Policy Risk and the Business Cycle[*]

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Abstract

The argument that uncertainty about monetary and fiscal policy has been holding back the recovery in the U.S. during the Great Recession has a large popular appeal. This paper uses an estimated New Keynesian model to analyze the role of policy risk in explaining business cycles. We directly measure risk from aggregate data and find a moderate amount of time-varying policy risk. The "pure uncertainty"-effect of this policy risk is unlikely to play a major role in business cycle fluctuations. In the estimated model, output effects are relatively small because policy risk shocks are i) too small and ii) not sufficiently amplified.

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1 Introduction

The supposedly negative influence of "policy risk", i.e., uncertainty about fiscal and monetary policy, has become a recurring theme in the political discourse. The popular argument espoused in speeches and newspaper articles by politicians and economists alike is that the uncertainty surrounding future policy stuns economic activity by inducing a "wait-and-see" approach. In the following, uncertainty is defined as the dispersion of the economic shock distribution, i.e., a mean-preserving spread. Rational consumers and firms react to the fact that future shocks will be drawn from a wider distribution. This reaction is distinct from the ex-post effect of higher volatility resulting from on average more extreme shock realizations. The goal of the present study is to isolate the first effect and answer the question: Are uncertainty shocks to policy variables quantitatively important?

Scientific evidence on the aggregate effects of uncertainty is still inconclusive. Empirical studies using different proxies and identification schemes to uncover the effects of uncertainty have produced a variety of results. One group of studies reports a large impact of uncertainty about productivity on aggregate variables like GDP and employment (Alexopoulos and Cohen, 2009; Bloom, 2009; Bloom et al., 2012). A one-standard deviation shock to uncertainty in these studies typically leads to a 1%-2% drop in GDP, followed by a recovery with a considerable overshooting. In contrast, a second group of studies reports little to no impact at all (Bachmann and Bayer, 2013; Bachmann et al., 2013; Bekaert et al., 2013; Chugh, 2011). In the theoretical literature, while most studies have emphasized the contractionary effects of uncertainty on economic activity, it is generally acknowledged that there are different effects working in opposite directions, thereby making the overall effect ambiguous. For example, an increase in uncertainty may depress investment due to the "wait-and-see" approach. But at the same time economic agents may want to self-insure by working more to build up a buffer capital stock, which ceteris paribus leads to an increase in investment.

This paper answers the question of whether policy risk shocks are quantitatively important in an estimated DSGE-model.[1] The focus is on aggregate uncertainty as it has been shown to have potentially important output effects (Fernández-Villaverde et al., 2011). The previous literature is expanded in the following ways. First, together with the independently conducted contemporaneous work by Fernández-Villaverde et al. (2012), we are the first to study the effect of policy risk on business cycles. Second, aggregate uncertainty is directly measured from the respective time series without the need to resort to proxies. Third, level shocks and uncertainty shocks are considered jointly. Regarding uncertainty shocks, the focus lies on policy risk, i.e., uncertainty about future tax liabilities, government spending, and monetary

[1] The online appendix accompanying this paper is available through ScienceDirect.

policy, to test the hypothesis that policy risk may be an important factor in explaining the prolonged Great Recession. Uncertainty with respect to total factor productivity (TFP) and investment-specific technology is also included in order to have a benchmark for comparison with our findings. Fourth, these processes are integrated into a medium-scale New Keynesian DSGE-model of the type typically used for policy analysis (see, e.g., Christiano et al., 2005; Smets and Wouters, 2007) and this model is solved using third-order perturbation methods. The model is then estimated using the Simulated Method of Moments. This approach allows us to control for the effects of level shocks to TFP, investment-specific technology, government spending, monetary policy, and taxes when estimating the importance of policy risk.

Our main finding is that the role of policy risk in explaining business cycles is overstated. Although the output effects of policy risk are seven times larger than the effects of TFP uncertainty, even a two-standard deviation shock to policy risk decreases output by a mere 0.065%. The are two reasons for this: First, uncertainty shocks are relatively small and, second, the propagation is too weak to result in a significant amplification of aggregate uncertainty shocks.

The most important mechanism driving the response to policy risk in our model is the price and wage setting behavior of firms and unions constrained by sticky prices and wages. An increase in uncertainty induces households to work more, which lowers wages and firms' marginal costs. As prices are sticky this translates into higher markups. In an economy that is fundamentally demand-driven in the short run, this increase in markups is contractionary. This economic mechanism has been documented in great detail in Basu and Bundick (2012). At the same time, there is an "inverse Oi-Hartman-Abel effect" because sticky prices make the firms' marginal profit function convex, as firms have to satisfy demand given their preset price. Being stuck with a too low relative price means selling more goods at a lower profit or even a loss, while too high a price reduces the quantity, but at the same time increases per-unit profits. Thus, in response to increased uncertainty firms will raise markups in order to self-insure against being stuck with too low a price, leading to a decrease in output and an increase in inflation.

