Fiscal Volatility Shocks and Economic Activity

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Abstract

We study the effects of changes in uncertainty about future fiscal policy on aggregate economic activity. First, we estimate tax and spending processes for the U.S. that allow for time-varying volatility. We uncover strong evidence of the importance of this time-varying volatility in accounting for the dynamics of tax and spending data. We then feed these processes into an otherwise standard New Keynesian business cycle model calibrated to the U.S. economy. We find that fiscal volatility shocks can have a sizable adverse effect on economic activity and inflation. An endogenous increase in markups accounts for about half of these.

Keywords: Dynamic economies, Uncertainty, Fiscal Policy, Monetary Policy.

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"The recovery in the United States continues to be held back by a number of other headwinds, including still-tight borrowing conditions for some businesses and households, and – as I will discuss in more detail shortly – the restraining effects of fiscal policy and fiscal uncertainty."

July 18, 2012, Ben S. Bernanke.

Policymakers and business leaders alike see the U.S. economy buffeted by larger-than-usual uncertainty about fiscal policy. As illustrated by a number of prolonged struggles at all levels of government in recent years, there is little consensus among policymakers about the fiscal mix and timing going forward.[1] Will government spending rise or fall? Will taxes rise or fall? And which ones? Taxes on labor or on capital (or both)? And when will it happen? This administration? The next one?

In this paper, we investigate whether all of this increased uncertainty about fiscal policy has a detrimental impact on economic activity (hereafter, and following the literature, we use the term "uncertainty" as shorthand for what would more precisely be referred to as "objective uncertainty" or "risk"). We first estimate fiscal rules for the U.S. that allow for time-varying volatility in their innovations while keeping the rest of the parameters constant. In particular, we estimate fiscal rules for capital and labor income taxes, consumption taxes, and government expenditure as a share of output. We interpret the changes in the volatility of the innovations in the fiscal rules as a representation of the variations in fiscal policy uncertainty. A key feature of our specification of the fiscal rules is that we clearly distinguish between fiscal shocks and fiscal volatility shocks. Thus, we will be able to consider shocks to fiscal volatility that would not have a contemporaneous effect on taxes or government expenditure as a share of output. Another important characteristic of our fiscal rules is that the changes in fiscal uncertainty are only temporary. This is a deliberate

[1] As regards the uncertain outlook created by the current political gridlock, a notorious example was the unending discussion of the Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010, which was signed into law only shortly before the Bush tax cuts and the extension of federal unemployment benefits would have expired. Part of this package was a cut in the payroll tax rate. Another case was the discussion surrounding the federal debt limit in 2011 that eventually saw the U.S. sovereign debt downgraded by S&P. Also witness the starkly different platforms in the 2012 presidential election. With regard to concerns by businesses, the Philadelphia Fed's July 2010 Business Outlook Survey is suggestive of heightened fiscal uncertainty as well: of those firms that saw their demand fall, 52 percent cited "Increased uncertainty about future tax rates or government regulations" as one of the reasons. Fiscal uncertainty is repeatedly mentioned by respondents to the Fed's Beige Book, and considerably more so now than in recent years. Finally see the indicator constructed by Baker, Bloom and Davis (2011).

choice as we already know from the work of Bi, Leeper and Leith (2012) and others that permanent changes in policy have important effects on economic activity. Our goal is to investigate a different question: the response of the economy to a temporary increase in fiscal policy uncertainty.

In a second step, we feed the estimated rules into a New Keynesian model, variants of which have been demonstrated to capture the properties of U.S. business cycles (Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007)). The model serves as a useful starting point both for analyzing the effects of fiscal uncertainty and for outlining –through counterfactuals– some of the implications for monetary policy. We calibrate the model to replicate observations of the U.S. economy. We then compute impulse response functions (IRFs) to a fiscal volatility shock (to be defined precisely below) by employing third-order perturbation methods to solve for the equilibrium. By using the estimated rules, we assume that the economy is temporarily subjected to higher fiscal uncertainty, but that the processes that govern taxes, government spending as a share of output, and uncertainty follow their historical behavior. As we said before, we model a temporary increase in fiscal uncertainty, not a permanent change in the fiscal rules. In the taxonomy of Leeper (1991), throughout our simulations, the economy stays in an active monetary/passive fiscal policy regime. Our argument will be that, even without a permanent change in the rules, we uncover significant effects of increased fiscal uncertainty.

Our main findings are as follows. First, there is a considerable amount of time-varying volatility in tax and government spending as a share of output processes in the U.S. We postulate that the evidence overwhelmingly supports the view that explicitly modeling time-varying volatility is crucial in any empirical investigation of fiscal policy in the U.S.

Second, fiscal volatility shocks reduce economic activity: aggregate output, consumption, investment, and hours worked drop on impact and stay low for several quarters. Most of the effect works through larger uncertainty about future tax rates on capital income. Endogenous markups are central to the mechanism. On the one hand, because of nominal rigidities, prices cannot fully accommodate the drop in demand triggered by precautionary behavior. On the other hand, fiscal volatility shocks make future marginal costs and demand harder to predict, which means that firms stand to lose more by setting relatively low prices. This leads firms to bias their prices upward.[2]

[2] There is some literature related to the markup channel that we emphasize in our work. An early contribution is Kimball (1989). A different take appears in Bachmann and Moscarini (2011), where firms can learn about their

Fiscal volatility shocks are therefore “stagflationary”: Inflation rises on impact while output falls. Third, in our calibration, the effect on output of a fiscal volatility shock is roughly equivalent to the effect of a one-standard-deviation contractionary monetary shock identified in VAR studies (a 30-basis-point increase in the federal funds rate). The effect is not bigger because the response of taxes and spending to a fall in GDP softens the recessionary impact of fiscal volatility shocks. If we reduce the role of these responses, output contracts by up to 10 times more.

Note that, quantitatively, we explore the effects of large fiscal volatility shocks, namely, a two-standard-deviation innovation shock. However, the size of the shock is in line with the volatility literature. Bloom (2009) uses a similar-sized shock to the volatility of idiosyncratic productivity. Bloom et al. (2012) look at the impact of a doubling of the volatility of the aggregate component of TFP and a tripling of the volatility of idiosyncratic productivity. Basu and Bundick (2011) evaluate the impact of about a doubling in the standard deviation of TFP and demand preference shocks. The key is not to think about fiscal volatility shocks as a main source of business cycle fluctuations every quarter, but just as a potentially important one from time to time (for instance, every decade or so).

To the best of our knowledge, our paper is the first attempt to fully characterize the dynamic consequences of fiscal volatility shocks. At the same time, our work is placed in a growing literature that analyzes how other types of volatility shocks interact with aggregate variables. Notable examples include Bloom (2009), Bloom et al. (2012), Justiniano and Primiceri (2008), and Fernández-Villaverde et al. (2011*b*). As a novelty with respect to these papers, our work focuses on the effects of fiscal volatility shocks. In addition, we focus on a monetary business cycle model, highlighting that this dimension is central to the transmission of fiscal volatility shocks even without non-convexities. Another recent example is Basu and Bundick (2011), who look at the consequences of increased uncertainty in technology and demand preferences on economic activity. Our work has the advantage of directly using past behavior of observables (taxes and spending) to inform the views about how uncertainty about these might evolve going forward. Arellano, Bai and Kehoe (2010), Christiano, Motto and Rostagno (2010), and Sim, Zakrajsek and Gilchrist (2010) analyze the interaction of uncertainty shocks with financial frictions. Furthermore, on the relation of uncertainty and the

demand curves by price experimentation.

business cycle, there is important empirical work by Baker and Bloom (2011), Baker, Bloom and Davis (2011), Bachmann and Bayer (2011), and Bachmann, Elstner and Sims (2012).[3]

In this paper, we evaluate one possible incarnation of the notion of fiscal uncertainty. In particular, we estimate fiscal rules for the U.S. that allow for temporary and smooth changes in the standard deviation of their innovations while keeping the rest of the fiscal rules parameters constant. Other scenarios could be possible. First, we could allow for changes in regimes on either the standard deviation of the innovations or the rest of the fiscal rules parameters. We believe that the former would provide results similar to the ones reported in the paper and that, given the dimensionality of our problem and that we analyze temporary changes, it would be difficult to handle the latter. In the literature, Bi, Leeper and Leith (2012) study a world in which the initial level of debt is high and can be permanently consolidated through either future tax increases or spending cuts. They explore how beliefs about the distribution of future realizations of these one-sided risks affect economic activity. The main difference is that they consider permanent changes in policy, while we want to focus on temporary ones. Davig and Leeper (2011) estimate Markov-switching processes for a monetary rule and a (lump-sum) tax policy rule. Using a simple New Keynesian model, they analyze the outcomes of government spending shocks in different combinations of regimes (see also Davig and Leeper (2007)). A nice feature of that paper is that the authors are able to implement changes in monetary and fiscal regime away from the active monetary/passive fiscal policy regime. They are able to do that because they consider a small three-equation model without capital (which plays a fundamental role in our results).

As a second alternative, we could investigate fiscal rules with time-varying parameters other than the standard deviation of their innovations. Although this route is a promising research program, we view our choice as a complementary scenario and as a required step for the agenda of exploring time-varying parameters in fiscal policy rules.

Our work has connections with several literatures. First is the literature that emphasizes the role of expectations of rare, but large disasters in accounting for business cycles and asset pricing, such as in Gourio (2012). In that paper, an increase in the probability of disasters makes a bad realization more likely without making a good realization equally likely as well. As a result, an increase in the

[3] After circulating a draft of this paper, we were made aware of related work by Born and Peifer (2011), who are also concerned with increased fiscal policy uncertainty.

probability of a disaster can be thought of as a simultaneous negative shock to the expected level of productive capacity and a shock to risk. We, instead, focus on a shock that, general equilibrium effects apart, acts as a pure mean-preserving spread.

Second, our paper is related to the literature that assesses how fiscal uncertainty affects the economy through long-run growth risks. Croce, Nguyen and Schmid (2012) propose a model with endogenous growth where agents base their decisions on worst-case beliefs. They find that short-run deficit-based stabilization policy raises the amount of long-run risk, rendering such policies welfare-decreasing. In a model with recursive preferences, financial frictions, and a negative impact of higher-than-expected taxes on TFP growth, Croce et al. (2012) show how different rules of financing government liabilities through corporate taxes distorts investment decisions. We, instead, focus on time-separable preferences and we abstract from long-run risks or financial frictions. In addition, agents in our paper have complete knowledge about the probability distribution of future outcomes. We do so to demonstrate that, even with these much more restrictive assumptions, higher tax uncertainty may depress economic activity. It would be trivial, for instance, to incorporate recursive preferences into our analysis and to make our results stronger. Our choice of time-separable utility functions, though, makes our argument more transparent.

Third, there are indirect links with another strand of the literature that focuses on the (lack of) resolution of longer-term fiscal uncertainty. Davig, Leeper and Walker (2010), for example, focus on uncertainty about how unfunded liabilities for Social Security, Medicare, and Medicaid would be resolved through taxation, inflation, or reneging on promised transfers.

Finally, we also follow the tradition in economics that studies the impact of uncertainty about future prices and demand on investment decisions. One channel emphasized in the literature is that, in many partial equilibrium settings, the marginal revenue product of capital is convex in the price of output. Then, higher uncertainty increases the expected future marginal revenue and thus investment (see, among others, Abel (1983)). A second channel operates through the real options effect that arises with adjustment costs. If investment can be postponed, but it is partially or completely irreversible once put in place, waiting for the resolution of uncertainty before committing to investing has a positive call option value (see Pindyck (1988)). This is the thread revived by Bloom (2009).

The remainder of the paper is structured as follows. Section 1 estimates the tax and spending processes that form the basis for our analysis. Section 2 discusses the model and section 3 its calibration and solution. Sections 4 to 6 report the main results, additional experiments, and a number of robustness exercises. We close with some final comments. Several appendices present further details.

1 Fiscal Rules with Time-Varying Volatility

In this section, we estimate fiscal rules with time-varying volatility using taxes, government spending, debt, and output data. Later, we will rely on these estimated rules to discipline our quantitative experiments. We thus build upon a scenario in which past fiscal behavior is a useful guide to assess current behavior.

There are, at least, two alternatives to our approach. First is the direct use of agents' expectations. This will avoid the problem that the timing of uncertainty that we will estimate and the actual uncertainty that agents face might be different. Unfortunately, and to the best of our knowledge, there are no surveys that inquire about individuals' expectations with regard to future fiscal policies. Furthermore, market prices of securities are hard to exploit to back out these expectations due to the intricacies of the tax code. We cannot, therefore, rely on measures of fiscal expectations to inform our views about what constitutes a reasonable degree of time-varying volatility. A second alternative would be to estimate a fully fledged business cycle model using likelihood-based methods and to smooth out the time-varying volatility in fiscal rules. However, the sheer size of the state space in that exercise would make the strategy too challenging for practical implementation.

1.1 Data

We build a data sample of average tax rates and spending of the consolidated government sector (federal, state, and local) at quarterly frequency from 1970.Q1 to 2010.Q2. The tax data are constructed from the national accounts as in Leeper, Plante and Traum (2010). Government spending is government consumption and gross investment, also taken from the national accounts. The debt series is federal debt held by the public recorded in the St. Louis Fed's FRED database. Output data come from national accounts. See appendix A for details.

We use average tax rates rather than marginal tax rates. The latter are employed by Barro and Sahasakul (1983) and Barro and Sahasakul (1986). Since the tax code for labor and capital income taxes is progressive, we may underestimate the extent to which these taxes are distortionary. Assuming that marginal income tax rates, in terms of persistence and volatility, display characteristics similar to those of the average tax rates, we would then undermeasure the effect of fiscal volatility shocks. Unfortunately, the update of the Barro-Sahasakul measure of average marginal income tax rates provided in Barro and Redlick (2010) has two shortcomings for our purposes. First, it is available only through 2006, which excludes the recent increase in volatility. Second, it only covers labor income.

1.2 The Rules

Our fiscal rules model the evolution of four fiscal policy instruments: government spending as a share of output, $\tilde{g}_t$, and taxes on labor income, $\tau_{l,t}$, on capital income, $\tau_{k,t}$, and on personal consumption expenditures, $\tau_{c,t}$. For each instrument, we postulate the law of motion:

$$x_t - x = \rho_x (x_{t-1} - x) + \phi_{x,y} \tilde{y}_{t-1} + \phi_{x,b} \left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y} \right) + \exp(\sigma_{x,t}) \varepsilon_{x,t}, \quad \varepsilon_{x,t} \sim \mathcal{N}(0,1), \tag{1}$$

for $x \in \{\tilde{g}, \tau_l, \tau_k, \tau_c\}$, where $\tilde{g}$ is the mean government spending as a share of output and τ_x is the mean of the tax rate. Above, $\tilde{y}_{t-1}$ is lagged detrended output, b_t is public debt (with $\frac{b}{y}$ being the mean debt-to-output ratio), and y_t is output. Equation (1) allows for two feedbacks: one from the state of the business cycle ($\phi_{\tau_x,y} > 0$ and $\phi_{\tilde{g},y} < 0$) and another from the debt-to-output ratio ($\phi_{\tau_x,b} > 0$ and $\phi_{\tilde{g},b} < 0$). This structure follows Bohn (1998), who models the primary fiscal surplus as an increasing function of the debt-to-output ratio, correcting for wartime spending and cyclical fluctuations.

The novel feature of our specification is that the processes for the fiscal instruments incorporate time-varying volatility in the form of stochastic volatility. Namely, the log of the standard deviation, $\sigma_{x,t}$, of the innovation to each policy instrument is random, and not a constant, as traditionally assumed. We model $\sigma_{x,t}$ as an $AR(1)$ process:

$$\sigma_{x,t} = \left(1 - \rho_{\sigma_x}\right) \sigma_x + \rho_{\sigma_x} \sigma_{x,t-1} + \left(1 - \rho_{\sigma_x}^2\right)^{(1/2)} \eta_x u_{x,t}, \; u_{x,t} \sim \mathcal{N}(0,1). \tag{2}$$

In our formulation, two independent innovations affect the fiscal instrument x. The first innovation, $\varepsilon_{x,t}$, changes the instrument itself, while the second innovation, $u_{x,t}$, determines the spread of values for the fiscal instrument. In what follows, we will call $\varepsilon_{x,t}$ an innovation to the fiscal shock to instrument x and $\sigma_{x,t}$ a fiscal volatility shock to instrument x with innovation $u_{x,t}$.

The innovations to the fiscal shocks, $\epsilon_{x,t}$, are not the observed changes in the fiscal instruments, but the deviations of the data with respect to the historical response to the regressors in equation (1). In that way, the innovations capture not only explicit changes in legislation, such as those considered by Romer and Romer (2010), but also a wide range of fiscal actions whenever government behavior deviates from what could have been expected on average given the past value of the fiscal instruments, the stage of the business cycle, and the level of government debt. Indeed, there may be innovations even in the absence of new legislation. Examples include changes in the effective tax rate if policymakers, through legislative inaction, allow for bracket creep in inflationary times, or for changes in effective capital tax rates in episodes of booming stock markets.

The parameter σ_x fixes the average standard deviation of an innovation to the fiscal shock to instrument x, η_x is the unconditional standard deviation of the fiscal volatility shock to instrument x, and ρ_{σ_x} controls its persistence. A value of $\sigma_{\tau_k,t} > \sigma_{\tau_k}$, for example, implies that the range of likely future capital tax rates is larger than usual. Variations of $\sigma_{x,t}$ over time, in turn, will depend on η_x and ρ_{σ_x}.

We interpret fiscal volatility shocks to a fiscal instrument as capturing greater-than-usual uncertainty about the future path of that instrument. After a positive fiscal volatility shock to capital taxes, agents' perceptions about probable movements of the tax rate are more spread out in either direction. Stochastic volatility offers an intuitive modeling of such changes. Bloom (2009), Bloom, Jaimovich and Floetotto (2008), Fernández-Villaverde et al. (2011*b*), and Justiniano and Primiceri (2008) use similar specifications to characterize the time-varying volatility associated with the evolution of productivity or with the cost of servicing sovereign debt. Relative to other specifications, equation (2) is parsimonious since it introduces only two new parameters for each instrument (ρ_{σ_x} and η_x).

