Fiscal Volatility Shocks and Economic Activity*

Jesús Fernández-Villaverde† Pablo Guerrón-Quintana‡ Keith Kuester§
Juan Rubio-Ramírez¶

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Abstract

We study the effects of changes in uncertainty about future fiscal policy on aggregate economic activity. In light of large fiscal deficits and high public debt levels in the U.S., a fiscal consolidation seems inevitable. However, there is notable uncertainty about the policy mix and timing of such a budgetary adjustment. To evaluate the consequences of the 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 can have a sizable adverse effect on economic activity.

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†University of Pennsylvania, <jesusfv@econ.upenn.edu >.
‡Federal Reserve Bank of Philadelphia, <pablo.guerron@phil.frb.org>.
§Federal Reserve Bank of Philadelphia, <keith.kuester@phil.frb.org>.
¶Duke University, <juan.rubio-ramirez@duke.edu>.

"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 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 financial crisis has strained government budgets. U.S. fiscal deficits remain exceptionally high and government debt is growing fast. An eventual fiscal consolidation seems inevitable. However, as 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 the fiscal mix and 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 fiscal policy has a detrimental impact on business conditions through its effect on the expectations and behavior of households and firms.[1] This investigation is relevant because, while the quotes above demonstrate that heightened fiscal policy uncertainty has been a concern of policymakers, there is not much work that measures its actual importance for economic activity.

To fill this gap, we first estimate fiscal rules for the U.S. that allow for time-varying volatility. In particular, we estimate fiscal rules for capital and labor income taxes, consumption taxes, and government expenditure. We interpret the changes in the volatility in the rules as a representation of the variations in fiscal policy uncertainty. The estimated rules discipline our exercise by forcing the evolution of fiscal policy uncertainty 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) and Smets and Wouters (2007). We calibrate the model to replicate observations of the U.S. economy and 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.

[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."

Our main findings are:

1. There is a considerable amount of time-varying volatility in the tax and government spending processes in the U.S. From an empirical perspective, we document how incorporating this time-varying volatility is crucial.

2. Fiscal volatility shocks reduce economic activity: aggregate output, consumption, investment, and hours worked drop on impact and stay low for several quarters. Central to the mechanism is an endogenous increase in mark-ups. Fiscal volatility shocks bring a higher chance of a large change in taxes that make marginal costs harder to predict. Fiscal volatility shocks also raise the volatility of demand, which means that firms stand to lose more by making mistakes in pricing. Both effects combined lead firms to bias their prices upward. The reason is that prices that are too high ex post have less impact on profits than prices that are too low ex post.

3. Furthermore, through the same mechanism, fiscal volatility shocks are "stagflationary": they create inflation while output falls.

4. The effect on output of a fiscal volatility shock in our benchmark calibration is roughly equivalent to the one from a one-standard-deviation contractionary monetary shock (a 30-basis-point increase in the federal funds rate). This effect is remarkable, since, in our benchmark calibration, the fiscal automatic stabilizers undo much of the negative impact that fiscal volatility shocks would otherwise have.

5. Thus, if we stop these automatic stabilizers from working, output contracts up to 1.5 percent, a considerable effect. This contraction is roughly equivalent to the one caused by a 300-basis-point negative monetary policy shock.

6. Most of the effects work through the larger uncertainty about the future tax rate on capital income.

7. An accommodative monetary policy, far from reducing the effects of fiscal volatility shocks, increases them even more. A stronger focus of monetary policy on inflation, rather than on the output gap, alleviates the negative outcomes of fiscal volatility shocks.

Although the size of these effects may not seem exceptionally big (although not small either, a fall of output at 1.5 percent in our pessimistic scenario is sizable), we think about them as a sensible lower bound on the importance of fiscal volatility shocks. For example, we do not include additional amplification mechanisms, such as irreversible investment (Bloom (2009)) or financial frictions (Christiano *et al.* (2010)). These mechanisms have been shown to be important in other contexts when time-varying volatility plays a role. Thus, it is likely that they would further increase the consequences 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 key driver of the business cycle. We claim, instead, that there are a number of situations, such as during the early 1980s or nowadays, where fiscal volatility shocks may have played an important role in aggregate fluctuations.

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, in a model with investment irreversibility, that volatility shocks to productivity at the firm level can induce decision makers to delay investment decisions, which results in a contraction in output. Fernández-Villaverde *et al.* (2011b) 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), Baker *et al.* (2011), Bloom *et al.* (2008), and Bachmann and Bayer (2009).[2]

There is also a closely related literature that emphasizes the role of disasters (a particular form of time-varying volatility) to account for business cycles and asset pricing. Examples include Barro (2006), Barro *et al.* (2011), Gourio (2008), and Nakamura *et al.* (2010). Detrimental policy changes induced by large fiscal volatility shocks can be interpreted as a potential source of the disasters these papers focus on.

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 investing has a positive call option value (see Pindyck (1988)). This is the thread revived by the aforementioned paper by Bloom (2009), who extends the analysis to the case with time-varying volatility.

Finally, there is a literature that studies the effect of the uncertainty regarding tax rates for investment and labor supply. Contributions include Barro (1989), Bizer and Judd (1989), Dotsey (1990), and, more recently, Bi *et al.* (2011).

[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.

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, additional experiments, and a number of robustness exercises. We close with some final remarks. An appendix reports details regarding the construction of the data, several quantitative exercises, and a simple analytic example of how volatility shocks affect the mark-ups that firms set.

2 Fiscal Rules with Time-Varying Volatility

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

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 due to 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 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 either of these two alternatives.

2.1 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 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 government 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 fiscal rules that we introduce next.

We use average tax rates rather than marginal tax rates, say, averaged over the population. The latter are employed by Barro and Sahasakul (1983) and Barro and Sahasakul (1986). To the extent that the tax code for labor and capital taxes is progressive, this may imply that we 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 undermeasure the effect of fiscal volatility shocks.

Unfortunately, the update of the Barro-Sahasakul measure of average marginal income tax rates provided in Barro and Redlick (2010) has two shortcomings that render it less useful for our purposes. First, it is available only through 2006, which would preclude us from analyzing the current episode of increased volatility. Second, it only covers, in its current version, labor income (and our results in section 5 will work mainly through taxes on capital income).

2.2 The Rules

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

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

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).

Equation (1) allows for two types of feedback: 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

[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.

Bohn (1998), who models the primary fiscal surplus as an increasing function of the debt-output ratio, correcting for wartime spending and cyclical fluctuations.

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

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

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

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

We interpret fiscal volatility shocks to a fiscal instrument as capturing greater-than-usual uncertainty about the future path of that instrument. After a positive fiscal volatility shock to capital taxes, for instance, agents' perceptions about probable movements of the tax rate are more spread out in either direction. Stochastic volatility offers an intuitive modeling of such changes. Bloom (2009), Bloom *et al.* (2008), Fernández-Villaverde *et al.* (2011b), and Justiniano and Primiceri (2008) use similar specifications to characterize the time-varying volatility associated with the evolution of productivity or with the cost of servicing sovereign debt. Relative to other specifications, equation (2) is parsimonious since it introduces only two additional parameters for each instrument (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 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 and after controlling for the situation of the business cycle. Indeed, there may be fiscal shock innovations even in the absence of new legislation. Examples include changes in the effective tax rate if policymakers, through legislative inaction, allow for bracket creep in inflationary times, or for changes in effective capital tax rates in episodes of booming stock markets. We now turn to our estimates.

2.3 Estimation

Our benchmark 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 rules with partial feedback*. Second, we will set both $\phi_{x,y} = 0$ and $\phi_{x,b} = 0$ and call this specification *fiscal rules 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 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, Fernández-Villaverde *et al.* (2011b) illustrate that eliciting priors for the parameters controlling stochastic volatility processes is difficult: we deal with units that are unfamiliar to most economists. Even with these flat priors, a relatively short draw suffices to achieve convergence, as verified by standard convergence tests. We draw 50,000 times from the posterior. These draws are obtained after an extensive search for appropriate initial conditions. We discarded an additional 5,000 burn-in draws at the beginning of our simulation. We selected the scaling matrix of the proposal density to induce the appropriate acceptance ratio of proposals as described in Roberts *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 us, time-varying volatility is significant; see the estimates reported in row "η_x." Except for labor income taxes, deviations from average volatility last for some time; see the large positive estimates in row "ρ_{σ_x}," although that persistence is not identified as precisely as the persistence of the fiscal shocks.

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

Table 2: Posterior Median Parameters – benchmark specification

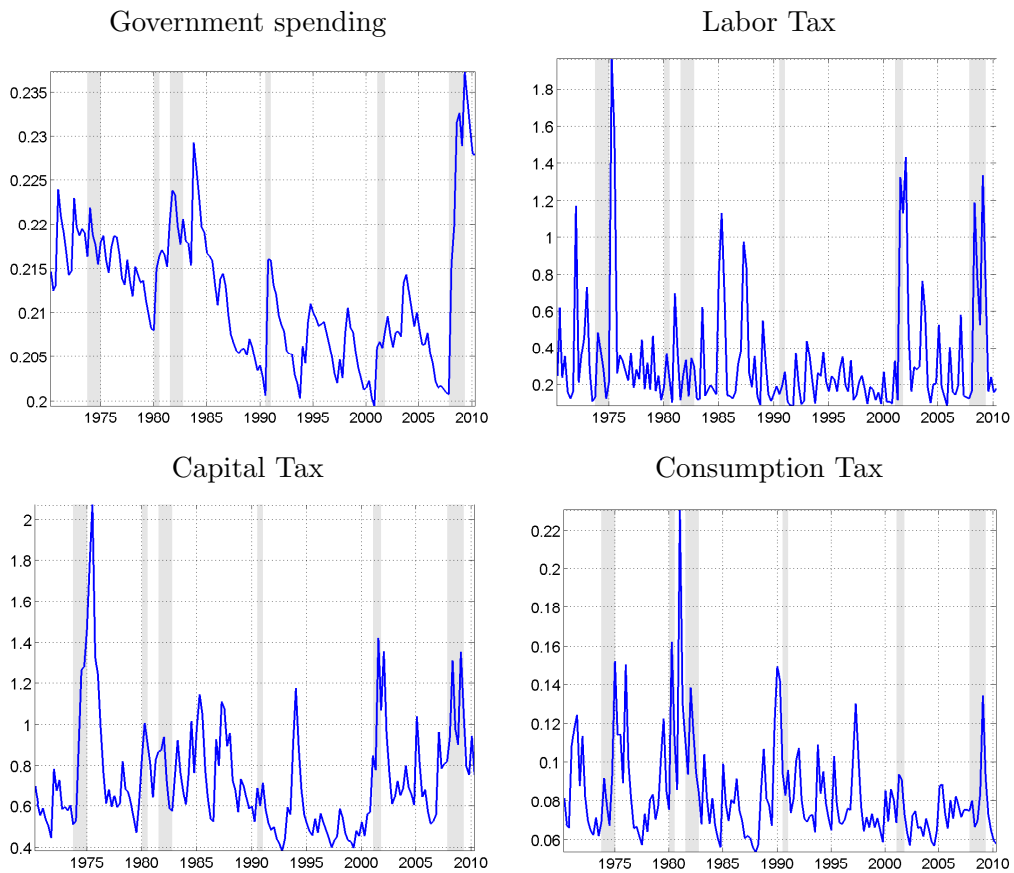
	Tax rate on			Government
	Labor	Consumption	Capital	Spending
ρ_x	0.99 [0.976,0.999]	0.99 [0.982,0.999]	0.97 [0.93,0.996]	0.97 [0.949,0.994]
σ_x	−6.01 [−6.29,−5.72]	−7.11 [−7.36,−6.81]	−4.96 [−5.26,−4.58]	−6.14 [−6.46,−5.54]
$\phi_{x,y}$	0.071 [0.025,0.125]	0.002 [0.001,0.011]	0.10 [0.007,0.252]	−0.009 [−0.04,0.00]
$\phi_{x,b}$	0.003 [0.00,0.007]	0.0006 [0.00,0.002]	0.004 [0.00,0.016]	−0.008 [−0.013,−0.003]
ρ_{σ_x}	0.30 [0.06,0.55]	0.63 [0.34,0.90]	0.77 [0.48,0.93]	0.93 [0.34,0.99]
η_x	0.95 [0.74,1.18]	0.60 [0.32,0.93]	0.56 [0.34,0.89]	0.18 [0.06,0.45]