After the first working paper version of this paper, we have become aware of independently conducted work by Fernández-Villaverde et al. (2012), studying a similar issue in a calibrated model. Due to the common antecedents in our contemporaneous work (Christiano et al., 2005; Fernández-Villaverde et al., 2011; Leeper et al., 2010; Smets and Wouters, 2007), the methodology and many modeling choices are similar. Differences lie in the set of shocks considered and in the details of the model specification and parametrization. In terms of results, the effects of policy uncertainty in their study are qualitatively similar to ours but somewhat larger, stemming mostly from a larger steady state demand elasticity. Also closely related to our work is the paper by Baker et al. (2013), who construct a measure of policy uncertainty from newspaper articles, legislative texts, and surveys. Using a structural VAR identification, they argue that policy uncertainty was a main factor driving the Great Recession, but find it hard to establish causality. Our study can be seen as a quantitative thought experiment that takes all uncertainty observed in the data as a causal driving force and analyzes its implications through the lens of a monetary DSGE model.

The outline of the paper is as follows: Section 2 discusses the theoretical transmission channels of uncertainty. Section 3 explains the model. In Section 4, uncertainty is measured directly from aggregate time series. Section 5 estimates the model and Section 6 studies the effects of policy risk in the estimated model. Section 7 concludes.

2 Uncertainty: potential transmission channels

Three different mechanisms through which aggregate uncertainty may affect economic activity have been identified in the microeconomic literature: Oi-Hartman-Abel effects, real option effects, and precautionary savings. While these categories are helpful in shaping our thinking about the effects of uncertainty, they are partial equilibrium effects. In general equilibrium, each of these effects necessarily induces equilibrating price and quantity changes that may significantly dampen the aggregate effects. In a partial equilibrium model, uncertainty may have ceteris paribus largely contractionary effects on investment and output (e.g., Bloom, 2009). However, in general equilibrium wages and interest rates may adjust, thereby significantly reducing the resulting net effect (Bachmann and Bayer, 2013).[2]

The first category are the so called Oi-Hartman-Abel effects (Abel, 1983; Hartman, 1972; Oi, 1961). Under certain conditions, it follows from the firm's FOC that the expected marginal revenue product of capital is convex in output prices and TFP.[3] Hence, due to Jensen's Inequality, larger uncertainty about these variables increases the demand for capital and thus investment. In our model, while capital is predetermined, both the utilization of capital and the labor input can be adjusted, opening up the possibility of expansionary Oi-Hartman-Abel effects.

However, given sticky prices, there may exist an "inverse Oi-Hartman-Abel effect". As

[2]While the main result of Bachmann and Bayer (2013) is that the overall volatility of uncertainty shocks is too small to matter for unconditional moments, they also report that when shutting off the general equilibrium effects in their model, the importance of uncertainty shocks increases by about 50%.

[3]The reason is that labor can flexibly react to shocks and hence the marginal revenue product reacts stronger than one for one to the movement in the respective variable. To see this, assume a fixed stock of capital and a rising output price. There is a direct positive effect of this price increase on profits via quantity times price change. Additionally, there is a positive indirect effect through the increase in optimal output that is achieved by increasing labor.

prices cannot be fully adjusted and all demand has to be satisfied, the marginal profit curve becomes convex in relative prices. Setting prices too low results in having to sell more goods at a lower markup/higher loss, while setting the price too high results in selling a lower quantity of goods, but at a higher profit per unit. Thus, firms will choose higher prices and thus higher markups over marginal costs if uncertainty increases, thereby dampening demand and, in general equilibrium, potentially output.[4]

Second, there may be real option effects at work (Bernanke, 1983), e.g., through investment being (partially) irreversible and/or only partially expandable. For example, if the resale (purchase) price of capital in the future differs from the current acquisition price, a firm installing capital that it may sell later, effectively acquires a put option. Moreover, investment today destroys a call option, namely the opportunity to buy capital later at a possibly lower price. Hence, in the investment decision these option values have to be taken into account (Abel et al., 1996). Higher uncertainty decreases investment as the call option to purchase the capital later, which is "killed" by investing today, becomes more valuable. However, in the presence of partial reversibility, the value of the put option that is obtained by investing today increases with higher uncertainty. Hence, the total effect of uncertainty on investment in such a framework is generally ambiguous.

In our model, several features give rise to option effects. First, capital is predetermined for one period. Second, the relative price of investment and consumption is stochastic, thereby giving rise to potentially costly irreversibility and expandability. Third, through the presence of depreciation allowances, investment generates a tax shield at historical costs of investment so that investment today effectively "kills" the option to purchase this tax shield later. Fourth, the interest rate in our model is stochastic, giving rise to additional countervailing option effects as discussed in Ingersoll and Ross (1992).

The third effect is the precautionary savings motive, defined as the "additional saving that results from the knowledge that the future is uncertain" (Carroll and Kimball, 2008). Faced with higher uncertainty, agents may both consume less and work more in order to self-insure against future shocks, i.e., they build up a buffer stock. As the preferences of the agents in our model feature prudence, uncertainty should increase precautionary savings in our model.

Apart from these microeconomic effects, Basu and Bundick (2012) recently identified a distinctively macroeconomic effect that is prominently at play in our model. They show that uncertainty shocks in standard closed economy RBC models always generate the counterintuitive results that uncertainty is expansionary. The precautionary motive of households leads to an increase in labor supply. Given that capital is predetermined and uncertainty shocks do not alter TFP, output will go up. This mechanism changes in a model with monopolistic com-

[4]See Pfeifer et al. (2012) for an example of this mechanism at work in an open economy context.

