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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. Fiscal deficits and public debt have risen sharply in the wake of the financial crisis. While these developments make fiscal consolidation inevitable, there is considerable uncertainty about the policy mix and timing of such budgetary adjustment. To evaluate the consequences of this increased uncertainty, we first estimate tax and spending processes for the U.S. that allow for time-varying volatility. 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 have an adverse effect on economic activity that is comparable to the effects of a 25-basis-point innovation in the federal funds rate.

Keywords: DSGE models, Uncertainty, Fiscal Policy, Monetary Policy.
JEL classification numbers: E10, E30, C11.

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"Expectations of large and increasing deficits in the future could inhibit current household and business spending — for example, by reducing confidence in the longer-term prospects for the economy or by increasing uncertainty about future tax burdens and government spending — and thus restrain the recovery. " (Ben S. Bernanke, 10/04/2010)

"The tax changes required to balance the budget in the future could be modest or enormous, depending on what happens to spending." (Christina Romer, 12/04/2010)

"The restraining effects of [fiscal] policy uncertainties are repeated frequently and with great vehemence. In my opinion, a first priority is that government authorities bring clarity to matters central to business planning." (Dennis P. Lockhart, 11/11/2010)

1 Introduction

The global financial crisis has strained public finances in the U.S. and in other industrialized countries: fiscal deficits remain exceptionally high and sovereign debt is growing fast. Despite the paralysis of many governments, a dire fiscal consolidation seems inevitable. However, as plainly illustrated by the prolonged struggle between the President and Congress regarding the debt limit during the summer of 2011, there exists little consensus among policymakers about both the fiscal mix and the timing of such an adjustment. Will it happen mainly through cuts in government spending or through higher taxes? And if through higher taxes, 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 this increased uncertainty about the mix and timing of fiscal austerity has a detrimental impact on current business conditions through its effect on the expectations and behavior of households and firms.[1] This investigation is important because, while the quotes above demonstrate that heightened fiscal policy uncertainty has clearly been a concern of policymakers, there is not much work in macroeconomics that measures its actual importance on economic activity. (Barro (1989) is an early attempt to describe the impact that fiscal uncertainty may have on real activity.)

To fill this gap, we first estimate tax and spending processes for the U.S. that allow for time-variant volatility. We interpret the changes in the volatility of the different fiscal instruments as an intuitive representation of the variations in fiscal policy uncertainty, that is, of the variations in uncertainty about the future path of fiscal policy.The estimated rules discipline our modeling exercise by forcing the evolution of volatility to follow its historical variation.

In a second step, we feed the estimated rules into an otherwise standard medium-sized New Keynesian business cycle model similar to those in Christiano *et al.* (2005) or Smets and Wouters

[1] In this work, and following the literature, we use the term "uncertainty" as shorthand for what would more precisely be referred to as "objective uncertainty" or "risk."

(2007). We calibrate the model to replicate observations of the U.S. economy and we simulate the equilibrium using a non-linear solution method (which is essential, since time-varying volatility is an inherently non-linear process that would disappear in a linerarization). In particular, we compute impulse response functions to fiscal volatility shocks (to be defined precisely below) that capture the idea of a burst in fiscal policy uncertainty.

Our main results are as follows:

1. Fiscal volatility shocks reduce economic activity: aggregate output, consumption, investment, and hours worked drop on impact and stay low for several quarters. The main transmission mechanism is through a fall in investment triggered by higher uncertainty about future returns on capital.

2. An increase in fiscal policy uncertainty of two standard deviations (for example, as happened around the "Reagan revolution" of the 1980s) has an effect similar to a 25-basis-point innovation in the federal funds rate.

3. An alternative comparison of the impact of the previous fiscal volatility shock can be made with the recent exercise in quantitative easing. The effects that we compute have roughly the same size (but opposite sign) as the effects of quantitative easing estimated by Hamilton (2008) and Hamilton and Wu (2010).

4. Heightened fiscal policy uncertainty is "stagflationary": it creates inflation while output falls. Fiscal volatility shocks mean a higher chance of a large change in tax policy. This makes marginal costs harder to predict. In particular, it raises the risk that firms will face much higher marginal costs in the future. In addition, an increase in fiscal policy uncertainty also raises the volatility of demand, which means that firms stand to lose more by making mistakes in pricing. In our model, this leads firms to take a cautionary approach, opting for higher prices, since prices too high ex post have less impact on profits than prices too low ex post.

5. Most of the effects of fiscal volatility shocks work through the larger uncertainty about the future tax rate on capital income.

Although the size of these effects may not seem exceptionally big, we think about them as a sensible lower bound on the importance of fiscal volatility shocks. We document much bigger effects in several counterfactuals. For example, eliminating the role of automatic stabilizers in the estimated fiscal rules or increasing the persistence of the fiscal volatility shocks multiplies the effects by 5 to 6 times. Furthermore, we do not include additional amplification mechanisms, such as irreversible investment (Bloom (2009)) or financial frictions (Christiano *et al.* (2010)), which have been shown to be important in other contexts when uncertainty plays a role and that, most likely, would further increase the results of fiscal volatility shocks.

More to the point, we do not claim that, in an average quarter of the U.S. economy, fiscal volatility shocks are a particularly key driver of the business cycle. We claim, instead, that there are a number of situations in the data, such as during the mid-1970s, the early 1980s, and most recently, in 2008-2009, where fiscal volatility shocks may have played an important role in determining aggregate fluctuations. In particular, if we eliminate the role of automatic stabilizers and consider a situation with very persistent fiscal volatility shocks (a not unreasonable description of the current situation in Washington), these can generate falls in output of 0.5 percent.

We perform a number of additional exercises to reinforce our message. First, we compare fiscal volatility shocks with fiscal shocks. Second, we show how an accommodative monetary policy, far from helping to reduce the effects of fiscal volatility shocks, increases them even more. We find, interestingly, that a stronger focus of monetary policy on inflation, rather than on employment, alleviates the negative outcomes of fiscal volatility shocks on economic activity. Third, we study how changing the degree of nominal rigidities affects the impact of fiscal volatility shocks and how eliminating depreciation allowances noticeably increases the shocks' consequences. This last result suggests that more distortionary tax systems exacerbate the importance of fiscal volatility shocks.

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 different types of volatility shocks interact with aggregate variables. Bloom (2009) demonstrates that volatility shocks in productivity at the firm level can induce decision makers to delay investment decisions, which results in a contraction in output. Fernández-Villaverde *et al.* (2011) use a small open economy model to document how volatility shocks in country spreads can generate recessions. Other examples include Basu and Bundick (2011), Arellano *et al.* (2010), Baker and Bloom (2011), Bloom *et al.* (2008), and Bachmann and Bayer (2009).[2]

In addition, we are also linked to a long tradition in economics that studies the impact of uncertainty about future prices and demand on investment decisions. One channel emphasized by the literature is that, in many settings, the marginal revenue product of capital is convex in the price of output. Then, higher uncertainty – general equilibrium effects apart – increases the expected future marginal revenue and thus investment (see, among others, Hartman (1972), Abel (1983), and Caballero (1991)). A second channel operates through the real options effect that arises with adjustment costs. If investment can be postponed, but is partially or completely irreversible once put in place, waiting for the resolution of uncertainty before committing to

[2] After circulating the draft of this paper, we have been made aware of related work by Born and Peifer (2011), who are also concerned with measuring the effect of fiscal policy uncertainty.

investing has a positive call option value. Thus a real options effect means that uncertainty depresses economic activity (see Pindyck (1988)).

A difference between our paper and some of the previous papers is our emphasis on the relevance of general equilibrium effects through changes in the rental rate of capital and wages. Indeed, in earlier work Pindyck (1993) stresses that price effects can reduce investment activity if aggregate uncertainty increases, and Craine (1989) highlights the connection of aggregate uncertainty and investment activity through the stochastic discount factor.

Naturally, since taxes affect both the revenue and the costs of firms, as well as the income streams of households, the consequences of the level of tax uncertainty for investment and labor supply decisions of households have been extensively studied as well. Notable contributions include Barro (1989), Bizer and Judd (1989), Dotsey (1990), Alm (1988), and, more recently, Bi *et al.* (2011).

The remainder of the paper is structured as follows. Section 2 estimates the tax and spending processes that form the basis for our quantitative analysis. Section 3 discusses the model and section 4 its calibration and solution. Sections 5 to 7 present the main results and several additional experiments. We also report in section 8 a number of robustness exercises. We close with some final remarks. An appendix reports details regarding the construction of the data.

2 Fiscal Policy Rules with Time-Varying Volatility

In this section, we estimate fiscal policy rules with time-varying volatility using time-series data. Later, we will rely on these estimated rules to discipline our quantitative exercise in section 3.

There are, at least, two alternatives to our approach. First, the direct use of agents' expectations. 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 because of the intricacies of the tax code. We cannot, therefore, rely on cross-sectional 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 policy rules. However, the sheer size of the state space in that exercise would make the strategy too challenging for practical implementation. Thus, we prefer our approach to any of these two alternatives.

2.1 Our Data

Before estimating the rules, we build a data sample of average tax rates and spending of the consolidated government sector (federal, state, and local) at quarterly frequency that goes from 1970.Q1 to 2010.Q2. The tax data are constructed from the national accounts as in Leeper *et al.* (2010). See Appendix A for details. Government spending is the ratio of government consumption expenditures and gross investment to output, also taken from the national accounts (we do not model, in the current paper, the time-varying volatility of transfers). The debt series is federal debt held by the public recorded in the St. Louis Fed's FRED database.

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
2010Q2	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.

Table 1 reports summary statistics of our sample. The first row displays sample averages and the second row the latest reading (2010.Q2). In 2010, government spending was above its historical average while tax rates were somewhat lower. Most important, government debt exceeded its historical average of 36 percent of output by 24 percentage points. Observers such as the OECD (2010) have forecast further steep increases of public debt ahead. This budgetary mismatch will need to be eventually resolved either by cutting expenditure, by raising taxes, or through a combination of the two.[3] However, the timing and the policy mix that will achieve the fiscal consolidation remain uncertain. This is the phenomenon that we aim to capture, in part, by the time-varying volatility in the law of motion of the fiscal instruments that we introduce next.

2.2 Law of Motion for Fiscal Policy Instruments

We 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:

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

for $x \in \{\tilde{g}, \tau_l, \tau_k, \tau_c\}$. Above, $\tilde{y}_{t-1}$ is lagged detrended output, $\tilde{g}$ is the average government spending, τ_x is the mean of the tax rate, and b_t is public debt (with target level b).

[3] Alternatively, it may be resolved through strong economic growth. Since the required growth rates to balance the budget without further action are unreasonably high, we do not entertain this possibility in our analysis.

Equation (1) allows for both automatic stabilizers ($\phi_{\tau_x,y} > 0$ and $\phi_{\tilde{g},y} < 0$) and a debt-stabilizing role of the fiscal instruments ($\phi_{\tau_x,b} > 0$ and $\phi_{\tilde{g},b} < 0$). This structure follows Bohn (1998), who models the primary fiscal surplus as an increasing function of the debt-output ratio, correcting for war time spending and cyclical fluctuations. Below, we will compare our fiscal rules with the literature in more detail.