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

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 impact of a 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 on the y-axis of the figure are 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 policy uncertainty as estimated by our procedure. For instance, the policy changes during the Reagan presidency appear in our estimation as a sustained increase in the volatility of government spending and capital and consumption taxes. Similarly, the fiscal overhauls by Presidents Bush senior and Clinton contributed to the increase in the volatility of all three taxes (both overhauls called for deficit cuts through a combination of tax increases and restraints on spending). These latter bursts of volatility happened during expansions. Our estimates reveal that fiscal volatility shocks to all instruments were typically higher during recessions (for instance 1981-1982). Based on our estimates, the fiscal policy uncertainty that agents faced during the latest recession is commensurate with the one that prevailed in the early 1980s. In sum, fiscal policy in the U.S. does display quantitatively significant time-varying volatility.

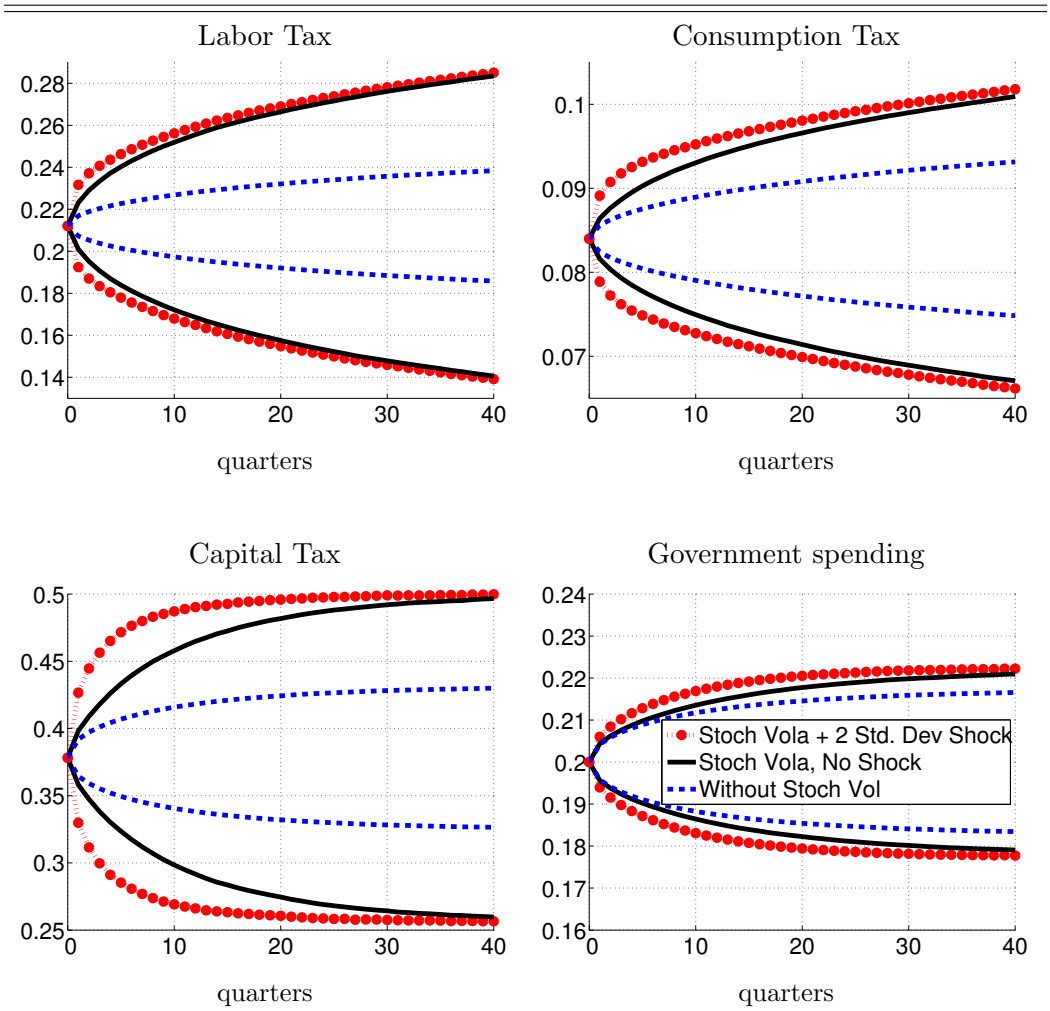
Figure 1: Smoothed fiscal volatility shocks to each instrument, $\sigma_{x,t}$



Notes: Volatilities expressed in percentage points.

Figure 2 shows how fiscal volatility shocks translate into changes in the distribution of future fiscal policy paths. The figure shows the 95 percent confidence intervals for 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 initial period. It is apparent how stochastic volatility increases fiscal policy uncertainty. The figure also shows, as red dots, the effect when, in the initial period, there is a two-standard-deviation innovation to the fiscal volatility shock to each of the fiscal instruments. The initial jump in volatility increases the dispersion of the possible paths of the fiscal instruments for some quarters. Due to the stationarity of the fiscal rules and stochastic volatility processes, the red dots and black lines converge after some time.

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 when the fiscal rules do not feature feedback to output and the debt level. Solid black line: benchmark specification when fiscal volatility shocks are set to zero in period 1. Red dots: benchmark specification with a two-standard-deviation fiscal volatility shock innovation to all instruments in period 1. Dashed blue line: specification with constant volatility held fixed at the steady-state value.

2.4 Endogeneity of the Fiscal Instruments

Although we feel comfortable that the specification of our fiscal rules is a good mechanism for estimating the effects we are interested in, we need to address the fact that there is no consensus among economists about how to specify fiscal rules. We do this in two ways. First, we stress that the core of our methodological contribution, the estimation of fiscal rules with stochastic volatility and their use in an otherwise standard model, is independent of the details of our specification. Researchers who prefer other forms for the rules just need to follow the steps we lay down: estimate their favorite rules and check, as we will do in the next sections, how impor-

tant the time-varying volatility of those fiscal rules is for economic activity. Second, we assess the robustness of our estimates as we entertain different assumptions about the specification of the rules. Summing up these experiments, we find our results to be 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.

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

However, the rules may not fully account for endogeneity when the economy is buffeted by large shocks (since the forecast based on lagged output may be a poor descriptor of today's output). To examine the extent to which this is a problem in practice, we estimate versions of our rules using the Aruoba-Diebold-Scotti (ADS) current business conditions index of the Federal Reserve Bank of Philadelphia (Aruoba *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 7, we will document how most of the action in the model comes from shocks to this instrument.

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

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

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

Table 3 compares the estimates of the benchmark specification of the rules (row labeled 0) with the three new versions using the ADS index (with the same order as above). The main lesson of the table is that the effects of relying on a different measure of the business cycle are small and

that the timing of the index does not have a strong bearing on the estimates of the parameters of the stochastic volatility process.[4] Thus, endogeneity does not seem to be a major concern in our benchmark specification once we control for lagged (detrended) output.

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

	Volatility Parameters			Fiscal Rule Parameters		
	σ_{τ_k}	$\rho_{\sigma_{\tau_k}}$	η_k	ρ_{τ_k}	$\phi_{\tau_k,ads}$	$\phi_{\tau_k,b}$
0	−4.96	0.77	0.37	0.96	0.10	0.005
	[−5.25,−4.58]	[0.20,0.91]	[0.22,0.57]	[0.93,0.99]	[0.007,0.25]	[0.001,0.02]
I	−5.01	0.75	0.38	0.95	0.003	0.003
	[−5.29,−4.62]	[0.44,0.94]	[0.29,0.52]	[0.91,0.98]	[0.002,0.005]	[0.001,0.01]
II	−4.97	0.69	0.34	0.96	0.003	0.003
	[−5.22,−4.72]	[0.20,0.91]	[0.18,0.56]	[0.92,0.99]	[0.001,0.004]	[0.001,0.01]
III	−4.96	0.77	0.34	0.96	0.002	0.004
	[−5.25,−4.64]	[0.49,0.93]	[0.25,0.48]	[0.93,0.99]	[0.001,0.003]	[0.001,0.014]

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

2.5 Comparison with Alternative Indexes of Policy Uncertainty

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

2.6 Comparison with Alternative Fiscal Rules

Now, we compare our estimated fiscal rules with the previous work in the literature. Our paper is closest to Leeper *et al.* (2010), who estimate a linearized RBC model with fiscal rules for several instruments without stochastic volatility.[5] The main difference between that paper and ours is

[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.

[5] Leeper *et al.* (2010) build on early contributions by Braun (1994), McGrattan (1994), and Jones (2002).

that Leeper *et al.* (2010) jointly estimate the model and the fiscal rules. 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 joint estimation using likelihood-based methods of a non-linear business cycle model of this dimensionality and the fiscal rules is a challenging task given current computational power.

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

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

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

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

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

3 Model

Motivated by our findings, we build a business cycle model to examine how our estimated processes for fiscal volatility translate into aggregate effects. We adopt a standard New Keynesian model in the spirit of Christiano *et al.* (2005) and 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 spending following the laws of motion estimated in section 2. The government also 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. There is a representative household whose preferences are separable in consumption, c_t, and labor:

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

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 capital, i_t, and hold government bonds, B_t, that pay a nominal gross interest rate of R_t in period $t+1$. The real value of those bonds at the end of the period is $b_t = B_t/P_t$. The real value at the start of the period of the bonds bought last period (before

coupon payments) is $b_{t-1}\frac{R_{t-1}}{\Pi_t}$, where P_t is the price level at period t and $\Pi_t = P_t/P_{t-1}$ is the inflation rate between $t-1$ and t.