Table 1: Overview: potential transmission mechanism

	Oi-Hartman-Abel effects	Inv. Oi-Hartman-Abel effect	Real option effects Call	Put	Int. rate	Precaut. savings	Basu-Bundick effect
Invest.	+	−	−	+	+/−	+	−
Cons.	+	−	?	?	?	−	−

Notes: + indicates a positive effect of uncertainty, − a negative effect, and +/− an ambiguous effect on the respective variable. ? denotes that the respective effect makes no prediction for this variable due to its partial equilibrium nature.

petition and sticky prices and/or wages: increased uncertainty leads to increases in firms' and unions' markups. Because in sticky price models output is fundamentally demand-determined, the increased wedge introduced by time-varying markups in response to uncertainty shocks reduces GDP instead of raising it. However, for this mechanism to be operative, prices and/or wages need to be sufficiently sticky. In the limit, New Keynesian models converge to the RBC model and will exhibit an expansion in response to uncertainty shocks.

In the end, due to these five effects, summarized in Table 1, acting on different variables and potentially working in opposite directions as well as the presence of general equilibrium effects and nominal rigidities, only a rigorous quantitative evaluation can answer the question of what the net effect of uncertainty on aggregate activity is. This question is pursued by estimating a structural model featuring time-varying volatility, which is present in the next section.

3 A DSGE-model with policy risk

A standard quantitative New Keynesian business cycle model (e.g., Smets and Wouters, 2007) serves as the starting point for the model analysis. The model economy is populated by a large representative family, a continuum of unions $j \in [0, 1]$ selling differentiated labor services to intermediate firms, a continuum of intermediate firms producing differentiated intermediate goods using bundled labor services and capital, and a final good firm bundling intermediate goods to a final good. In addition, the model features a government sector that finances government spending with distortionary taxation and transfers, and a monetary authority, which sets the nominal interest rate according to an interest rate rule.

3.1 Household sector

The economy is populated by a large representative family with a continuum of members, each consuming the same amount and working the same number of hours. Preferences are defined over per capita consumption C_t and per capita labor effort L_t. Following the framework in Schmitt-Grohé and Uribe (2006), labor is supplied to a continuum of unions $j \in [0,1]$, which are monopolistically competitive and supply differentiated labor services $L_t(j)$. Household members supply their labor uniformly to all unions. Hence, total labor supply of the representative family is given by the integral over all labor markets j, i.e., $L_t = \int_0^1 L_t(j)dj$. The labor market structure will be discussed in more detail below. The preference specification is based on Jaimovich and Rebelo (2009), but includes habits in consumption:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma_c} \left\{ \left(C_t - \phi_c C_{t-1} - \gamma \frac{L_t^{1+\sigma_l}}{1+\sigma_l} S_t \right)^{1-\sigma_c} - 1 \right\}, \tag{1}$$

where $\phi_c \in [0,1]$ measures the degree of internal habit persistence, $\sigma_c \geq 0$ governs the intertemporal elasticity of substitution, $\sigma_l \geq 0$ is related to the Frisch elasticity of labor supply, and $\gamma \geq 0$ measures the relative disutility of labor effort.[5] The term

$$S_t = (C_t - \phi_c C_{t-1})^{\sigma_G} S_{t-1}^{1-\sigma_G} \tag{2}$$

makes the preferences non-separable in both consumption and work effort, where $\sigma_G \in [0,1]$ parameterizes the strength of the wealth effect on the labor supply. When $\sigma_G = 1$, the preference specification is equal to the one discussed in King et al. (1988), while with $\sigma_G = 0$ the preference specification of Greenwood et al. (1988) with no wealth effect on the labor supply is obtained.

The household faces the budget constraint

$$\begin{aligned} C_t + z_t^I I_t + \frac{B_t}{P_t} =& (1-\tau_t^n) \int_0^1 W_t(j) L_t(j)dj + \left(1-\tau_t^k\right) r_t^k u_t K_{t-1} \\ &+ \left(1-\tau_t^k\right)(R_{t-1}-1)\frac{B_{t-1}}{P_t} + \frac{B_{t-1}}{P_t} + \Phi_t + T_t + \left(1-\tau_t^k\right)\Xi_t \ , \end{aligned} \tag{3}$$

where the household earns income from supplying differentiated labor services $L_t(j)$ at the real wage $W_t(j)$ to union j, and from renting out capital services $u_t K_{t-1}$ at the rental rate r_t^k.[6] In addition, it receives lump sum transfers T_t from the government and profits Ξ_t from owning the firms in the economy. All forms of income are taxed at their respective tax rates

[5] Adding a preference shock hardly improved the ability of the model to fit the data.

[6] Throughout the paper, the stock-at-the-end-of-period timing convention is used.

