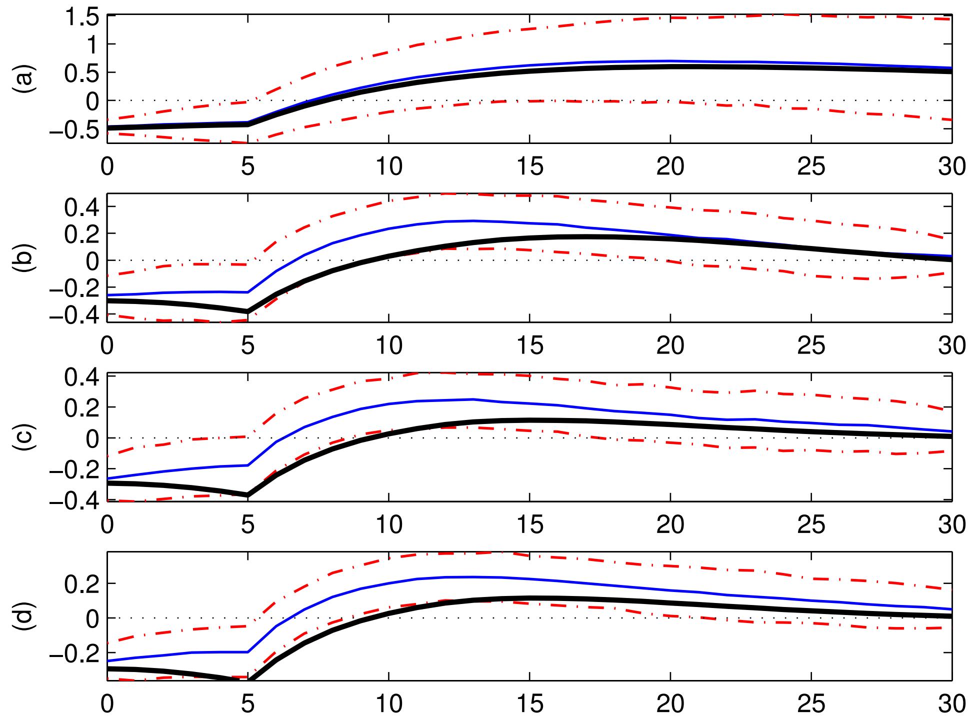


Figure 5. Responses of Consumption to 6-Period Foresight of Capital Taxes.
Panel (a) $\mu^C = 0, \mu^T = 0, \gamma_T = -.1, \sigma_K = .025, \sigma_L = .02$
Panel (b) $\mu^C = 1, \mu^T = 0, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (c) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (d) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_{Ka} = .0375, \sigma_{Ku} = .0125, \sigma_{La} = .03, \sigma_{Lu} = .01$

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 Romer's 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 5 (see also figure 6). But it can also perform very poorly. Figure 4 shows that an anticipated cut in labor taxes creates a boom in consumption in the foresight period, while estimates of (IV.4) 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 7]. The inference that a recession occurs before an anticipated cut in taxes coincides closely with Merten and Ravn's results from estimating (IV.4) based on the Romer's 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 4 shows that over horizons of five or more years, it is very unlikely that estimates of (IV.4), which die out rather quickly, will recover the medium-run