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:

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

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 likely 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 parameter σ_x determines 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} determines its persistence. A value of $\sigma_{\tau_k,t} > \sigma_{\tau_k}$, for example, implies that the range of possible future capital tax rates is larger than usual. Variations of $\sigma_{x,t}$ over time, in turn, will depend on the size of 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, for instance, agents' perceptions about likely movements of the tax rate are more spread out in either direction. Stochastic volatility offers an intuitive modeling of such changes. Bloom (2009), Bloom *et al.* (2008), and Fernández-Villaverde *et al.* (2011) 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 additional parameters for each irnstrument (ρ_{σ_x} and η_x). At the same time, it is flexible enough to capture important features of the data and it is simple to enrich it, as we will do later, with further elements such as correlated innovations.

Our fiscal shocks 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. Indeed, there may be fiscal shock innovations even if no new legislation alters the tax code. Examples we have in mind 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. We now turn to our estimates.

2.3 Estimation

Our baseline specification focuses on the case that we have both automatic stabilizers and a debt-stabilizing role of fiscal instruments. This means that we impose $\phi_{\tau_\bullet,\bullet} \geq 0$ and $\phi_{\tilde{g}_\bullet,\bullet} \leq 0$. In some of the robustness exercises below, we will suppress either one or both of the feedback terms and consider two alternative specifications. In a first exercise, we will set $\phi_{x,y} = 0$ and call this specification *fiscal policies with partial feedback*. Second, we will set both $\phi_{x,y} = 0$ and $\phi_{x,b} = 0$ and call this specification *fiscal policies without feedback*.

Before proceeding, we set the means for taxes and expenditures in equation (1) to the average values reported in table 1. Then, we estimate the rest of the parameters in equations (1) and (2) using a likelihood-based approach. The non-linear interaction between the innovations to fiscal shocks and their volatility shocks complicates this task. We overcome this problem by using the particle filter as described in Fernández-Villaverde *et al.* (2010). We follow a Bayesian approach to inference by combining the likelihood function with a prior and sampling from the posterior with a Markov Chain Monte Carlo.

In the estimation, we entertain flat priors over the respective 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 from pre-sample information. Second, the discussion in Fernández-Villaverde *et al.* (2011) illustrates 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, given the parsimonious nature of the fiscal rules, 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 *et al.* (1997). Each evaluation of the likelihood was performed using 10,000 particles.

Table 2 reports estimates of the posterior median along with 95 percent probability intervals. The tax rates and government spending are estimated to be quite persistent. Importantly for our exercise, time-varying volatility is significant; see the estimates reported in row "η_x." Except for labor income taxes, episodes of deviation from average volatility last for some time; see the significantly positive estimates in row "ρ_{σ_x}," although that persistence is not identified as precisely as the persistence of the fiscal shocks.

Table 2: Posterior Median Parameters – baseline specification

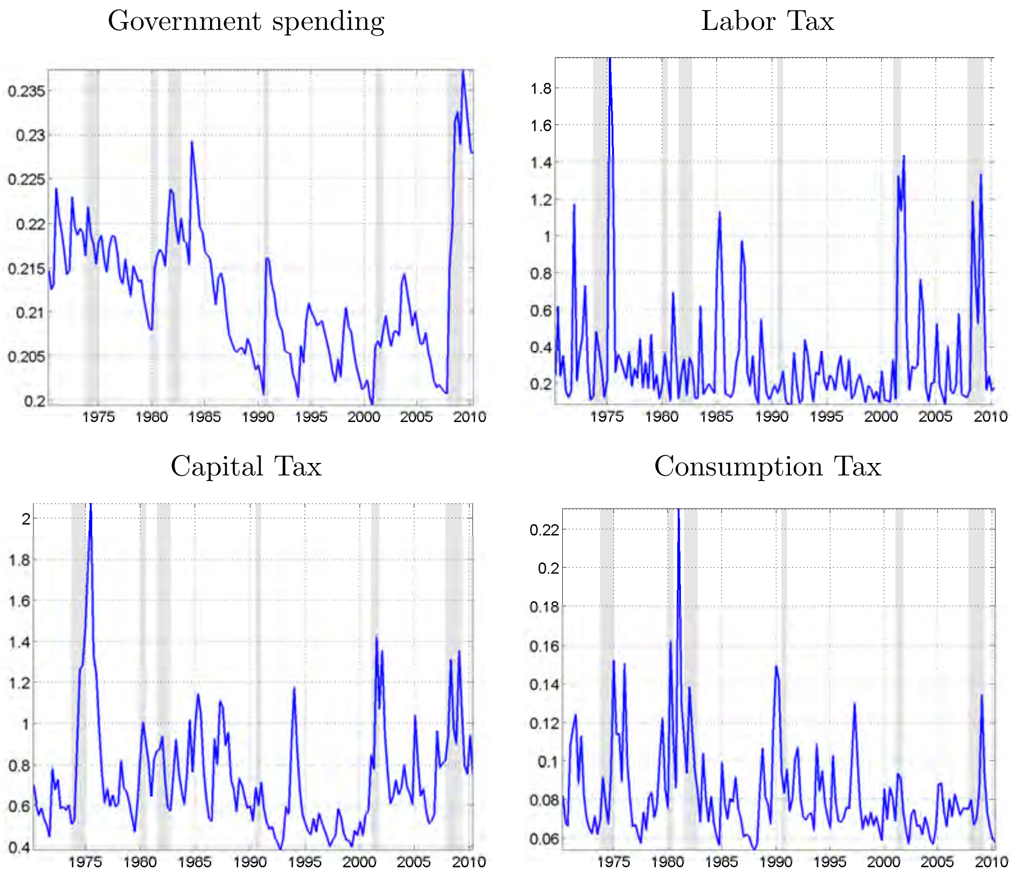
	Tax rate on			Government
	Labor	Consumption	Capital	Spending
ρ_x	0.9919 [0.976,0.999]	0.9946 [0.982,0.999]	0.9668 [0.93,0.996]	0.9710 [0.949,0.994]
σ_x	−6.005 [−6.29,−5.72]	−7.107 [−7.36,−6.81]	−4.962 [−5.26,−4.58]	−6.144 [−6.46,−5.54]
$\phi_{x,y}$	0.0709 [0.025,0.125]	0.0023 [0.001,0.011]	0.1005 [0.007,0.252]	−0.009 [−0.04,0.00]
$\phi_{x,b}$	0.0033 [0.00,0.007]	0.0006 [0.00,0.002]	0.0048 [0.00,0.016]	−0.0082 [−0.013,−0.003]
ρ_{σ_x}	0.3010 [0.06,0.55]	0.6248 [0.34,0.90]	0.7659 [0.48,0.93]	0.9251 [0.34,0.99]
η_x	0.9454 [0.74,1.18]	0.6017 [0.32,0.93]	0.5758 [0.34,0.89]	0.1804 [0.06,0.45]

Notes: For each parameter, the posterior median is given and a 95 percent probability interval (in parenthesis).

To put these numbers into context, let us, momentarily, concentrate on the estimates for the law of motion of capital taxes in the third column in table 2. 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, if we observe 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 only by 0.70 percentage point as would be the case if the fiscal volatility shock did not happen). The half-life of that change to the tax rate is 20 quarters ($\rho_{\tau_k} = 0.97$). As a result, the persistence in the fiscal shock propagates the effects generated by the fiscal volatility shock.

Conditional on our median estimates, 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 in the figure can be interpreted as percentage points of the respective fiscal instrument. More precisely, 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 reform coincided with times of a high fiscal 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). Interestingly, these latter bursts of volatility happened during expansions. Our estimates reveal that fiscal volatility shocks to all instruments were typically higher during recessions (for instance 1981-1982). Based on our estimates, the

Figure 1: Smoothed fiscal volatilities, $\sigma_{x,t}$

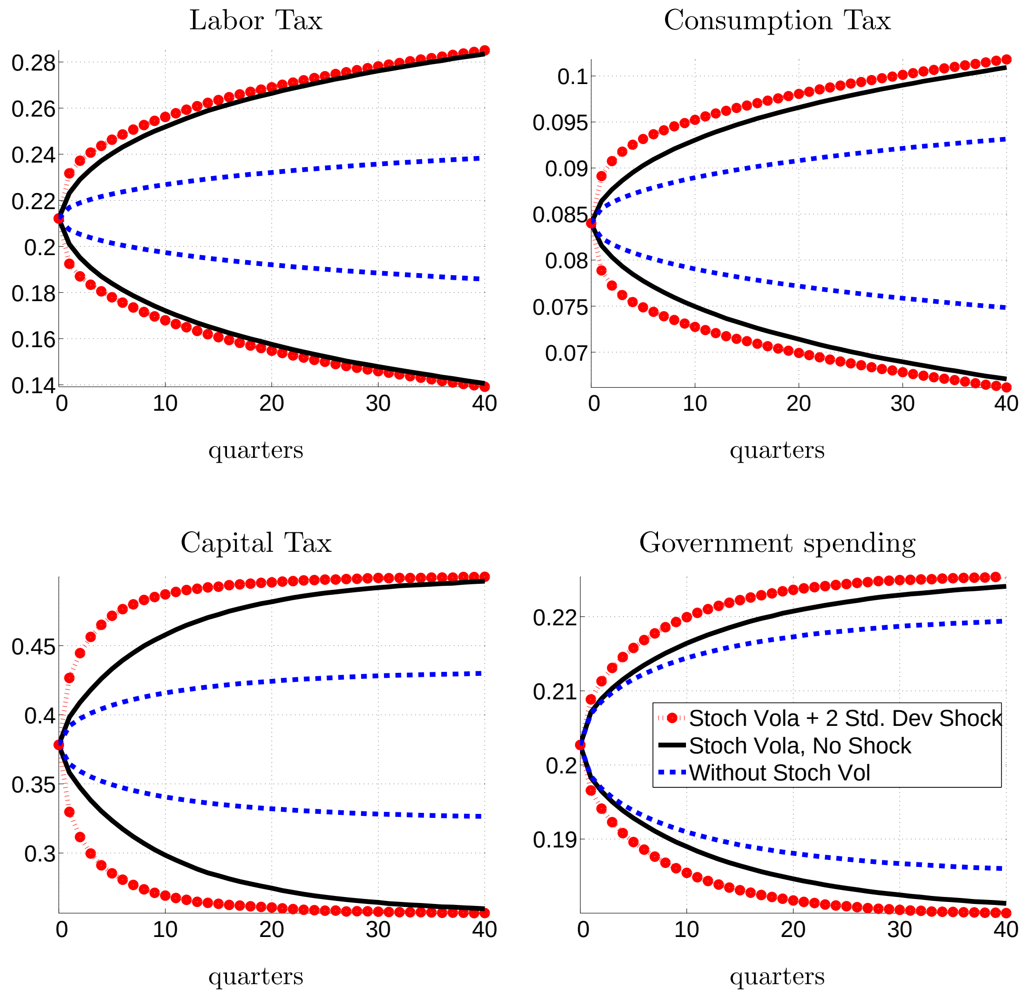


Notes: Volatilities expressed in percentage points.

level of fiscal volatility that agents faced during the latest recession is commensurate with the volatility that prevailed in the early 1980s. In sum, fiscal policy in the U.S. does display quantitatively significant time-varying volatility.

Figure 2 shows how this time-varying volatility translates into changes in expected fiscal policy paths. The figure shows the 95 percent confidence intervals for future tax rates and government spending. In each panel, we set $\phi_{x,b} = \phi_{x,y} = 0$ for all the fiscal instruments. 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 stay at their mean for the whole simulation. It is apparent how stochastic volatility increases the uncertainty around future fiscal policy. 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 both processes, the

Figure 2: Dispersion of future fiscal instruments



Notes: 95 percent confidence intervals for forecasts made at period 0 for fiscal instruments up to 40 quarters ahead. Solid black line: baseline specification. Red dots: baseline specification with a two-standard-deviation fiscal volatility shock innovation to all instruments in period 0. Dashed blue line: specification with constant volatility held fixed at the steady-state value.

red dots and black lines converge after some time.