τ_t^n and τ_t^k. The term $\left(1-\tau_t^k\right)(R_{t-1}-1)\frac{B_{t-1}}{P_t}+\frac{B_{t-1}}{P_t}$ is the after-tax return on savings in government bonds, where the net returns are taxed at the capital tax rate. The household spends its income on consumption C_t and investment $z_t^I I_t$, where I_t is gross investment and z_t^I denotes a shock to the relative price of investment in terms of the consumption good. This price is equal to the technical rate of transformation between investment and consumption goods. Due to the presence of a temporary shock, it is exogenous and stochastic. Changes in z_t^I do not affect the productivity of already installed capital, but do affect newly installed capital and become embodied in it. The shock follows an AR(2)-process[7]

$$\log z_t^I \;=\; \rho_1^{zI}\log z_{t-1}^I+\rho_2^{zI}\log z_{t-2}^I+e^{\sigma_t^{zI}}\nu_t^{zI}\;,\quad \nu_t^{zI}\overset{iid}{\sim}\mathcal{N}(0,1)\;, \tag{4}$$

where σ_t^{zI} allows for time-varying volatility and is discussed in detail in Section 4. Apart from the fact that this form of investment-specific technology may be an important source of economic fluctuations (Greenwood et al., 1997, 2000), a stochastic relative price of investment introduces costly reversibility and expandability of investment into the model as the future purchase/resale price is stochastic.

The term Φ_t captures depreciation allowances, i.e., the fact that the replacement of depreciated capital can be deducted from the tax base, which is an important feature of the U.S. tax code. Depreciation allowances follow the form

$$\Phi_t=\tau_t^k\sum_{s=1}^{\infty}\delta_\tau\left(1-\delta_\tau\right)^{s-1}z_{t-s}^I I_{t-s}\;, \tag{5}$$

which works as follows: $z_{t-s}^I I_{t-s}$ is the historical purchase price of capital investment. The depreciation schedule is geometric with depreciation rate δ_τ. Thus, $(1-\delta_\tau)^{s-1}z_{t-s}^I I_{t-s}$ is the non-depreciated book value of the capital bought s periods before, while $\delta_\tau(1-\delta_\tau)^{s-1}z_{t-s}^I I_{t-s}$ is the depreciation of this remaining book value of capital at time t. The infinite sum then sums up the current period's depreciation of the non-depreciated book values of all previous capital investments. Finally, this amount of depreciation for tax purposes lowers the tax base by the corresponding amount and thus decreases the tax liabilities by the capital tax rate τ_t^k times the tax base. By providing new investment with a tax shield, depreciation allowances may be important in capturing the dynamics of investment following shocks (Christiano et al., 2011a; Yang, 2005). Through this tax shield at historical investment prices, combined with a stochastic relative price of investment z^I, depreciation allowances also contribute to costly reversibility and expandability of investment.

[7] The lag lengths for the individual exogenous driving processes are chosen to provide a good empirical fit. Details are provided in Section 4.

The household owns the capital stock K_t, whose law of motion is given by

$$K_t = \left[1 - \left(\delta_0 + \delta_1 (u_t - 1) + \frac{\delta_2}{2} (u_t - 1)^2\right)\right] K_{t-1} + \left[1 - \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t \ . \tag{6}$$

Household members do not simply rent out capital, but capital services $u_t K_{t-1}$, where u_t denotes the capital utilization, i.e., the intensity with which the existing capital stock is used. Without loss of generality, capital utilization in steady state is normalized to 1. Using capital with an intensity higher than normal incurs costs to the household in the form of a higher depreciation $\delta(u_t) = \delta_0 + \delta_1 (u_t - 1) + \delta_2/2 (u_t - 1)^2$, which, assuming $\delta_0, \delta_1, \delta_2 > 0$, is an increasing and convex function of capital utilization. The last term in equation (6) captures investment adjustment costs at the household level of the form introduced by Christiano et al. (2005), where $\kappa \geq 0$ is a parameter governing the curvature of the cost function. This functional form implies that investment adjustment costs are minimized and equal to 0 in steady state. While this functional form clearly is unable to explain some micro-level phenomena like lumpy investment, it has nevertheless been shown to provide a good fit of firm level investment data (Eberly et al., 2012).

Thus, the household maximizes its utility (1) by choosing $C_t, B_t, u_t, K_t, I_t, S_t, L_t$, subject to the constraints (2) - (6) and the resource constraint for aggregate labor.

3.2 Labor market

The household supplies labor $L_t(j)$ equally to a continuum of unions j, $j \in [0, 1]$. This labor market structure allows to introduce differentiated labor services and staggered wage setting without letting idiosyncratic wage risk affect the individual household members, which would make aggregation intractable. Monopolistically competitive unions supply differentiated labor $L_t(j)$ to intermediate firms at wage $W_t(j)$. Every period, each union may re-optimize its wage with probability $(1 - \theta_w), 0 < \theta_w < 1$. If a union j cannot re-optimize, its nominal wage is indexed to the price level according to $W_t(j) P_t = \Pi_{t-1}^{\chi_w} W_{t-1}(j) P_{t-1}$, where $\chi_w \in [0, 1]$ measures the degree of indexation to past inflation Π_{t-1}. Hence, when the union has not been able to re-optimize for τ periods, its real wage τ periods ahead, $W_{t+\tau}(j)$, is given by $W_{t+\tau}^{opt}(j)$ if the union is able to re-optimize in $t + \tau$ and $\prod_{s=1}^{\tau} (\Pi_{t+s-1}^{\chi_w} / \Pi_{t+s}) W_t(j)$ otherwise. Household members supply the amount of labor services that is demanded at the current wage. The objective of each union able to reset its wage is to choose the real wage that maximizes the expected utility of its members, given the demand for its labor services $L_t(j) = (W_t(j)/W_t)^{-\eta_w} L_t^{comp}$, where L_t^{comp} is the aggregate demand for composite labor services and η_w is the substitution elasticity, the respective resource constraint $L_t =$

$L_t^{comp} \int_0^1 (W_t(j)/W_t)^{-\eta_w} dj$, and the aggregate wage level $W_t = \left(\int_0^1 W_t(j)^{1-\eta_w} dj \right)^{\frac{1}{1-\eta_w}}$.