Table 1: Posterior Median Parameters

	Tax rate on			Government
	Labor	Consumption	Capital	Spending
ρ_x	0.99 [0.976,0.999]	0.99 [0.982,0.999]	0.97 [0.93,0.996]	0.97 [0.949,0.994]
σ_x	-6.01 [-6.29,-5.72]	-7.11 [-7.36,-6.81]	-4.96 [-5.26,-4.58]	-6.14 [-6.46,-5.54]
$\phi_{x,y}$	0.071 [0.025,0.125]	0.002 [0.001,0.011]	0.10 [0.007,0.252]	-0.009 [-0.04,0.00]
$\phi_{x,b}$	0.003 [0.00,0.007]	0.0006 [0.00,0.002]	0.004 [0.00,0.016]	-0.008 [-0.013,-0.003]
ρ_{σ_x}	0.30 [0.06,0.55]	0.63 [0.34,0.90]	0.77 [0.48,0.93]	0.93 [0.34,0.99]
η_x	0.95 [0.74,1.18]	0.60 [0.32,0.93]	0.58 [0.34,0.89]	0.18 [0.06,0.45]

Note: For each parameter, we report the posterior median and, in brackets, a 95 percent probability interval.

1.3 Estimation

We estimate equations (1) and (2) for each fiscal instrument. We set the means in equation (1) to their average values. Then, we estimate the rest of the parameters in the equations following a Bayesian approach by combining the likelihood function with flat priors and sampling from the posterior with a Markov Chain Monte Carlo (see appendix B for details). The non-linear interaction between the innovations to fiscal shocks and their volatility shocks complicates this task. We overcome this problem with the particle filter as described in Fernández-Villaverde, Guerrón-Quintana and Rubio-Ramírez (2010). To be cautious, we estimate the model assuming uncorrelated innovations. It is straightforward to consider correlation. Indeed, when we do that, the results reported below about the role of time-varying volatility would become stronger.

Table 1 reports the posterior median for the parameters along with 95 percent probability intervals. Both tax rates and government spending as a share of output are quite persistent. The posterior also provides us with overwhelming evidence that time-varying volatility is crucial; see the positive numbers in the row "η_x". Except for labor income taxes, deviations from average volatility last for some time -see the row "ρ_{σ_x}"- although that persistence is not identified as precisely as the persistence of the fiscal shocks. Evaluated at the posterior median, the half-life of the fiscal volatility shocks is 0.6 quarter for the labor tax, 1.5 quarters for the consumption tax, 2.6 quarters for the capital tax rate, and 9.6 quarters for government spending.

To gauge these numbers, let us focus on the estimates for the law of motion of capital taxes in the third column in table 1. The innovation to the capital tax rate has an average standard deviation of 0.70 percentage point ($100 \exp(-4.96)$). A one-standard-deviation fiscal volatility shock to capital taxes increases the standard deviation of the innovation to taxes to $100 \exp(-4.96 + (1 - 0.77^2)^{1/2} 0.58)$, or to 1.02 percentage points. Starting at the average tax, after a simultaneous one-standard-deviation innovation to the rate and its fiscal volatility shock, the tax rate jumps by about 1 percentage point (rather than by 0.70 percentage point, as would be the case without the fiscal volatility shock). The half-life of the change to the tax rate is 20 quarters ($\rho_{\tau_k} = 0.97$). As a result, the persistence in the fiscal shock propagates the impact of a fiscal volatility shock.

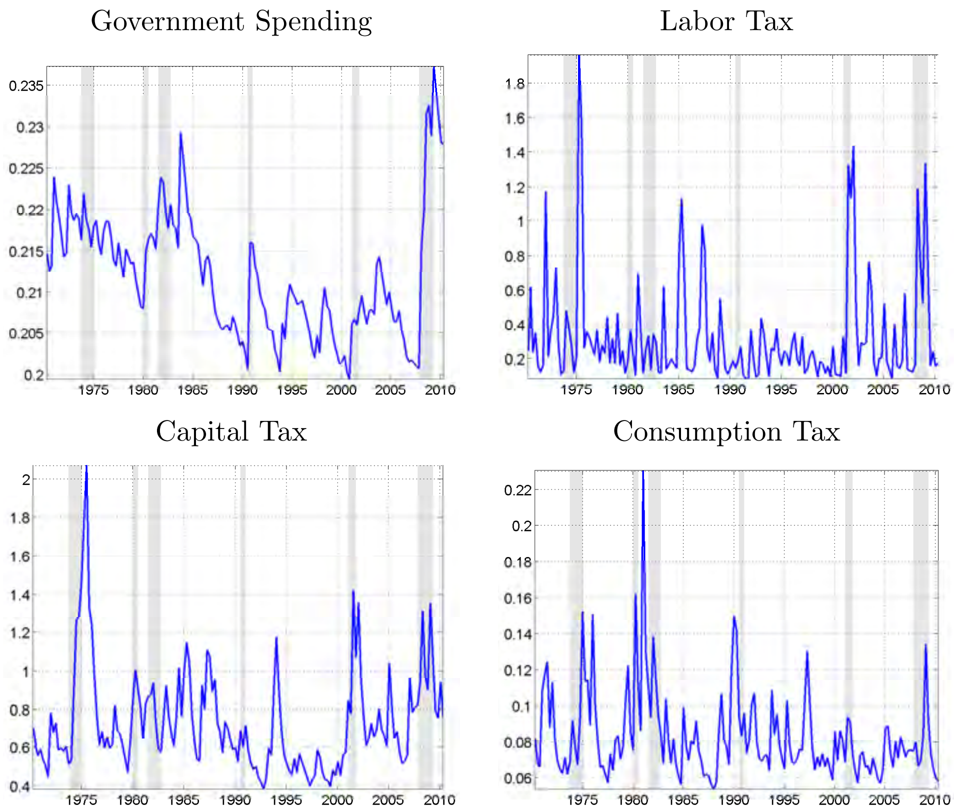

Figure 1: Smoothed fiscal volatility shocks to each instrument, $\sigma_{x,t}$

Note: Volatilities expressed in percentage points.

Conditional on our posterior medians, figure 1 displays the evolution of the (smoothed) fiscal volatility shocks, $100 \exp \sigma_{x,t}$, for each of the four fiscal instruments. The numbers on the y-axis of the figure are percentage points of the respective fiscal instrument. The figure shows by how many percentage points a one-standard-deviation fiscal shock would have moved that instrument at different points in time. For example, we estimate that a one-standard-deviation fiscal shock would have moved the capital tax rate by anywhere between more than two percentage points (in 1976) or just 0.4 percentage point (in 1993). Periods of fiscal change coincided with times of high fiscal policy uncertainty as estimated by our procedure. For instance, the policy changes during the Reagan presidency appear in our estimation as a sustained increase in the volatility of government spending and capital and consumption taxes. Similarly, the fiscal overhauls by Presidents Bush senior and Clinton contributed to the increase in the volatility of all three taxes (both overhauls called for deficit cuts through a combination of tax increases and restraints on spending). These latter bursts of volatility happened during expansions. Nevertheless, our estimates reveal that fiscal volatility shocks to all instruments typically were higher during recessions (for instance, 1981-1982). Also, the fiscal volatility shocks during the latest recession is commensurate with the one that prevailed in the early 1980s. In sum, fiscal policy in the U.S. displays quantitatively significant time-varying volatility.

1.4 Comparison with Alternative Indexes of Policy Uncertainty

Contemporaneously with us, Baker, Bloom and Davis (2011) have built an index of policy-related uncertainty. Their index weights several components that reflect the frequency of news media references to economic policy uncertainty, the number of federal tax code provisions set to expire in future years, and the extent of forecaster disagreement over future inflation and federal government purchases. We can compare our measure of fiscal policy uncertainty with their index. Remarkably, the correlation with this index is 0.44 for our smoothed series of the volatility of capital taxes, 0.31 for labor taxes, and 0.67 for government expenditures. All correlations are significant at a 1 percent level. We find these positive correlations between two measures generated using such different approaches rather reassuring and constituting corroborating independent evidence. These results make us believe that our approach captures well the movements in fiscal policy uncertainty that agents face in the U.S. economy.

In appendix B, we present evidence of the robustness of our estimates with respect to the endogeneity of fiscal instruments and we compare our fiscal rules with alternatives proposed in the literature.

2 Model

Motivated by our findings, we build a business cycle model to investigate how our estimated processes for fiscal volatility affect economic activity. We adopt a standard New Keynesian model in the spirit of Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007), extending it to allow for fiscal policy. This model has been shown to fit many dimensions of U.S. business cycle fluctuations. In addition, it forms the basis for much applied policy analysis, particularly in central banks. It is, therefore, a natural environment for our goal.

2.1 Household

In the following, capital letters refer to nominal variables and small letters to real variables. Letters without a time subscript indicate steady-state values. There is a representative household that consists of a unit mass of members who supply differentiated types of labor $l_{j,t}$ and whose preferences are separable in consumption, c_t, and labor:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t d_t \left\{ \frac{(c_t - b_h c_{t-1})^{1-\omega}}{1-\omega} - \psi \int_0^1 \frac{l_{j,t}^{1+\vartheta}}{1+\vartheta} dj \right\}.$$

Here, $\mathbb{E}_0$ is the conditional expectation operator, β is the discount factor, ϑ is the inverse of the Frisch elasticity of labor supply, and b_h is the habit formation parameter.

Preferences are subject to an intertemporal shock d_t that follows:

$$\log d_t = \rho_d \log d_{t-1} + \sigma_d \varepsilon_{dt},\ \varepsilon_{dt} \sim \mathcal{N}(0,1).$$

These preference shocks provide flexibility for the equilibrium dynamics of the model to capture fluctuations in interest rates not accounted for by variations in consumption.

The household can invest in capital, i_t, and hold government bonds, B_t, that pay a nominal gross interest rate of R_t in period $t+1$. The real value of the bonds at the end of the period is $b_t = B_t/P_t$, where P_t is the price level. The real value at the start of period t (before coupon payments) of bonds bought last period is $b_{t-1}\frac{R_{t-1}}{\Pi_t}$, where $\Pi_t = \frac{P_t}{P_{t-1}}$ is inflation between $t-1$ and t.

The household pays consumption taxes $\tau_{c,t}$, labor income taxes $\tau_{l,t}$, and capital income taxes $\tau_{k,t}$. In addition, it pays lump-sum taxes Ω_t. The capital tax is levied on capital income, which is given by the product of the amount of capital owned by the household k_{t-1}, the rate of utilization of capital u_t, and the rental rate of capital $r_{k,t}$. There is a depreciation allowance for the book value of capital, k_{t-1}^b. Finally, the household receives the profits of the firms in the economy F_t. Hence, the household's budget constraint is given by:

$$\begin{aligned} &(1+\tau_{c,t})c_t + i_t + b_t + \Omega_t + \textstyle\int_0^1 AC_{j,t}^w dj \\ = (1-\tau_{l,t}) &\textstyle\int_0^1 w_{j,t} l_{j,t} dj + (1-\tau_{k,t})\, r_{k,t} u_t k_{t-1} + \tau_{k,t}\delta k_{t-1}^b + b_{t-1}\frac{R_{t-1}}{\Pi_t} + F_t. \end{aligned} \tag{3}$$

The function:

$$AC_{j,t}^w = \frac{\phi_w}{2}\left(\frac{w_{j,t}}{w_{j,t-1}} - 1\right)^2 y_t,$$

stands in for real wage adjustment costs for labor type j, where $w_{j,t}$ is the real wage paid for labor of type j. Aggregate output y_t appears in the adjustment cost function to scale it. We prefer a Rotemberg-style wage setting mechanism to a Calvo setting because it is more transparent when thinking about the effects of fiscal volatility shocks. In a Calvo world, we would have an endogenous reaction of the wage (and price) dispersion to changes in volatility that would complicate the analysis without delivering additional insight.[4]

The different types of labor $l_{j,t}$ are aggregated by a packer into homogeneous labor l_t with the production function:

$$l_t = \left(\int_0^1 l_{j,t}^{\frac{\epsilon_w - 1}{\epsilon_w}} dj\right)^{\frac{\epsilon_w}{\epsilon_w - 1}},$$

where ϵ_w is the elasticity of substitution among types. The homogeneous labor is rented to intermediate good producers at real wage w_t. The labor packer is perfectly competitive and takes the wages $w_{j,t}$ and w_t as given.

The law of motion of capital is $k_t = (1-\delta(u_t))\, k_{t-1} + \left(1 - S\left[\frac{i_t}{i_{t-1}}\right]\right) i_t$ where $\delta(u_t)$ is the depreciation rate that depends on the utilization rate according to

$$\delta(u_t) = \delta + \Phi_1(u_t - 1) + \frac{1}{2}\Phi_2(u_t - 1)^2. \tag{4}$$

Here, Φ_1 and Φ_2 are strictly positive. We assume a quadratic adjustment cost $S\left[\frac{i_t}{i_{t-1}}\right] = \frac{\kappa}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2$,

[4] We will solve the model non-linearly. Hence, Rotemberg and Calvo settings are not equivalent, as would be the case in a linearization without inflation in the steady state. In any case, our choice turns out not to be consequential. We also computed the model with Calvo stickiness and we obtained very similar results.

which implies $S(1) = S'(1) = 0$ and $S''(1) = \kappa$.

To keep the model manageable, our representation of the U.S. tax system is stylized. However, it is important to incorporate the fact that, in the U.S., depreciation allowances are based on the book value of capital and a fixed accounting depreciation rate rather than on the replacement cost and economic depreciation (we consider adjustment costs of investment and a variable depreciation rate depending on the utilization rate). Hence, the value of the capital stock employed in production differs from the book value of capital used to compute tax depreciation allowances.[5]

To approximate the depreciation allowances, we assume a geometric depreciation schedule, under which in each period a share δ of the remaining book value of capital is tax-deductible. For simplicity, this parameter is the same as the intercept in equation (4). Thus, the depreciation allowance in period t is given by $\delta k_{t-1}^b \tau_{k,t}$, where k_t^b is the book value of the capital stock that evolves according to $k_t^b = (1-\delta)k_{t-1}^b + i_t$.

2.2 Firms

There is a competitive final good producer that aggregates the continuum of intermediate goods:

$$y_t = \left(\int_0^1 y_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{5}$$

where ε is the elasticity of substitution.

Each of the intermediate goods is produced by a monopolistically competitive firm. The production technology is Cobb-Douglas $y_{it} = A_t k_{it}^{\alpha} l_{it}^{1-\alpha}$, where k_{it} and l_{it} are the capital and homogeneous labor input rented by the firm. A_t is neutral productivity that follows:

$$\log A_t = \rho_A \log A_{t-1} + \sigma_A \varepsilon_{At},\ \varepsilon_{At} \sim \mathcal{N}(0,1) \text{ and } \rho_A \in [0,1).$$

Intermediate good producers produce the quantity demanded of the good by renting labor and capital at prices w_t and $r_{k,t}$. Cost minimization implies that, in equilibrium, all intermediate good

[5] The U.S. tax system incorporates some exceptions. In particular, at the time that firms sell capital goods to other firms, any actual capital loss is realized (reflected in the selling price). As a result, when ownership of capital goods changes hands, firms can lock in the economic depreciation rate. Since in our model all capital is owned by the representative household, we abstract from this margin.

producers have the same capital-to-labor ratio and the same marginal cost:

$$mc_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\frac{w_t^{1-\alpha}r_{k,t}^{\alpha}}{A_t}.$$

The intermediate good producers are subject to nominal rigidities. Given the demand function, the monopolistic intermediate good producers maximize profits by setting prices subject to adjustment costs as in Rotemberg (1982) (expressed in terms of deviations with respect to the inflation target Π of the monetary authority). Thus, firms solve:

$$\max_{P_{i,t+s}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_t}\left(\frac{P_{i,t+s}}{P_{t+s}}y_{i,t+s} - mc_{t+s}y_{i,t+s} - AC_{i,t+s}^{p}\right)$$
$$\text{s.t. } y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon} y_t,$$
$$AC_{i,t}^{p} = \frac{\phi_p}{2}\left(\frac{P_{i,t}}{P_{i,t-1}} - \Pi\right)^2 y_{i,t}$$

where they discount future cash flows using the pricing kernel of the economy, $\beta^s \frac{\lambda_{t+s}}{\lambda_t}$.
In a symmetric equilibrium, and after some algebra, the previous optimization problem implies an expanded Phillips curve:

$$0 = \left[(1-\varepsilon) + \varepsilon mc_t - \phi_p \Pi_t (\Pi_t - \Pi) + \frac{\varepsilon\phi_p}{2}(\Pi_t - \Pi)^2\right] + \phi_p\, \beta\mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t}\Pi_{t+1}(\Pi_{t+1} - \Pi)\frac{y_{t+1}}{y_t} \quad (6)$$

2.3 Government

The model is closed by a description of the monetary and fiscal authorities. The monetary authority sets the nominal interest rate according to a Taylor rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{1-\phi_R}\left(\frac{\Pi_t}{\Pi}\right)^{(1-\phi_R)\gamma_\Pi}\left(\frac{y_t}{y}\right)^{(1-\phi_R)\gamma_y} e^{\sigma_m \xi_t}.$$

The parameter $\phi_R \in [0,1)$ generates interest-rate smoothing. The parameters $\gamma_\Pi > 0$ and $\gamma_y \geq 0$ control the responses to deviations of inflation from target Π and of output from its steady-state value y. R marks the steady-state nominal interest rate. The monetary policy shock, ξ_t, follows a

$\mathcal{N}(0,1)$ process. As regards the fiscal authority, its budget constraint is given by:

$$b_t = \quad b_{t-1}\frac{R_{t-1}}{\Pi_t} + g_t - \Big(c_t\tau_{c,t} + w_t l_t \tau_{l,t} + r_{k,t}u_t k_{t-1}\tau_{k,t} - \delta k^b_{t-1}\tau_{k,t} + \Omega_t\Big).$$

where g_t is government spending. Keeping with the majority of the literature, g_t is pure waste.

To finance spending, the fiscal authority levies taxes on consumption and on labor and capital income, according to the fiscal rules described in equations (1) and (2). Lump-sum taxes stabilize the debt-to-output ratio. More precisely, we impose a passive fiscal regime as defined by Leeper (1991): $\Omega_t = \Omega + \phi_{\Omega,b}\,(b_{t-1} - b)$, where $\phi_{\Omega,b} > 0$ and just large enough to ensure a stationary debt.[6] In appendix C, we show the first-order conditions of the household, firms, and the aggregate market clearing conditions of the model. Also, the definition of equilibrium for this economy is standard and, thus, we skip it.