2.4 Robustness of the Estimates

While reading our previous results, we must remember that the literature has not yet reached a consensus on how to specify fiscal rules or on how to interpret the result from their estimation. As Barro and Redlick (2010) put it "The empirical evidence on the response of real GDP and other economic aggregates to changes in government purchases and taxes is thin." Similarly, Perotti (2007) argues that "perfectly reasonable economists can and do disagree on the basic theoretical effects of fiscal policy and on the interpretation of the existing empirical evidence."

Although we feel comfortable that our specification of fiscal rules is a good mechanism for estimating the effects we are interested in, we need to address the implications of the lack of consensus we just described. We do it 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 business cycle model, is independent of the details of our specification. Researchers who prefer other forms for the fiscal rules just need to follow the steps laid down in the paper: estimate their favorite rules and check, as we will do in the next sections, how important the time-varying volatility of those fiscal rules is. Second, we assess the robustness of our estimated volatility components as we entertain different assumptions. Summing up these experiments, we find our estimates to be remarkably robust. Thus, we can consider the innovations that we back up in our fiscal rules as structural in the sense of Hurwicz (1962), that is, as invariant to the class of policy interventions that we are interested in.

Instead of reviewing all the robustness exercises, for clarity, we focus here on how to control for the endogeneity of fiscal instruments, perhaps the biggest bone of contention in the literature. The interested reader can find additional exercises in section 7, where we explore the role of anticipation in fiscal shocks.

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 easily think about it 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) business conditions index of the Federal Reserve Bank of Philadelphia (Aruoba *et al.* (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. Below, in section 5, we will document how most of the action in the model comes from shocks to this instrument.

We estimate three 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 fiscal rule 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:

$$\tau_{k,t} - \tau_k = \rho_{\tau_k}(\tau_{k,t-1} - \tau_k) + \phi_{\tau_k,ads} ads_t + \phi_{\tau_k,b}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) + \exp(\sigma_{\tau_k,t})\varepsilon_{\tau_k,t},\ \varepsilon_{\tau_k,t} \sim \mathcal{N}(0,1). \tag{3}$$

The dynamics of $\sigma_{\tau_k,t}$ are the same as in equation 2.

Table 3 compares the estimates of the baseline specification (row labeled 0) with the three 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.[4] Thus, we infer that endogeneity is not a major concern in our baseline specification once we control for lagged (detrended) output and that we can safely use our estimated rules as a component in our business cycle model below.

Table 3: Posterior Median Parameters – Fiscal Rules with ADS Index

	Volatility Parameters			Level 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]	0.37 [0.22,0.57]	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]	0.38 [0.29,0.52]	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]	0.34 [0.18,0.56]	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]	0.34 [0.25,0.48]	0.96 [0.93,0.99]	0.002 [0.001,0.003]	0.004 [0.001,0.014]

Notes: Row 0 is the baseline 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 parenthesis).

Another potential criticism is that our estimates of the tax rules are based on average tax rates rather than on marginal tax rates, say, averaged over the population, which are employed in some of the literature, such as in Barro and Sahasakul (1983) and Barro and Sahasakul (1986). To the extent that the tax code for labor and capital taxes is progressive, we may therefore underestimate the extent to which the respective tax rates are distortionary in the first place. 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 underestimate the detrimental effect of

[4] 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.

fiscal volatility shocks. To check that hypothesis, we could estimate our fiscal rules using the update of the Barro-Sahasakul measure of average marginal income tax rates provided in Barro and Redlick (2010). These measures include both federal income tax rates (individual income tax rates and Social-Security payroll taxes) as well as state income tax rates. Unfortunately, the Barro and Redlick (2010) data are available only through 2006, which would preclude us from analyzing the current episode of increased uncertainty and it only covers, in its current version, labor income (and, as we have already argued, our results below work mainly through taxes on capital income). In addition, the frequency of the data is annual, which complicates the estimation of time-varying volatility as these type of processes usually operate at higher frequencies.

2.5 Comparison with the Literature

Now, we compare our estimated fiscal rules with the previous work in the literature. Our paper is closest to Leeper *et al.* (2010), who estimate a linearized RBC model with fiscal rules for several instruments without stochastic volatility. These rules allow for feedback from output and the debt level and simultaneous shocks to the instruments.[5] The main difference between that paper and ours is that it estimates the model and the fiscal rules simultaneously. While there may be efficiency gains, Leeper *et al.* (2010) can do that because they linearize their model and, hence, can evaluate the likelihood function with the Kalman filter. As we argued above, stochastic volatility is inherently a non-linear process that cannot be linearized. A simultaneous estimation using likelihood-based methods of a non-linear business cycle model solved up to third-order 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 as in, for example, Bohn (1998). Thus, it is hard to compare most of the estimated rules with our specification.[6]

Nevertheless, and because of its influence in the literature, of particular interest is Galí and Perotti (2003), who study the cyclically adjusted primary deficit d_t for OECD countries. On annual data, they estimate a rule for d_t using output gap x_t and debt b_t of the form:

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

[5] Leeper *et al.* (2010) build on early contributions by Braun (1994), McGrattan (1994), and Jones (2002). McGrattan uses maximum likelihood to estimate an RBC model with exogenous stochastic processes for fiscal instruments. Braun follows a similar approach but using GMM. Jones estimates fiscal rules for government spending, capital, and labor taxes by means of GMM and allows for contemporaneous feedback to output and employment, as well as a number of lags of these and the dependent variable. His model, however, assumes balanced budgets, achieved through lump-sum taxes. As a result, he does not have debt as a feedback variable.

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

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 that isolates exogenous shocks to expenditure (Ramey and Shapiro (1998) and Ramey (2011)) or taxes (Romer and Romer (2010)). In contrast with the aforementioned papers, we do not aim to identify the entire fiscal transmission process in the data and we do not intend to use our estimates to conduct inference about the rigidities that prevail in the economy. Rather, we estimate fiscal rules that we consider one reasonable representation of the fiscal policymakers' behavior. We then examine how fiscal volatility shocks in these rules affect economic activity in a standard New Keynesian model. Therefore, we do not require to impose additional identification restrictions, the details of which unfortunately have been shown to be important in determining the innovations that VARs recover.

3 Model

Motivated by our previous findings, we build a business cycle model to examine whether our estimated processes for fiscal uncertainty translate into aggregate effects. We adopt a standard New Keynesian model in the spirit of Christiano *et al.* (2005) or Smets and Wouters (2007) and extend it to allow for fiscal policy. Since this model is the basis of much applied analysis at policymaking institutions, it is the natural environment for our investigation.

The structure of the model is as follows. There is a representative household that works, consumes, and invests in capital and government bonds. The household sets wages for differentiated types of labor input subject to nominal rigidities. A continuum of monopolistically competitive firms 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 nominal rigidities. The final good used for investment and consumption is competitively produced by a firm that aggregates all intermediate goods. The government taxes labor and capital income and consumption and engages in public spending following the laws of motion estimated in section 2. The model is closed by a monetary authority that steers the short-term nominal interest rate following the prescriptions of a Taylor rule.

3.1 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. The economy is populated by a representative household whose preferences are separable in consumption, c_t, and labor of the form:

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

The household consists of a unit mass of members who supply differentiated types of labor $l_{j,t}$, as in Erceg *et al.* (2000). $\mathbb{E}_0$ 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 physical assets, i_t, and hold government bonds, B_t, that pay a nominal gross interest rate of R_t in period $t+1$. Then $b_t = B_t/P_t$ is the real value of those bonds at the end of the period and $b_{t-1}\frac{R_{t-1}}{\Pi_t}$ the real value at the start of the period of the bonds bought last period (before interest payments), where P_t is the price level and $\Pi_t = P_t/P_{t-1}$ is the inflation rate between periods $t-1$ 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. Capital tax is levied on capital income defined as the rental rate of capital $r_{k,t}$ times its utilization rate u_t times the amount of capital owned by the household k_{t-1}. There is a depreciation allowance for the book value of capital, k_{t-1}^b. Finally, the household receives its share of the profits of the firms in the economy F_t. Hence, the household's budget constraint is given by:

$$\begin{aligned} &(1+\tau_{c,t})c_t + i_t + b_t + \Omega_t + \int_0^1 AC_{j,t}^w dj \\ &= (1-\tau_{l,t}) \int_0^1 w_{j,t} l_{j,t} dj + (1-\tau_{k,t})\, r_{k,t} u_t k_{t-1} + \tau_{k,t}\delta k_{t-1}^b + b_{t-1}\frac{R_{t-1}}{\Pi_t} + F_t. \end{aligned} \tag{4}$$

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 and y_t is aggregate output. We prefer this á la Rotemberg wage setting mechanism over the more common Calvo setting because it is a more natural framework to think about the responses of the agents to fiscal volatility shocks. In a Calvo world, we would have many wages stuck at old levels that cannot react whatsoever to the changes in volatility.[7] Aggregate output appears in the adjustment cost function to scale it.

The different types of labor $l_{j,t}$ are aggregated by a labor 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 labor 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. 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

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

The capital accumulated by the household at the end of period t is given by:

$$k_t = (1 - \delta(u_t))\, k_{t-1} + \left(1 - S\left[\frac{i_t}{i_{t-1}} \right] \right) i_t$$

where $\delta(u_t)$ is the depreciation rate that depends on the utilization rate according to

$$\delta(u_t) = \delta + \Phi_1(u_t - 1) + \frac{1}{2}\Phi_2(u_t - 1)^2. \tag{5}$$

Here, Φ_1 and Φ_2 are strictly positive. We assume a standard quadratic adjustment cost:

$$S\left[\frac{i_t}{i_{t-1}} \right] = \frac{\kappa}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2,$$

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 highly stylized. However, it is important to incorporate the observation that, in the U.S. tax system, 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

[7] We will derive a non-linear solution of the model and, hence, the two settings are not equivalent, as would be the case in a standard linearization without inflation in the steady state. In any case, our choice is not particularly consequential. We also computed the model with Calvo pricing and we obtained, with our baseline calibration, very similar results.

value of the capital stock employed in production differs from the book value of capital used to compute tax depreciation allowances.[8]

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 (5). Thus, the depreciation allowance in period t is given by $\delta k^b_{t-1}\tau_{k,t}$, where k^b_t is the book value of the capital stock that evolves according to

$$k^b_t = (1-\delta)k^b_{t-1} + i_t.$$

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^b_t, and i_t can be written as:

$$\begin{aligned}
\frac{d_t}{(c_t - b_h c_{t-1})^\omega} - \mathbb{E}_t \frac{b_h \beta d_{t+1}}{(c_{t+1} - b_h c_t)^\omega} &= \lambda_t (1+\tau_{c,t}), \\
\phi_w y_t \left(\tfrac{w_t}{w_{t-1}} - 1\right)\tfrac{w_t}{w_{t-1}} &= \mathbb{E}_t \left\{\beta \tfrac{\lambda_{t+1}}{\lambda_t}\phi_w y_{t+1}\left(\tfrac{w_{t+1}}{w_t} - 1\right)\tfrac{w_{t+1}}{w_t}\right\} \\
&\quad + \left[\tfrac{d_t}{\lambda_t}\varphi_t \psi \epsilon_w (l^d_t)^{1+\vartheta} - (\epsilon_w - 1)(1-\tau_{l,t}) w_t l^d_t\right], \\
\lambda_t &= \beta \mathbb{E}_t \left\{\lambda_{t+1}\frac{R_t}{\Pi_{t+1}}\right\}, \\
r_{k,t}(1-\tau_{k,t})\lambda_t &= q_t \delta'[u_t], \qquad (6) \\
q_t &= \mathbb{E}_t \left\{\beta \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\delta[u_{t+1}])q_{t+1} + (1-\tau_{k,t+1}) r_{k,t+1} u_{t+1}\right]\right\}, \\
q^b_t &= \mathbb{E}_t \left\{\beta \frac{\lambda_{t+1}}{\lambda_t}\left[(1-\delta)q^b_{t+1} + \delta \tau_{k,t+1}\right]\right\},
\end{aligned}$$

and

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

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^b_t, is the normalized multiplier on the book value of capital.