3.3 Firm side

There is a continuum of monopolistically competitive intermediate goods firms i, $i \in [0, 1]$, which produce differentiated intermediate goods Y_{it} using capital services $K_{it}^{serv} = u_{it} K_{it-1}$ and a composite labor bundle L_{it}^{comp} according to a Cobb-Douglas production function with capital share α

$$Y_{it} = z_t (K_{it}^{serv})^\alpha (L_{it}^{comp})^{1-\alpha} - \phi \ , \quad \text{if} \ \ z_t (K_{it}^{serv})^\alpha (L_{it}^{comp})^{1-\alpha} - \phi > 0 \tag{7}$$

and $Y_{it} = 0$ otherwise. The fixed cost of production ϕ is set to reduce economic profits to 0 in steady state, thereby ruling out entry or exit (Christiano et al., 2005).[8] The stationary TFP shock z_t follows an $AR(1)$-process

$$\log z_t = \rho_1^z \log z_{t-1} + e^{\sigma_t^z} \nu_t^z \ , \quad \nu_t^z \overset{iid}{\sim} \mathcal{N}(0, 1) \ . \tag{8}$$

The composite labor bundle is built from differentiated labor inputs $L_{it}(j)$ according to a Dixit-Stiglitz aggregator $L_{it}^{comp} = \left(\int_0^1 L_{it}(j)^{\frac{\eta_w - 1}{\eta_w}} dj \right)^{\frac{\eta_w}{\eta_w - 1}}$.

Staggered price setting is modeled a la Calvo-Yun. Each period, intermediate firms can re-optimize their prices with probability $(1 - \theta_p), 0 < \theta_p < 1$. In between two periods of re-optimization, prices are indexed to the aggregate price index P_t according to $P_{it} = \left(\frac{P_{t-1}}{P_{t-2}} \right)^{\chi_p} P_{it-1} = (\Pi_{t-1})^{\chi_p} P_{it-1}$, where $\chi_p \in [0, 1]$ governs the degree of indexation to past inflation Π_{t-1}. Intermediate goods producers maximize their discounted stream of profits subject to the demand from composite goods producers.

There is a competitive final goods firm, which bundles a final good Y_t from a continuum of intermediate goods using a Dixit-Stiglitz aggregation technology with substitution elasticity η_p

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{\eta_p - 1}{\eta_p}} di \right)^{\frac{\eta_p}{\eta_p - 1}} \ . \tag{9}$$

Expenditure minimization yields the optimal demand for intermediate good i as $Y_{it} = (P_{it}/P_t)^{-\eta_p} Y_t \ \forall i$.

[8] In an earlier version of the paper, we included a real supply shock that induced time-variation in the firms' fixed costs. However, its volatility was estimated to be effectively zero. Using the more commonly used shocks to firms' markups as a means of introducing real supply shocks is not possible in our model. The use of higher order approximations relies on a finite recursive formulation of the equilibrium conditions, which is not available with Calvo pricing and mark-up shocks.

3.4 Government sector

Government spending and taxes react to the state of the economy and the government's financial situation, but only with a one period lag. Specifically, the fiscal variables respond to lagged output and to the lagged debt to GDP ratio. Government spending, which may be thought of as entering the utility function additively separable, follows the process

$$\begin{aligned}\log\left(G_t/G\right) =& \rho_1^g \log\left(G_{t-1}/G\right) + \rho_2^g \log\left(G_{t-2}/G\right) \\ &+ \phi_{gD} \log\left(\frac{D_{t-1}}{Y_{t-1}} / \frac{D}{Y}\right) + \phi_{gY} \log\left(Y_{t-1}/Y\right) + e^{\sigma_t^g} \nu_t^g \ ,\end{aligned} \tag{10}$$

where real debt B_t/P_t is denoted by D_t, and variables without time indices denote steady state values. The government finances its expenditures by distortionary taxation of labor income at the rate τ_t^n and capital and interest income at rate τ_t^k. We assume $AR(2)$-processes for the tax rates as this has been found to be a good empirical description for the U.S.