3 Solution and Calibration

We solve the model by a third-order perturbation around its steady state. Perturbation is, in practice, the only method that can compute a model with as many state variables as ours in any reasonable amount of time. A third-order perturbation is important because, as shown in Fernández-Villaverde, Guerrón-Quintana and Rubio-Ramírez (2010), innovations to volatility shocks only appear by themselves in the third-order terms. Our non-linear solution implies moments of the ergodic distribution of endogenous variables that are different from the ones implied by linearization. We will use these moments generated by the non-linear solution to calibrate our model. Once we solve and calibrate the economy, we compute moments and IRFs of several endogenous variables.

Before proceeding to the calibration, we fix several parameters to conventional values. We are dealing with a large model that would make a more targeted calibration onerous. With respect to preferences, we set the risk aversion parameter to $\omega = 2$.[7] We set $\vartheta = 2$, implying a Frisch elasticity

[6] Because of the debt-to-output ratio feedback in the fiscal rules in equation (1), we could assume that $\phi_{\Omega,b} = 0$. However, later we will have, as sensitivity analysis, cases where the debt-to-output ratio feedback is shut down. Hence, a positive $\phi_{\Omega,b}$ ensures that we stay within the passive fiscal/active monetary regime across all our exercises.

[7] This value is within the range entertained in the literature. Smets and Wouters (2007) estimate this parameter to be 1.4. The literatures on volatility shocks, for example, Fernández-Villaverde et al. (2011*b*), and on rare disasters, for example, Barro (2009), choose values around 4. In any case, quantitatively, the transmission of fiscal volatility shocks is hardly affected by the value for ω. Corresponding IRFs are available upon request.

Table 2: Summary of Calibration

Preferences		*Rigidities*		*Policy*		*Technology*		*Shocks*	
β	0.9945	ϕ_w	4889	Π	1.0045	α	0.36	ρ_A	0.95
ω	2	ϵ_w	21	ϕ_R	0.6	δ	0.011	σ_A	0.001
ϑ	2	ϕ_p	236.10	γ_Π	1.25	Φ_1	0.0165	ρ_d	0.18
ψ	75.66	ϵ	21	γ_y	0.25	Φ_2	0.0001	σ_d	0.078
b_h	0.75			Ω	$-4.3e-2$	κ	3	σ_m	0.0001
				$\phi_{\Omega,b}$	0.0005				
				b	2.64				

of labor supply of 0.5. This number, in line with the recommendation of Chetty et al. (2011), is appropriate given that our model does not distinguish between an intensive and extensive margin of employment (in fact, a lower elastic labor supply would increase the effect that fiscal volatility shocks have on economic activity). Habit formation is fixed to the value estimated in Christiano, Eichenbaum and Evans (2005).

With respect to nominal rigidities, we set the wage stickiness parameter, ϕ_w, to a value that would replicate, in a linearized setup, the slope of the wage Phillips curve derived using Calvo stickiness with an average duration of wages of one year. The parameter ϕ_p renders the slope of the Phillips curve in our model consistent with the slope of a Calvo-type Phillips curve without strategic complementarities when prices last for a year on average. Similar values are used in Galí and Gertler (1999).

For technology, we fix the elasticity of demand to $\epsilon = 21$ as in Altig et al. (2011).[8] By symmetry, we also set $\epsilon_w = 21$. The cost of utilization and adjusting investment, $\Phi_1 = 0.0165$, comes from the first-order condition for capacity utilization. We set α to the standard value of 0.36.

For policy, the values for $\gamma_\Pi = 1.25$ and $\gamma_y = 0.25$ follow Boivin (2006) and Fernández-Villaverde, Guerrón-Quintana and Rubio-Ramírez (2010). Our choice of size of the response of lump-sum taxes to the debt level $\phi_{\Omega,b}$ has negligible quantitative effects. We set the steady-state value of lump-sum taxes to Ω to $-4.3e-2$ to satisfy the government's budget constraint. Finally, we chose 0.95 and

[8] The literature entertains a wide range of values for ϵ, which is often not precisely identified; see the discussion in Altig et al. (2011). As examples: $\epsilon = 6$ in Christiano, Eichenbaum and Evans (2005), $\epsilon = 11$ in Boivin and Giannoni (2006)), or $\epsilon = 101$ in Altig et al. (2005). Our value of $\epsilon = 21$ is also roughly what Kuester (2010) has estimated ($\epsilon = 22.7$). We report robustness checks in appendix F. Note also that with a reasonable calibration of Rotemberg price adjustment costs, as used here, it is nearly a zero probability event that firms price below marginal cost even with low average mark-ups. We have corroborated this in simulations of our model.

Table 3: Second Moments in the Model and the Data

	Model			Data		
	std	AR(1)	Cor(x,y)	std	AR(1)	Cor(x,y)
Output, consumption and investment						
y_t	1.59	0.62	1	1.57	0.87	1
c_t	1.22	0.67	0.53	1.28	0.89	0.87
i_t	6.52	0.93	0.27	7.69	0.83	0.91
Wages, labor and capacity utilization						
w_t	0.10	0.95	0.45	0.88	0.76	0.10
h_t	1.39	0.52	0.94	1.93	0.92	0.87
u_t	2.21	0.68	0.89	3.24	0.87	0.86
Nominal variables						
R_t	3.85	0.85	0.18	3.67	0.93	0.18
Π_t	3.83	0.68	0.36	2.47	0.98	-0.004

Note: Data for the period 1970.Q1 - 2010.Q3 are taken from the St. Louis Fed's FRED database (mnemonics GDPC1 for output, GDPIC96 for investment, PCECC96 for consumption, FEDFUNDS for nominal interest rates, GDPDEF for inflation, HCOMPBS for nominal wages, HOABS for hours worked, and TCU for capacity utilization). All data are in logs, HP-filtered, and multiplied by 100 to express them in percentage terms. Inflation and interest rate are annualized.

0.18 for the persistence of the productivity and the intertemporal shocks, both standard values in the literature (King and Rebelo (1999) and Smets and Wouters (2007)).

The rest of the parameters are calibrated using the ergodic distribution and quarterly data from the U.S. economy. The time discount factor, β, targets an annualized average real rate of interest of 2 percent. The parameters ψ and Π target an average share of hours worked of 1/3 and an average annualized inflation rate of 2 percent. Finally, we set the following parameters $\{\Phi_2, \kappa, \delta, \phi_R, \sigma_A, \sigma_d, \sigma_m, b\}$ to match the standard deviations of output, consumption, investment, capacity utilization, inflation, and interest rates, the average ratio of investment to output, and the average government debt-to-output ratio (40 percent of annual GDP) found in the data (table 3 provides details on data sources). Table 2 summarizes our parameter values except for those governing the processes for the fiscal instruments, which we set equal to the posterior median values reported in table 1. Hence, our calibration allows for feedback in the fiscal rules.

As a preliminary diagnosis of the model, table 3 presents summary information for first and second moments of selected endogenous variables and compares them with the data. The model does a fairly good job at matching those moments we do not use for calibration.

4 Results

Heightened fiscal policy uncertainty can be parsimoniously captured by a simultaneous increase in the volatilities of the innovations to all fiscal instruments. That is, we model a spike in fiscal policy uncertainty as positive innovations $u_{x,t}$ for all x. Here we confront an important choice: the magnitude of the increase. While a one-standard-deviation increase may seem the obvious choice, the smoothed volatilities in figure 1 suggest that this may underestimate the degree of fiscal policy uncertainty that the U.S. economy faces. Thus, we define a fiscal volatility shock as a simultaneous increase of two standard deviations in the innovations to the volatility of the four fiscal policy instruments. We are interested here in analyzing the effects of an exceptional degree of fiscal uncertainty that marks a once-in-a-decade event. At the same time, this event is by no means extreme. Rather, after Bloom (2009), the size of volatility shocks that we look at is customary.

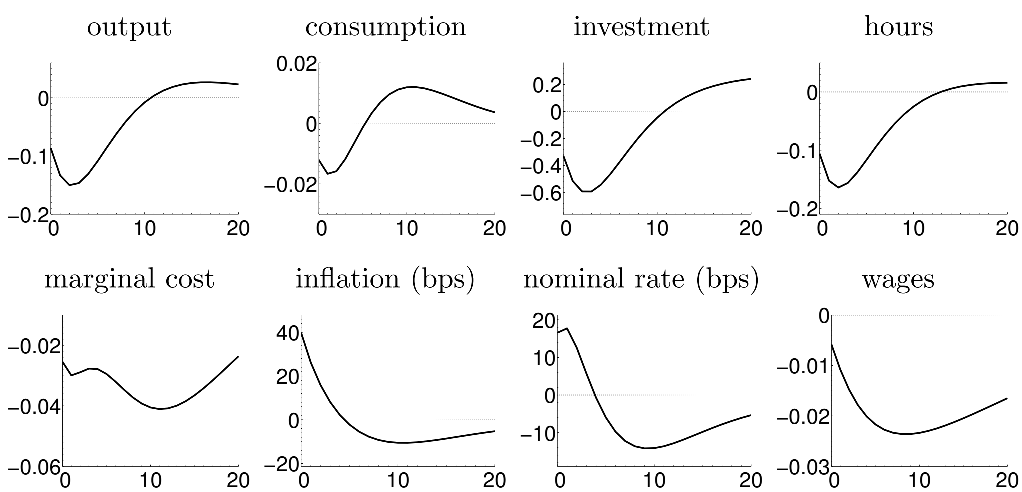

Figure 2: Impulse response to a fiscal volatility shock

Note: The solid black lines are the IRFs to a fiscal volatility shock. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

The first result documented by the IRFs in figure 2 is that fiscal volatility shocks cause a prolonged contraction in economic activity: output, consumption, investment, hours, and real wages fall, while inflation rises. Output reaches its lowest point about three quarters after the shock. Most of the decline comes from a drop in investment, which falls around four times more in percentage terms. The more modest decline in consumption illustrates households' desire for smoothing. The second result is the "stagflation" -lower output amid higher inflation- caused by higher fiscal volatility.

Note that the responses in figure 2 happen in the absence of a fall today in government spending as a share of output or an increase in taxes. To the contrary, the endogenous feedback of the fiscal rules with respect to the state of the economy will reduce in expectation the tax rates and increase government spending currently and in future periods, which stabilizes output. We will return to this issue in section 5.

The transmission mechanism for fiscal volatility shocks is an increase in markups. This rise in markups is best illustrated by the first two panels of the bottom row. The first panel shows that real marginal costs fall after a fiscal volatility shock. With Rotemberg pricing, the gross markup equals the inverse of real marginal costs. A fall in marginal costs thus means that markups are endogenously rising. In the model, markups work like a distortionary wedge. In particular, higher markups reduce labor supply because they resemble a higher tax on consumption. This generates positive co-movement between the consumption and output that was difficult to deliver in Bloom (2009). The second panel on the bottom row illustrates that, despite lower marginal costs, firms raise their prices, so that inflation increases and markups increase even more.

4.1 Accounting for the Rise in Markups

Markups rise in the model because of two channels: an aggregate demand channel and an upward pricing bias channel, both related to nominal rigidities in price setting.

The first channel starts with a fall in aggregate demand. Faced with higher uncertainty, households want to consume less and save more. At the same time, saving in capital comes with riskier returns. In the absence of nominal rigidities, the effect of the scramble to save would be small. With rigidities, however, a desire to increase saving reduces demand. Prices do not fully accommodate the lower demand, so that markups rise and aggregate output falls. However, while this channel is important, by itself it would induce a drop in inflation, whereas inflation increases in figure 3.

The increase in inflation in the IRFs (and a further fall in output) comes from a second channel: the upward pricing bias channel. The best way to understand this channel is to look at the period profits of intermediate goods firms (to simplify the exposition, we abstract for a moment from price adjustment costs and we focus on the steady state):

$$\left(\frac{P_j}{P}\right)^{1-\epsilon} y - mc\left(\frac{P_j}{P}\right)^{-\epsilon} y,$$

where $mc = (\epsilon - 1)/\epsilon$. Marginal profits, thus, are strictly convex in the relative price of the firm's product. Figure 3 illustrates this for three different levels of the demand elasticity (implying a 10 percent, 5 percent, and 2.5 percent markup, respectively). Figure 3 also shows that, given the Dixit-Stiglitz demand function, it is more costly for the firm to set too low a price relative to its competitors, rather than setting it too high. This effect is the stronger the more elastic the demand.

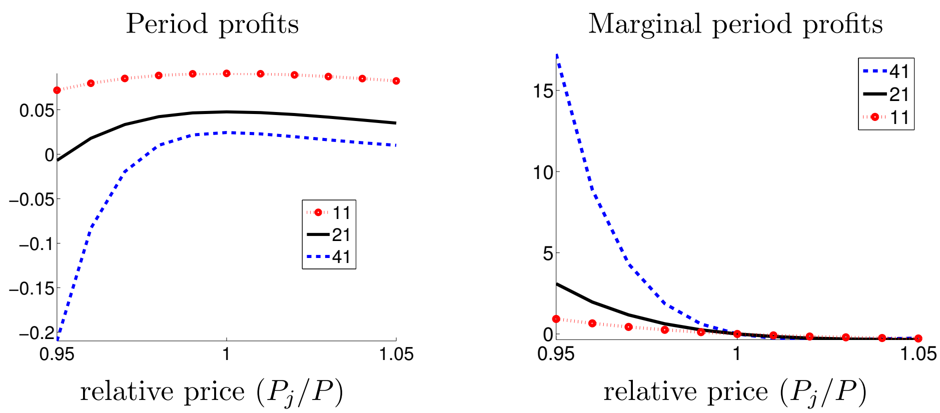

Figure 3: Properties of the profit function

Note: Profit function and marginal profits (relative to output) for different demand elasticities as functions of the relative price. Dotted red line: $\epsilon = 11$ (implying a markup of 10 percent), solid black: $\epsilon = 21$ (implying a markup of 5 percent), dashed blue: $\epsilon = 41$ (implying a markup of 2.5 percent).

The constraint for the firm is that the price that it sets in the current period determines how costly it will be to change to a new price in the next period. When uncertainty increases, firms will bias their current price toward the high relative price region. If, tomorrow, a large shock pushes the firm to raise its price, it will be less costly in terms of adjustment costs to get closer to that price if today's price was already high. If a large shock pushes the firm to lower its price, it will not be very costly in terms of profit loss to keep a high relative price because of the shape of the profit function. A similar mechanism would also work under Calvo pricing. Appendix D elaborates on these arguments.[9]

[9] Our argument is close to that in Kimball (1989). While Kimball emphasizes a precommitment in prices and the effect of the uncertainty level, we focus on the presence of adjustment costs to prices and the effect of changes in uncertainty. Thus, while his mechanism works through convex marginal cost, ours works through the shape of the demand function (in our model, we have constant returns to scale at the firm level and, hence, marginal costs are constant given input prices). Our result also resembles equation (10) in Ball and Romer (1990), although again our mechanism is slightly different since the term W_{211} in their equation is zero in our model.

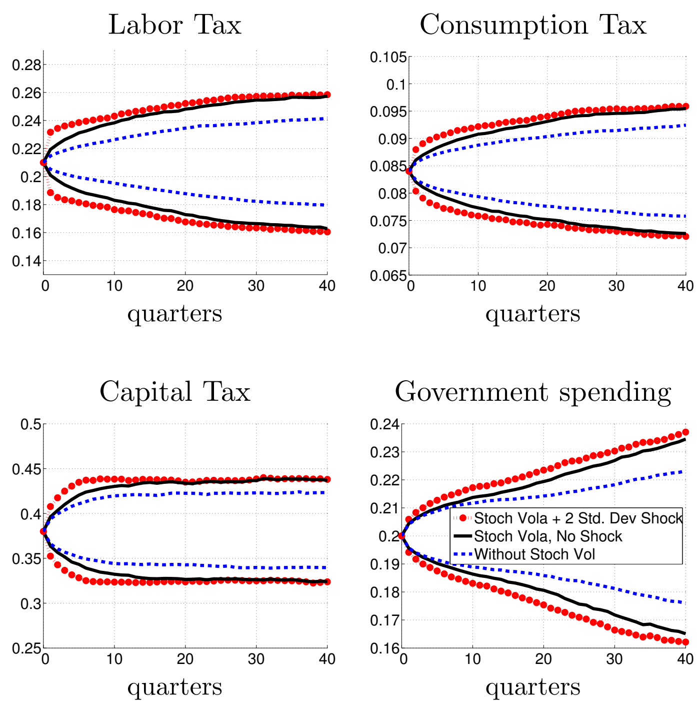

Figure 4: Dispersion of future fiscal instruments

Note: 95 percent confidence intervals for forecasts made at period 0 for fiscal instruments up to 40 quarters ahead. Solid black line: fiscal volatility shock innovations are set to zero in period 1. Red dots: a two-standard-deviation fiscal volatility shock innovation to all instruments in period 1. Dashed blue line: fiscal volatility shocks when $\eta_x = 0$ for all instruments.

A fiscal volatility shock increases the dispersion of likely future aggregate demand and marginal costs and, hence, the probable range for the optimal price tomorrow. This can be seen in the future paths of fiscal instruments displayed in figure 4, where we show forecast confidence intervals (see also appendix B for additional confidence bands). Consider, for instance, the increase in the dispersion of the capital income tax, shown in the lower left panel of figure 3. This will raise the dispersion of marginal costs through its effects on the rental rate of capital (both directly, through the utilization decision, and indirectly, through investment). Firms respond to the fiscal volatility shock by biasing their pricing decision upward even more than when fiscal volatility is at its average value. Realized marginal costs fall because, at a higher price and lower production, firms rent less capital and this lowers the rental rates. Wages, since they are subject to real rigidities, barely move and the labor market clears through a reduction in hours worked. This same line of reasoning will help us to understand, below, why the tax on capital income is the main driving force of the effects of fiscal volatility shocks.