[8] 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.

3.2 The Final Good Producer

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

$$y_t = \left(\int_0^1 y_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{7}$$

where ε is the elasticity of substitution.

Taking prices as given, the final good producer minimizes its costs subject to the previous production function (7). The optimality conditions of this problem result in a demand function for each intermediate good:

$$y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\varepsilon} y_t \qquad \forall i \tag{8}$$

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

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

3.3 Intermediate Good Producers

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 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 producers have the same marginal cost:

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

and that, in addition, all firms have the same capital to labor ratio:

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

The intermediate good producers are subject to nominal rigidities. Given demand function (8), 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:

$$\max_{P_{i,t+s}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_t} \left(\frac{P_{i,t+s}}{P_{t+s}} y_{i,t+s} - mc_{t+s} y_{i,t+s} - AC^p_{i,t+s} \right)$$

$$\text{s.t. } y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\varepsilon} y_t,$$

$$AC^p_{i,t} = \frac{\phi_p}{2} \left(\frac{P_{i,t}}{P_{i,t-1}} - \Pi \right)^2 y_{i,t}.$$

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:

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

3.4 Government

The model is closed by a description of the monetary and fiscal authorities. The monetary authority sets the nominal interest rate following a modified 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 $\phi_R \in [0,1)$ captures the degree of interest-rate smoothing. The parameters $\gamma_\Pi > 0$ and $\gamma_y \geq 0$ are the responses to inflation from target Π and steady-state output y. The steady-state nominal interest rate R is determined by the equilibrium of the economy and, hence, it is not a choice for the monetary authority once it has picked Π. The monetary policy shock, ξ_t, follows a $\mathcal{N}(0,1)$ process.

As regards the fiscal authority, its budget constraint is given by:

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

The fiscal authority levies taxes on personal consumption expenditures, on labor income, and on capital income, and engages in government spending according to the rules described in equations (1) and (2). Finally, for consistency, we also assume that lump-sum taxes operate to gradually stabilize the debt to output ratio over the longer term; that is, we restrict ourselves to a passive fiscal regime as defined by Leeper (1991):

$$\Omega_t = \Omega + \phi_{\Omega,b} (b_{t-1} - b), \tag{9}$$

where $\phi_{\Omega,b} > 0$ and just large enough to ensure a stationary debt level.[9]

3.5 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 is the same for all firms and that,

$$k_{t-1} = \int_0^1 k_{it} di \tag{10}$$

we can 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

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

The definition of equilibrium for this economy is standard and, thus, we skip it. Now we are ready to calibrate the model.

4 Calibration and Solution

We calibrate the model to the U.S. economy. One time period is one quarter. Table 4 summarizes our parameter values except those governing the processes for the fiscal instruments, which we set equal to the posterior median values that we obtain in the estimation of the fiscal rules, as reported in table 2. Most of the calibrated parameters are standard choices in the literature.

The time discount factor, β, targets an annual real rate of interest of 2.4 percent in steady state to match the average real interest rate in Fernández-Villaverde *et al.* (2010). We set $\omega = 2$ and $\vartheta = 2$. The first value is conventional. The second one implies a Frisch elasticity of labor supply of 0.5, which is appropriate given that our model does not distinguish between an intensive and

[9] In the absence of distortionary taxes and a cyclical response of government spending, a stationary debt level would be ensured whenever $|1/\beta - \phi_{\Omega,b}| < 1$; see Leeper (1991) for details.

Table 4: Parameters and Targets

Preferences and consumer		
β	0.994	Annual real rate of 2.4%.
ω	2	Elasticity of intertemporal substitution = $1/\omega$.
ϑ	2	Frisch elasticity of 0.5.
ψ	125.9	steady-state hours ($l = 1/3$).
b_h	0.75	Habit formation as in Christiano *et al.* (2005)
ϕ_w	4868	in line with Calvo wage stickiness of 0.75; Altig *et al.* (2011).
ϵ	21	markup of 5% in Altig *et al.* (2011).
Cost of utilization and investment		
Φ_1	0.0310	From steady-state utilization FOC.
Φ_2	0.0001	Flexible capital utilization adjustment
κ	3	Investment adjustment cost
Firms		
α	0.36	Labor share of 64%.
δ	0.025	Steady-state investment/output ratio of 18%.
ϕ_p	235.75	In line with Calvo price stickiness of 0.75.
ϵ_w	21	markup of 5%.
Monetary policy and lump-sum taxes		
Π	1.005	Steady-state inflation of 2%.
ϕ_R	0.7	Fernández-Villaverde *et al.* (2010).
γ_Π	1.25	Fernández-Villaverde *et al.* (2010).
γ_y	1/4	Fernández-Villaverde *et al.* (2010).
Ω	-4.3e-4	Follows from gov. budget constraint
$\phi_{\Omega,b}$	0.0005	Stabilize debt
Shocks		
ρ_A	0.95	King and Rebelo (1999)
σ_A	0.0040	Calibrated to match volatility of output
ρ_d	0.18	Smets and Wouters (2007)
σ_d	0.0075	Calibrated to match volatility of consumption
σ_m	0.0025	Fernández-Villaverde *et al.* (2010).

extensive margin of employment (Rogerson and Wallenius (2009)) and it is in line with the recommendation of Chetty *et al.* (2011) based on an extensive survey of the literature. The value of ψ targets $l = 1/3$. Habit formation is set to the value estimated in Christiano *et al.* (2005). 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. Finally, an elasticity of demand $\epsilon = 21$ is reported in Altig *et al.* (2011). As regards the costs of utilization and adjusting investment, $\Phi_1 = 0.031$ follows from the first-order condition for capacity utilization in steady state, $\Phi_2 = 0.0001$ implies that capital utilization can be adjusted at a low cost, and $\kappa = 3$ is a value consistent with the estimates typically reported in the literature.

We set $\alpha = 0.36$ to get a labor income share of about 64 percent. The depreciation rate $\delta = 0.025$ delivers a steady-state ratio of investment to output of 18 percent. Parameter ϕ_p renders the slope of the Phillips curve in the current model consistent with the slope of a Calvo-type New Keynesian Phillips curve without strategic complementarities when prices last for a year on average. Similar values are commonly used in the literature; see, for example, Galí and Gertler (1999). As we chose for ϵ, the elasticity of demand for the respective types of labor is $\epsilon_w = 21$.

For the Taylor rule, we pick $\phi_R = 0.7$, $\gamma_\Pi = 1.25$, and $\gamma_y = 0.25$, following the estimates in Boivin (2006) and Fernández-Villaverde *et al.* (2010). We set $\pi = 1.005$ to get an annualized steady-state inflation target of 2 percent. The size of the steady-state lump-sum taxes ensures that the government's budget constraint is satisfied in that steady state. The response of lump-sum taxes to the debt level is inconsequential if there is no feedback of distortionary taxes or spending to the debt level ($\phi_{x,b} = 0$) as long as debt is stabilized (Leeper (1991)). In practice, we set a value for $\phi_{\Omega,b}$ that is large enough to achieve this. When there is feedback, however, the value of $\phi_{\Omega,b}$ does matter for the real allocations. Thus, we set it to the smallest numerically possible non-negative value for which a unique bounded equilibrium exists.

Last, the persistence for the productivity and the intertemporal shock is set to standard values in the literature. Their standard deviation is set such that the model replicates the HP-filtered standard deviation of output and consumption in the data. The size of the monetary shock follows the estimates of Fernández-Villaverde *et al.* (2010).

We solve the model by third-order perturbation around the steady state. As discussed in more detail in Fernández-Villaverde *et al.* (2011), models with volatility shocks such as ours are inherently non-linear and linearization cannot be applied to compute them. Perturbation is, in practice, the only method that can solve a business cycle model with as many state variables as the one in this paper in any reasonable amount of time. A third-order approximation is important because, as shown in Fernández-Villaverde *et al.* (2010), innovations to volatility shocks to different instruments only appear by themselves in the solution of the model in the third-order terms. This will be particularly important when, below, we compute impulse response functions (IRFs) to fiscal volatility shocks.

Once the model is solved, we can simulate it and compute IRFs. As a preliminary diagnosis of the model and to give the reader an indication of its fit, table 5 presents summary information for second moments of selected endogenous variables and compares them with the data. The model does a fair job at matching the data, especially given that we use only two of the observed moments for calibration.

Table 5: 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						
$\widehat{y}_t$	1.59	0.61	1	1.57	0.87	1
$\widehat{c}_t$	1.18	0.66	0.41	1.28	0.89	0.87
$\widehat{i}_t$	4.60	0.93	0.32	7.69	0.83	0.91
Wages, labor and capacity utilization						
$\widehat{w}_t$	0.10	0.95	0.40	0.88	0.76	0.10
$\widehat{h}_t$	1.68	0.52	0.92	1.93	0.92	0.87
$\widehat{u}_t$	2.11	0.62	0.82	3.24	0.87	0.86
Nominal variables						
$\widehat{R}_t$	2.82	0.84	0.09	3.67	0.93	0.18
$\widehat{\Pi}_t$	3.09	0.65	0.41	2.47	0.98	-0.004

Notes: The moments in the model are taken from HP-filtered simulations of the model. Data correspond to the period 1970.Q1 - 2010.Q3 and are taken from the St. Louis Fed's FRED database (mnemonics GDPC1 for output, GDPIC96 for investment, PCECC96 for personal consumption, FEDFUNDS for the effective fed funds rate, GDPDEF for the price deflator, HCOMPBS for compensation per hour, HOABS for hours worked, and TCU for capacity utilization). All data are in logs, HP-filtered, and multiplied by 100 in order to express them in percentage terms. Inflation and interest rate are annualized.