The household pays consumption taxes $\tau_{c,t}$, labor income taxes $\tau_{l,t}$, and capital income taxes $\tau_{k,t}$. In addition, it pays lump-sum taxes Ω_t. 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^b_{t-1}. Finally, the household receives the profits of the firms in the economy $\digamma_t$. Hence, the household's budget constraint is given by:

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

The function:

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

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. Aggregate output appears in the adjustment cost function to scale it. We prefer a Rotemberg-style wage setting mechanism to a Calvo setting because it is more transparent when thinking about the effects of fiscal volatility shocks. In a Calvo world, we would have an endogenous reaction of the wage (and price) dispersion to changes in volatility that would complicate the analysis without delivering additional insight.[7]

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

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

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

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

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

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

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

$$\begin{aligned}\phi_w y_t \left(\tfrac{w_t}{w_{t-1}} - 1\right)\tfrac{w_t}{w_{t-1}} \quad = \quad & \mathbb{E}_t\left\{\beta \tfrac{\lambda_{t+1}}{\lambda_t}\phi_w y_{t+1}\left(\tfrac{w_{t+1}}{w_t} - 1\right)\tfrac{w_{t+1}}{w_t}\right\} \\ & + \left[\tfrac{d_t}{\lambda_t}\psi\epsilon_w (l^d_t)^{1+\vartheta} - (\epsilon_w - 1)(1 - \tau_{l,t}) w_t l^d_t\right],\end{aligned}$$

[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.

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

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

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

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

and

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

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

3.2 The Final Good Producer

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

$$y_t = \left(\int_0^1 y_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{6}$$

where ε is the elasticity of substitution.
Taking prices as given, the final good producer minimizes its costs subject to (6). The optimality conditions of this problem result in a demand function for each intermediate good:

$$y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\varepsilon} y_t \qquad \forall i \tag{7}$$

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 (7), 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 according to a Taylor rule:

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

The parameter $\phi_R \in [0,1)$ generates interest-rate smoothing. The parameters $\gamma_\Pi > 0$ and $\gamma_y \geq 0$ control the responses to deviations of inflation from target Π and of output from its steady-state value y. Given the inflation target Π, the steady-state nominal interest rate R is determined by the equilibrium of the economy. The monetary policy shock, ξ_t, follows a $\mathcal{N}(0,1)$ process.

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

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

The fiscal authority spends and levies taxes on personal consumption expenditures, on labor income, and on capital income, according to the fiscal rules described in equations (1) and (2). Finally, for consistency, we assume that lump-sum taxes operate to stabilize the debt to output ratio over the longer term. More precisely, we impose a passive fiscal regime as defined by Leeper (1991): $\Omega_t = \Omega + \phi_{\Omega,b}\left(b_{t-1} - b\right)$, 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 the capital market must clear, 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.

[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.

4 Solution and Benchmark Calibration

We solve the model by a third-order perturbation around its steady state. Models with volatility shocks are inherently non-linear and linearization cannot be applied to compute them (see Fernández-Villaverde *et al.* (2011b) for details). Perturbation is, in practice, the only method that can solve a model with as many state variables as ours 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 only appear by themselves in the third-order terms. This will be crucial below, when we compute impulse response functions (IRFs). Furthermore, our non-linear solution implies moments of the ergodic distribution of endogenous variables that are different from the ones implied by a linearization. Hence, we use the moments implied by our non-linear approach to calibrate the model. Once we solve our economy, we simulate it to compute first and second moments of endogenous variables and IRFs.

Before proceeding to the benchmark calibration, we fix several parameters to conventional values. We are dealing with a large model that would make a more targeted calibration quite challenging. With respect to preferences, we set $\omega = 2$ and $\vartheta = 2$. This second value implies a Frisch elasticity of labor supply of 0.5. This number, in line with the recommendation of Chetty *et al.* (2011) based on an extensive survey of the literature, is appropriate given that our model does not distinguish between an intensive and extensive margin of employment (Rogerson and Wallenius (2009)). Habit formation is fixed to the value estimated in Christiano *et al.* (2005).

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

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

For policy, the values for $\gamma_\Pi = 1.25$ and $\gamma_y = 0.25$ follow Boivin (2006) and Fernández-Villaverde *et al.* (2010). We pick a value for $\phi_{\Omega,b}$ that is sufficient to stabilize the debt level. This parameter is inconsequential for allocations if there is no feedback of distortionary taxes or spending to the debt level ($\phi_{x,b} = 0$) (see Leeper (1991)). When there is feedback, however, this is not the case but our small value ensures that the effects are minimal. We set Ω to $-4.3e-2$ to satisfy the government's budget constraint in the absence of feedback in the fiscal rules. Finally, we chose 0.95 and 0.18 for the persistence of the productivity and the intertemporal shocks, both

Table 4: Parameters and Targets

Preferences and consumer		
β	0.9945	Calibrated.
ω	2	Standard choice.
ϑ	2	Chetty *et al.* (2011).
ψ	75.66	Calibrated.
b_h	0.75	Christiano *et al.* (2005).
ϕ_w	4889	Altig *et al.* (2011).
ϵ	21	Altig *et al.* (2011).
Cost of utilization and investment		
Φ_1	0.0165	From utilization FOC.
Φ_2	0.0001	Calibrated.
κ	3	Calibrated.
Firms		
α	0.36	Standard choice.
δ	0.011	Calibrated.
ϕ_p	236.10	Galí and Gertler (1999).
ϵ_w	21	Altig *et al.* (2011).
Monetary policy and lump-sum taxes		
Π	1.0045	Calibrated.
ϕ_R	0.6	Calibrated.
γ_Π	1.25	Fernández-Villaverde *et al.* (2010).
γ_y	1/4	Fernández-Villaverde *et al.* (2010).
Ω	-4.3e-2	Follows from gov. budget constraint.
$\phi_{\Omega,b}$	0.0005	Small number to stabilize debt.
b	2.64	Calibrated.
Shocks		
ρ_A	0.95	King and Rebelo (1999).
σ_A	0.001	Calibrated.
ρ_d	0.18	Smets and Wouters (2007).
σ_d	0.078	Calibrated.
σ_m	0.0001	Calibrated.

standard values in the literature (King and Rebelo (1999) and Smets and Wouters (2007)).

The rest of the parameters are calibrated using the ergodic distribution and quarterly data from the U.S. economy. The time discount factor, β, targets an annualized average real rate of interest of 2 percent. The parameters ψ and Π target an average share of hours worked of 1/3 and an average annualized inflation rate of 2 percent. Finally, we set the following parameters $\{\Phi_2, \kappa, \delta, \phi_R, \sigma_A, \sigma_d, \sigma_m, b\}$ to match the standard deviations of output, consumption, invest-

ment, capital utilization, inflation, and interest rates, the average ratio of investment to output (0.2), and the average debt-to-output ratio (1.6) found in the data (table 5 provides details on data sources.)

Table 5: Second Moments in the Model and the Data

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

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

Table 4 summarizes our parameter values except for those governing the processes for the fiscal instruments, which we set equal to the posterior median values reported in table 2. Hence, our benchmark calibration allows for feedback in the fiscal rules. As a preliminary diagnosis of the model and to give the reader an indication of its fit, table 5 presents summary information for first and second moments of selected endogenous variables and compares them with the data. The model does a fair job at matching the data, even for moments we do not use for calibration.

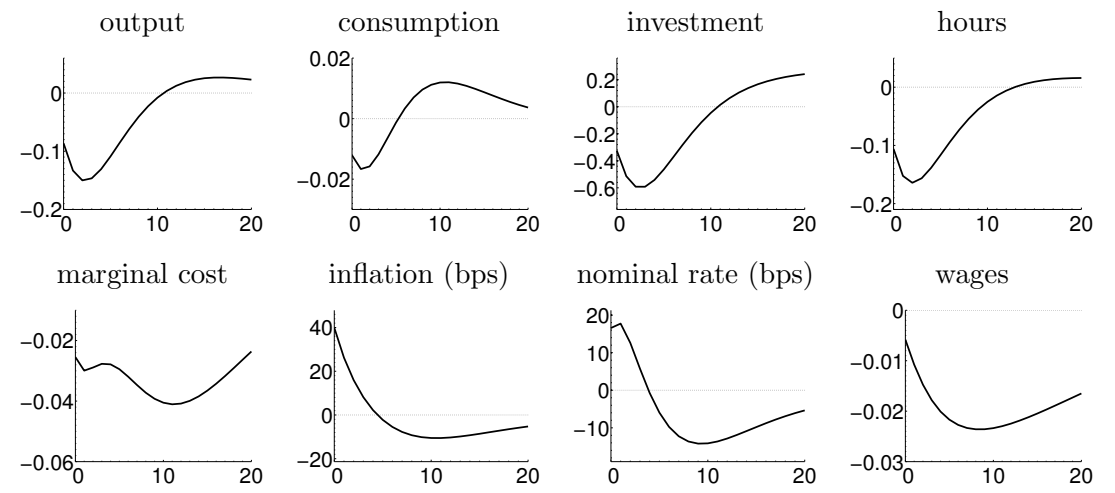
5 Results

In this section, we present our main results. First, we show the IRFs to a fiscal volatility shock. Second, we explain why fiscal volatility shocks are stagflationary and, third, why nominal rigidities matter for this finding. Fourth, we discuss some empirical implications of our results. Fifth, we compare the IRFs to fiscal volatility shocks with those to monetary policy shocks.

5.1 Impact of Fiscal Volatility Shocks

Heightened fiscal policy uncertainty can be parsimoniously captured by a simultaneous increase in the volatilities of the innovations to all fiscal instruments. That is, we model a spike in fiscal policy uncertainty as positive innovations $u_{x,t}$ for all x. Here we confront an important choice: the magnitude of the increase (recall that we are dealing with a non-linear model and the size of the innovations matters). 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 size of volatility shocks that Bloom (2009) uses.

Figure 3: Fiscal volatility shock



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

The first result of this section, documented by the IRFs in figure 3, is that fiscal volatility shocks cause a prolonged contraction in economic activity: output, consumption, investment, hours, and real wages fall, while inflation rises. Output reaches its lowest point about three quarters after the shock. Most of the decline comes from a drop in investment, which falls around four times more in percentage terms. The more modest decline in consumption illustrates households' desire for smoothing.[10] The "stagflation" triggered by lower output and higher inflation, the second result of this section, is a particularly intriguing property of the model.

[10] In contrast, Fernández-Villaverde *et al.* (2011b) 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.

The responses in figure 3 happen 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 will reduce the tax rates and increase government spending in future periods, which stabilizes output. We will later return to this issue.

The transmission mechanism for fiscal volatility shocks can be discovered in the first two panels of the bottom row. In the first panel, the real marginal cost goes down after the volatility shock, while, in the second one, inflation increases. Given that we are in a Rotemberg price setting (where the real marginal cost times the gross mark-up is always one), this means that mark-ups are rising endogenously. Mark-ups work in the model as a distortionary wedge. In particular, higher mark-ups reduce hours worked because they are equivalent to a higher tax on consumption. The subsequent fall in output pushes consumption down, a result that was difficult to deliver in Bloom (2009).

5.2 Why Do Markups Rise?

Why do we have this increase in inflation and fall in real marginal cost that raise the markup? Because of two channels: an aggregate demand channel and an upward pricing bias channel, both related to nominal rigidities in price setting.

The first channel is a fall in aggregate demand. Because of higher uncertainty regarding future tax rates and the associated higher precautionary behavior, households want to consume and invest less and save more. In the absence of price and wage rigidities, the effect of this heightened precautionary behavior would be small. With rigidities, prices and wages cannot fully accommodate the lower demand and we have a fall in output and an increase in the mark-up. However, this channel alone induces a drop in inflation, whereas inflation increases in figure 3.