$$\begin{aligned}\tau_t^i =& (1 - \rho_1^{\tau i} - \rho_2^{\tau i})\tau^i + \rho_1^{\tau i}\tau_{t-1}^i + \rho_2^{\tau i}\tau_{t-2}^i \\ &+ \phi_{iD} \log\left(\frac{D_{t-1}}{Y_{t-1}} / \frac{D}{Y}\right) + \phi_{iY} \log\left(Y_{t-1}/Y\right) + e^{\sigma_t^{\tau i}} \nu_t^{\tau i} \quad \text{for } i = k, n \ ,\end{aligned} \tag{11}$$

where τ^n and τ^k are the unconditional means of the labor and capital tax rates, respectively. The government also sets lump-sum transfers T_t as a function of the lagged debt to GDP ratio to assure stability of the model:

$$\frac{T_t}{T} = \left(\frac{D_{t-1}}{Y_{t-1}} / \frac{D}{Y}\right)^{\phi_{Td}} \ . \tag{12}$$

This assumed structure yields the government budget constraint

$$G_t + T_t + \Phi_t + R_{t-1}\frac{B_{t-1}}{P_t} = \tau_t^n W_t L_t^{comp} + \tau_t^k \left(R_t^K u_t K_{t-1} + \Xi_t + \left(R_{t-1} - 1\right)\frac{B_{t-1}}{P_t}\right) + \frac{B_t}{P_t} \ . \tag{13}$$

Transfers plus government spending plus depreciation allowances plus repayment of bonds equal tax revenues from taxing labor, capital income, bond income and profits plus proceeds from new bonds.

The model is closed by assuming that the central bank follows a Taylor rule that reacts to inflation and output:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\phi_{R\pi}} \left(\frac{Y_t}{Y_t^{HP}}\right)^{\phi_{Ry}}\right)^{1-\rho_R} \exp\left(m_t\right) . \tag{14}$$

Here, ρ_R is a smoothing parameter introduced to capture the empirical evidence of gradual movements in interest rates, Π is the target inflation rate set by the central bank, and the parameters $\phi_{R\pi}$ and ϕ_{Ry} capture the responsiveness of the nominal interest rate to deviations of inflation from its steady state value and output from its Hodrick and Prescott (HP) filter trend Y_t^{HP}, respectively.[9] Finally, m_t is a shock to the nominal interest rate that follows an $AR(1)$-process

$$\log m_t = \rho_1^m \log m_{t-1} + e^{\sigma_t^m} \nu_t^m \ . \tag{15}$$

The definition of equilibrium and the market aggregation are standard and omitted for brevity.

4 Policy risk: time series evidence

This section presents empirical evidence on the importance of time-varying volatility in modeling macroeconomic time series. We demonstrate that the data tend to reject the homoskedasticity of macroeconomic driving processes and show that a stochastic volatility (SV) model is able to capture the salient features of the data. In addition, the historical series of uncertainty shocks can be recovered using a particle smoother.

4.1 Estimation methodology

A two-step estimation procedure is performed as, due to the non-linear solution of the model required to capture uncertainty effects and the high-dimensional state space, it is computationally infeasible to jointly estimate all model parameters. Hence, the exogenous stochastic driving processes of the model featuring time-varying volatility are first estimated using Sequential Monte Carlo (SMC) methods. In the next section, these processes are then fed into the model presented in Section 3 and the parameters of the remaining model equations are estimated with a Simulated Method of Moments (SMM) approach.

The model includes 6 exogenous stochastic driving processes with time-varying volatility, i.e., capital and labor tax rates, government spending, a monetary policy shock, total factor productivity, and investment-specific technology. These processes are estimated on quarterly U.S. time series, starting in 1970Q1 and using the longest available sample for each series (usually 2012Q2). Details about the data sources can be found in Online Appendix A. Because of our stationary model, deviations of the non-stationary time series from their respective trend have to be computed by applying a one-sided HP-filter to the logarithms of government spending, output, TFP, and investment-specific technology. Using a one-sided, i.e., "causal" filter (Stock and Watson, 1999) assures that the time ordering of the data remains undisturbed

[9] The HP filter is embedded into the dynamic rational expectations model following the approach of Curdia et al. (2014). See their online appendix for details.

and the autoregressive structure is preserved. TFP (equation (8)) and the monetary policy shocks are modeled as AR(1)-processes, while investment-specific technology (equation (4)) is modeled as AR(2)-process, because for the latter the partial autocorrelation indicates the presence of a second root different from zero. The estimated policy rules are given by equations (10)-(11), and (15). Figure A.1 in the online appendix shows the time series of the exogenous driving processes on which our laws of motion are estimated. In particular for monetary policy, the presence of time-varying volatility is immediately evident. Online Appendix C.1 provides further evidence for the presence of time-varying volatility.

The standard deviations σ_t^i follow an AR(1) stochastic volatility process[10] (see, e.g., Fernández-Villaverde et al., 2011; Shephard, 2008)

$$\sigma_t^i = (1 - \rho^{\sigma_i})\,\sigma^i + \rho^{\sigma_i}\sigma_{t-1}^i + \eta_i\varepsilon_t^i \ , \quad \varepsilon_t^i \overset{iid}{\sim} \mathcal{N}(0,1), \tag{16}$$

where σ^i is is the unconditional mean of σ_t^i, $i \in \{\tau k, \tau n, g, m, z, zI\}$. The shock to the volatility ε_t^i is assumed to be independent of the level shock ν_t^i.