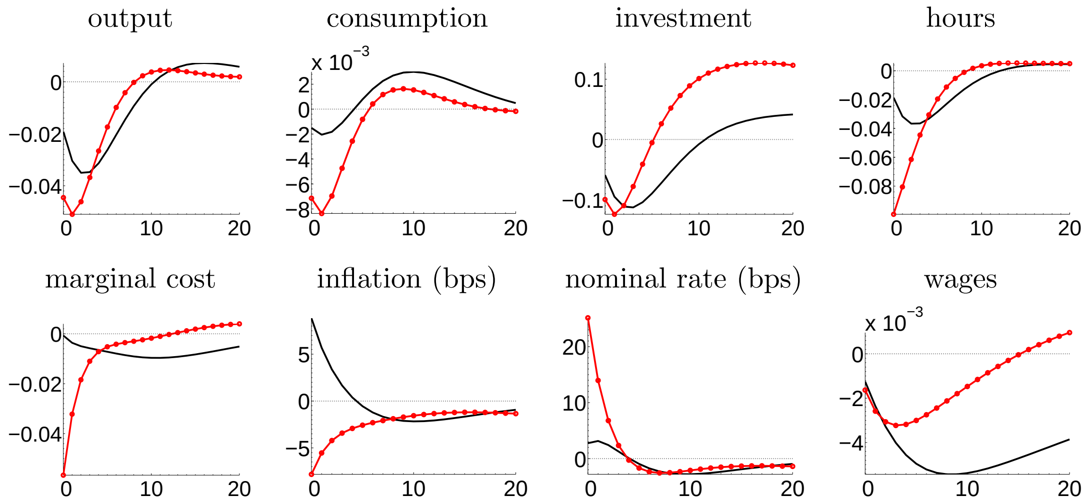
5 Results

In this section, we present five sets of results. First, we show the IRFs to a fiscal volatility shock. Second, we compare the IRFs to fiscal volatility shocks with those to monetary policy shocks and, third, with those to fiscal level shocks. Fourth, we explain why nominal rigidities matter for our result. Fifth, we decompose the response to fiscal volatility shocks into its different parts. In the three sections thereafter, we will explore results when we change some aspect of the estimated fiscal rules or of the model.

5.1 Impact of Fiscal Policy Uncertainty

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 currently faces. Thus, we define a fiscal volatility shock as a simultaneous increase of two standard deviations in the innovations to the standard deviation of the four fiscal policy instruments. This is the same measure of volatility shocks that Bloom (2009) uses.

Figure 3: Fiscal volatility shock vs. 25 bps monetary shock



Notes: The solid black lines correspond to a fiscal volatility shock. The dashed red line corresponds to a 25-basis-point shock to the annualized nominal interest 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. From left to right: standard-deviation, first-order autocorrelation, and correlation with output.

We start by plotting the IRFs to that fiscal volatility shock as the solid lines in figure 3. To gauge the economic significance of the magnitude of the responses, we also plot the IRFs to a typical monetary policy shock, namely, a 25-basis-point increase in the nominal rate of interest.

The first main result of this paper is that heightened fiscal policy uncertainty causes a prolonged contraction in economic activity. This happens, as illustrated by the IRFs, even in the absence of a fall today in government spending or an increase in taxes. To the contrary, the endogenous feedback of the fiscal rules with respect to the state of the economy reduces the tax rates contemporaneously, which stabilizes output. We will later return to this point. Output reaches its lowest point about three quarters after the shock. Most of the decline comes from a drop in investment. Given that the increase in volatility operates through expectations, it is not surprising that investment, a forward-looking variable, is so responsive. The more modest decline in consumption illustrates households' strong desire for smoothing. In contrast, Fernández-Villaverde *et al.* (2011) show that consumption smoothing is less feasible when volatility shocks directly affect the interest rate. In their paper, the recession created by a volatility shock is driven by a significant drop in consumption. These differences demonstrate that, although volatility shocks generate slowdowns in economic activity regardless of their origin, the transmission mechanism depends on the source of the shock.

The intuition for these effects is as follows. Take capital taxes (as we will document later, the main driving force of our results). General equilibrium effects apart, a positive fiscal volatility shock to capital income taxes ($\sigma_{k,t}$) represents a mean-preserving spread of the distribution of future tax rates on capital income. As a result, both a steep increase in tax rates and a large decrease become more likely in the future. Since the distortions associated with capital taxation are convex in the tax rate, the increased likelihood of a negative outcome outweighs the benefits of a higher chance of lower taxes. The prospect of tax increases thus impedes capital accumulation. Amplified (but not caused) by capital adjustment costs, this leads to a contemporaneous decline in investment. Reducing the stock of future capital in turn decreases the expected wage. The combined effect of lower future capital and labor income induces a contraction in consumption and, in sum with a lower investment, in aggregate demand. Firms respond to lower aggregate demand by reducing hours and capital utilization. Finally, wages and the return on capital drop, reflecting the slack created by uncertainty.

A similar set of arguments can be presented for a positive fiscal volatility shock to labor income taxes, $\sigma_{l,t}$. This increase makes future labor income and, hence, consumption more volatile. This unpleasant variability results in an increase in the expected marginal utility of consumption, which, through the Euler equation, translates into a contemporaneous contraction in consumption (this result requires convexity of the marginal utility and separable preferences). Furthermore, this fiscal volatility shock raises the likelihood of future jumps in the labor income tax and hence lower economic activity. But lower future output reduces the demand for capital, which leads to a contemporaneous decline in investment. Ultimately, weak demand forces firms to cut hours worked and capital utilization. In the same vein, a positive fiscal volatility shock to consumption taxes increases the expected value of marginal utility, resulting in a fall of consumption today. Last, more volatile government spending, due to a jump in $\sigma_{g,t}$, increases the volatility of demand. The resulting uncertainty about labor and capital income discourages investment through the channels discussed in the previous lines.

One interesting additional observation is that inflation increases after the fiscal volatility shock. This is because the intermediate good producer faces a higher probability of high marginal cost due to higher labor and capital taxes. Since the adjustment cost is quadratic, it is optimal to increase prices contemporaneously to preempt even larger (and more costly) increases in the future. As we will discuss below, this is a fundamental mechanism in our model.

5.2 Fiscal Volatility Shocks versus a Monetary Policy Shock

Figure 3 also shows the IRFs of the economy to a 25-basis-point (annualized) increase in the nominal interest rate (dotted red lines). From this comparison, we obtain the second main result of the paper. Fiscal volatility shocks and monetary shocks induce contractions of comparable size but of different persistence. The effect of a fiscal volatility shock on output lasts longer than the monetary shock and it is around 70 percent of the monetary shock at its peak. In the case of investment, the fiscal volatility shock has more or less the same impact as the monetary policy shock and lasts about twice as long. Its effects on wages and inflation look even bigger. Figure 3 also reveals that the mechanism through which the contraction comes to pass differs. The decline in economic activity after a fiscal volatility shock is driven by a strong decline in investment, whereas a monetary shock works mainly through consumption. The response of inflation is also different: it falls after a monetary shock but rises in the wake of a fiscal volatility shock.

The finding that a fiscal volatility shock and a 25-basis-point change in monetary policy have comparable implications is quite suggestive. 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.[10] In other words, the effects of a fiscal volatility shock are equivalent to the size (but of opposite sign) of the effects of the stimulus achieved through the recent exercise in quantitative easing.

5.3 Fiscal Volatility Shocks versus Fiscal Shocks

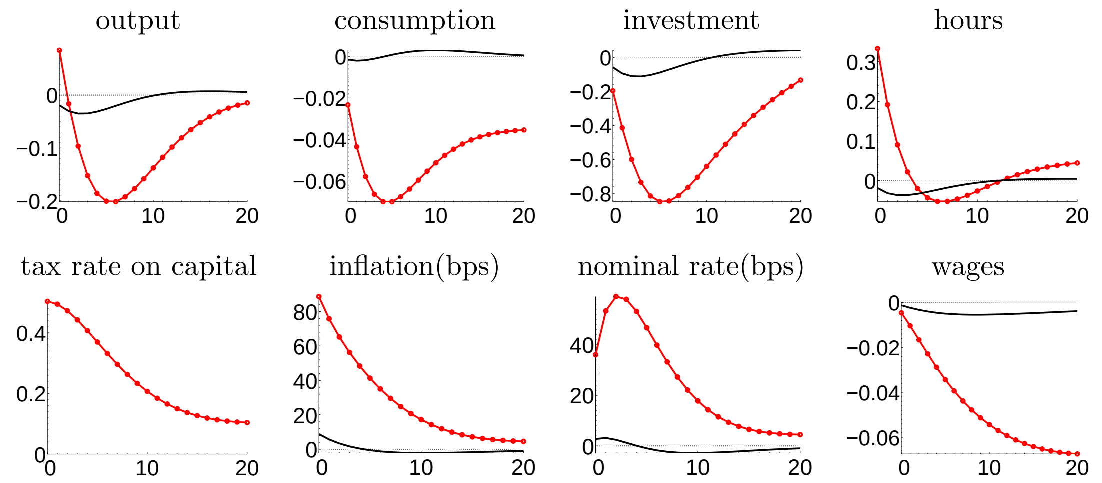
Our next exercise is to compare, in figure 4, the IRFs to a fiscal volatility shock (solid black line) to the IRFs to a 50-basis-point fiscal shock in the capital tax rate (dotted red line). Note that in a fiscal shock, the tax rate goes up, while, in a fiscal volatility shock, it is the variance of its future changes that goes up, while the tax rate itself does not move.

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 clearly much larger. While the tax rate changes the returns to capital today, and hence has a first-order impact, time-varying volatility works through households' and firms' expectations, a quantitatively weaker channel.

[10] Hamilton (2008) finds that a $300 billion purchase of 10-year Treasuries amounts to a decline of about 10 basis points in their yield. Hamilton and Wu (2010), in turn, find that a 40-basis-point change in the 10-year yield is equivalent to a change of 100 basis points in the fed funds rate. Combining the two results, we arrive at the number in the text.

Figure 4: Fiscal volatility shock vs. 50bps fiscal shock in the capital tax rate



Notes: The solid black line corresponds to a fiscal volatility shock. The dotted red line corresponds to a 50-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.

5.4 The Role of Nominal Rigidities

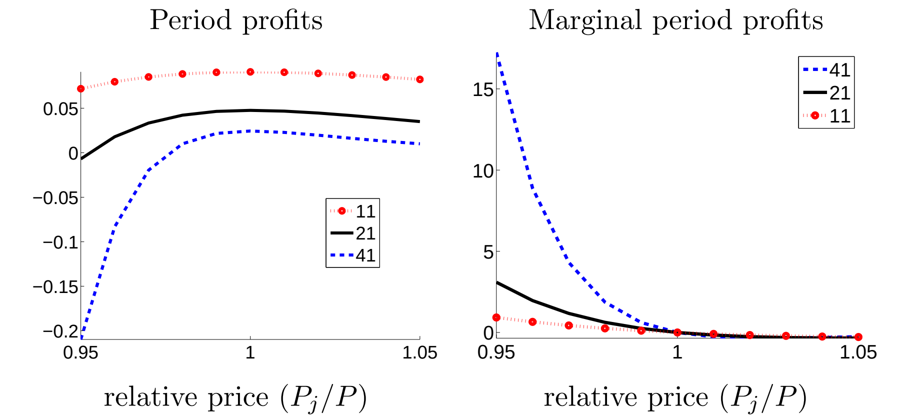
The increase in inflation after a fiscal volatility shock that we pointed out above is an intriguing phenomenon. To a casual observer, the spike in inflation may suggest that the fall in output was triggered by a negative supply shock. Yet figure 3 reveals that the marginal cost is declining, not rising as it would be after a negative supply shock. Similarly, one could think that the fall in output was caused by a negative preference shock, but then we should observe a fall in inflation, not an increase. The true mechanism that explains this "stagflation" of lower output and higher inflation, the higher probability of future large marginal costs, is somewhat hidden from more traditional analyses that assume constant volatility.

Hence, it is important to illustrate how, in our model, nominal rigidities are key for the effects on aggregate activity of fiscal volatility shocks. The best way to understand the mechanism 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 5 illustrates this for three different levels of the demand elasticity (implying a 10 percent, 5 percent, and 2.5 percent markup, respectively).