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

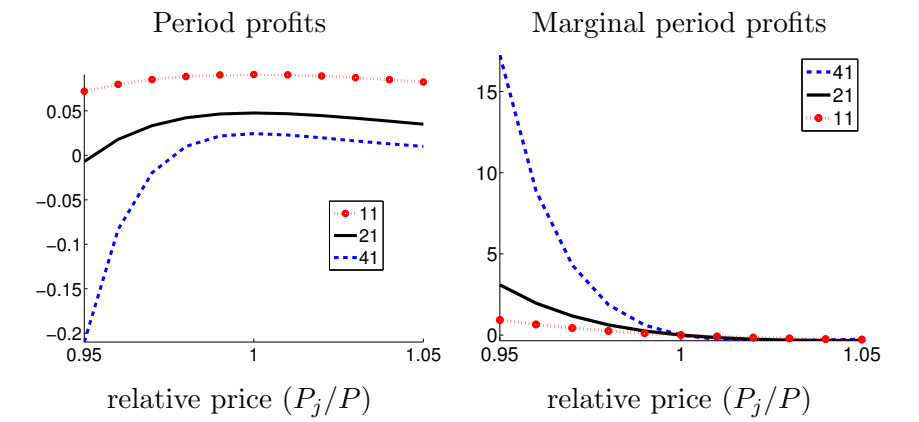
$$\left(\frac{P_j}{P}\right)^{1-\epsilon} y - mc\left(\frac{P_j}{P}\right)^{-\epsilon} y,$$

where $mc = (\epsilon - 1)/\epsilon$. Marginal profits, thus, are strictly convex in the relative price of the firm's product. Figure 4 illustrates this for three different levels of the demand elasticity (implying a 10 percent, 5 percent, and 2.5 percent markup, respectively).

Figure 4 also shows that, given the Dixit-Stiglitz demand function, it is more costly for the firm

to set too low a price relative to its competitors, rather than setting it too high. This effect is the stronger the more elastic the demand, since the expenditure-switching effect is more pronounced.

Figure 4: 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).

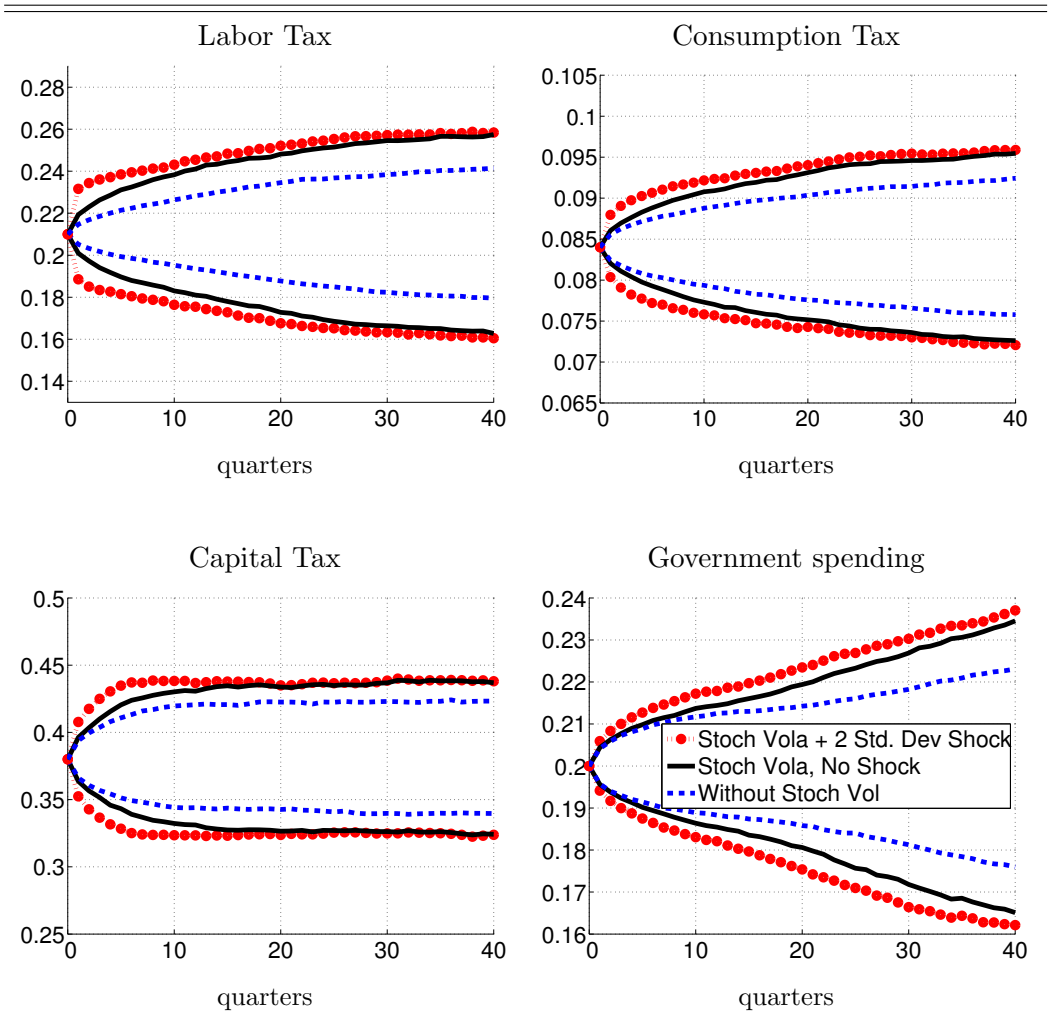
The constraint for the firm is that the price that it sets in the current period determines how costly it will be to change to a new price in the next period. Under uncertainty, firms will bias their current price toward the high relative price region. If, tomorrow, a large shock pushes the firm to raise its price, it will be less costly in terms of adjustment costs to get closer to that price if today's price was already set at a high level. If a large shock pushes the firm to lower its price, it will be less costly to get stuck with a high price because of the shape of the profit function.[11] Appendix D elaborates in much more detail.[12]

A fiscal volatility shock increases the dispersion of likely future aggregate demand and marginal costs and, hence, the probable range for the optimal price tomorrow. This can be seen in the future paths of fiscal instruments displayed in figure 5. Contrary to figure 2, these now show forecast confidence intervals when the fiscal rules respond to output and the debt level (see also appendix C for some additional confidence bands). For instance, the increase in the dispersion of

[11] A 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.

[12] Our argument is close, but not equal to, the one in Kimball (1989). While Kimball emphasizes a precommitment in prices and the effect of the uncertainty level, we focus on the presence of adjustment costs to prices and the effect of changes in uncertainty. Consequently, while his mechanism works through convex marginal cost, ours works through the shape of the demand function (in our model, we have constant returns to scale at the firm level and, hence, marginal costs are constant given input prices.) Our result also resembles equation (10) in Ball and Romer (1990), although again our mechanism is slightly different since the term W_{211} in their equation is zero in our model.

Figure 5: 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: benchmark specification when fiscal volatility shocks are set to zero in period 1. Red dots: benchmark specification with a two-standard-deviation fiscal volatility shock innovation to all instruments in period 1. Dashed blue line: specification with constant volatility held fixed at the steady-state value.

the capital income tax will raise the dispersion of marginal costs through its effects on the rental rate of capital (both directly, through the utilization margin decision, and indirectly, through investment). Firms respond to that volatility shock by biasing their pricing decision toward the high price region even more than when fiscal volatility is at its average value. Marginal costs fall because, at a higher price and lower production, firms rent less capital and this lowers its rental rates. Wages, since they are subject to real rigidities, barely move and the labor market clears through a reduction in hours worked. This same line of reasoning will help us to understand, below, why the tax on capital income is the main driving force of the effects of fiscal volatility shocks.

5.3 How Important Is the Upward Pricing Bias?

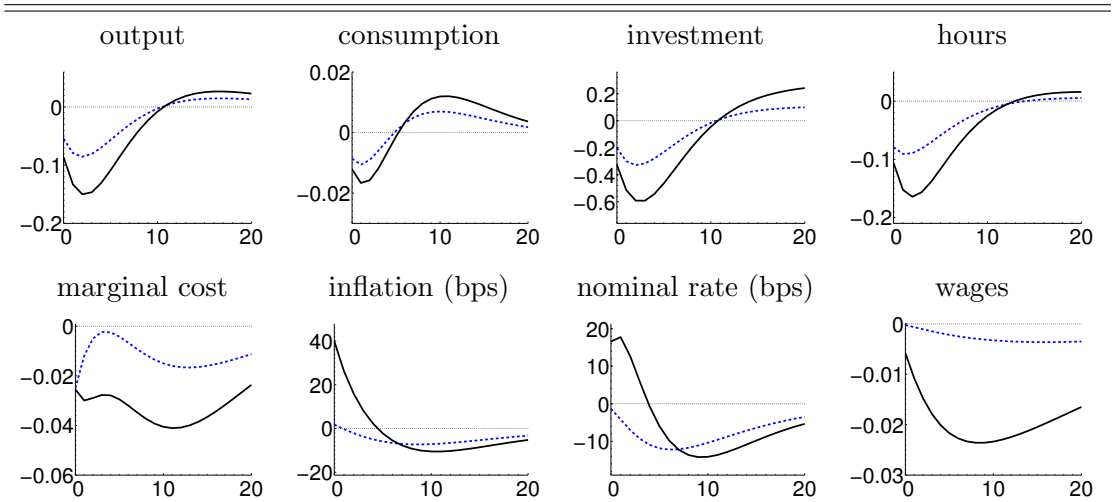
We described two channels behind the fall in output: an aggregate demand channel and a upward pricing bias channel. We seek now to disentangle the importance of each of them.

Toward that end, figure 6 compares the IRFs in the benchmark economy (solid black line) and in a counterfactual one (dashed blue line). All the equilibrium conditions of the counterfactual economy are the same as in the benchmark case except that now inflation evolves according to the linearized version of the Phillips curve shown in section 3:

$$\Pi_t - \Pi = \beta \mathbb{E}_t \left(\Pi_{t+1} - \Pi\right) + \frac{\epsilon}{\phi_p \Pi} \left(mc_t - mc\right), \tag{8}$$

where $mc = (\epsilon - 1)/\epsilon$. Equation (8) imposes that inflation is governed only by a linear function of marginal costs. We interpret this system as one where the upward pricing bias is missing because we suppress the nonlinearities regarding the price setting at the core of that bias.[13]

Figure 6: The role of precautionary price setting

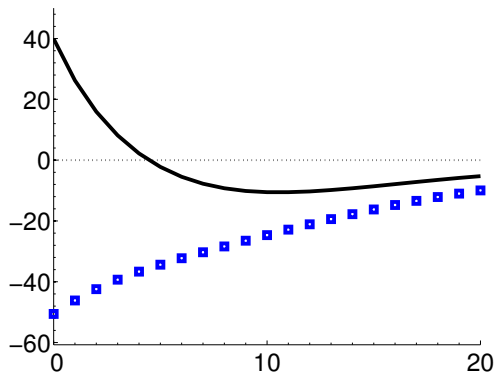


Notes: The solid black lines are the IRFs to a fiscal volatility shock in the benchmark economy. The blue dashed lines are the IRFs when inflation follows the linear Phillips curve (8). The figures are expressed as percentage changes from the mean of the ergodic distribution of each variable. Interest rates and inflation rates are in annualized basis points.

Comparing the blue dashed line and the black solid line tells us that both channels are roughly of the same importance for explaining the impact of fiscal volatility shocks. Namely, output falls about twice as much when the upward pricing bias is present as when it is absent.