4.2 How Important Is the Upward Pricing Bias?

We have described two channels behind the fall in output: an aggregate demand channel and an upward pricing bias channel. We seek now to disentangle the importance of each of them.
Toward that end, figure 5 compares the IRFs in the baseline economy in section 2 (solid black line) and in a counterfactual one (dashed blue line). All the equilibrium conditions of the counterfactual economy are the same as in the baseline case except that now inflation evolves according to the linearized version of equation (6). That is, the Phillips curve now is given by:

$$\Pi_t - \Pi = \beta \mathbb{E}_t \left(\Pi_{t+1} - \Pi \right) + \frac{\epsilon}{\phi_p \Pi} \left(mc_t - mc \right), \tag{7}$$

where $mc = (\epsilon - 1)/\epsilon$. Equation (7) imposes that inflation is governed only by a linear function of marginal costs. We interpret this system as one where the upward pricing bias is absent because we suppress the nonlinearities that are at the core of the bias.[10] Comparing the blue dashed line and

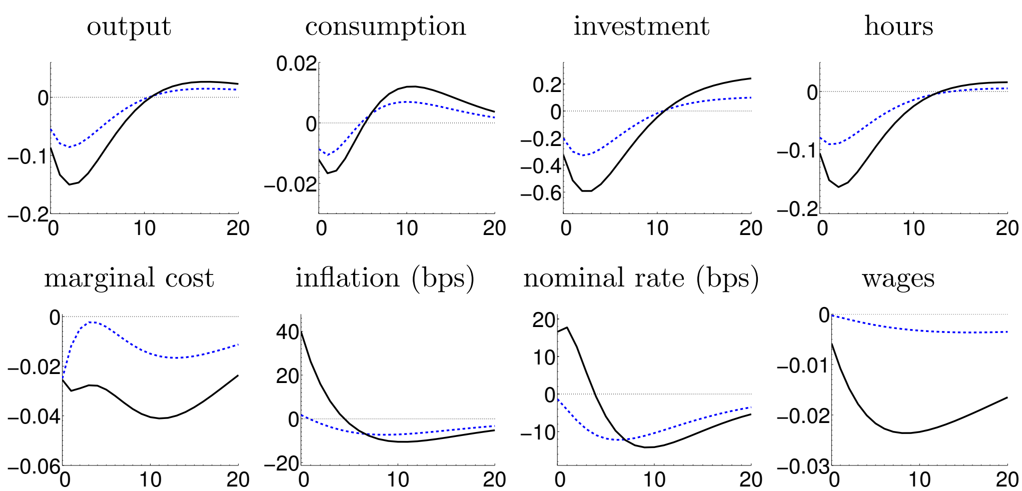

Figure 5: The role of precautionary price setting

Note: The solid black lines are the IRFs to a fiscal volatility shock in the baseline economy. The blue dashed lines are the IRFs in the counterfactual economy. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

the black solid line indicates that both channels are of roughly equal importance for explaining the impact of fiscal volatility shocks on aggregate activity. Namely, output falls about twice as much when, in addition to the demand channel, the upward-pricing bias is also present.

[10] We still solve the model through a third-order expansion. This means that the demand channel of fiscal volatility shocks is still present since (7) implies that firms set prices in response to current and expected marginal cost.

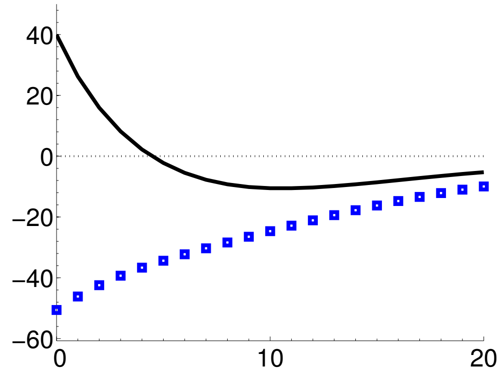

Figure 6: The inflation gap

Note: IRFs of inflation to a fiscal volatility shock. The solid black line shows the IRF in the baseline economy. The blue squares show the counterfactual response of inflation. Inflation rates are in annualized basis points.

An alternative way of communicating the importance of the upward pricing bias is to define and quantify an "inflation gap." We ask: how would inflation have evolved absent the upward pricing bias? To do so, we compute first the evolution of the economy according to the baseline case and we plot, in figure 6 and with a black line, the IRF of inflation to a fiscal volatility shock. Then, we take the evolution of marginal costs period by period from the baseline economy and we feed it into equation (7) to generate a counterfactual path for inflation.[11] The result is shown by the blue squares in figure 6. The measured inflation gap is the difference between the black line and the blue squares. The gap is large, around 90 basis points, and it closes only slowly over time. Absent the upward pricing bias, inflation would fall after a fiscal volatility shock. But since firms bias their pricing decision toward higher prices, actual inflation rises.

4.3 Some Empirical Implications

The discussion in this section has powerful empirical implications because it demonstrates that fiscal volatility shocks have different effects on the dynamics of key variables than supply and demand shocks. Furthermore, fiscal volatility shocks can generate correlations among variables that would otherwise be puzzling.

The combination of falling output, falling real marginal cost, and increasing inflation after a fiscal

[11] Note the difference with the exercise underlying figure 5: now we use equation (7) only to back out a measure of inflation given the path of mc_t in the baseline economy. This counterfactual inflation rate here does not feed back into the economy; that is, we abstract from the general equilibrium effects of altering the price setting. In figure 5, instead, equation (7) is part of the equilibrium conditions of the counterfactual economy and hence it feeds back into the dynamics of the economy.

volatility shock would be hard to interpret as a negative demand shock (which would deliver falling output and real marginal cost but also less inflation) or a negative supply shock (which would mean falling output and higher inflation but an increasing real marginal cost). Fiscal volatility shocks are, thus, potentially important forces while reading the data. For instance, the channels we have discussed may partially account for the recent experience of the U.S., where a large negative output gap was not accompanied by a steep fall in inflation. If fiscal volatility shocks were large during this period, these are precisely the observations that our model would predict: falling output and rising inflation.[12]

At the same time, in our model, a fiscal volatility shock affects the economy in a way that, at first glance, would look similar to the effect of an exogenous positive shock to price markups: there is a fall in output and hours worked and an increase in inflation. However, there is a key difference: the response of capital utilization. While after a fiscal volatility shock capital utilization drops at impact, it increases after a positive shock to the price markup. This difference is relevant because Smets and Wouters (2007), without using capital utilization data, found markup shocks to be important drivers of inflation and business cycles dynamics. The policy implications of this distinction are also relevant. Contrary to the case with exogenous markups shocks, we show in section 6.2 that in our model fiscal volatility shocks do not create a trade-off between stabilizing output and inflation. The reason is that the response of markups to fiscal volatility shocks strongly depends on monetary policy.

4.4 Fiscal Volatility Shocks versus a Monetary Policy Shock

How big are the effects of fiscal volatility shocks in comparison with other shocks that the literature has emphasized? A simple comparison is to plot the IRFs in our model to a fiscal volatility shock together with the IRFs from other shocks as computed by standard VARs. Note that we are just using that second set of IRFs as a yardstick, and hence, whether or not or the model satisfies the identifying restrictions behind them is somewhat irrelevant.[13] Similarly, we could easily compare

[12] This is, of course, without denying the role of many other shocks that have hit the U.S. economy over the last few years. This notwithstanding, fiscal volatility shocks may help us to reconcile recent data and theory.

[13] We thank Jesper Linde for kindly providing the code to replicate their results. It would be straightforward to rewrite our model such that the identifying timing assumptions were satisfied.

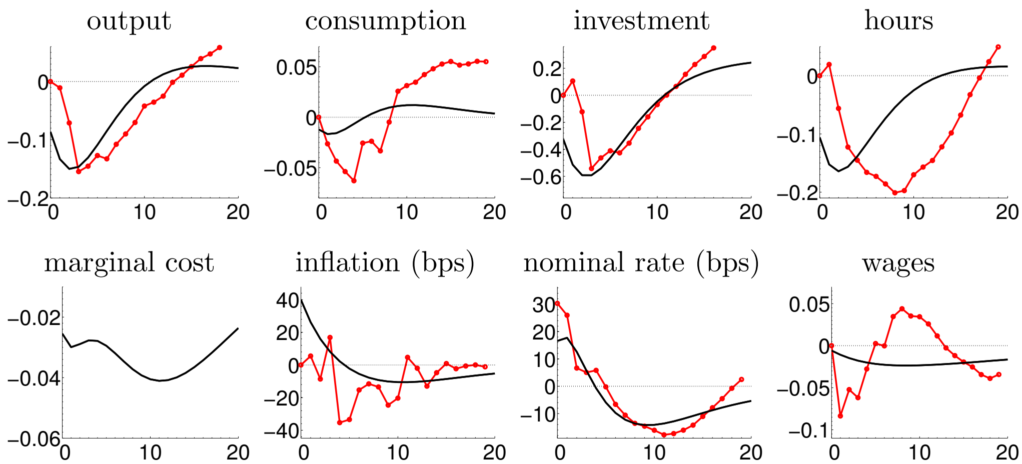

Figure 7: Fiscal volatility shock vs. 30 bps monetary shock

Note: The solid black lines are the IRFs to a fiscal volatility shock. The dashed red lines are the IRFs to a 30-basis-point shock to the annualized nominal interest rate from Altig et al. (2011). The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

the IRFs to a fiscal volatility shock with the IRFs to a monetary shock, both delivered by the model. However, this approach would suffer from the problem that we are comparing two objects created by the model and not bringing any new independent information as we do by employing the IRFs from a VAR.

Figure 7 compares, then, the effects of a fiscal volatility shock in our model and the IRFs to a 30-basis-point (annualized) increase in the nominal interest rate (dotted red lines) implied by Altig et al. (2011)'s VAR of the U.S. economy. We pick a 30-basis-point increase in the federal funds rate because it corresponds to a one-standard-deviation contractionary monetary innovation as typically identified in empirical studies. From this comparison, we obtain the information that fiscal volatility shocks induce contractions that are the same size as those that the empirical literature associates with a typical contractionary monetary shock. And to reiterate a previous point, the response of inflation is different: it falls after a monetary shock but rises in the wake of a fiscal volatility shock.[14]

[14] An alternative comparison is as follows. Hamilton (2008) and Hamilton and Wu (2010) estimate that a purchase of $300 billion in long-term securities such as the one undertaken by the Fed between March and October 2009 translates into a drop of roughly 25 basis points in the fed funds rate. Against these numbers, the effects of a fiscal volatility shock appear to be about the same size (but of opposite sign) the effects of the stimulus achieved through the recent exercise in quantitative easing.

5 The Uncertain Fiscal Future Ahead

Next, we show results when we depart from our benchmark calibration described in section 3. We vary the calibration in three ways. First, we suppress feedback in the fiscal rules. Second, we increase the persistence of the fiscal volatility shocks for all instruments. Finally, we combine both modifications. In these three exercises, the rest of the parameters will stay at the values in tables 1 and 2. In particular, we do not recalibrate the model, but rather conduct a counterfactual experiment.

5.1 Rules with Partial and Without Feedback

The benchmark calibration in section 3 incorporated feedback from output and from the debt-to-output ratio to fiscal instruments. Tax rates fell and government spending as a share of output increased in the wake of a fiscal volatility shock because the rules responded to the drop in output. A logical extension is to eliminate the feedbacks and to revaluate our finding. This might also be a more relevant exercise for the current situation in the U.S., which so far has not seen fiscal policy react much to the debt-to-output ratio.

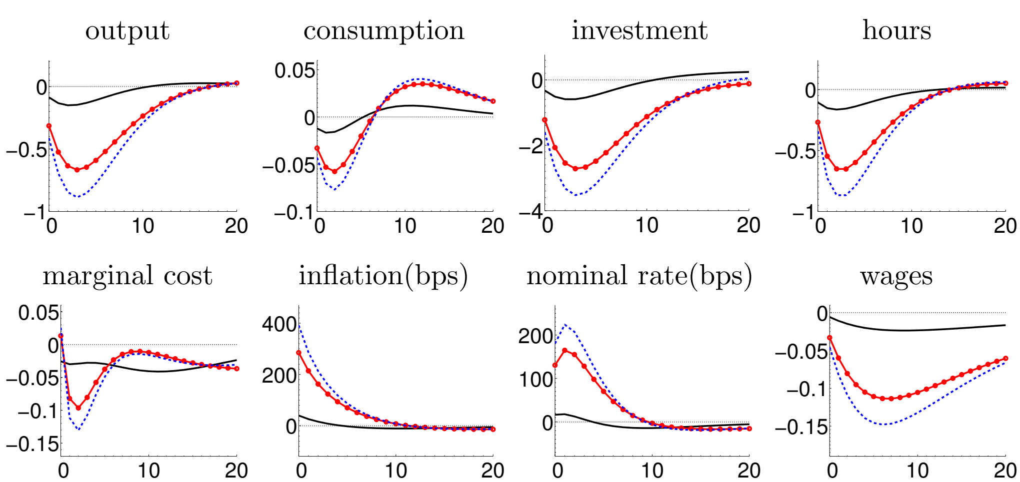

Figure 8: Fiscal volatility shocks – effect of feedback

Note: The solid black lines are the IRFs to a fiscal volatility shock in the benchmark calibration. The dotted red lines are the IRFs for the model with partial feedback. The dashed blue lines are the IRFs for the model without feedback. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

In a first experiment, we will set, in the fiscal policy rules, $\phi_{x,y} = 0$ for all $x \in \{\tilde{g}, \tau_l, \tau_k, \tau_c\}$ and call this specification the *model with partial feedback*. Second, we will set both $\phi_{x,y} = 0$ and $\phi_{x,b} = 0$

for all $x \in \{\tilde{g}, \tau_l, \tau_k, \tau_c\}$ and call this specification the *model without feedback*. Figure 8 compares the IRFs under the benchmark calibration (solid black line) to the IRFs of the model with partial feedback (dotted red lines) and without feedback (dashed blue line). The scenarios do not represent an altogether sweeping regime change, however. In particular, throughout we let lump-sum taxes react sufficiently to debt so as to ensure a bounded debt path despite active monetary policy; that is, we stay within the confines of an active monetary/passive fiscal policy regime.[15]

The main finding is that the impact of fiscal volatility shocks is considerably stronger than in the benchmark calibration. For instance, in the case without feedback, output falls by 0.88 percent, almost five times more than in the benchmark calibration. Much of this decline is due to a sharper drop in investment (-3.5 percent). Hence, without the dampening effect of feedback, the impact of a fiscal volatility shock can be considerable. If, as argued by some observers, feedback is currently not working in the U.S., fiscal volatility shocks might be playing an important role in the performance of the economy.

5.2 A More Persistent Fiscal Volatility Shock

We evaluate, now, the effect of a fiscal volatility shock that is more persistent than the median of the posterior reported in table 1. The exercise is motivated by the large variance in the posterior distributions of the persistence parameters of the fiscal volatility shocks to every instrument.

In figure 9, we consider the case that the fiscal volatility shocks have a half-life of about one and a half years by setting the persistence parameter for the volatility of all four instruments to $\rho_{\sigma_x} = 0.90$. We rescale the innovations to keep the unconditional variance of volatility unaffected by the change in persistence. The red dots illustrate that a more persistent fiscal volatility shock generates a deeper and longer recession. Now firms fear that tax changes are more likely beyond the next few quarters. As a result, they reduce their exposure to future taxes by increasing the markup even more.

[15] Following Leeper, Plante and Traum (2010), instead of switching off the response to debt completely for all fiscal instruments but lump-sum taxes, we could have scaled the speed of fiscal adjustment to government debt ($\phi_{x,b}$) by the same factor for each instrument. This scaling factor needs to be bigger than zero to ensure stable debt, but a value of just 2 percent of the size of the estimated response suffices to still stay in an active monetary/passive fiscal regime. Our results are robust to this alternative way of phrasing the counterfactual: for this value of the scaling factor, the impulse responses look virtually identical to those currently shown as dashed blue lines in figure 8.

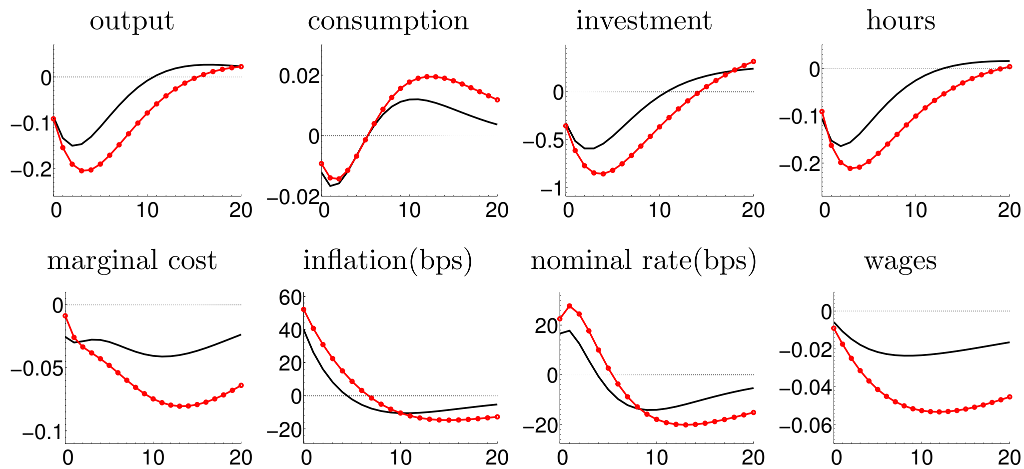

Figure 9: Fiscal volatility shocks – effect of persistence

Note: The solid black lines are the IRFs to a fiscal volatility shock in the benchmark calibration. The dotted red lines are the IRFs to a more persistent fiscal volatility shock (with a half-life of about 1.5 years) while rescaling the variances of the innovations. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

5.3 A (Very) Pessimistic Scenario?

The stance of the political debate in the U.S. suggests that fiscal policy is up for grabs. For example, it is unclear when and how fiscal consolidation will be implemented. Also, in an attempt to balance its accounts, the government may not be able to react to business cycles. As discussed above, the lack of a clear time frame for implementation (high persistence of volatility) or the ability to react to the state of the economy (absence of feedback) has large consequences for the impact of fiscal volatility shocks. These considerations imply that our benchmark calibration may paint a too cautious picture of the effect of fiscal volatility shocks. As an exercise to capture a pessimist's assessment of the current fiscal situation, we eliminate the feedback component in the rules that govern the fiscal instruments and, simultaneously, we increase the persistence of all of the fiscal volatility shocks to 0.90. This pessimistic scenario provides us with guidance about what could happen under particularly negative, but not implausible, circumstances. As before, we set up the scenario such that the economy always stays in an active monetary/passive fiscal policy regime.[16]

[16] A farther-reaching counterfactual would have changed the description of both fiscal and monetary policy. For example, if we compute IRFs for an active fiscal regime (no response to debt by any of the fiscal instruments, including lump-sum taxes) and a passive monetary regime (taken to be a constant nominal interest rate), the contractionary effect of fiscal uncertainty shocks would be an order of magnitude larger than reported in figure 10. The reason is that, in contrast to the active monetary/passive fiscal policy regime, none of the policy makers works to stabilize the markup.