Figure 5: Properties of the profit function



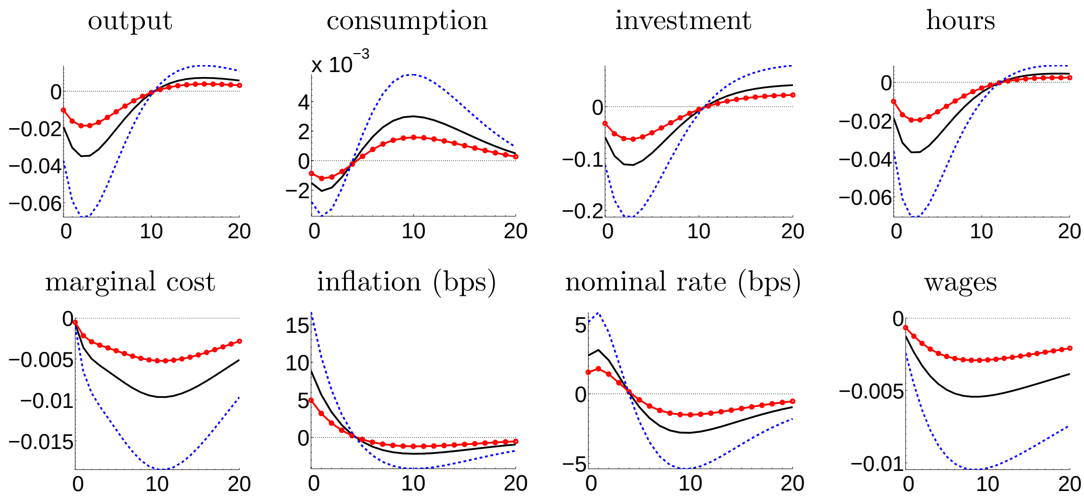
Notes: Profit function and marginal profits (relative to output) for different demand elasticities as functions of the relative price. Dotted red line: $\epsilon = 11$ (implying a markup of 10 percent), solid black: $\epsilon = 21$ (implying a markup of 5 percent), dashed blue: $\epsilon = 41$ (implying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

The immediate consequence is that it is relatively more costly for a firm to set too low a price relative to its competitors, rather than setting it too high. Figure 5 illustrates that this effect is the stronger the more elastic the demand, since the expenditure-switching effect is more pronounced. These properties of the profit function generate an incentive for firms to raise prices in the wake of an increase in demand volatility or cost volatility, both of which could be induced by a fiscal volatility shock. As a result, inflation rises after a fiscal volatility shock despite the fall in marginal costs.[11] Indeed, figure 6 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. In comparison, changing the demand elasticity barely has an effect on the IRFs to a monetary policy shock (we omit plotting those exercises 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.

The discussion in this subsection has powerful empirical implications because it demonstrates how fiscal volatility shocks impinge different dynamics than supply and demand shocks in key variables. Furthermore, fiscal volatility shocks can generate correlations among variables that would be otherwise difficult to interpret (especially because the shock, the increase to uncertainty, is not directly observed in any “fundamental” of the economy).

[11] A very similar mechanism works with Calvo pricing: firms are afraid of being stuck with a price that is too low and pre-empt this risk by raising prices as soon as they can after a fiscal volatility shock

Figure 6: Fiscal volatility shock – effect of demand elasticity



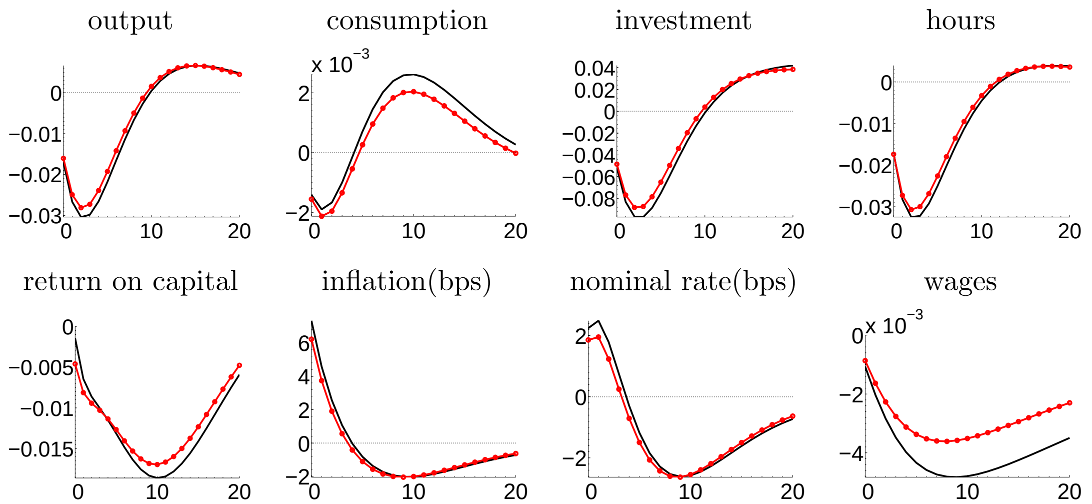
Notes: IRFs to a fiscal volatility shock when setting $\epsilon = 11$ (red line marked by dots, implying a steady-state markup of 10 percent), $\epsilon = 21$ (solid black line, a markup of 5 percent), and $\epsilon = 41$ (dashed blue line, a markup of 2.5 percent). The figure keeps the slope of the 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.

5.5 Decomposing the Response to a Fiscal Volatility Shock

We have defined a 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 particular instrument. While a simple variance decomposition cannot be implemented (our solution method is non-linear), we can compare the IRFs with one instrument alone with the IRFs with all four instruments.

This is what we do in figure 7, where we show (in black) the response of the economy to a fiscal volatility shock and (in the dotted red lines) the IRFs where there is a fiscal volatility shock only to the tax rate of capital. Clearly, the increase in volatility of capital taxes accounts for most of the effect of the fiscal volatility shock that we found in subsection 5.1. This is due to the fact that, in our model, capital taxes are the only fiscal instrument that directly distorts the intertemporal resource allocation. Additional unreported figures with different combinations of increases in volatility of policy instruments further confirm this result: nearly all of the economy's response to fiscal volatility shocks works through the tax on capital income.

Figure 7: Fiscal volatility shocks vs. fiscal volatility shock only to capital tax rate



Notes: The solid black line corresponds to responses to a fiscal volatility shock. The dotted red line corresponds 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.

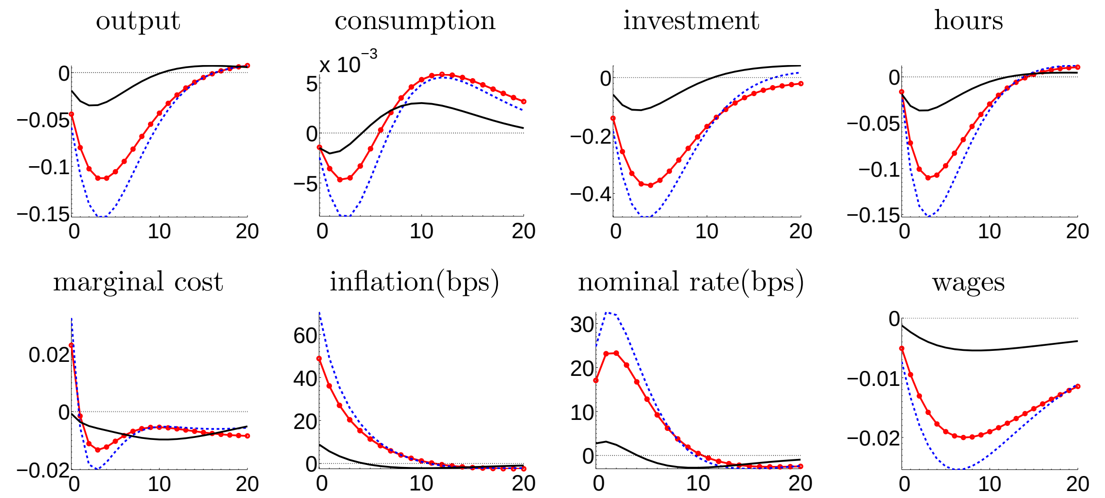
6 Fiscal Policies with Partial and Without Feedback

In our baseline specification, we considered feedbacks from output and public debt ratios to fiscal instruments. In particular, the feedback coefficients ($\phi_{\bullet,y}$ and $\phi_{\bullet,b}$ in equations 1 and 2) acted as automatic stabilizers that dampened the impact of fiscal uncertainty. According to these rules, tax rates fall somewhat and government spending increases to some extent in the wake of a fiscal volatility shock. This response automatically ameliorated any negative impact of a fiscal volatility shock.

A logical exercise is, then, to eliminate this feedback as we described in section 2.3 and just rely on the responses of lump-sum taxes to ensure stability of the equilibrium. This may also be a more relevant exercise for the current situation in the U.S., which so far seems not to have experienced much of a response of taxes or government expenditure to the increased fiscal volatility. The absence of a feedback component also captures the notion that, moving forward, the government would conduct less stabilization policy via taxes in its attempt to balance the budget.

Figure 8 compares the responses under the baseline rules (solid black line) to the responses with partial feedback and without feedback. The dotted red lines switch off the response to output in the fiscal rules ($\phi_{x,y} = 0$ for all $x \in \{\tilde{g}, \tau_l, \tau_k, \tau_c\}$). The dashed blue lines switch off in addition the response to debt ($\phi_{x,b} = 0$). The main finding is that, in the absence of feedback in the fiscal rules, the impact of fiscal volatility shocks is considerably stronger. For

Figure 8: Fiscal volatility shocks – effect of feedback



Notes: The solid black line corresponds to responses to a fiscal volatility shock with the baseline fiscal rules. The dotted red line corresponds to fiscal rules with partial feedback. The dashed blue line is the response when fiscal rules without feedback are considered. 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.

instance, output falls almost five times more. Much of this decline is due to a sharper drop in investment (-0.48 percent). We conclude that, in situations such as those without feedback, the impact of an increase in fiscal urcentainty can be considerable. If, as argued by some observers, we are currently in such a situation in the U.S., fiscal volatility shocks might be a factor to be considered in more detail.

7 Timing of Shocks

A growing literature, exemplified by Leeper *et al.* (2009), has suggested that time-series approaches may not allow identification of the true structural fiscal shocks in the face of legislative or implementation lags of fiscal measures. This can be clearly seen in Ramey (2011), who presents compelling evidence that military buildups require time to be carried through.[12] Thus, the news component of the fiscal shock has a different timing than the realization of the purchases recorded in the data. Consequently, the shocks identified by VARs or other time-series methods would reflect a mixture of past and current innovations instead of the true shock, which invalidates inference about the fiscal transmission mechanism. This is shown by the fact that the shocks recovered by VARs are partly predictable.

[12] Similarly Romer and Romer (2010) build a narrative to identify changes in tax policy that can reasonably be considered exogenous to current economic conditions. Using their data, Mertens and Ravn (2011) argue that the median implementation lag of these measures is six quarters.