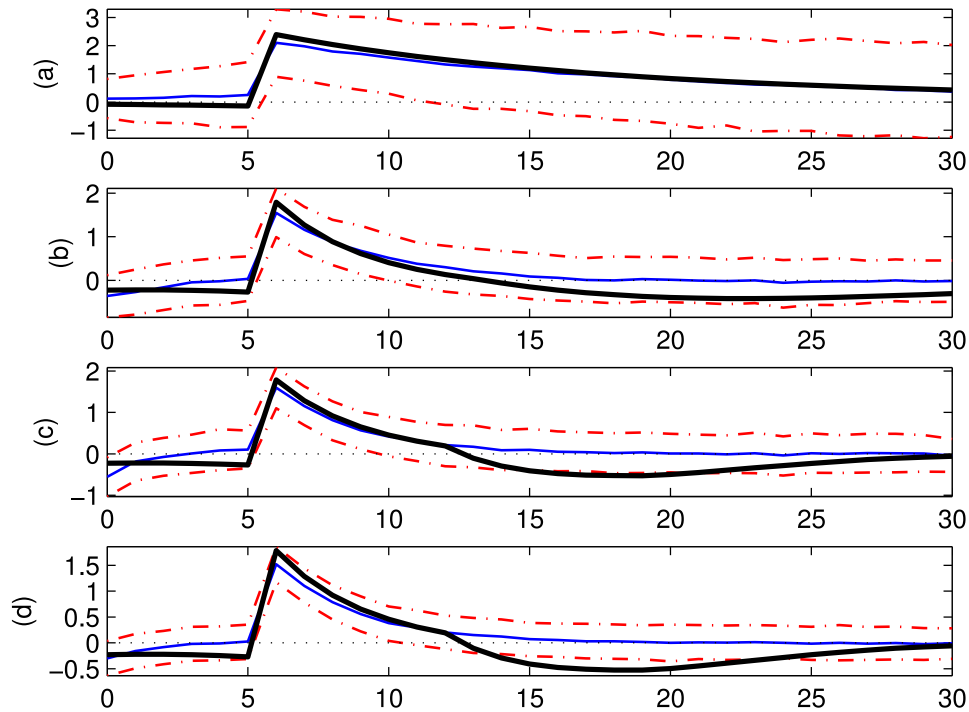


Figure 6. Responses of Output to 6-Period Foresight of Labor Taxes.
Panel (a) $\mu^C = 0, \mu^T = 0, \gamma_T = -.1, \sigma_K = .025, \sigma_L = .02$
Panel (b) $\mu^C = 1, \mu^T = 0, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (c) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (d) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_{Ka} = .0375, \sigma_{Ku} = .0125, \sigma_{La} = .03, \sigma_{Lu} = .01$

decline in consumption following a reduction in labor tax rates. The source of the mispredictions is that the VAR system in (IV.4) 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 4 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 (IV.4) 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.

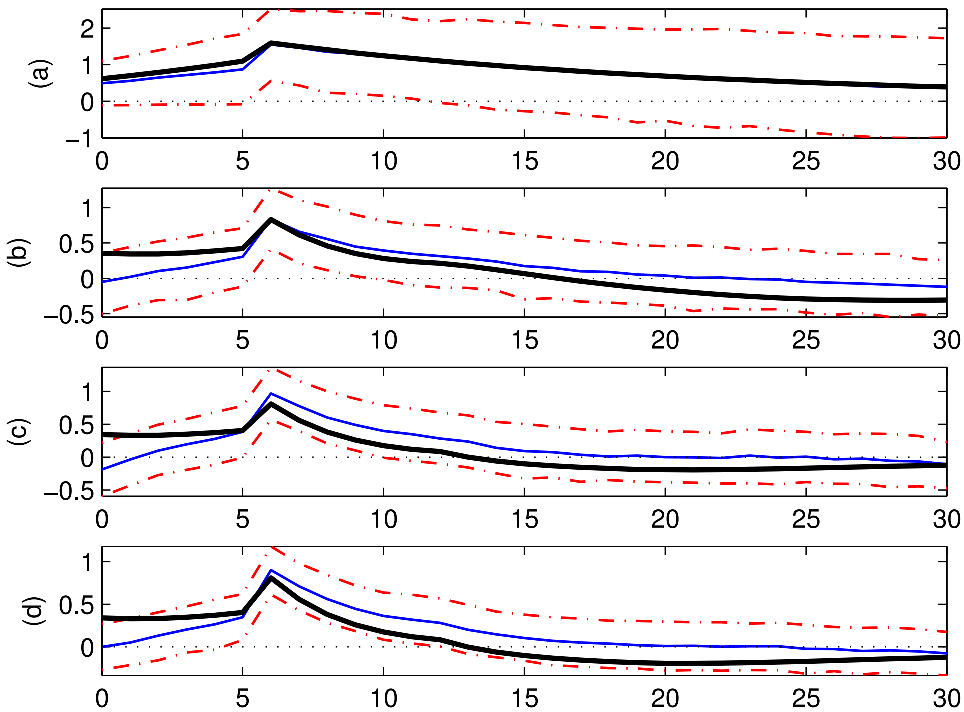


Figure 7. Responses of Output to 6-Period Foresight of Capital Taxes.
Panel (a) $\mu^C = 0, \mu^T = 0, \gamma_T = -.1, \sigma_K = .025, \sigma_L = .02$
Panel (b) $\mu^C = 1, \mu^T = 0, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (c) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_K = .025, \sigma_L = .02$
Panel (d) $\mu^C = 1, \mu^T = .5, \gamma_\tau = .05, \sigma_{Ka} = .0375, \sigma_{Ku} = .0125, \sigma_{La} = .03, \sigma_{Lu} = .01$

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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