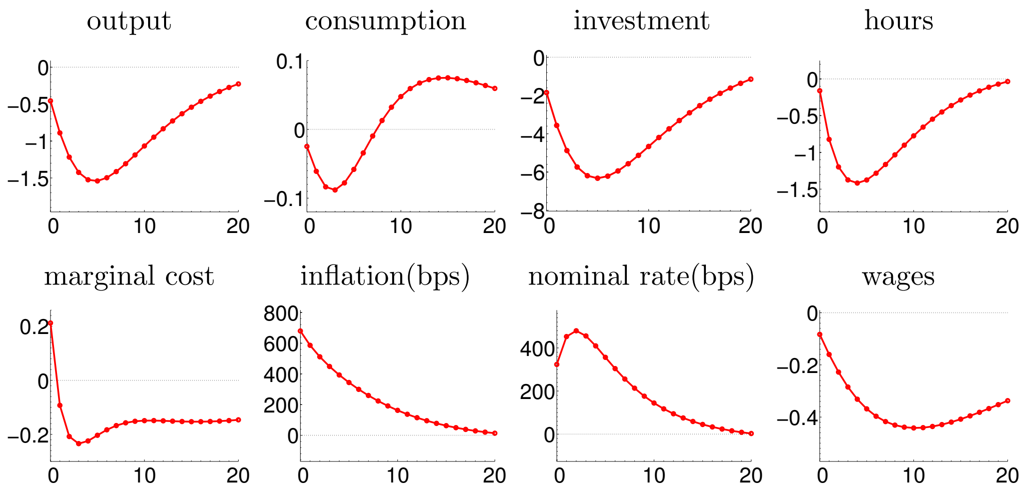

Figure 10: Fiscal volatility shocks – pessimistic scenario

Note: The dotted red lines are the IRFs to a more persistent fiscal volatility shock (with a half-life of about 1.5 years) for the model without feedback. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

The red dotted lines in figure 10 display the impact of a fiscal volatility shock without feedback and with high persistence. The recession that we compute is now severe. At its trough, output contracts by 1.5 percent. In order to put the magnitude into context, the Congressional Budget Office currently estimates an output gap for 2012 of 5.2 percent. The peak effect of the pessimistic fiscal uncertainty scenario reported here amounts to 30 percent of this. Even on impact, variables react substantially to the fiscal volatility shock: output experiences a decline on impact of 0.45 percent and inflation increases considerably as well. To put these results in context, Baker and Bloom (2011), using a VAR, find that an increase in their political uncertainty index similar to the one observed over the last few years leads to a deep and persistent decline in industrial production (the trough happens about a year and a half after the shock with a decline of 3.6 percent).

Thus, under a pessimist's reading of the current situation, fiscal volatility shocks may be an important force dragging down the economy even if the regime of monetary-fiscal interaction stays such that monetary policy remains focused on price stability and fiscal policy remains focused on eventual debt stabilization.

6 Additional Analysis

In this section, we discuss two additional points. First, we decompose the effect of the fiscal volatility shock among each of the different instruments. Second, we explore how monetary policy interacts with fiscal volatility shocks. In appendix E, we compare the effects of fiscal volatility shocks with the effect of fiscal shocks (shocks to the level of the instrument) and, in appendix F, we assess the role of the elasticity of demand and price and wage rigidities.

6.1 Decomposing the Response to a Fiscal Volatility Shock

So far, we have defined a fiscal volatility shock as a simultaneous increment of two standard deviations in the volatilities of the innovations of each fiscal instrument. Here we are interested in decomposing the total impact among the effects of each fiscal instrument. While a variance decomposition cannot be implemented (our solution method is non-linear), we can compare each of the IRFs associated with a shock to one instrument alone with the IRFs to a fiscal volatility shock as defined in section 4.

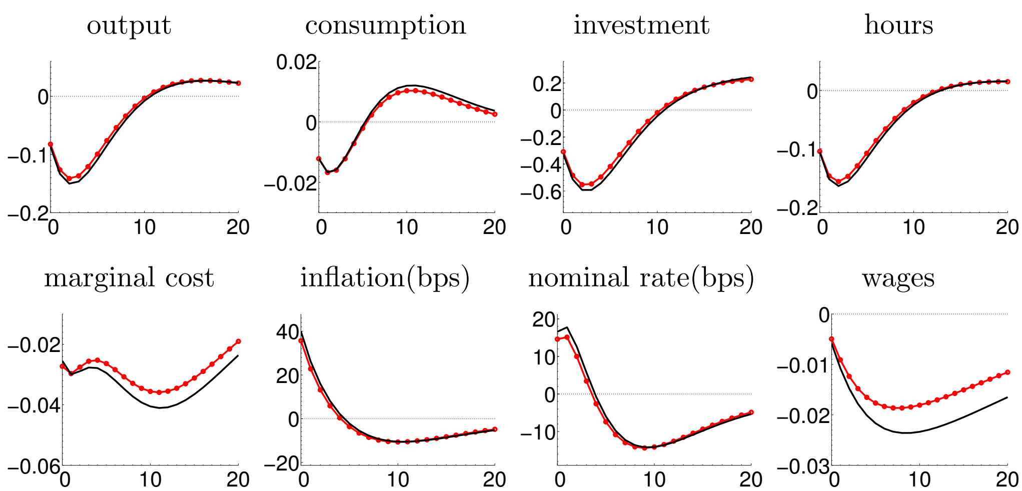

Figure 11: Fiscal volatility shocks vs. fiscal volatility shock only to capital tax rate

Note: The solid black lines are the IRFs to a fiscal volatility shock as described in section 4. The dotted red lines are the IRFs to a fiscal volatility shock to capital taxes only. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

We do this in figure 11, where we show (in black) the IRFs to a fiscal volatility shock as described in section 4 and (in the dotted red lines) the IRFs where there is a fiscal volatility shock only to the capital tax rate. Clearly, the increase in volatility of capital taxes accounts for most of the effect of the fiscal volatility shock that we found in section 4. Additional unreported figures with different combinations of increases in the volatility of fiscal instruments confirm this result: nearly all of the economy's response to fiscal volatility shocks works through the tax on capital income.

The intuition is simple. Higher uncertainty about consumption taxes or government spending as a share of output has little effect on the problem of the firm and the markup, which are at the core of the mechanism linking fiscal volatility shocks with lower output. The uncertainty about the tax on labor income could be important through its effect on marginal costs, but since wages are rigid, its impact is muted. Hence, the time-varying volatility of the capital income tax is the main thrust of volatility shocks.

6.2 The Role of Monetary Policy

The "stagflation" (the combination of a fall in output amid higher inflation) induced by a fiscal volatility shock hints at a difficult trade-off for monetary policymakers. The monetary authority could try to accommodate fiscal volatility shocks. However, this would increase inflation in a situation where it is already higher than usual. It is interesting, then, to explore how the economy responds to fiscal volatility shocks under different values of the parameters on the Taylor rule.

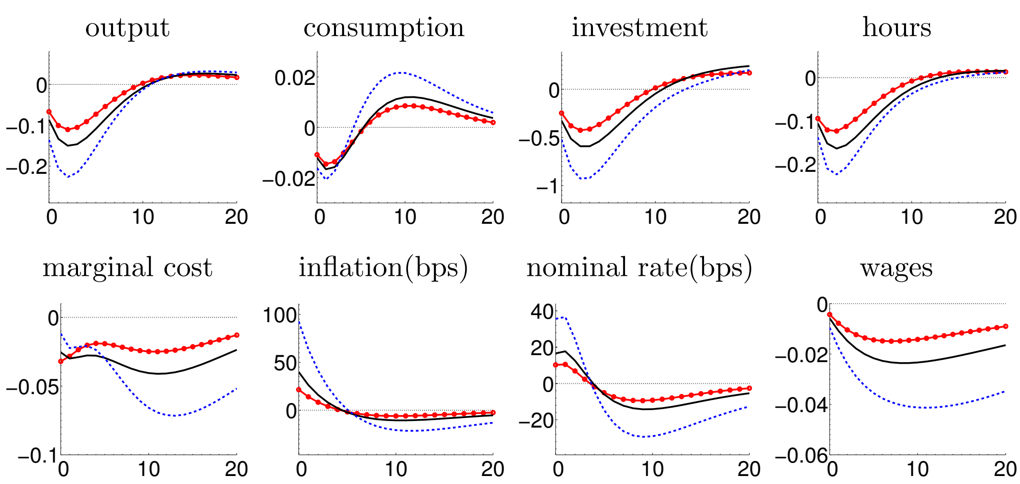

Figure 12: Fiscal volatility shocks – effect of Taylor rule

Note: The solid black lines are the IRFs to a fiscal volatility shock in the benchmark calibration. The dashed blue lines are the IRFs when $\gamma_y = 0.5$. The dotted red lines are the IRFs when $\gamma_\Pi = 1.5$. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

The IRFs in figure 12 show the response under our benchmark calibration as a solid line and two alternative scenarios. In the first one, the monetary authority reacts more strongly to output (a value of $\gamma_y = 0.5$ instead of $\gamma_y = 0.25$, dashed blue lines). In the second one, the monetary authority reacts more aggressively to inflation (a value of $\gamma_\Pi = 1.5$ instead of $\gamma_\Pi = 1.25$, dotted red lines).

The economics behind the new IRFs is the following. When the response to output in the Taylor rule (γ_y) is high, firms anticipate that inflation will be tolerated. To counterbalance declining profits, firms aggressively increase prices with a view toward higher markups. Firms' anticipation of a loose stance of monetary policy would, therefore, result in still higher inflation and lower output (the dashed blue lines). Accommodative monetary policy then exacerbates the effects of fiscal volatility in all dimensions. In contrast, if the central bank assigns less weight to stabilizing output, firms consider future inflation less likely, which reduces the upward pricing bias. In addition, a firm commitment to price stability prevents markups from rising under the aggregate demand channel. Thus, in equilibrium, the smaller the monetary response to output, the more moderate is the inflation response and the contraction in output. An analogous argument explains why a stronger focus of monetary policy on inflation alleviates the negative outcomes of fiscal volatility shocks on output and stabilizes inflation at the same time (the dotted red lines). If the central bank becomes more responsive to inflation (higher γ_Π), the stagflationary effects of fiscal volatility shocks are much less pronounced. Thus, fiscal volatility shocks do not create a trade-off between stabilizing output and inflation, as we would have, for instance, with markup shocks.

We can push our argument further and assume an exclusive and strong commitment of monetary policy to price stability by letting the central bank ignore the Taylor rule and set interest rates instead such that inflation always remains at the target level $\Pi_t = \overline{\Pi}$, $\forall t$. This is shown as the dashed blue line in figure 13. Now, the effects of the fiscal volatility shock on economic activity are, at least, one order of magnitude smaller than in the baseline economy.

7 Conclusions

Most economic decision-making is subject to pervasive uncertainty, some of it introduced by the political process itself. This applies, in particular, to uncertainty about future tax and spending plans. Several observers have argued that the increase in fiscal policy uncertainty has weighed negatively on the U.S. economy's recovery from the recent financial crisis. To assess this concern,

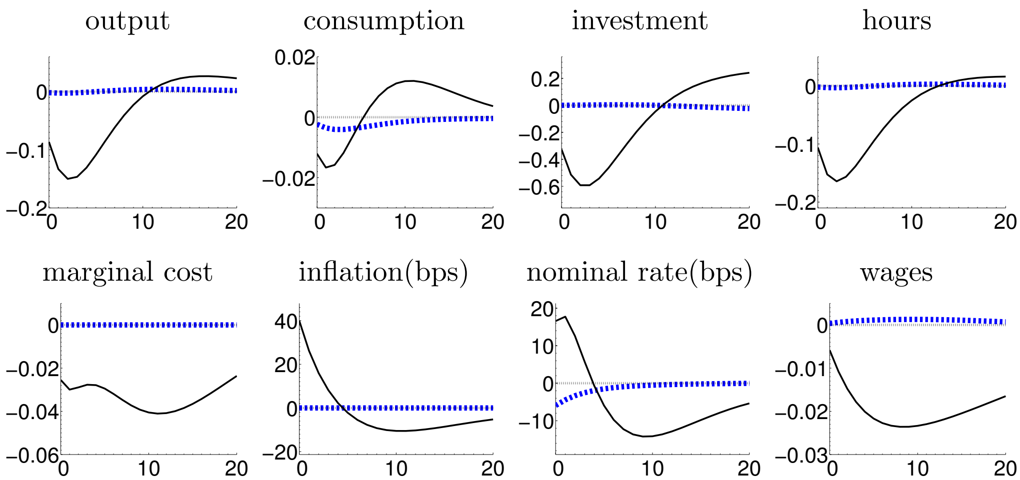

Figure 13: Fiscal volatility shocks – Strict inflation targeting

Note: The solid black lines are the IRFs to a fiscal volatility shock in the baseline economy. The dashed blue lines are the IRFs to the economy under strict inflation targeting. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

we have analyzed the effect that fiscal volatility shocks can have on economic activity and have discussed the mechanisms behind our results, in particular the endogeneity of markups.

We have found that fiscal volatility shocks can shave up to about 1.5 percentage points from output in a very adverse scenario characterized by high persistence of the fiscal volatility shocks and the absence of feedback from output and the debt-to-output ratio in the fiscal rules. Our results may well be, however, a lower bound. We have ignored, longer-term budgetary issues –such as the impact of entitlement programs–, financial frictions, and non-convexities on investment. All of these channels might further increase the effects of fiscal volatility shocks. In future work, it will be interesting to compare these considerations with the channels we have emphasized in the current paper.

Our experiments considered a spread in tax and spending risk, so the risk was two-sided. To the extent that observers have in mind one-sided risks (for example, a lack of clarity about the size of future increases alone in taxes), the effects of fiscal volatility shocks, if they are defined to include those mean effects, could also be larger. Unfortunately, with current models of stochastic volatility, it is not clear how to perform one-sided risk analysis.

We have also ignored the fact that, at the time of writing, the federal funds rate is at its zero lower bound (ZLB) and the FOMC's forward guidance indicates that interest rates are likely to remain exceptionally low for some time (Federal Open Market Committee (2011)). Thus, it is natural to ask how fiscal volatility shocks interact with the ZLB. In particular, the literature has highlighted that the response of the economy to disturbances may differ at the ZLB. See, among others, Christiano, Eichenbaum and Rebelo (2011) or Eggertsson (2011). Unfortunately, and because of the size of the state space, a numerical assessment of the implications of fiscal volatility shocks at the lower bound is technically well beyond the scope of this paper.[17]

We have also abstracted from modeling explicitly the political process that generates the fiscal volatility shocks. Thus, we do not have clear policy recommendations about how to eliminate or reduce the "noise" from fiscal policy. This modeling of the political economic determinants of fiscal volatility shocks is a key issue that we plan to take up in future work.

References

Abel, Andrew B. 1983. "Optimal Investment Under Uncertainty." *American Economic Review*, 73(1): 228–233.

Altig, David, Lawrence Christiano, Martin Eichenbaum, and Jesper Linde. 2005. "Firm-Specific Capital, Nominal Rigidities and the Business Cycle." NBER Working Papers 11034.

Altig, David, Lawrence J Christiano, Martin Eichenbaum, and Jesper Linde. 2011. "Firm-specific Capital, Nominal Rigidities and the Business Cycle." *Review of Economic Dynamics*, 14: 225–247.

Arellano, Cristina, Yan Bai, and Patrick Kehoe. 2010. "Financial Markets and Fluctuations in Uncertainty." *Federal Reserve Bank of Minneapolis Working Paper.*

Bachmann, Rüdiger, and Guiseppe Moscarini. 2011. "Business Cycles and Endogenous Uncertainty." *Yale University mimeo.*

[17] See Fernández-Villaverde et al. (2011*a*) for a full non-linear exploration of the ZLB in a smaller model. Note that the standard practice of adding anticipated shocks that keep the path of the nominal rate plotted in IRFs from falling below zero does not implement the ZLB constraint. This procedure works if there is just one path of the interest rate to take into account, as is the case in standard perfect foresight simulations. In our model, instead, where the uncertainty about the future matters, the ZLB would need to be enforced for each possible future state. This cannot be done using perturbation methods.

Bachmann, Rüdiger, Steffen Elstner, and Eric R Sims. 2012. "Uncertainty and Economic Activity: Evidence from Business Survey Data." *University of Aachen mimeo.*

Bachmann, Ruediger, and Christian Bayer. 2011. "Uncertainty Business Cycles - Really?" National Bureau of Economic Research NBER Working Papers 16862.

Baker, Scott, and Nicholas Bloom. 2011. "Does Uncertainty Drive Business Cycles? Using Disasters as Natural Experiments." *Stanford University mimeo.*

Baker, Scott, Nicholas Bloom, and Steve Davis. 2011. "Measuring Policy-Related Economic Uncertainty." *Stanford University mimeo.*

Ball, Laurence, and David Romer. 1990. "Real Rigidities and the Non-Neutrality of Money." *Review of Economic Studies*, 2: 183 – 203.

Barro, Robert J. 2009. "Rare Disasters, Asset Prices, and Welfare Costs." *American Economic Review*, 99(1): 243–64.

Barro, Robert J, and Chaipat Sahasakul. 1983. "Measuring the Average Marginal Tax Rate from the Individual Income Tax." *Journal of Business*, 56(4): 419–52.

Barro, Robert J, and Chaipat Sahasakul. 1986. "Average Marginal Tax Rates from Social Security and the Individual Income Tax." *Journal of Business*, 59(4): 555–66.

Barro, Robert J, and Charles J Redlick. 2010. "Macroeconomic Effects from Government Purchases and Taxes." *Harvard University mimeo.*

Basu, Susanto, and Brent Bundick. 2011. "Uncertainty Shocks in a Model of Effective Demand." *Boston College mimeo.*

Bi, Huixin, Eric M. Leeper, and Campbell B. Leith. 2012. "Uncertain Fiscal Consolidations." NBER Working Papers 17844.