Since this can be a potentially important concern, and as a robustness check, we estimate fiscal rules that allow for implementation lags of the form:

$$x_t - x = \rho_x(x_{t-1} - x) + \phi_{x,y}\tilde{y}_{t-1} + \phi_{x,b}\left(\frac{b_{t-1}}{y_{t-1}} - \frac{b}{y}\right) + \exp(\sigma_{x,t})\varepsilon_{x,t} + \exp(\sigma_{x,t-j})\upsilon_{x,t-j}, \quad (11)$$

where $\varepsilon_{x,t}, \ \upsilon_{x,t} \sim \mathcal{N}(0,1)$ still follows 2. Equation 11 allows for the fiscal measures to be affected by both a contemporaneous shock and by a shock that was realized j quarters ago (and the size of which was, therefore, influenced by the fiscal volatility back then). In our model, this shock j quarters ago is part of the information set of the agents, since it was realized and hence it has affected their decisions rules from that moment on.

Since we documented in the previous section that the tax on capital income is the most important for our results, we restrict ourselves to estimating the tax rule with anticipation for that instrument. Also, in the interest of space, it suffices to report only the case where $j = 1$. Our main finding below is that the role of anticipation is small and unreported cases with $j > 1$ generate similarly small impacts.

Table 6: Posterior Median Parameters – Fiscal Rules with Anticipation

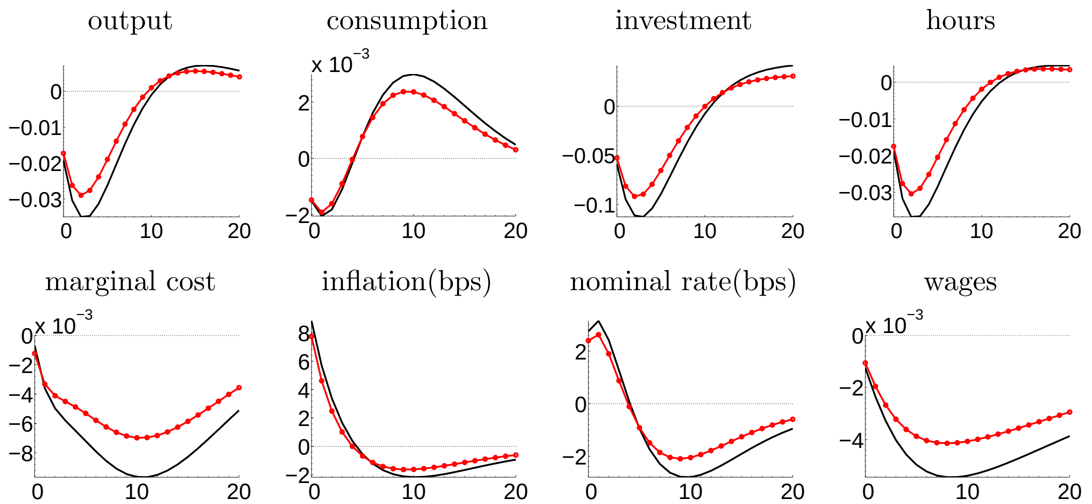
	Volatility Parameters			Level Parameters		
	σ_{τ_k}	$\rho_{\sigma_{\tau_k}}$	η_k	ρ_{τ_k}	$\phi_{\tau_k,ads}$	$\phi_{\tau_k,b}$
No Anticp (j=0)	-4.96 [-5.26,-4.58]	0.76 [0.48,0.93]	0.57 [0.34,0.89]	0.96 [0.93,0.99]	0.10 [0.007,0.25]	0.005 [0.001,0.02]
One Period (j=1)	-5.36 [-5.68,-5.05]	0.70 [0.29,0.91]	0.60 [0.33,1.02]	0.96 [0.93,0.99]	0.095 [0.006,0.24]	0.004 [0.002,0.01]

Notes: For each parameter, the posterior median is given and a 95 percent probability interval (in parenthesis).

Table 6 compares the posterior median estimates and probability intervals of the parameters of the fiscal rule with and without anticipation. The first row, the case without anticipation, is equal to the corresponding row in table 2. Direct inspection shows that the inclusion of anticipation has only a secondary impact on those estimates.

We care, however, about the IRFs implied by the new rules rather than by the point estimates themselves (we worry much less about the smoothed volatilities in any given quarter within the sample since they are not the object of our analysis). Thus, we plot in figure 9 the new IRFs (dotted red line) and compare them with the original IRFs without anticipation (solid black line). Output, for instance, falls somewhat less because part of the effect already happened in period $t = -1$ when the agents incorporated into their information sets the news about future tax rates. This small difference goes through for all the other variables. However, we conclude, from this figure, that the role of anticipation in the effects of fiscal volatility shocks is minor.

Figure 9: Fiscal volatility shocks – effect of anticipation



Notes: The solid black line corresponds to responses to a fiscal volatility shock with the baseline fiscal rules. The dotted red line is the response when fiscal rules with anticipation are considered. 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.

8 Robustness Analysis

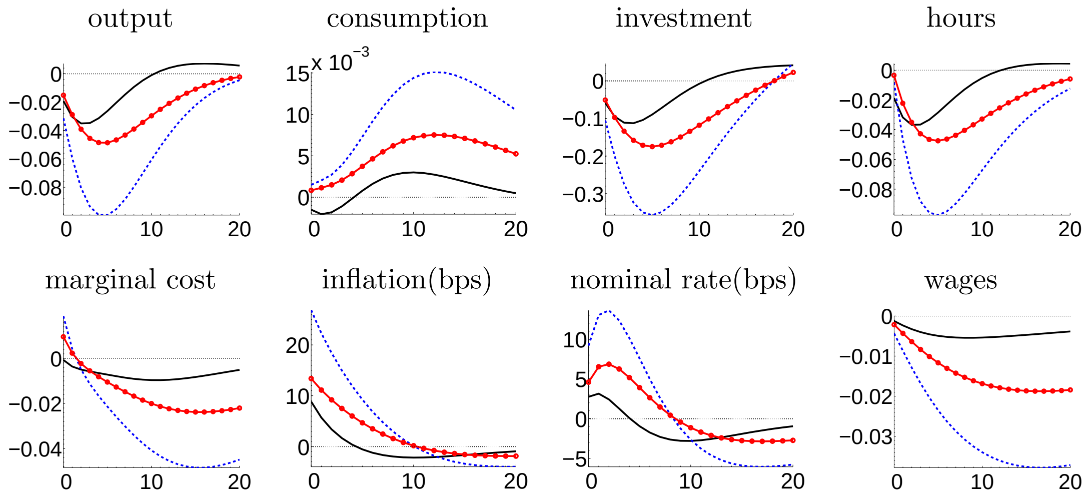
In this section we explore how robust our results in previous sections are to several of our assumptions. A common thread that emerges from this section is that our baseline IRFs should be understood as a lower bound on the effect of fiscal uncertainty. Simple departures from our assumptions noticeably increase the importance of fiscal volatility shocks.

We have already encountered this result. In section 6, we argued that when we eliminate the feedback of output and public debt in the policy rules, the effects of an increase in fiscal uncertainty are considerably larger. Now, we show first how a larger persistence of the fiscal volatility shocks also increases their impact. Second, we document the consequences if the monetary authority accommodates an increase in fiscal uncertainty. Third, we study the consequences of eliminating the depreciation allowance, which makes the tax system more distortionary. Finally, we measure how the IRFs to a fiscal volatility shock depend on the degree of nominal rigidity in the economy.

8.1 More Persistent Fiscal Volatility Shocks

We assess, first, the effect of a fiscal volatility shock that is more persistent than the median of the posterior would suggest. This exercise is motivated by the large uncertainty surrounding the posterior estimates of the persistence parameters of the volatility shocks to any of the fiscal instruments (see table 2).

Figure 10: Fiscal volatility shocks – effect of persistence



Notes: The solid black line corresponds to responses to a fiscal volatility shock with the baseline fiscal rules. The other lines correspond to highly persistent fiscal volatility shocks. The dotted red line rescales the variances of the innovations. The dashed blue line does not rescale 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.

For illustrative purposes, in figure 10, we consider a persistence parameter of $\rho_{\sigma_\cdot} = 0.95$ for all volatility shocks to all fiscal instruments. Then, the volatility shocks have a half-life of about three and a half years. The red dots illustrate the effect of more persistent fiscal volatility shocks when rescaling the innovations to keep the unconditional variance of volatility unaffected by the change in persistence.

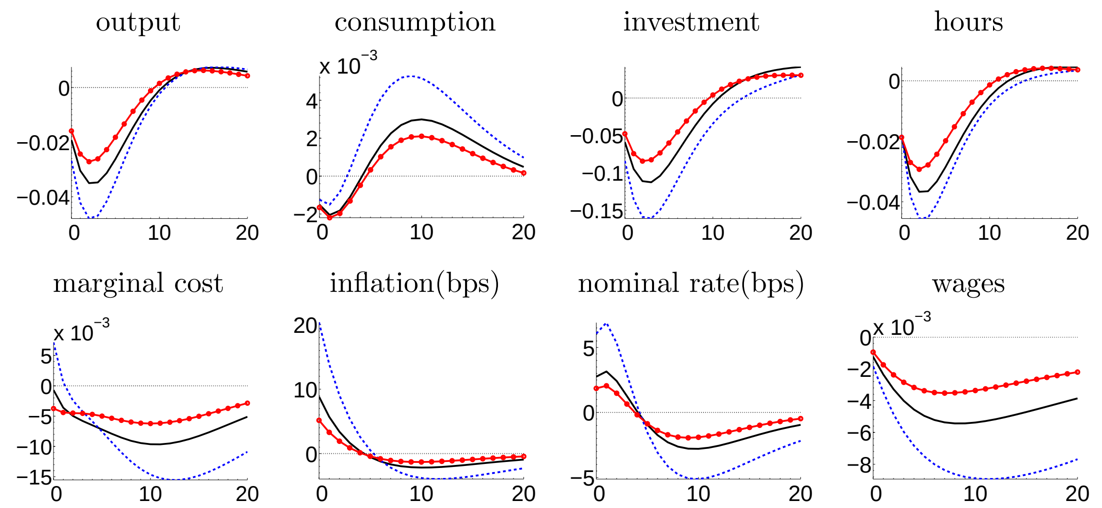
A more persistent fiscal volatility shock generates a deeper and longer recession. Now households fear that large tax increases are more likely for more than the next few quarters. As a result, they reduce their exposure to future taxes by reducing investment. The dashed blue line shows the same exercise without rescaling the innovations. In that case, output, for example, drops about three times as much as in the baseline.

As we argued in the introduction, the current fiscal impasse has made the future path of fiscal policy quite uncertain for a longer than normal horizon. Hence, we think that the exercise documented in figure 10 suggests that fiscal volatility may be, at this moment, a drag on the economy.

8.2 The Role of Monetary Policy

The “stagflation” (the combination of a fall in output and higher inflation) induced by a fiscal volatility shock hints at a difficult trade-off for monetary policymakers. The monetary authority could try to smooth fiscal volatility shocks by lowering interest rates. However, this would increase inflation in a situation when inflation is already higher than usual.

Figure 11: Fiscal volatility shocks – effect of Taylor rule



Notes: The solid black lines correspond to responses to a fiscal volatility shock. The dashed blue line corresponds to baseline model with $\gamma_y = 0.5$. The dotted red line corresponds to the baseline model with $\gamma_\Pi = 1.5$. 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.