Due to the nonlinearity embedded in the stochastic volatility setup of the shocks, one cannot simply employ the Kalman filter as in the case of linearity and normally distributed shocks. For this case, Fernández-Villaverde and Rubio-Ramírez (2007) propose to use the *Sequential Importance Resampling* (*SIR*) particle filter, a special application of the more general class of *SMC* methods, to evaluate the likelihood.[11]

After obtaining the likelihood of the observables given the parameters, a *Tailored Randomized Block Metropolis-Hastings (TaRB-MH)* algorithm (Chib and Ramamurthy, 2010) is used to maximize the posterior. The prior distributions of the parameters, which are relatively weak, are given in Table 2. Note that we do not a priori impose debt stabilizing feedback for every single fiscal instrument, but use a symmetric prior around zero feedback.

After filtering, it is straightforward to employ the *backward-smoothing routine* (Godsill et al., 2004) to obtain a historical distribution of the volatilities.

4.2 Estimation results

The estimation results are presented in Table 2.[12] In general, all parameters are quite precisely estimated as evidenced by the percentiles. All shocks, except for the monetary policy shock, exhibit a high degree of persistence in their levels, with less persistence in

[10]For a motivation of the modeling choice, see Online Appendix B.1.

[11]Technical details of the algorithms used in this subsection can be found in Online Appendices B.2-B.4.

[12]Detailed convergence diagnostics are shown in Online Appendix C.2. Online Appendix C.3 shows the results of model misspecification tests applied to the SV model. In general, the model fits the data well and cannot be rejected.

their volatilities. Moreover, the estimated processes show moderate evidence of time-varying uncertainty, with η^i ranging between 0.30 and 0.65. A one-standard deviation uncertainty shock increases the volatility of the respective process by $(exp(\eta^i) - 1) \times 100$ percent, i.e., such a shock increases the standard deviation of capital taxes, labor taxes, TFP, investment specific technology, monetary policy, and government spending by 48%, 86%, 37%, 36%, 43%, and 45%, respectively.[13]

Regarding the feedback rules, our estimates show a relatively strong (indirect) debt stabilizing feedback from output to taxes. This contrasts with the direct debt feedback itself. Both labor and capital taxes tend to decrease if debt increases, but the estimates are only marginally significant. Most of the debt stabilization seems to derive from government spending.

The relevance of stochastic volatility in modeling the behavior of the exogenous driving processes can be seen in the smoothed estimates of the historical variances of the shocks in Figure 1. The 1970s and early 1980s were plagued by high shock volatilities, both in technology and policy shocks. Volatilities are at their sample maxima for both tax rates and technology shocks. In contrast, the decade from 1985 to 2000 was characterized by shock volatilities to the technology variables below their unconditional mean. From about 1990 onwards volatilities of tax and government spending shocks also declined, although the change in volatility is not as pronounced for the latter. For monetary policy shocks, there is clear evidence of a lower shock volatility following the Volcker disinflation from 1979-1983, a trend that continued under Greenspan. In contrast, the early tenure of Volcker experienced a volatility of monetary shocks considerably larger than during the first oil price shock. In the late 2000s the volatility of TFP shocks somewhat increased again. The largest changes in volatility in the 2000s came under George W. Bush who considerably changed the tax law, resulting in a pronounced increase in the volatility of tax rates. At the end of our sample, the Great Recession again results in an increase in policy risk with a rise in the volatility of government spending, tax rates, and monetary policy to comparable levels as after 9/11. For government spending and taxes, this mostly reflects the provisions in the *American Recovery and Reinvestment Act* that contained $288 billion in tax relief to companies and individuals, e.g., in the form of $116 billion in payroll tax relief.

[13] Thus, e.g., a one-standard deviation capital tax risk shock increases the volatility of the capital tax shocks from $exp(-5.07) = 0.63\%$ to $exp(-5.07 + 0.39) = 0.93\%$.