Bloom, Nicholas. 2009. "The Impact of Uncertainty Shocks." *Econometrica*, 77(3): 623–685.

Bloom, Nicholas, Max Floetotto, Nir Jaimovich, Itay Saporta-Eksten, and Stephen J Terry. 2012. "Really Uncertain Business Cycles." NBER Working Papers 18245.

Bloom, Nicholas, Nir Jaimovich, and Max Floetotto. 2008. "Really Uncertain Business Cycles." *Stanford University mimeo.*

Bohn, Henning. 1998. "The Behavior of U.S. Public Debt and Deficits." *Quarterly Journal of Economics*, 113(3): 949–963.

Boivin, Jean. 2006. "Has U.S. Monetary Policy Changed? Evidence from Drifting Coefficients and Real-Time Data." *Journal of Money, Credit, and Banking*, 38(5): 1149–1173.

Boivin, Jean, and Marc P. Giannoni. 2006. "Has Monetary Policy Become More Effective?" *The Review of Economics and Statistics*, 88(3): 445–462.

Born, Benjamin, and Johannes Peifer. 2011. "Policy Risk and the Business Cycle." *University of Bonn mimeo.*

Chetty, Raj, Adan Guren, Day Manoli, and Andrea Weber. 2011. "Micro versus Macro Labor Supply Elasticities." *American Economic Review: Papers and Proceedings*, 101: 472–475.

Christiano, Lawrence J., Martin Eichenbaum, and Sergio Rebelo. 2011. "When Is the Government Expenditure Multiplier Large?" *Journal of Political Economy*, 119(1): 78–121.

Christiano, Lawrence, Martin Eichenbaum, and Charles L Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy*, 113: 1–45.

Christiano, Lawrence, Roberto Motto, and Massimo Rostagno. 2010. "Financial Factors in Economic Fluctuations." *Working paper, European Central Bank*, 1192.

Croce, Mariano M., Howard Kung, Thien T. Nguyen, and Lukas Schmid. 2012. "Fiscal Policies and Asset Prices." *Review of Financial Studies*, forthcoming.

Croce, Mariano M., Thien T. Nguyen, and Lukas Schmid. 2012. "The Market Price of Fiscal Uncertainty." *Journal of Monetary Economics*, 59(5): 401–416.

Davig, Troy, and Eric Leeper. 2007. "Monetary and Fiscal Policy Switching." In *NBER Macroeconomics Annual 2006*. Vol. 21, , ed. Kenneth Rogoff Daron Acemoglu and Michael Woodford, 247–316. Cambridge:MIT Press.

Davig, Troy, and Eric M. Leeper. 2011. "Monetary-fiscal policy interactions and fiscal stimulus." *European Economic Review*, 55(2): 211–227.

Davig, Troy, Eric Leeper, and Todd Walker. 2010. ""Unfunded Liabilities" and Uncertain Fiscal Financing." *Journal of Monetary Economics*, 57(5): 600 – 619.

Eggertsson, Gauti B. 2011. "What Fiscal Policy is Effective at Zero Interest Rates?" In *NBER Macroeconomics Annual 2010*. Vol. 25, , ed. Daron Acemoglu and Michael Woodford, 113–124. Chicago:University of Chicago Press.

Federal Open Market Committee. 2011. "FOMC Statement." Board of Governors of the Federal Reserve System Press Release Nov. 2, 2011.

Fernández-Villaverde, Jesus, Grey Gordon, Pablo Guerrón-Quintana, and Juan Rubio-Ramírez. 2011*a*. "Nonlinear Adventures at the Zero Lower Bound." *Federal Reserve Bank of Philadelphia Working Paper*, 12-10.

Fernández-Villaverde, Jesus, Pablo Guerrón-Quintana, and Juan Rubio-Ramírez. 2010. "Fortune or Virtue: Time-Variant Volatilities versus Parameter Drifting." *Federal Reserve Bank of Philadelphia Working Paper*, 10-14.

Fernández-Villaverde, Jesus, Pablo Guerrón-Quintana, Juan Rubio-Ramírez, and Martín Uribe. 2011*b*. "Risk Matters: The Real Effects of Volatility Shocks." *American Economic Review*, 101: 2530–61.

Galí, Jordi, and Mark Gertler. 1999. "Inflation Dynamics: A Structural Econometric Analysis." *Journal of Monetary Economics*, 44(2): 195–222.

Gourio, Francois. 2012. "Disaster Risk and Business Cycles." *American Economic Review*, forthcoming.

Hamilton, James. 2008. "Assessing Monetary Policy Effects Using Daily Federal Funds Future Contracts." *Federal Reserve Bank of St. Louis Review*, 90: 377 – 93.

Hamilton, James, and Jing Wu. 2010. "The Effectiviness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment." *University of California San Diego mimeo.*

Justiniano, Alejandro, and Giorgio E Primiceri. 2008. "Time Varying Volatility of Macroeconomic Fluctuations." *American Economic Review*, 98: 604–641.

Kimball, Miles S. 1989. "The Effects of Demand Uncertainty on a Precommited Monopoly Price." *Economic Letters*, 30: 1–5.

King, Robert, and Sergio Rebelo. 1999. "Resuscitating Real Business Cycles." *Handbook of Macroeconomics*, 927–1007. Amsterdam:North-Holland.

Kuester, Keith. 2010. "Real price and wage rigidities with matching frictions." *Journal of Monetary Economics*, 57(4): 466–477.

Leeper, Eric M. 1991. "Equilibria under 'Active' and 'Passive' Monetary and Fiscal Policies." *Journal of Monetary Economics*, 27(1): 129–147.

Leeper, Eric, Michael Plante, and Nora Traum. 2010. "Dynamics of Fiscal Financing in the United States." *Journal of Econometrics*, 156(2): 304–321.

Pindyck, Robert S. 1988. "Irreversible Investment, Capacity Choice, and the Value of the Firm." *American Economic Review*, 78(5): 969–985.

Romer, Christina D, and David H Romer. 2010. "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks." *American Economic Review*, 100: 763–801.

Rotemberg, Julio J. 1982. "Sticky Prices in the United States." *Journal of Political Economy*, 90: 1187–1211.

Sim, Jae, Egon Zakrajsek, and Simon Gilchrist. 2010. "Uncertainty, Financial Frictions, and Investment Dynamics." *Boston University Working Paper.*

Smets, Frank, and Rafael Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review*, 97(3): 586–606.

Online Appendices to

Fiscal Volatility Shocks and Economic Activity

(Not for Publication)

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A Tax Data

In this appendix, we describe how we build our sample. We follow (most of) the methodology of Leeper, Plante and Traum (2010), who construct aggregate effective tax rates using national account information. Their work in turn is based on earlier contributions by Mendoza, Razin and Tesar (1994) and Jones (2002).

We aggregate all levels of the government (state, local, and federal) into one general government sector. While state, local, and federal governments are legally different entities that could merit a separate treatment, in practice, the different levels of government are closely interconnected. For instance, there are joint programs such as Medicaid or federal matching funds for UI and education. Also, as we have seen recently, changes in federal policy such as the American Recovery and Reinvestment Act of 2009 have a direct impact on the fiscal situation of state and local governments. There are two alternatives to our choice. One would be to explicitly model three levels of government (or perhaps just two, federal and non-federal). However, this would considerably increase the state space and would come at the expense of reduced transparency. For example, state and local governments are largely subject to balanced-budget requirements, while the federal government can engage in tax-smoothing by issuing debt. Besides, the different levels of government use different bases for their taxation. All these aspects would need to be (at least partially) included in a model with several levels of government. A second possibility could be to disregard local and state tax revenue altogether and focus entirely on the federal side as in Leeper, Plante and Traum (2010). However, state and local finances have been hit hard by the last recession. As a result, at least some of the uncertainty about the fiscal mix going forward appears to originate at the state and local levels (and what the federal government may eventually do about the weaknesses at the local and state fiscal levels).

We now explain how we derive measures of tax rates.

A.1 Consumption taxes

The average tax rate on consumption is defined as:

$$\tau_c = \frac{\mathrm{TPI} - \mathrm{PRT}}{\mathrm{PCE} - (\mathrm{TPI} - \mathrm{PRT})}. \tag{1}$$

The numerator is taxes on production and imports (TPI, NIPA Table 3.1 line 4) less state and local property taxes (PRT, NIPA Table 3.3 line 8). The denominator is personal consumption expenditures (PCE, NIPA Table 1.1.5, line 2). Property taxes make up a large share of the cost of housing. In the national accounts, homeowners are treated as businesses who rent out their properties to themselves. Property taxes are therefore accounted for as taxes on capital.

A.2 Labor income taxes

Following Jones (2002), the average personal income tax is computed as:

$$\tau_p = \frac{\text{PIT}}{\text{WSA} + \text{PRI}/2 + \text{CI}}. \tag{2}$$

The numerator is federal, state, and local taxes on personal income (PIT, NIPA Table 3.2, line 3 plus NIPA Table 3.3, line 4). The denominator is given by wage and salary accruals (WSA, NIPA Table 1.12, line 3), proprietor's income (PRI, NIPA Table 1.12, line 9), and capital income (CI). We define CI = PRI/2 + RI + CP + NI, where the first term is half of the proprietor's income, and the latter three terms are, respectively, rental income (RI, NIPA Table 1.12, line 12), corporate profits (CP, NIPA Table 1.12, line 13), and interest income (NI, NIPA Table 1.12, line 18).
The average tax on labor income is computed as:

$$\tau_l = \frac{\tau_p\,[\text{WSA} + \text{PRI}/2] + \text{CSI}}{\text{CEM} + \text{PRI}/2}. \tag{3}$$

In the numerator are taxes paid on personal income plus contributions to Social Security (CSI, NIPA Table 3.1, line 7). The denominator features compensation of employees (CEM, NIPA Table 1.12, line 2) and proprietor's income.

A.3 Capital taxes

The average capital tax rate is calculated as:

$$\tau_k = \frac{\tau_p \text{CI} + \text{CT} + \text{PRT}}{\text{CI} + \text{PRT}}. \tag{4}$$

The denominator features taxes on capital income, taxes on corporate income (CT, NIPA Table 3.1, line 5), and property taxes (PRT, NIPA Table 3.3, line 8).

A.4 Other variables

Real domestic product is obtained by dividing seasonally adjusted nominal domestic product (NIPA Table 1.1.5) by the output deflator (NIPA Table 1.1.4). Real output is detrended using the Christiano-Fitzgerald band pass filter (Christiano and Fitzgerald (2003)).

A.5 Plots of the data

Figure 1 plots the resulting data series for the tax rates and government spending.

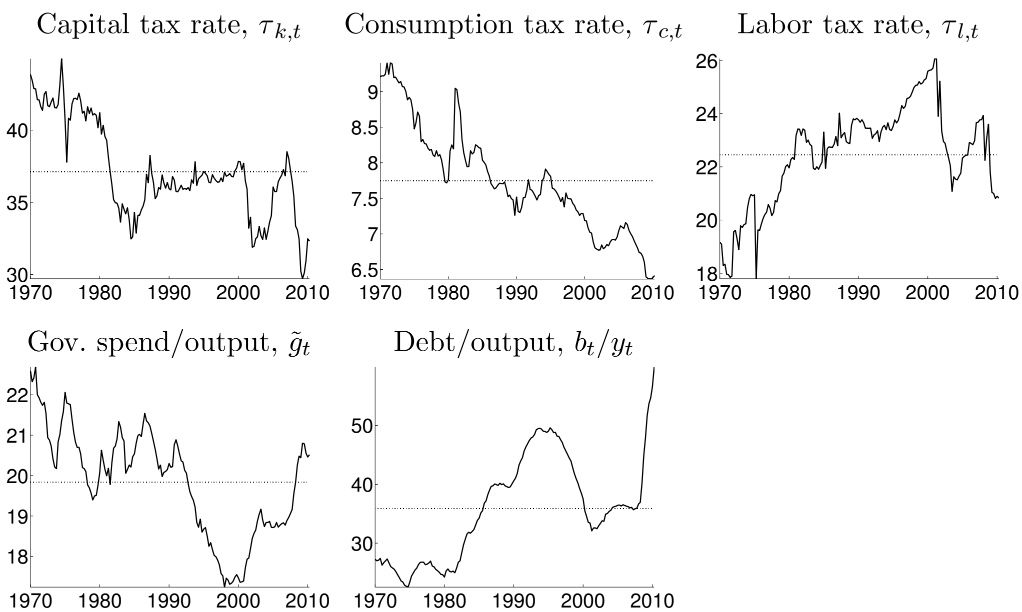

Figure 1: Data: taxes and government spending

Note: The figure shows the time series for the three tax rates and the government spending series entertained in this paper. Also shown is the debt-to-output series used in the estimation.

Table 1 reports summary statistics of our sample.

B Estimation

In the estimation, we entertain uniform priors over the support of each of the parameters for two reasons. First, we want to show how our results arise from the shape of the likelihood and not

Table 1: Average and Current Tax Rates, Expenditure and Debt Level

	Tax on (percent)			Ratio to GDP (percent)	
	Labor	Consumption	Capital	Gov. spending	Debt
Average	22.44	7.75	37.12	19.84	35.86
2010.Q2	20.82	6.41	32.32	20.51	60.00

Notes: Average and current tax rates, and ratios of spending and debt to output in the sample.

from pre-sample information. Second, Fernández-Villaverde et al. (2011) illustrate that eliciting priors for the parameters controlling stochastic volatility processes is difficult: We deal with units that are unfamiliar to most economists. Even with these flat priors, a relatively short draw suffices to achieve convergence, as verified by standard convergence tests. We draw 50,000 times from the posterior. These draws are obtained after an extensive search for appropriate initial conditions. We discarded an additional 5,000 burn-in draws at the beginning of our simulation. We selected the scaling matrix of the proposal density to induce the appropriate acceptance ratio of proposals as described in Roberts, Gelman and Gilks (1997). Each evaluation of the likelihood was performed using 10,000 particles.

Figure 2 shows how fiscal volatility shocks translate into changes in the distribution of future fiscal policy paths. The figure shows the 95 percent confidence intervals for forecasts of future tax rates and government spending formed in the initial period. In each panel, we set $\phi_{x,b} = \phi_{x,y} = 0$ for all the fiscal instruments.[1] The blue dashed lines at the center correspond to fiscal processes with constant volatility; that is, we set $\eta_x = 0$ for all instruments. The black solid lines mark confidence intervals when fiscal volatility shocks can occur in later periods, but for the initial period volatility takes on the steady-state value. It is apparent how stochastic volatility increases fiscal policy uncertainty. The figure also shows, as red dots, the effect when, in the initial period, there is a two-standard-deviation innovation to the fiscal volatility shock to each of the fiscal instruments. The initial jump in volatility increases the dispersion of the possible paths of the fiscal instruments for some quarters. Due to the stationarity of the fiscal rules and stochastic volatility processes, the red dots and black lines converge after some time.

[1] We set the feedback terms to zero, only to produce this figure, to present charts that do not rely on the model. See the main text for the corresponding forecast bands using the rule within our calibrated business cycle model.

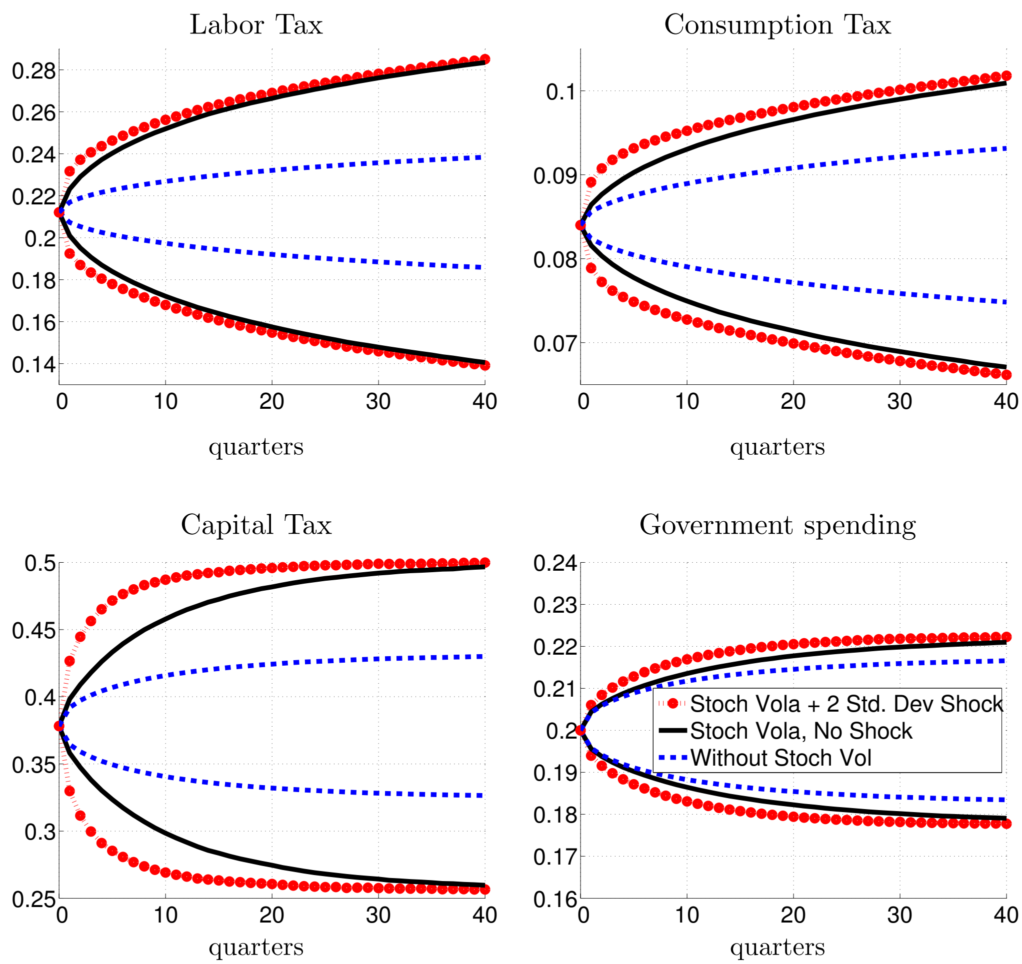

Figure 2: Dispersion of future fiscal instruments

Note: 95 percent confidence intervals for forecasts made at period 0 for fiscal instruments up to 40 quarters ahead when the fiscal rules do not feature feedback to output and the debt level. Solid black line: specification when fiscal volatility shocks are set to zero in period 1. Red dots: specification with a two-standard-deviation fiscal volatility shock innovation to all instruments in period 1. Dashed blue line: specification with constant volatility held fixed at the steady-state value.