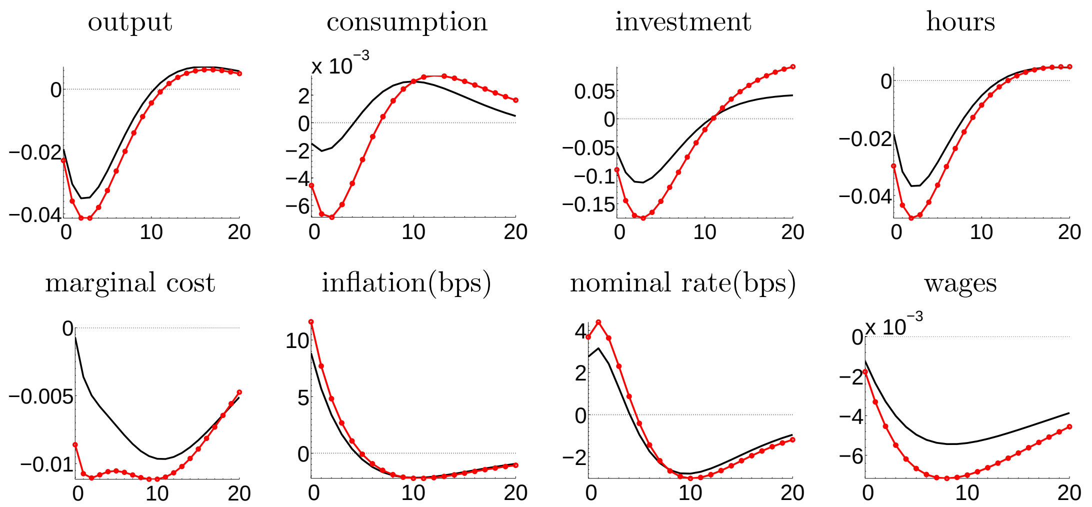
The IRFs in figure 11 show the baseline response, as a solid line, and two alternative scenarios. In the first one, the monetary authority reacts more strongly to output than in the baseline case (a value of $\gamma_y = 0.5$ instead of $\gamma_y = 0.25$, dashed blue line). In the second one, the monetary authority reacts more aggressively to inflation (a value of $\gamma_\Pi = 1.5$ instead of $\gamma_\Pi = 1.25$, dotted red line).

The mechanism behind these IRFs is the following. In the model, inflation rises after a fiscal volatility shock while output falls. 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. The anticipation by firms of a loose stance of monetary policy would, therefore, result in still higher inflation and lower output. In contrast, if the central bank assigns less weight to stabilizing output, firms consider future inflation a less likely event, which reduces their temptation to increase prices ahead of any actual tax increase. Thus, in equilibrium, the smaller the monetary response to output, the more moderate is the inflation response and the more moderate the contraction in output. As a result, if the central bank becomes more responsive to inflation (higher γ_Π), the stagflationary effects of fiscal uncertainty become less pronounced.

8.3 Eliminating Depreciation Allowances

Next, we assess the impact of eliminating depreciation allowances. These allowances impact the utilization decision in equation (6) because they change the value of the marginal Tobin's Q that appears on the right-hand side of that expression. In particular, we can think about depreciation allowances as a hedge against the capital income tax. When the capital income tax rises, the depreciation allowance also rises. Similarly, when the tax rate falls, the depreciation allowance falls. Thus, when allowances are eliminated, the fear of future changes in capital taxation due to a fiscal volatility shock today is exacerbated. Figure 12 shows how, consequently, output is more sensitive to a fiscal volatility shock and how the economy experiences a recession that is stronger than in the baseline case.

Figure 12: Fiscal volatility shocks – effect of depreciation allowances



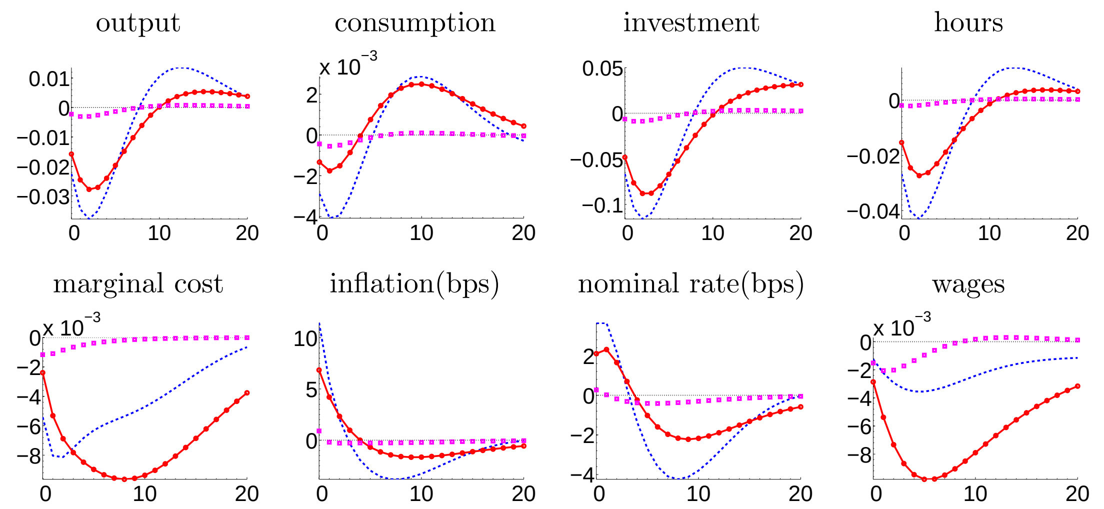
Notes: The solid black lines correspond to responses to a fiscal volatility shock. The dotted red line corresponds to the model without depreciation allowances. The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

Since we can think about depreciation allowances as a reduction in the distortions created by the tax system, our result can be read as indicating that more distortionary tax systems increase the effects of fiscal volatility shocks.

8.4 The Role of Nominal Rigidities

In our last exercise, figure 13 shows how the degree of nominal rigidity affects the impact of fiscal uncertainty. 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 two quarters. The response is both more pronounced on impact, but also shorter-lived, since the economy recovers more rapidly.

Figure 13: Fiscal volatility shocks – effect of nominal rigidities



Notes: The dashed blue line corresponds to responses of a fiscal volatility shock if price stickiness is equivalent to a Calvo $\phi_p = 0.5$. The dotted red line corresponds to the case if wage stickiness is equivalent to a Calvo $\phi_w = 0.5$. The magenta-colored squares pertain to the case of (Calvo) $\phi_p = 0.1$ and $\phi_w = 0.1$. 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.

The dotted red line reduces wage stickiness to the one equivalent to a Calvo model with an average wage duration of two quarters. From these IFRs we can see how wage stickiness amplifies the response of the economy to the shock. Finally, the figure also shows, in the magenta line marked by squares, the responses when both price and wage stickiness are set to values that make them close to irrelevant (corresponding to price and wage durations of just above a quarter). In this absence of nominal rigidities, fiscal uncertainty – due to being short-lived and small – has only a negligible impact on economic activity. This finding resembles the results in the real models of Bloom (2009) and Bloom *et al.* (2008) that require irreversibilities at the individual firm level for generating the propagation of uncertainty. At the same time, it also suggests that irreversibilities will make the effects of fiscal volatility shocks bigger.

9 Conclusions

Most economic decision-making is subject to pervasive uncertainty, some of this 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 uncertainty has weighed negatively on the U.S. economy's recovery from the recent financial crisis. To assess this concern, in this paper, we have analyzed the effect that fiscal volatility shocks can have on economic activity and have discussed the mechanisms behind our results.

We have found that uncertainty can shave off up to about 0.15 percentage point from output. We interpret this result, though, as a lower bound. We have ignored, for instance, longer-term budgetary issues, such as the impact of entitlement programs, financial frictions, or non-convexities on investment. All these channels are likely to increase the effects of fiscal volatility shocks. Furthermore, 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, lack of clarity about the size of future *increases* alone in taxes), the effects of fiscal uncertainty on economic activity could also be considerably larger.

It would be simple to extend our model to incorporate this one-sided risk: we would only need to feed our fiscal policy rules with a trend in the average tax rate and government consumption over the next few years. We have not done so in the interest of clarity: fiscal volatility matters even when the risk is two-sided.

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 the fiscal policy and, with it, to help the recovery from the recession. This modeling of the political economic determinants of fiscal volatility shocks is an important issue that we plan to take up in future work.

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A Tax data

In this appendix, we describe how we build our sample of tax data. In particular, we follow (most of the) methodology of Leeper *et al.* (2010), who construct aggregate effective tax rates using readily available national account information. Their work in turn is based on earlier contributions by Mendoza *et al.* (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, and, as we have seen in the last several years, 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 *et al.* (2010). However, state and local finances have been hit hard by the current recession. As a result, at least some of the uncertainty about the fiscal mix going forward appears to originate at the state and local level (and what the federal government may eventually do about the weaknesses at the local and state fiscal level).

We now explain how we derive measures of tax rates.

A.1 Consumption Taxes

The average tax rate on consumption is defined as:

$$\tau_c = \frac{\mathrm{TPI} - \mathrm{PRT}}{\mathrm{PCE} - (\mathrm{TPI} - \mathrm{PRT})}. \tag{12}$$

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:

$$\tau_p = \frac{\text{PIT}}{\text{WSA} + \text{PRI}/2 + \text{CI}}. \tag{13}$$

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 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:

$$\tau_l = \frac{\tau_p \left[\text{WSA} + \text{PRI}/2\right] + \text{CSI}}{\text{CEM} + \text{PRI}/2}. \tag{14}$$

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:

$$\tau_k = \frac{\tau_p \text{CI} + \text{CT} + \text{PRT}}{\text{CI} + \text{PRT}}. \tag{15}$$

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).

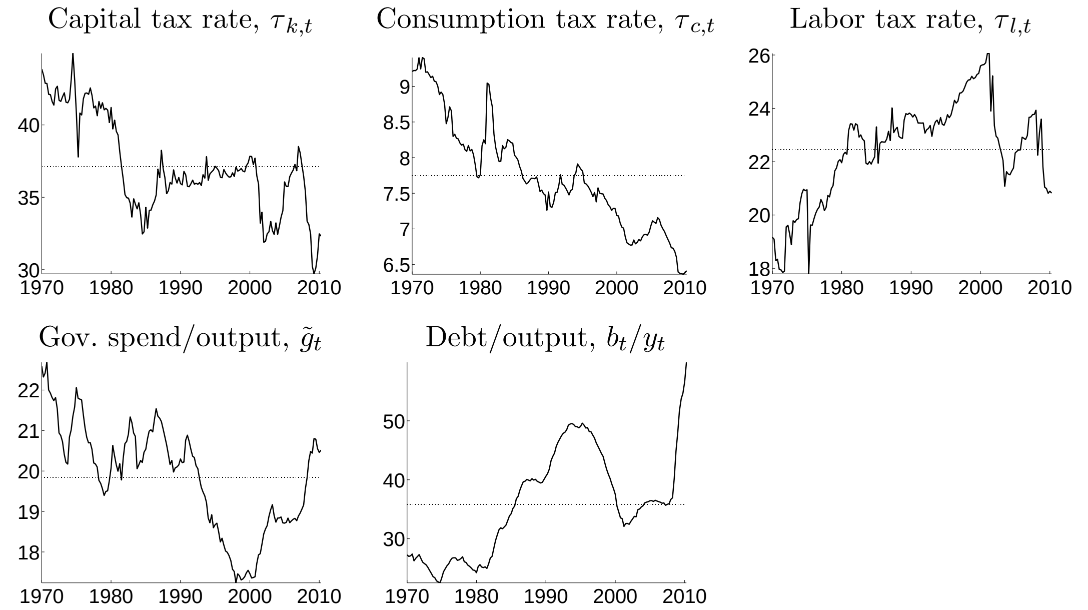
A.4 Other variables

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

Figure 14: Data: taxes and government spending



Notes: 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.