[13] Note, though, that we still solve the model through a third-order expansion, which means that firms forecast inflation using non-linear rules and, thus, consider fiscal volatility shocks. These indirect effects, though, are small.

Figure 7: The inflation gap



Notes: IRFs of inflation to a fiscal volatility shock. The solid black line shows the IRF in the benchmark economy. The blue squares show the IRF if inflation followed equation (8). Inflation rates are in annualized basis points.

Another way to communicate the importance of the upward pricing bias is by defining and quantifying an "inflation gap." That is, we ask: how would inflation have evolved absent the upward pricing bias? To do so, we compute first the evolution of the economy according to the benchmark case and we plot, in figure 7 and with a black line, the IRF of inflation to a fiscal volatility shock. Then, we take the evolution of marginal costs period by period from the benchmark economy and we feed it into equation (8) to generate a counterfactual path for inflation.[14] The result is shown by the blue squares in figure 7. The measured inflation gap is the difference between the black line and the blue squares. We find that the inflation gap is large, around 90 basis points, and that it closes slowly over time. Absent the upward pricing bias, inflation would fall after a fiscal volatility shock. But since firms bias their pricing decision toward higher prices, actual inflation rises.

5.4 Some Empirical Implications

The discussion in this section has powerful empirical implications because it demonstrates how fiscal volatility shocks impose different dynamics than supply and demand shocks on key variables. Furthermore, fiscal volatility shocks can generate correlations among variables that would otherwise be difficult to understand, especially because the fiscal volatility shock is not directly observed in any "fundamental" of the economy.

Imagine, for example, that we simulate data from our model and we estimate a conventional Phillips curve with it. The combination of falling output, falling real marginal cost, and in-

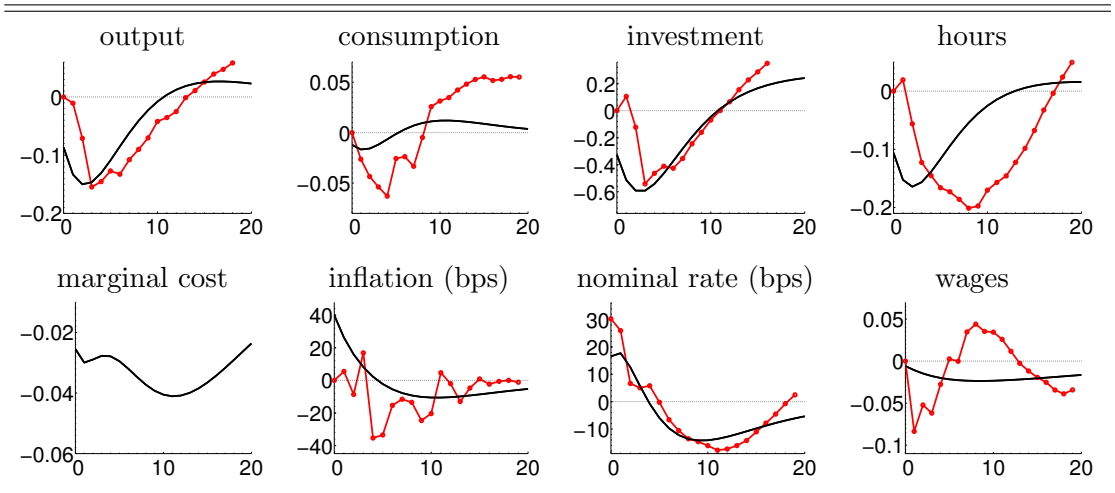
[14] Note the difference with the exercise in figure 6: now we only use equation (8) to back up inflation given the path of mc_t from the benchmark economy, but this inflation does not feed back into the economy. In figure 6, equation (8) is part of the equilibrium conditions of the counterfactual economy and hence it feeds back into the dynamics of the economy.

creasing inflation would be hard to interpret as a negative demand shock (which would deliver falling output and real marginal cost but also less inflation) or a negative supply shock (which would mean falling output and inflation but an increasing real marginal cost). Fiscal volatility shocks are, thus, potentially important forces while reading the data. For instance, this channel may partially account for the recent experience of the U.S., where a large negative output gap was not accompanied by a steep fall in inflation. If fiscal volatility shocks were large, these are precisely the observations that our model would predict: falling output and rising inflation.[15]

5.5 Fiscal Volatility Shocks versus a Monetary Policy Shock

Figure 8 shows the effects of a fiscal volatility shock in our model and the IRFs to a 30-basis-point (annualized) increase in the nominal interest rate (dotted red lines) implied by Altig *et al.* (2011)'s VAR of the U.S. economy.[16] We pick a 30-basis-point increase in the federal funds rate because it corresponds to a one-standard-deviation contractionary monetary innovation in the data. From this comparison, we obtain the third result of this section. Fiscal volatility shocks induce contractions that are equivalent to those coming from a typical contractionary monetary shock. And to reiterate a previous point, the response of inflation is different: it falls after a monetary shock but rises in the wake of a fiscal volatility shock.

Figure 8: Fiscal volatility shock vs. 30 bps monetary shock



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

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

[16] We thank Jesper Linde for kindly providing the code to replicate their results.

An alternative assessment of fiscal volatility shocks is as follows. Hamilton (2008) and Hamilton and Wu (2010) estimate that a purchase of $300 billion in long-term securities such as the one undertaken by the Fed between March and October 2009 translates into a drop of roughly 25 basis points in the fed funds rate.[17] In other words, against these numbers, the effects of a fiscal volatility shock appear to be about the same size (but of opposite sign) as the effects of the stimulus achieved through the recent exercise in quantitative easing.

6 The Uncertain Fiscal Future Ahead

Next, we show some results when we depart from the benchmark calibration discussed above. We vary the calibration in three ways. First, we suppress feedback from the fiscal rules. Second, we increase the persistence of the fiscal volatility shocks for all instruments. Finally, we show a scenario in which we combine both modifications.

6.1 Rules with Partial and Without Feedback

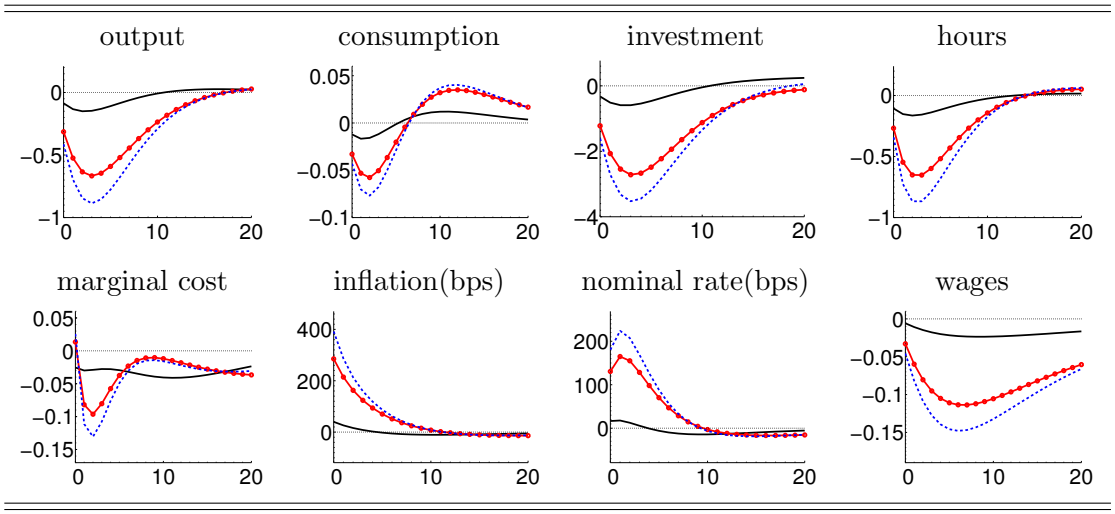
In our benchmark calibration, we considered feedback from output and from the debt to output ratio to fiscal instruments. According to these rules, tax rates fall and government spending increases in the wake of a fiscal volatility shock because the rules respond to the drop in output. A comparison between figures 2 (without feedback) and 5 (with feedback) shows how important the feedback effect is. When feedback is present (figure 5), future taxes are less spread out because of the smoothing effect of the feedback, while government expenditure is more spread out for the same reason. This smoothing effect disappears when feedback is absent (figure 2): future taxes are more spread out while government expenditure is less.

A logical exercise is, then, to eliminate the feedback and to revaluate the results in the previous section. This may also be a more relevant exercise for the current situation in the U.S., which so far does not seem to have experienced much of a reaction of taxes or government expenditure to the debt to output ratio. The absence of feedback also captures the notion that, moving forward, the government might conduct less stabilization policy via taxes and spending in its attempt to balance the budget.

Figure 9 compares the IRFs under the benchmark calibration (solid black line) to the IRFs of the model with partial feedback and without feedback as defined in section 2, but where the rest of the parameters are kept as in the benchmark calibration. 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

[17] 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 9: Fiscal volatility shocks – effect of feedback



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

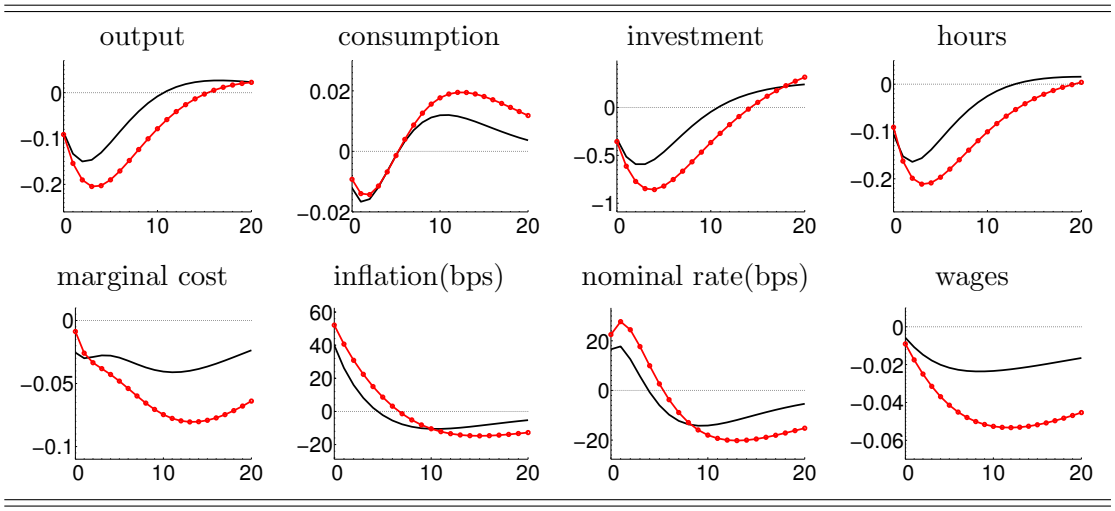
feedback, the impact of fiscal volatility shocks is considerably stronger. For instance, in the case without feedback, output falls by 0.88 percent, almost five times more than in the benchmark calibration. Much of this decline is due to a sharper drop in investment (-3.5 percent). We conclude that, without the dampening effect of feedback, the impact of a fiscal volatility shock can be considerable. If, as argued by some observers, feedback is currently not working in the U.S., these shocks might be a factor to be assessed in more detail.