B.1 Endogeneity of the Fiscal Instruments

Although we feel comfortable that the specification of our fiscal rules is a good mechanism for estimating the effects we are interested in, we need to address the fact that there is no consensus among economists about how to specify fiscal rules. We do this in two ways. First, we stress that the core of our methodological contribution, the estimation of fiscal rules with stochastic volatility and their use in an otherwise standard model, is independent of the details of our specification. Researchers who prefer other forms for the rules just need to follow the steps we lay down: estimate their favorite rules and check how important the time-varying volatility of those fiscal rules is for economic activity. Second, we assess the robustness of our estimates as we entertain different assumptions about the specification of the rules. Summing up these experiments, we find our results to be consistently robust. Thus, we can consider that our fiscal rules are structural in the sense of Hurwicz (1962), that is, as invariant to the class of policy interventions that we are interested in.

Regarding our second point above, and in the interest of space, we focus here on how to control for the endogeneity of fiscal instruments. An important concern in our rules is the potential two-way dependence between fiscal policy and the business cycle. In the presence of small disturbances, current output is highly correlated with lagged output. Our rules control for that endogeneity by incorporating a feedback in terms of lagged (detrended) output. One can think about lagged output as an instrument for current output.

However, the rules may not fully account for endogeneity when the economy is buffeted by large shocks (since the forecast based on lagged output may be a poor descriptor of today's output). To examine the extent to which this is a problem in practice, we estimate versions of our rules using the Aruoba-Diebold-Scotti (ADS) current business conditions index of the Federal Reserve Bank of Philadelphia (Aruoba, Diebold and Scotti (2009)) as our measure of economic activity. This index tracks real business conditions at high frequency by statistically aggregating a large number of data series, and hence it is a natural alternative to our detrended output measure. For brevity, we report only the case for the tax on capital. In the main text, we document how most of the effects in the model come from shocks to this instrument.

We estimate three new versions of the fiscal rule: (I) with the value of the ADS index at the beginning of the quarter, (II) with the value of the ADS index in the middle of the quarter, and (III) with the value of the ADS index at the end of the quarter. To the extent that fiscal and other structural shocks arrive uniformly within the quarter, the ADS index with different timings incorporates different information that may or may not be correlated with our fiscal measures. If endogeneity is an issue, our estimates should be sensitive to the timing of the ADS index. With these considerations in mind, the new law of motion for capital taxes as a function of the value of the ADS index, ads_t is:

$$\tau_{k,t}-\tau_k = \rho_{\tau_k}(\tau_{k,t-1}-\tau_k)+\phi_{\tau_k,ads}ads_t+\phi_{\tau_k,b}\left(\frac{b_{t-1}}{y_{t-1}}-\frac{b}{y}\right)+\exp(\sigma_{\tau_k,t})\varepsilon_{\tau_k,t},\ \varepsilon_{\tau_k,t}\sim\mathcal{N}(0,1)\,. \quad (5)$$

The dynamics of $\sigma_{\tau_k,t}$ are the same as in equation (2) in section 1 of the main text.

Table 2 compares the estimates of the benchmark specification of the rules (row labeled 0) with the three new versions using the ADS index (with the same order as above). The main lesson of the table is that the effects of relying on a different measure of the business cycle are small and that the timing of the index does not have a strong bearing on the estimates of the parameters of the stochastic volatility process.[2] Thus, endogeneity does not seem to be a major concern in our benchmark specification once we control for lagged (detrended) output.

Table 2: Posterior Median Parameters – Fiscal Rules with ADS Index

	Volatility Parameters			Fiscal Rule Parameters		
	σ_{τ_k}	$\rho_{\sigma_{\tau_k}}$	η_k	ρ_{τ_k}	$\phi_{\tau_k,ads}$	$\phi_{\tau_k,b}$
0	−4.96 [−5.25,−4.58]	0.77 [0.20,0.91]	0.58 [0.34,0.89]	0.96 [0.93,0.99]	0.10 [0.007,0.25]	0.005 [0.001,0.02]
I	−5.01 [−5.29,−4.62]	0.75 [0.44,0.94]	0.57 [0.44,0.79]	0.95 [0.91,0.98]	0.003 [0.002,0.005]	0.003 [0.001,0.01]
II	−4.97 [−5.22,−4.72]	0.69 [0.20,0.91]	0.47 [0.25,0.77]	0.96 [0.92,0.99]	0.003 [0.001,0.004]	0.003 [0.001,0.01]
III	−4.96 [−5.25,−4.64]	0.77 [0.49,0.93]	0.53 [0.39,0.75]	0.96 [0.93,0.99]	0.002 [0.001,0.003]	0.004 [0.001,0.014]

Notes: Row 0 is the benchmark specification, row I is the specification with the value of the ADS index at the beginning of the quarter, row II with the value of the ADS index in the middle of the quarter, and row III with the value of the ADS index at the end of the quarter. For each parameter, the posterior median is given and a 95 percent probability interval (in parentheses).

B.2 Comparison with Alternative Fiscal Rules

Now, we compare our estimated fiscal rules with the previous work in the literature. Our paper is closest to Leeper, Plante and Traum (2010), who, building on early contributions by Braun (1994), McGrattan (1994), and Jones (2002), estimate a linearized RBC model with fiscal rules for several instruments without stochastic volatility. The main difference between that paper and ours is that Leeper, Plante and Traum (2010) jointly estimate the model and the fiscal rules. While there may

[2] The parameter $\phi_{x,ads}$ is naturally different from the feedback parameter $\phi_{x,y}$ that we estimated earlier, since detrended output and the ADS index are measured in different units.

be efficiency gains, Leeper, Plante and Traum (2010) can do that because they linearize their model and, hence, can evaluate the likelihood function with the Kalman filter. However, in our paper, stochastic volatility is inherently a non-linear process that cannot be linearized. A joint estimation using likelihood-based methods of a non-linear business cycle model of this dimensionality and the fiscal rules is a challenging task given current computational power.

In contrast, most of the literature focuses on more aggregated fiscal reaction functions, such as those centered on the (primary) deficit that nets out the various spending and revenue components rather than on specific fiscal instruments (see Bohn (1998)). Thus, it is hard to compare most of the estimated rules with our specification.[3]

Nevertheless, and because of its influence in the literature, it is of particular interest to compare our fiscal rules with Galí and Perotti (2003), who study the cyclically adjusted primary deficit, deficit_t, for OECD countries. On annual data, they estimate a rule for the deficit_t using the output gap x_t and debt b_t. The rule takes the form:

$$\text{deficit}_t = const + \alpha_1 \mathbb{E}_{t-1} x_t + \alpha_2 b_{t-1} + \alpha_3 \text{deficit}_{t-1} + u_t,$$

instrumenting for the output gap using the lagged output gap and the output gap of another economic area (in their case, they instrument for the output gap in the euro area using the output gap in the U.S. and vice versa). Their rule is close to our specification once we realize that the regressor $\mathbb{E}_{t-1} x_t$ and our measure of the business cycle component with a lag are similar.

Finally, a large literature has concentrated on the identification of the fiscal transmission mechanism with vector autoregressions (VARs), either through the use of timing conventions (Blanchard and Perotti (2002)), of sign restrictions (Mountford and Uhlig (2009)), or of a narrative approach (Ramey and Shapiro (1998), Ramey (2011), and Romer and Romer (2010)). In contrast with these papers, we do not aim to identify the fiscal transmission process in the data, and we do not intend to use our estimates to conduct inference about the rigidities in the economy. Rather, we estimate fiscal rules that we consider one reasonable representation of the fiscal policymakers' behavior and examine how fiscal volatility shocks in these rules affect economic activity in a business cycle model.

[3] An exception is Lane (2003), who focuses on the cyclical responses of subcomponents of government spending for OECD countries to measures of activity.

In addition, VARs are inherently linear time-series representations of the data, that are not without problems in a time-varying environment like ours, as shown by Benati and Surico (2009).

C Model

In this appendix we offer some additional details about the model. Remember that its basic structure is as follows. There is a representative household that works, consumes, and invests in capital and government bonds. The government taxes labor and capital income, as well as consumption, and engages in spending following the laws of motion estimated in section 1 of the main text. The household sets wages for differentiated types of labor input subject to wage rigidities. There is a continuum of monopolistically competitive firms. They produce intermediate goods by renting capital services from the household and homogeneous labor from a packer that aggregates the different types of labor. Intermediate goods firms set their prices subject to price rigidities. The final good used for investment and consumption is competitively produced by a firm that aggregates all intermediate goods. The monetary authority steers the short-term nominal interest rate following the prescriptions of a Taylor rule.

C.1 Households

First, note that optimal behavior by the labor packer implies a demand for each type of labor:

$$l_{j,t} = \left(\frac{w_{j,t}}{w_t}\right)^{-\epsilon_w} l_t.$$

Then, by a zero-profit condition

$$w_t = \left(\int_0^1 w_{j,t}^{1-\epsilon_w}\right)^{\frac{1}{1-\epsilon_w}}.$$

Focusing on a symmetric equilibrium in the labor market, the first-order conditions of the household problem of maximizing expected utility with respect to $w_{j,t}$, $j \in (0,1)$, c_t, b_t, u_t, k_t, k_t^b, and i_t can be written as:

$$\frac{d_t}{(c_t - b_h c_{t-1})^{\omega}} - \mathbb{E}_t \frac{b_h \beta d_{t+1}}{(c_{t+1} - b_h c_t)^{\omega}} = \lambda_t (1 + \tau_{c,t}),$$

$$\phi_w y_t \left(\frac{w_t}{w_{t-1}} - 1\right) \frac{w_t}{w_{t-1}} = \mathbb{E}_t \left\{\beta \frac{\lambda_{t+1}}{\lambda_t} \phi_w y_{t+1} \left(\frac{w_{t+1}}{w_t} - 1\right) \frac{w_{t+1}}{w_t}\right\} + \left[\frac{d_t}{\lambda_t} \psi \epsilon_w (l_t^d)^{1+\vartheta} - (\epsilon_w - 1)(1 - \tau_{l,t}) w_t l_t^d\right],$$

$$\lambda_t = \beta \mathbb{E}_t \left\{ \lambda_{t+1} \frac{R_t}{\Pi_{t+1}} \right\},$$

$$r_{k,t}(1-\tau_{k,t}) = q_t \delta' \left[u_t\right],$$

$$q_t = \mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \left[(1-\delta[u_{t+1}]) q_{t+1} + (1-\tau_{k,t+1}) r_{k,t+1} u_{t+1} \right] \right\},$$

$$q_t^b = \mathbb{E}_t \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \left[(1-\delta) q_{t+1}^b + \delta \tau_{k,t+1} \right] \right\},$$

and

$$1 = q_t \left(1 - S\left[\frac{i_t}{i_{t-1}} \right] - S'\left[\frac{i_t}{i_{t-1}} \right] \frac{i_t}{i_{t-1}} \right) + \beta \mathbb{E}_t \left\{ q_{t+1} \frac{\lambda_{t+1}}{\lambda_t} S'\left[\frac{i_{t+1}}{i_t} \right] \left(\frac{i_{t+1}}{i_t} \right)^2 \right\} + q_t^b.$$

Above, λ_t is the Lagrange multiplier associated with the budget constraint and q_t is the marginal Tobin's Q, that is, the multiplier associated with the investment adjustment constraint normalized by λ_t. Similarly, q_t^b is the normalized multiplier on the book value of capital.

C.2 Firms

Taking prices as given, the final good producer minimizes its costs subject to equation (5) in section 2 of the main text. This results in a demand function for each intermediate good:

$$y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\varepsilon} y_t \qquad \forall i \tag{6}$$

where y_t is the aggregate demand and the price index for the final good is:

$$P_t = \left(\int_0^1 P_{it}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}.$$

C.3 Aggregation

Aggregate demand is given by:

$$y_t = c_t + i_t + g_t + \frac{\phi_p}{2} \left(\Pi_t - \Pi \right)^2 y_t + \frac{\phi_w}{2} \left(\frac{w_t}{w_{t-1}} - 1 \right)^2 y_t.$$

By relying on the observation that the capital-labor ratio

$$\frac{k_{it}}{l_{it}} = \frac{w_t}{r_{k,t}} \frac{\alpha}{1-\alpha}.$$

is the same for all firms and that the capital market must clear, we derive that aggregate supply is:

$$y_t = A_t \left(u_t k_{t-1} \right)^{\alpha} l_t^{1-\alpha}.$$

Market clearing requires that

$$y_t = c_t + i_t + g_t + \frac{\phi_p}{2} \left(\Pi_t - \Pi \right)^2 y_t + \frac{\phi_w}{2} \left(\frac{w_t}{w_{t-1}} - 1 \right)^2 y_t = A_t \left(u_t k_{t-1} \right)^{\alpha} l_t^{1-\alpha}.$$

Aggregate profits of firms in the economy are given by

$$F_t = y_t - w_t l_t - r_t^k u_t k_{t-1} - \frac{\phi_p}{2} \left[\Pi_t - \Pi \right]^2 y_t.$$

D Uncertainty and Markups: A Simple Example

In this appendix, we use a standard Dixit-Stiglitz monopolistic competition setup to show the relation between the uncertainty level and the pricing decision of firms. To simplify, we will assume a volatility shock that the firm takes as given and abstract from fully specified general equilibrium feedbacks. Also, and only in this appendix, we will assume risk-neutral investors. This further clarifies our argument in section 4 of the main text.

Monopolistic producers set their price $P_{i,t}$ subject to adjustment costs and given that they face the demand function

$$y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\epsilon} y_t,$$

where P_t is the aggregate price level, y_t is aggregate demand, and ϵ is the demand elasticity. Each firm's production function is given by $y_{i,t} = l_{i,t}$. Firms hire labor $l_{i,t}$ at the real wage w_t.

D.1 Aggregate demand and costs

Aggregate demand is exogenously determined according to

$$y_t = y + \exp\{\sigma^0_{y,t}\}\varepsilon_{y,t},\ \varepsilon_{y,t} \sim \mathcal{N}(0, \sigma_{e_y}). \tag{7}$$

Without loss of generality, let the steady-state level of demand be $y = 1$. We look at the effect of volatility shocks for period t, $\sigma^0_{y,t} > 0$, that are realized at the start of period 0. This volatility shock causes a mean-preserving spread of the distribution of future demand.

In any period j, the real wage is linked "endogenously" to aggregate demand

$$w_t = w + \chi(y^\phi_t - \mathbb{E}_0 y^\phi_t),\ \chi > 0,\ \phi > 0,\ \text{with } w = \frac{\epsilon - 1}{\epsilon}. \tag{8}$$

We subtract $\mathbb{E}_0 y^\phi_t$, since we are interested in a shock in period 0 that induces a mean-preserving spread of future y_t's and possibly w_t's but does not affect the mean of w_t. Without this term, a volatility shock to y_t would lead to higher average marginal cost, so inflation would rise still more. The w_t process that is meant to capture that uncertainty about aggregate demand will translate into uncertainty about costs.

D.2 Price-setting

Given risk-neutral investors and the quadratic adjustment cost in prices, the problem of the firm is:

$$\mathbb{E}_0 \sum_{j=0}^{\infty} \beta^j \left[\left(\frac{P_i t + j}{P_{t+j}} \right)^{1-\epsilon} y_{t+j} - w_{t+j} \left(\frac{P_{i,t+j}}{P_{t+j}} \right)^{-\epsilon} y_{t+j} - \frac{\phi_p}{2} \left(\frac{P_{i,t+j}}{P_{i,t+j-1}} - 1 \right)^2 \right],$$

where $\phi_p > 0$ is the price adjustment-cost parameter.

Denote by P^*_t the optimal price in t. The firm's first-order condition is:

$$(1-\epsilon) \left(\frac{P^*_t}{P_t} \right)^{1-\epsilon} y_t + \epsilon w_t \left(\frac{P^*_t}{P_t} \right)^{-\epsilon} y_t - \phi_p \left(\frac{P^*_t}{P^*_{t-1}} - 1 \right) \frac{P^*_t}{P^*_{t-1}} + \beta \phi_p \mathbb{E}_t \left(\frac{P^*_{t+1}}{P^*_t} - 1 \right) \frac{P^*_{t+1}}{P^*_t} = 0.$$

In a symmetric equilibrium, $P_t = P^*_t$ in all periods, so

$$(1-\epsilon) y_t + \epsilon w_t y_t - \phi_p (\pi_t - 1)\pi_t + \beta \phi_p \mathbb{E}_t (\pi_{t+1} - 1)\pi_{t+1} = 0,$$

where $\pi_t = P_t/P_{t-1}$ is the gross inflation rate, with steady state $\pi = 1$. Iterating forward, evaluating in period 0, and using $\mathbb{E}_0 y_j = y$ and $\mathbb{E}_0 w_j = w$, we get:

$$\begin{aligned}
\phi_p(\pi_0 - 1)\pi_0 &= \mathbb{E}_0 \textstyle\sum_{j=0}^{\infty} \beta^j [(1-\epsilon)y_j + \epsilon w_j y_j] \\
&= \textstyle\sum_{j=0}^{\infty} \beta^j [(1-\epsilon)\mathbb{E}_0 y_j + \epsilon \mathbb{E}_0 w_j y_j] \\
&= \textstyle\sum_{j=0}^{\infty} \beta^j [(1-\epsilon)y + \epsilon \mathbb{E}_0 w_j y_j] \\
&= \textstyle\sum_{j=0}^{\infty} \beta^j [(1-\epsilon)y + \epsilon w y + \epsilon Cov\,(w_j, y_j)],
\end{aligned}$$

In the following, we will focus on solutions with a positive price level, that is on $\pi_0 > 0$. Then, we take advantage of the fact that $w = \frac{\epsilon-1}{\epsilon}$ and that, given (8), $Cov\,(w_j, y_j) = \chi Cov\left(y_j^{\phi}, y_j\right)$ to get

$$\phi_p(\pi_0 - 1)\pi_0 = \chi\epsilon \sum_{j=0}^{\infty} \beta^j Cov\left(y_j^{\phi}, y_j\right). \tag{9}$$

Note that $Cov(y_j^{\phi}, y_j) > 0$ as long as the support of y is restricted to the real line. Thus, an increase in uncertainty in future periods leads to a precautionary increase in prices in the period of the shock as long as marginal costs are positively correlated with demand ($\phi > 0$). In the main text, the general equilibrium effects generate that positive covariance: a fiscal volatility shock pushes down both aggregate demand and marginal costs. Equation (9) also shows that the effect will be the bigger, the more elastic demand is (the larger ϵ).