6.2 More Persistent Fiscal Volatility Shocks

We evaluate, now, the effect of a fiscal volatility shock that is more persistent than the median of the posterior that we reported in table 2. This exercise is motivated by the large variance in the posterior distributions of the persistence parameters of the fiscal volatility shocks to every instrument.

In figure 10, we present IRFs of the model with persistence parameters equal to 0.90 for the fiscal volatility shocks to all four instruments. Then, the volatility shocks have a half-life of about one 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 firms fear that tax changes are more likely for more than the next few quarters. As a result, they reduce their exposure to future taxes by increasing the mark-up even more.

Figure 10: Fiscal volatility shocks – effect of persistence



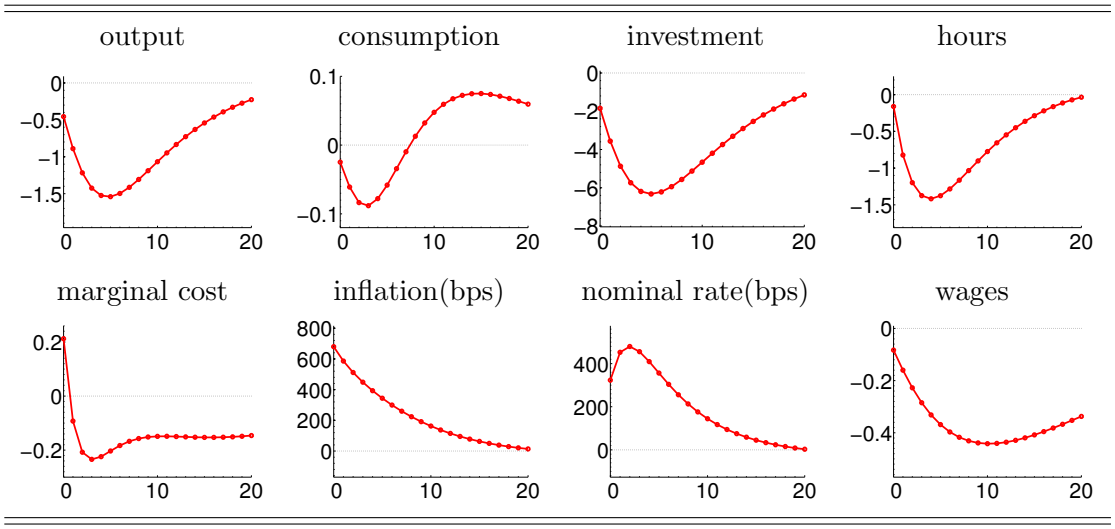
Notes: The solid black lines are the IRFs to a fiscal volatility shock with the benchmark fiscal rules. The dotted red lines are the IRFs to a more persistent fiscal volatility shock (with a half-life of about 1.5 years) while rescaling the variances of the innovations. The figures are expressed as percentage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

6.3 A Pessimistic Scenario?

The stance of the political debate in the U.S. suggests that any change in fiscal policy is up for grabs. For example, it is unclear when fiscal consolidation will be implemented and whether it will be staggered over a period of time or introduced in one step. Also, in this attempt to balance its accounts, the government may not be able to react to business cycles. As discussed above, the lack of a clear time frame for implementation (high persistence of volatility) or the ability to react to the state of the economy (absence of feedback) has large consequences for the impact of fiscal volatility shocks. Together these considerations imply that our benchmark calibration may paint a too conservative picture of fiscal volatility shocks. As an exercise to capture a pessimist's assessment of the current fiscal situation, we eliminate the feedback component in the fiscal rules and increase the persistence of all the fiscal volatility shocks to 0.90.

The red dotted lines in figure 11 display the impact of a fiscal volatility shock without feedback and with high persistence. The recession that we compute is now severe. At its trough, output contracts by 1.5 percent (roughly equivalent to a contractionary shock of 300 basis points in the federal funds rate). Even on impact, variables react substantially to the fiscal volatility shock: output experiences a decline of 0.45 percent and inflation increases considerably. Thus, in the current situation, fiscal volatility shocks may be an important force dragging down the economy.

Figure 11: Fiscal volatility shocks – pessimistic scenario



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

7 Additional Analysis

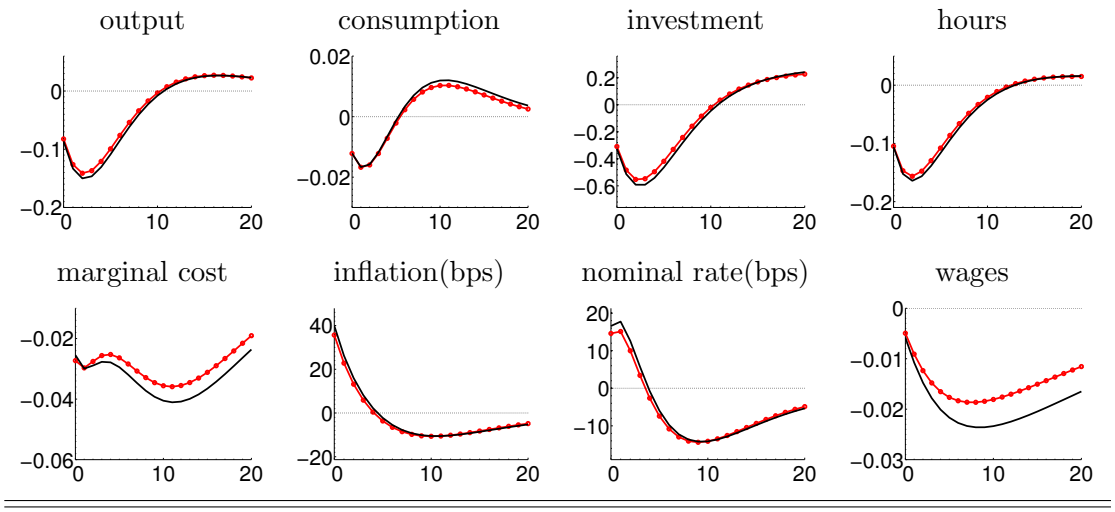
In this section, we discuss three additional points. First, we decompose the effect of the fiscal volatility shock among each of the different instruments. Second, we explore how monetary policy interacts with fiscal volatility shocks. Third, we measure how the IRFs to a fiscal volatility shock depend on the degree of price and wage rigidity in the economy.

7.1 Decomposing the Response to a Fiscal Volatility Shock

We have defined a fiscal volatility shock as a simultaneous increment of two standard deviations in the volatilities of the innovations of each fiscal instrument. Here we are interested in decomposing the total impact among the effects of each fiscal instrument. While a variance decomposition cannot be implemented (our solution method is non-linear), we can compare each of the IRFs associated with a shock to one instrument alone with the IRFs to a fiscal volatility shock as defined in section 5.

We do this in figure 12, where we show (in black) the IRFs to a fiscal volatility shock and (in the dotted red lines) the IRFs where there is a fiscal volatility shock only to the capital tax rate. Clearly, the increase in volatility of capital taxes accounts for most of the effect of the fiscal volatility shock that we found in subsection 5.1. Additional unreported figures with different combinations of increases in volatility of fiscal instruments confirm this result: nearly all of the economy's response to fiscal volatility shocks works through the tax on capital income.

Figure 12: Fiscal volatility shocks vs. fiscal volatility shock only to capital tax rate



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

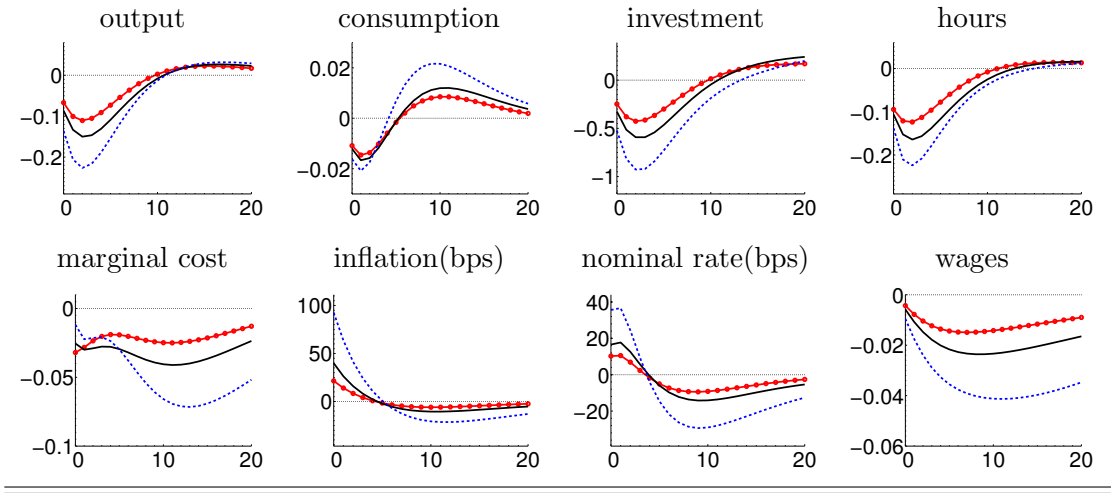
The intuition is simple. Higher uncertainty in consumption taxes or on government spending has little effect on the problem of the firm and the markup, which we argued before was at the core of the mechanism linking fiscal volatility shocks with lower output. The uncertainty about the tax on labor income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

7.2 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 where it is already higher than usual. It is interesting, then, to explore how the economy responds to fiscal volatility shocks under different values of the parameters on the Taylor rule.

The IRFs in figure 13 show the benchmark response, as a solid line, and two alternative scenarios. In the first one, the monetary authority reacts more strongly to output than in the benchmark case (a value of $\gamma_y = 0.5$ instead of $\gamma_y = 0.25$, dashed blue lines). In the second one, the monetary authority reacts more aggressively to inflation (a value of $\gamma_\Pi = 1.5$ instead of $\gamma_\Pi = 1.25$, dotted red lines).

Figure 13: Fiscal volatility shocks – effect of Taylor rule



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

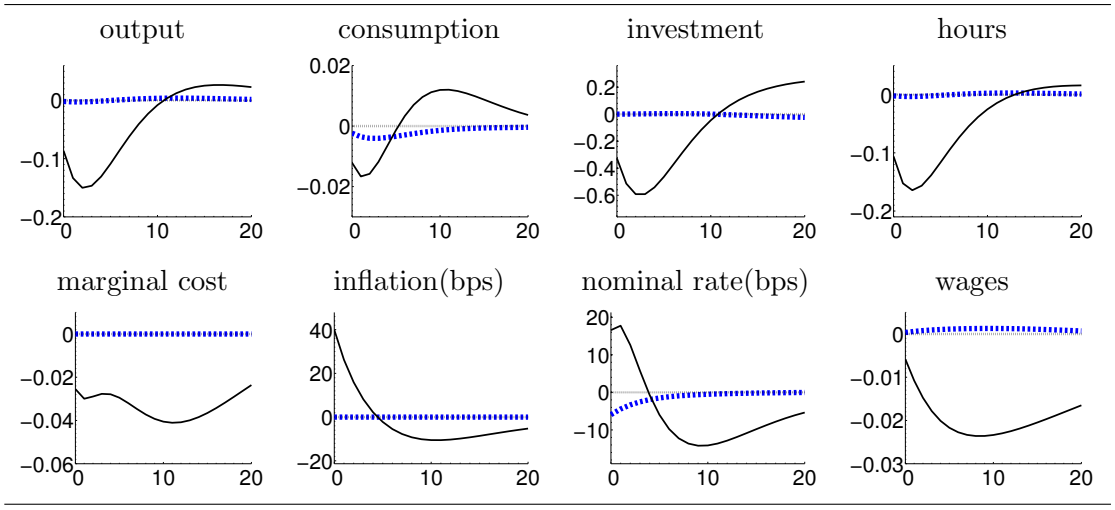
The mechanism behind these new IRFs is the following. In the model, inflation rises after a fiscal volatility shock while output falls. When the response to output in the Taylor rule (γ_y) is high, firms anticipate that inflation will be tolerated. To counterbalance declining profits, firms aggressively increase prices with a view toward higher markups. Firms' anticipation 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 less likely, which reduces their upward price bias ahead of any actual tax change. Thus, in equilibrium, the smaller the monetary response to output, the more moderate is the inflation response and the contraction in output. An analogous argument explains why, if the central bank becomes more responsive to inflation (higher γ_Π), the stagflationary effects of fiscal volatility shocks are less pronounced.

We can push our argument above further and assume a strong commitment of monetary policy to price stability by letting the central bank ignore the Taylor rule and set interest rates instead such that

$$\Pi_t = \overline{\Pi}, \ \forall t.$$

This is shown as the dashed blue line in figure 14. Now, the effects of the fiscal volatility shock on economic activity are, at least, one order of magnitude smaller than in the benchmark economy.

Figure 14: Fiscal volatility shocks – Strict inflation targeting



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

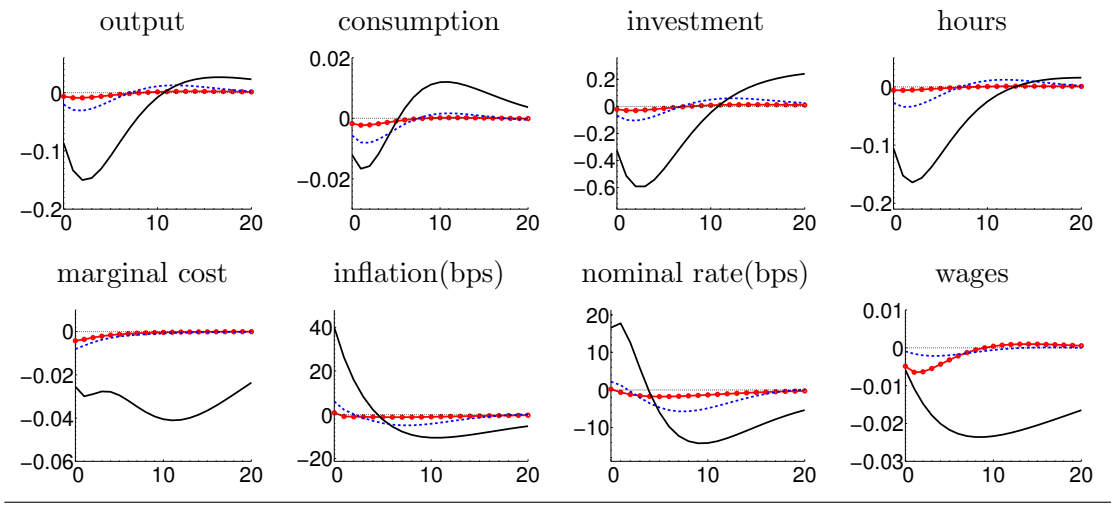
7.3 The Role of Price and Wage Rigidities

In our last exercise, figure 15 shows how the degree of price and wage rigidity affects the impact of fiscal volatility shocks. The dashed blue line plots the IRFs when we reduce price stickiness to the one equivalent to a Calvo model with an average price duration of about one quarter. The response is both less pronounced and shorter-lived. The dotted red line reduces price and wage stickiness to the one equivalent to a Calvo model with an average price and wage duration of one quarter. In the absence of nominal rigidities, fiscal volatility shocks have only a negligible impact on economic activity. This finding resembles the results in the real models of Bloom (2009) and Bloom *et al.* (2008) that require irreversibilities at the individual firm level for generating a propagation of volatility shocks. At the same time, it also suggests that irreversibilities could make the effects of fiscal volatility shocks bigger. Appendix E illustrates this point further by assessing the importance of the elasticity of demand and its relation to the curvature of the profit function.

8 Conclusions

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

Figure 15: Fiscal volatility shocks – effect of price/wage rigidities



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

We have found that fiscal volatility shocks can shave off up to about 1.5 percentage points from output in an adverse scenario characterized by high persistence of the volatility and the absence of fiscal stabilizers. Our results may well be, however, 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, a lack of clarity about the size of future *increases* alone in taxes), the effects of fiscal volatility shocks could also be larger. It would be simple to incorporate this one-sided risk: we would only need to feed our fiscal rules with a trend in the average tax rate and government consumption over the next few years and report the evolution of the economy relative to a baseline without that trend. We have not done so in the interest of clarity: fiscal volatility matters even when the risk is two-sided.

We have also ignored the fact that, at the time of writing, the federal funds rate is at its zero lower bound (ZLB) and the FOMC's forward guidance indicates that interest rates are likely to remain exceptionally low for some time (Federal Open Market Committee (2011)). Thus, it is natural to ask how fiscal volatility shocks interact with the ZLB. This is important because

several papers have highlighted that the response of the economy to disturbances may differ at the ZLB. See, among others, Christiano *et al.* (2011), Eggertsson (2011), and Woodford (2011). Unfortunately, and because of the size of the state space, a numerical assessment of the implications of fiscal volatility shocks at the lower bound is technically well beyond the scope of this paper.[18] This is, nevertheless, an important topic that deserves further study.

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 a key issue that we plan to take up in future work.

[18] See, however, Fernández-Villaverde *et al.* (2011a) for a full non-linear exploration of the ZLB in a much smaller model.

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Technical Appendixes

A Tax Data

In this appendix, we describe how we build our sample of tax data. We follow (most of) the methodology of Leeper *et al.* (2010), who construct aggregate effective tax rates using 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. Also, as we have seen recently, changes in federal policy such as the American Recovery and Reinvestment Act of 2009 have a direct impact on the fiscal situation of state and local governments.

There are two alternatives to our choice. One would be to explicitly model three levels of government (or perhaps just two, federal and non-federal). However, this would considerably increase the state space and would come at the expense of reduced transparency. For example, state and local governments are largely subject to balanced-budget requirements, while the federal government can engage in tax-smoothing by issuing debt. Besides, the different levels of government use different bases for their taxation. All these aspects would need to be (at least partially) included in a model with several levels of government. A second possibility could be to disregard local and state tax revenue altogether and focus entirely on the federal side as in Leeper *et al.* (2010). However, state and local finances have been hit hard by the last recession. As a result, at least some of the uncertainty about the fiscal mix going forward appears to originate at the state and local level (and what the federal government may eventually do about the weaknesses at the local and state fiscal levels).

We now explain how we derive measures of tax rates.

A.1 Consumption taxes

The average tax rate on consumption is defined as:

$$\tau_c = \frac{\text{TPI} - \text{PRT}}{\text{PCE} - (\text{TPI} - \text{PRT})}. \tag{9}$$

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:

$$\tau_p = \frac{\text{PIT}}{\text{WSA} + \text{PRI}/2 + \text{CI}}. \tag{10}$$

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:

$$\tau_l = \frac{\tau_p \left[\text{WSA} + \text{PRI}/2\right] + \text{CSI}}{\text{CEM} + \text{PRI}/2}. \tag{11}$$

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:

$$\tau_k = \frac{\tau_p \text{CI} + \text{CT} + \text{PRT}}{\text{CI} + \text{PRT}}. \tag{12}$$

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).

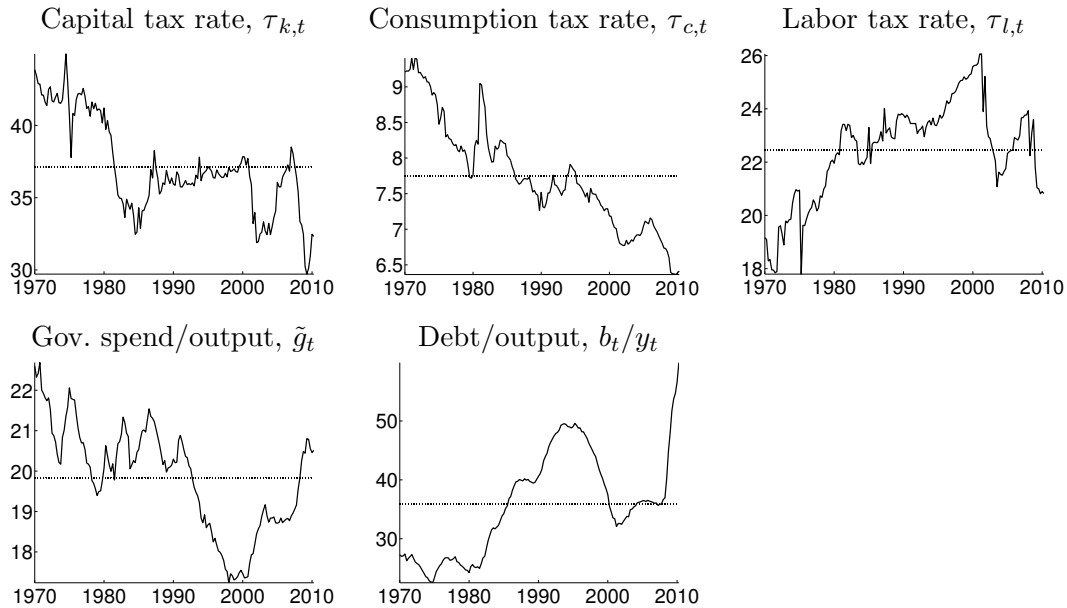
A.4 Other variables

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

Figure 16: Data: taxes and government spending

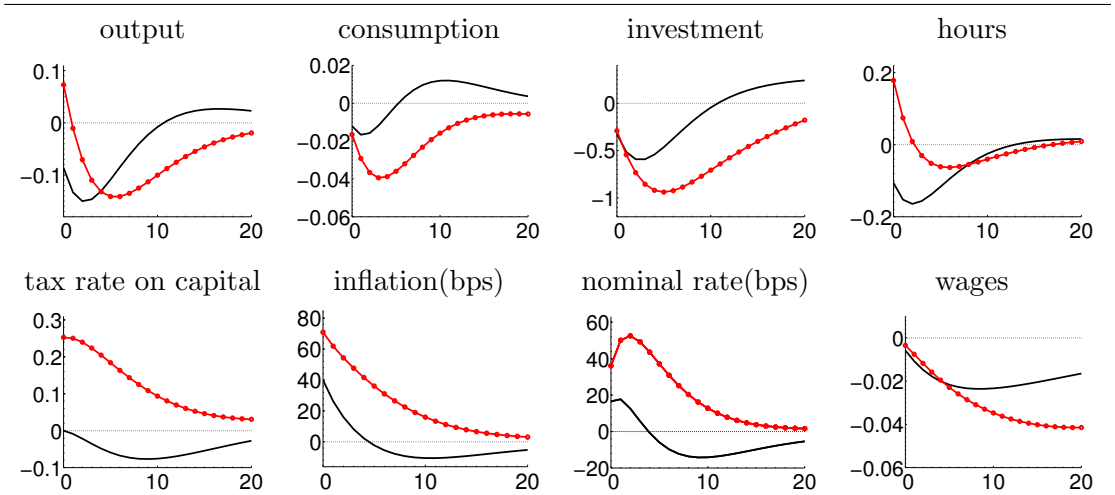


Notes: The figure shows the time series for the three tax rates and the government spending series entertained in this paper. Also shown is the debt-to-output series used in the estimation.