D.3 The effect of an uncertainty shock on inflation

We are ready now to state the following proposition.

PROPOSITION:

Consider the model above and two realizations A and B of the spread shock such that $\sigma_{y,t}^{0,A} > \sigma_{y,t}^{0,B}$ for all t. In other words, for every date t, the distribution of y_t under A is a mean-preserving spread of the distribution under B. Then,

1. For $\phi = 0$ (marginal costs are not correlated with demand), inflation π_0 is invariant to the spread shock: $\pi_0^A = \pi_0^B = 1$.

2. For $\phi > 0$ (marginal costs are positively correlated with demand), up to a second-order approximation $\pi_0^A > \pi_0^B > 1$. In other words, inflation is larger, the larger the uncertainty is.

3. For $\phi \in (0,1]$, the statement in item 2 can be shown without taking an approximation.

Proof. The proof goes through each case one by one.

1. For $\phi = 0$, $Cov(y_j^\phi, y_j) = 0$, so by equation (9), $\pi_0 = 1$.

2. For $\phi > 0$, $Cov(y_j^\phi, y_j) > 0$, so $\pi_0^A > 1$ and $\pi_0^B > 1$.

   Note that:

$$\begin{aligned} Cov_A(y_j^\phi, y_j) &= \textstyle\int_0^\infty y_j^{1+\phi} dF_A(y_j) - y \int_0^\infty y_j^\phi dF_A(y_j) \\ &\approx \textstyle\int_0^\infty \left[y^{1+\phi} + (1+\phi)y^\phi(y_j - y) + \frac{1}{2}(1+\phi)\phi y^{\phi-1}(y_j-y)^2\right] dF_A(y_j) \\ &\qquad \textstyle -y\int_0^\infty \left[y^\phi + \phi y^{\phi-1}(y_j-y) + \frac{1}{2}\phi(\phi-1)y^{\phi-2}(y_j-y)^2\right] dF_A(y_j) \\ &= \textstyle\phi\int_0^\infty (y_j-y)^2 dF_A(y_j) \quad \text{where } y = 1. \\ &= \phi V_A(y_j) \quad \text{ where } V() \text{ marks the variance.} \end{aligned}$$

   Now, a mean-preserving spread means $V_A(y_j) > V_B(y_j)$, which establishes the claim.

3. Last, some exact results.

   For $\phi = 1$, we have exactly that $Cov(y_j^\phi, y_j) = V(y_j)$, so π_0 will be larger, the bigger the variance of y_j, which will be the case with a mean-preserving spread.

   For $\phi \in (0,1)$ the proof proceeds by contradiction. Suppose that $\pi_0^A \leq \pi_0^B$. By (9), this requires $Cov_A(y_j^\phi, y_j) \leq Cov_B(y_j^\phi, y_j)$. This is the same as

$$\int_0^\infty y^{1+\phi} dF_A(y) - y\int_0^\infty y^\phi dF_A(y) \leq \int_0^\infty y^{1+\phi} dF_B(y) - y\int_0^\infty y^\phi dF_B(y),$$

   or

$$\underbrace{\int_0^\infty y^{1+\phi} dF_A(y) - \int_0^\infty y^{1+\phi} dF_B(y)}_{(a)} < y\underbrace{\left[\int_0^\infty y^\phi dF_A(y) - \int_0^\infty y^\phi dF_B(y)\right]}_{(b)}.$$

   If A is a mean-preserving spread of B, and $y \sim F_A(y)$, $x \sim F_B(x)$, then one can find some mean-zero distribution $H(z|x)$, such that $y = x + z$, with $z \sim H(z|x)$.

   Note that if $\phi \in (0,1)$, $y^{1+\phi}$ is convex on the support of y so

$$\begin{aligned} \textstyle\int_0^\infty y^{1+\phi} dF_A(y) &= \textstyle\int_0^\infty \int (x+z)^{1+\phi} dH(z) dF_A(B) \\ &> \textstyle\int_0^\infty (x + \int z dH(z))^{1+\phi} dF_B(x) = \int_0^\infty x^{1+\phi} dF_B(x), \end{aligned}$$

where the inequality follows from Jensen's inequality. So $(a) > 0$. Also, for $\phi \in (0, 1)$ y^{ϕ} is concave on the support of y, so $(b) < 0$ by Jensen's inequality. This contradicts the assumption $\pi_0^A \leq \pi_0^B$. So, $\pi_0^A > \pi_0^B (> 1)$.

∎

The previous proposition also indicates that the increase in inflation will be bigger, the more steeply marginal costs rise with output (the bigger χ and/or ϕ).

E Fiscal Volatility Shocks versus Fiscal Shocks

We compare, in figure 3, the IRFs to a fiscal volatility shock (solid black line) to the IRFs to a 25-basis-point fiscal shock to the capital tax rate (dotted red line). Note that in a fiscal shock, the tax rate goes up, while in a fiscal volatility shock, it is the variance of its future changes that goes up, while the tax rate itself does not move on impact (although it falls later because of the feedback from output to the tax rate).

A persistent shock to the capital tax rate implies that capital is less profitable in the short to medium run. Consequently, households reduce their investment. Higher taxes increase expected marginal costs, thus inducing an increase in inflation. Monetary policy responds with higher real interest rates that further curb economic activity. Simultaneously, the negative wealth effect leads households to supply more labor to compensate for lower capital income, which drives wages down. As the shock unfolds, investment and output continue their decline, as do wages. With lower capital and labor income, households reduce their consumption.

The effects of the fiscal shock are somewhat larger than the effects of the fiscal volatility shock. While the tax rate changes the returns to capital today, and hence has a first-order impact, fiscal volatility shocks work through households' and firms' expectations, a quantitatively weaker channel. Remember, though, that fiscal volatility shocks can induce a far larger contraction in the economy under the alternative, more pessimistic parameterizations in section 5.

It is informative to compare the size of these IRFs with those that other papers find. We do that with Leeper, Plante and Traum (2010), who look only at the federal government, and with Zubairy (2010), who aggregates all levels of the government, as we do. For government spending, we find

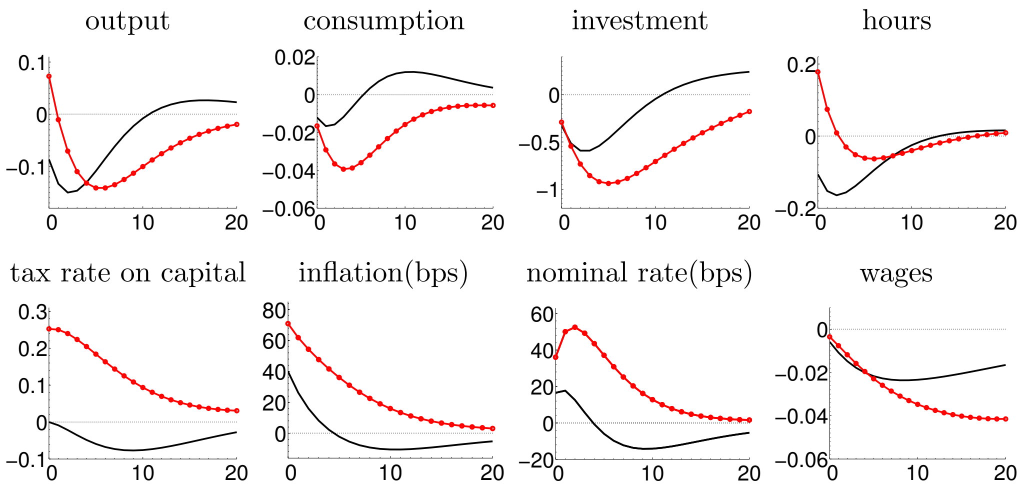

Figure 3: Fiscal volatility shock vs. 25 bps fiscal shock to the capital tax rate

Note: The solid black lines are the IFRs to a fiscal volatility shock. The dotted red lines are the IRFs to a 25-basis-point fiscal shock to the capital tax rate. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

that an increase of g/y by one percentage point raises output by just under one percentage point. In comparison, Leeper, Plante and Traum (2010) find that output rises by 0.7 percent, while Zubairy (2010) estimates that the increase is about 1.1 percent. For labor tax increases, a one percentage point increase in labor taxes reduces output 0.22 in Zubairy (2010), 0.11 in Leeper, Plante and Traum (2010), and in 0.10 in our model. For capital income and consumption tax increases, our results are stronger than the ones in these two papers, although within a wide range of estimates reported in the literature.

F Additional Analysis

In our final appendix, we present some additional robustness analysis: with respect to the role of the elasticity of demand and with respect to the role of price and wage rigidities.

F.1 The Role of the Elasticity of Demand

Figure 4 documents how the effect of a fiscal volatility shock on inflation is stronger, the larger the elasticity of demand, and, hence, the more curved the marginal profit function is. This effect does not appear, for instance, in the model's IRFs to monetary shocks: Those IRFs are roughly invariant to changes in the elasticity of demand (we omit plotting them in the interest of space).

This observation highlights that the role of the demand elasticity is due to the interaction of the curvature of the profit function with uncertainty, rather than to a level effect.

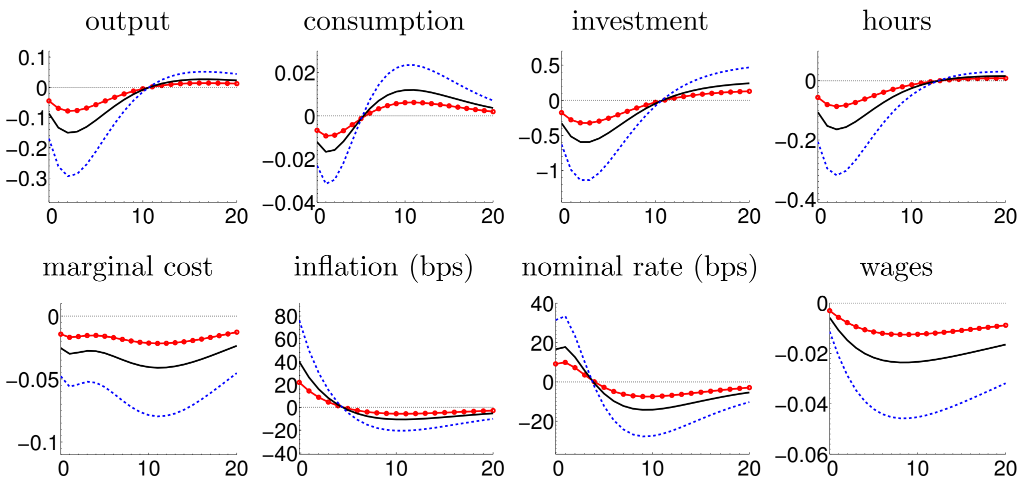

Figure 4: Fiscal volatility shock – effect of demand elasticity

Note: IRFs to a fiscal volatility shock when setting $\epsilon = 11$ (red line marked by dots, implying a steady-state markup of 10 percent), $\epsilon = 21$ (solid black line, a markup of 5 percent), and $\epsilon = 41$ (dashed blue line, a markup of 2.5 percent). The figure keeps the slope of the Phillips curve constant, adjusting ϕ_p accordingly as it varies the value of ϵ. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

F.2 The Role of Price and Wage Rigidities

In our last exercise, figure 5 shows how the degree of price and wage rigidity affects the impact of fiscal volatility shocks. The dashed blue line plots the IRFs when we reduce price stickiness to the one equivalent to a Calvo model with an average price duration of about one quarter. The response is both less pronounced and shorter-lived. The dotted red line reduces price and wage stickiness to the one equivalent to a Calvo model with an average price and wage duration of one quarter. In the absence of nominal rigidities, fiscal volatility shocks have only a negligible impact on economic activity. This finding resembles the results in the real models of Bloom (2009) and Bloom, Jaimovich and Floetotto (2008) that require irreversibilities at the individual firm level for generating a propagation of volatility shocks. At the same time, their findings suggest that irreversibilities could make the effects of fiscal volatility shocks still bigger.

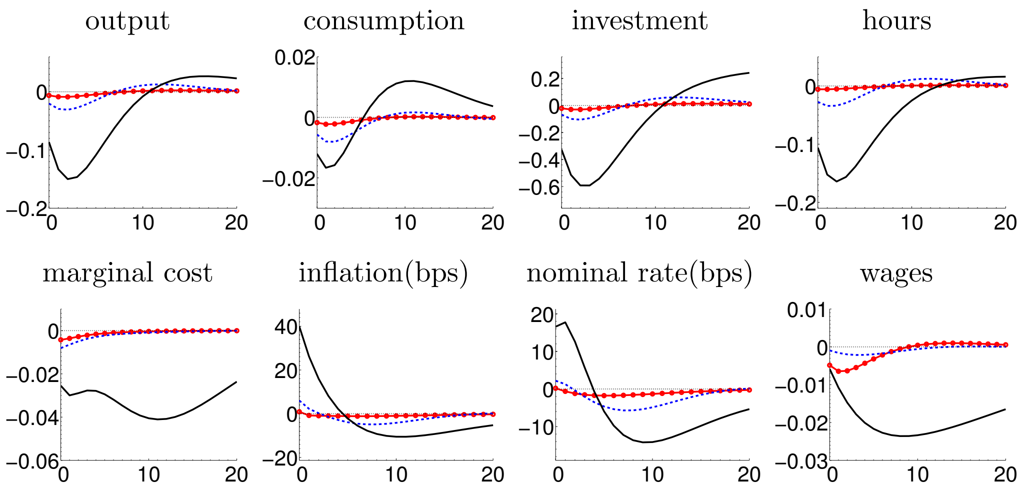

Figure 5: Fiscal volatility shocks – effect of price/wage rigidities

Note: The solid black lines are the IRFs to a fiscal volatility shock in the benchmark calibration. The dashed blue lines are the IRFs if price stickiness is equivalent to a Calvo parameter $\phi_p = 0.1$. The dotted red lines are the IRFs if price stickiness is equivalent to a Calvo parameter $\phi_p = 0.1$ and wage stickiness to a Calvo parameter $\phi_w = 0.1$. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

References

Aruoba, S. Boragan, Francis X. Diebold, and Chiara Scotti. 2009. "Real-Time Measurement of Business Conditions." *Journal of Business and Economic Statistics*, 27: 417–427.

Benati, Luca, and Paolo Surico. 2009. "VAR Analysis and the Great Moderation." *American Economic Review*, 99(4): 1636–52.

Blanchard, Olivier, and Roberto Perotti. 2002. "An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output." *Quarterly Journal of Economics*, 117(4): 1329–1368.

Bloom, Nicholas. 2009. "The Impact of Uncertainty Shocks." *Econometrica*, 77(3): 623–685.

Bloom, Nicholas, Nir Jaimovich, and Max Floetotto. 2008. "Really Uncertain Business Cycles." *Stanford University mimeo.*

Bohn, Henning. 1998. "The Behavior of U.S. Public Debt and Deficits." *Quarterly Journal of Economics*, 113(3): 949–963.

Braun, R. Anton. 1994. "Tax Disturbances and Real Economic Activity in the Postwar United States." *Journal of Monetary Economics*, 33(33): 441–462.

Christiano, Lawrence, and Terry Fitzgerald. 2003. "The Band Pass Filter." *International Economic Review*, 44: 435–465.

Fernández-Villaverde, Jesús, Pablo Guerrón-Quintana, Juan Rubio-Ramírez, and Martín Uribe. 2011. "Risk Matters: The Real Effects of Stochastic Volatility Shocks." *American Economic Review*, 101: 2530–61.

Galí, Jordi, and Roberto Perotti. 2003. "Fiscal Policy and Monetary Integration in Europe." *Economic Policy*, 18(37): 533–572.

Hurwicz, Leonid. 1962. "On the Structural Form of Interdependent Systems." *Studies in Logic and the Foundations of Mathematics*, 44: 232–239.

Jones, John Bailey. 2002. "Has Fiscal Policy Helped Stabilize the Postwar U.S. Economy?" *Journal of Monetary Economics*, 49: 709–746.

Lane, Philip R. 2003. "The Cyclical Behaviour of Fiscal Policy: Evidence from the OECD." *Journal of Public Economics*, 87(12): 2661–2675.

Leeper, Eric, Michael Plante, and Nora Traum. 2010. "Dynamics of Fiscal Financing in the United States." *Journal of Econometrics*, 156(2): 304–321.

McGrattan, Ellen R. 1994. "The Macroeconomic Effects of Distortionary Taxation." *Journal of Monetary Economics*, 33(3): 573–601.

Mendoza, Enrique G, Assaf Razin, and Linda L Tesar. 1994. "Effective Tax Rates in Macroeconomics – Cross-country Estimates of Tax Rates on Factor Incomes and Consumption." *Journal of Monetary Economics*, 34: 297–323.

Mountford, Andrew, and Harald Uhlig. 2009. "What Are the Effects of Fiscal Policy Shocks?" *Journal of Applied Econometrics*, 24(6): 960–992.

Ramey, Valerie A. 2011. "Identifying Government Spending Shocks: It's All in the Timing." *Quarterly Journal of Economics*, 126(1): 1–50.

Ramey, Valerie A, and Matthew Shapiro. 1998. "Costly Capital Reallocation and the Effects of Government Spending." *Carnegie Rochester Conference on Public Policy*, 48(1): 145–194.

Roberts, G O, A Gelman, and W R Gilks. 1997. "Weak Convergence and Optimal Scaling of Random Walk Metropolis Algorithms." *Annals of Appplied Probability*, 7: 110–120.

Romer, Christina D, and David H Romer. 2010. "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks." *American Economic Review*, 100: 763–801.

Zubairy, Sarah. 2010. "On Fiscal Multipliers: Estimates from a Medium Scale DSGE Model." *Bank of Canada Working Paper 2010-30.*