B Fiscal Volatility Shocks versus Fiscal Shocks

We compare, in figure 17, the IRFs to a fiscal volatility shock (solid black line) to the IRFs to a 25-basis-point fiscal shock to the capital tax rate (dotted red line). Note that in a fiscal shock, the tax rate goes up, while, in a fiscal volatility shock, it is the variance of its future changes that goes up, while the tax rate itself does not move on impact (although it falls later because of the feedback from output to the tax rate).

Figure 17: Fiscal volatility shock vs. 25 bps fiscal shock to the capital tax rate



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

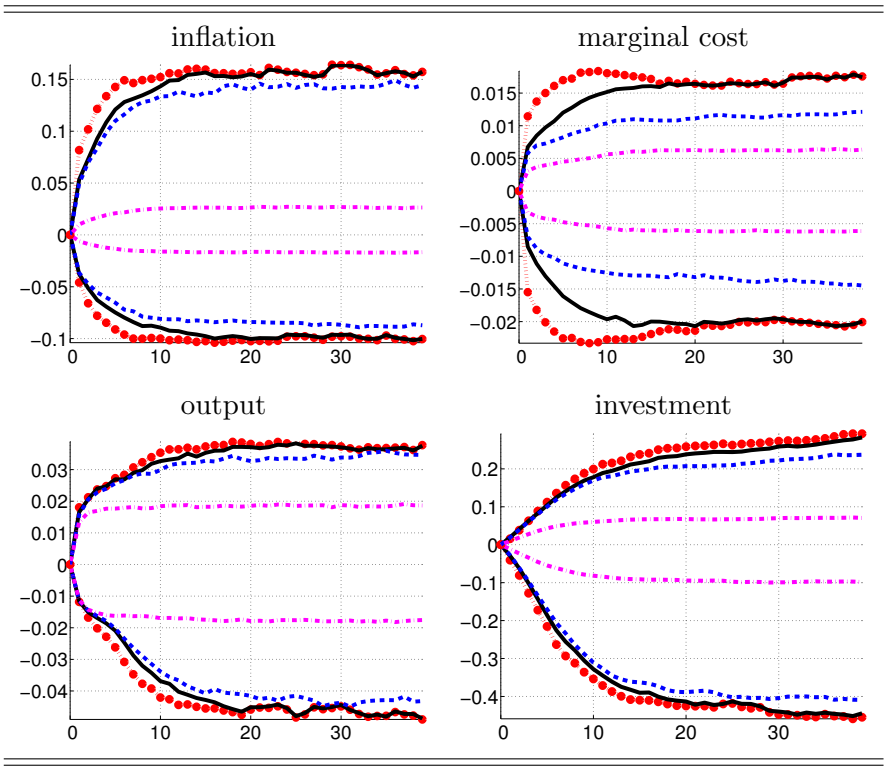
A persistent shock to the capital tax rate implies that capital is less profitable in the short to medium run. Consequently, households reduce their investment. Higher taxes increase expected marginal costs, thus inducing an increase in inflation. Monetary policy responds with higher real interest rates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

The effects of the fiscal shock are somewhat larger than the effects of the fiscal volatility shock. While the tax rate changes the returns to capital today, and hence has a first-order impact, fiscal volatility shocks work through households' and firms' expectations, a quantitatively weaker channel. Remember, though, that fiscal volatility shocks can induce a far larger contraction in the economy under the alternative, more pessimistic parameterizations in section 6.

C Forecast Bands

In this appendix, we report 95 percent forecast intervals for endogenous variables in our model. It serves to highlight two features. First, the model's inherent non-linearity, particularly with respect to the inflation process. Second, the additional uncertainty (and its direction) introduced by stochastic volatility.

Figure 18: Forecast dispersion



Notes: 95 percent confidence intervals for forecasts made at period 0 for fiscal instruments up to 40 quarters ahead. Solid black line: benchmark specification. Red dots: benchmark specification with a two-standard-deviation fiscal volatility shock innovation to all instruments in period 1. Dashed blue line: specification with constant volatility held fixed at the steady-state value. Magenta dotted line: specification without shocks to the fiscal instruments.

In line with the arguments made in section 5, figure 18 shows that the inflation process is skewed toward a higher likelihood of larger realizations. This comes at the same time that marginal costs are skewed in the opposite direction, with lower realization of marginal costs being more likely. Fiscal volatility shocks slightly increase the skewness. Similarly, realizations of output that are lower than the steady state are more likely than those above the steady state.

D Uncertainty and Markups: A Simple Example

In this appendix, we use a standard Dixit-Stiglitz monopolistic competition setup to show the relation between the uncertainty level and the pricing decision of firms. To simplify, we will assume a volatility shock that the firm takes as given and without a fully specified general equilibrium feedback. Also, and only in the appendix, we will assume risk-neutral investors. This further clarifies our argument in section 5 of the main text.

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

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

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

D.1 Aggregate demand and costs

Aggregate demand is exogenously determined according to

$$y_t = y + \exp\{\sigma^0_{y,t}\}\varepsilon_{y,t},\ \varepsilon_{y,t} \sim \mathcal{N}(0, \sigma_{e_y}). \tag{13}$$

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

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

$$w_t = w + \chi(y_t^\phi - \mathbb{E}_0 y_t^\phi),\ \chi > 0,\ \phi > 0,\ \text{with } w = \frac{\epsilon - 1}{\epsilon}. \tag{14}$$

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

D.2 Price-setting

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

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

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

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

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

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

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

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

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

In the following, we will focus on solutions with a positive price level, that is on $\pi_0 > 0$. Then, we take advantage of the fact that $w = \frac{\epsilon-1}{\epsilon}$ and that, given (14), $Cov\,(w_j, y_j) = \chi Cov\left(y_j^{\phi}, y_j\right)$ to get

$$\phi_p(\pi_0 - 1)\pi_0 = \chi\epsilon \sum_{j=0}^{\infty} \beta^j Cov\left(y_j^{\phi}, y_j\right). \tag{15}$$

Note that $Cov(y_j^{\phi}, y_j) > 0$ as long as the support of y is restricted to the real line. Thus, an increase in uncertainty in future periods leads to a precautionary increase in prices in the period of the shock as long as marginal costs are positively correlated with demand ($\phi > 0$). In the main text, the general equilibrium effects generate that positive covariance: a fiscal volatility shock pushes down both aggregate demand and marginal costs. Equation (15) also shows that the effect will be the bigger, the more elastic demand is (the larger ϵ).

D.3 The effect of an uncertainty shock on inflation

We are ready now to state the following proposition.

Proposition 1. *Consider the model above and two realizations A and B of the spread shock such that $\sigma_{y,t}^{0,A} > \sigma_{y,t}^{0,B}$ for all t. In other words, for every date t, the distribution of y_t under A is a mean-preserving spread of the distribution under B. Then,*

1. *For $\phi = 0$ (marginal costs are not correlated with demand), inflation π_0 is invariant to the spread shock: $\pi_0^A = \pi_0^B = 1$.*
2. *For $\phi > 0$ (marginal costs are positively correlated with demand), up to a second-order approximation $\pi_0^A > \pi_0^B > 1$. In words, inflation is larger, the larger the uncertainty is.*
3. *For $\phi \in (0, 1]$, the statement in item 2 can be shown without taking an approximation.*

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

1. For $\phi = 0$, $Cov(y_j^{\phi}, y_j) = 0$, so by equation (15), $\pi_0 = 1$.

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

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

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

3. Last, some exact results.
   For $\phi = 1$, we have exactly that $Cov(y_j^\phi, y_j) = V(y_j)$, so π_0 will be larger, the bigger the variance of y_j, which will be the case with a mean-preserving spread.
   For $\phi \in (0,1)$ the proof proceeds by contradiction. Suppose that $\pi_0^A \leq \pi_0^B$. By (15), this requires $Cov_A(y_j^\phi, y_j) \leq Cov_B(y_j^\phi, y_j)$. This is the same as

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

   or

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

   If A is a mean-preserving spread of B, and $y \sim F_A(y)$, $x \sim F_B(x)$, then one can find some mean-zero distribution $H(z|x)$, such that $y = x + z$, with $z \sim H(z|x)$.
   Note that if $\phi \in (0,1)$, $y^{1+\phi}$ is convex on the support of y so

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

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

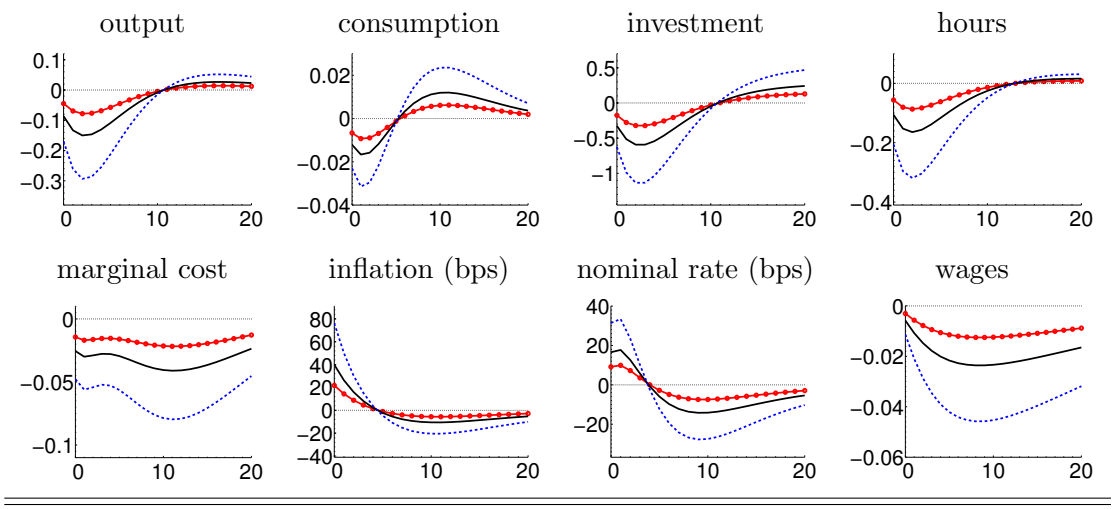
∎

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

E The Role of Elasticity of Demand

We conclude by presenting an alternative way to understand the importance of nominal rigidities that we emphasize in the main text. Figure 19 documents how the effect of a fiscal volatility shock on inflation is stronger, the larger the elasticity of demand, and, hence, the more curved the marginal profit function is. This effect does not appear, for instance, in the model's IRFs to monetary shocks: those IRFs are roughly invariant to changes in the elasticity of demand (we omit plotting them in the interest of space). This observation highlights that the role of the demand elasticity is due to the interaction of the curvature of the profit function with uncertainty, rather than to a level effect.

Figure 19: 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.