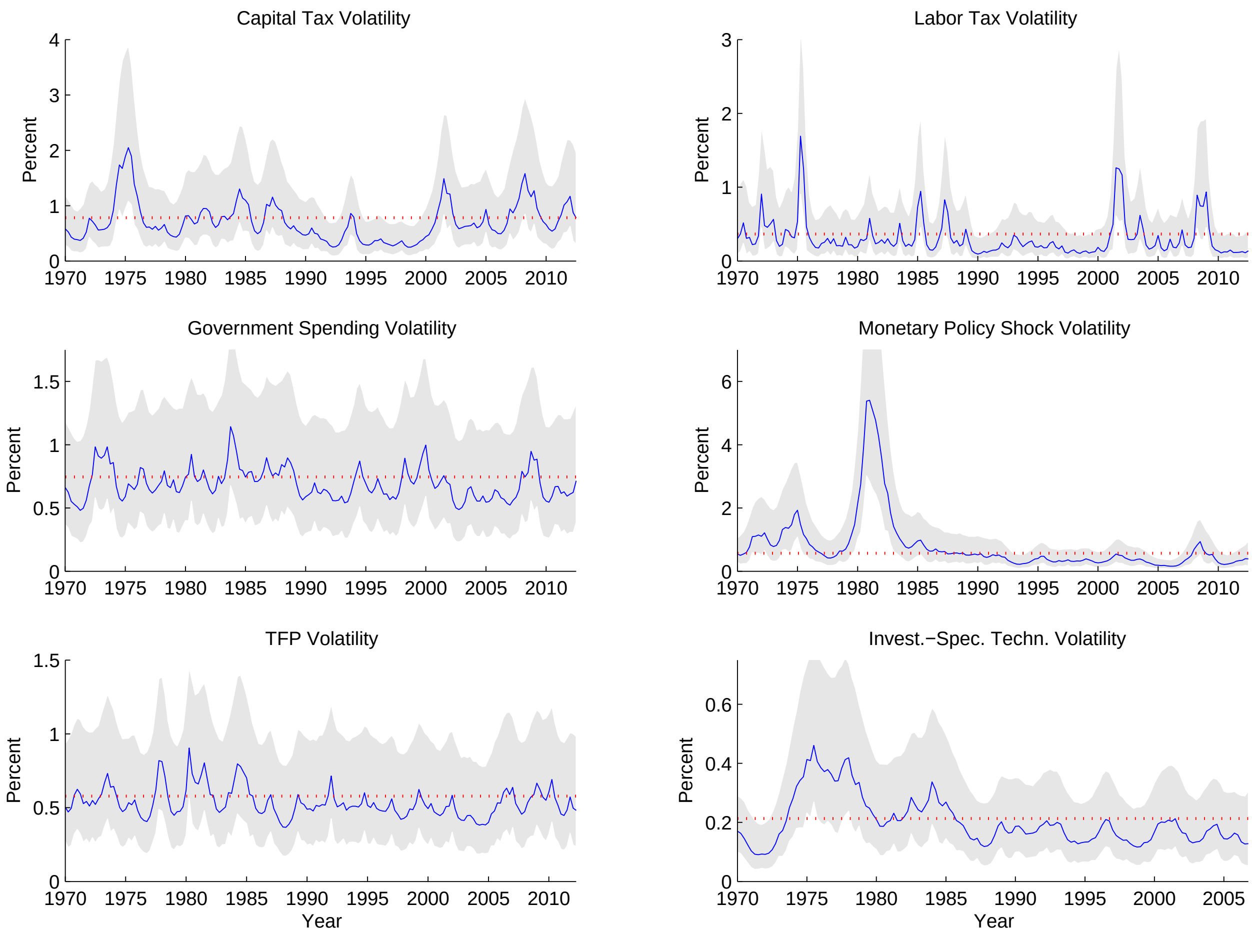

Figure 1: Historical smoothed standard deviations in percent.
Notes: Red dotted line: unconditional mean; shaded area: two standard deviation bands.

Table 2: Prior and posterior distributions of the shock processes

Parameter	Prior distribution			Posterior distribution		
	Distribution	Mean	Std. Dev.	Mean	5 Percent	95 Percent
			Capital Tax Rates			
ρ_1	Uniform*	0.00	0.577	0.743	0.705	0.784
ρ_2	Uniform*	0.00	0.577	0.189	0.153	0.224
ρ_σ	Beta*	0.90	0.100	0.806	0.761	0.867
η_σ	Gamma	0.50	0.100	0.394	0.350	0.435
$\bar{\sigma}$	Uniform	-7.00	5.333	-5.073	-5.351	-4.820
ϕ_d	Normal	0.00	1.000	-0.001	-0.002	0.000
ϕ_y	Normal	0.00	1.000	0.079	0.058	0.099
			Labor Tax Rates			
ρ_1	Uniform*	0.00	0.577	0.971	0.936	1.004
ρ_2	Uniform*	0.00	0.577	0.029	-0.005	0.064
ρ_σ	Beta*	0.90	0.100	0.658	0.588	0.758
η_σ	Gamma	0.50	0.100	0.619	0.552	0.683
$\bar{\sigma}$	Uniform	-7.00	5.333	-5.948	-6.329	-5.577
ϕ_d	Normal	0.00	1.000	-0.000	-0.000	0.000
ϕ_y	Normal	0.00	1.000	0.038	0.030	0.047
			Investment Specific Technology			
ρ_1	Uniform*	0.00	0.577	1.482	1.445	1.519
ρ_2	Uniform*	0.00	0.577	-0.549	-0.576	-0.520
ρ_σ	Beta*	0.90	0.100	0.842	0.805	0.892
η_σ	Gamma	0.50	0.100	0.304	0.275	0.334
$\bar{\sigma}$	Uniform	-7.00	5.333	-6.310	-6.527	-6.130
			Government Spending			
ρ_1	Uniform*	0.00	0.577	0.874	0.803	0.948
ρ_2	Uniform*	0.00	0.577	-0.035	-0.123	0.030
ρ_σ	Beta*	0.90	0.100	0.655	0.551	0.849
η_σ	Gamma	0.50	0.100	0.308	0.228	0.396
$\bar{\sigma}$	Uniform	-7.00	5.333	-4.983	-5.310	-4.657
ϕ_d	Normal	0.00	1.000	-0.003	-0.005	-0.002
ϕ_y	Normal	0.00	1.000	-0.000	-0.017	0.016
			Total Factor Productivity			
ρ_1	Uniform*	0.00	0.577	0.814	0.768	0.859
ρ_σ	Beta*	0.90	0.100	0.632	0.576	0.739
η_σ	Gamma	0.50	0.100	0.312	0.270	0.361
$\bar{\sigma}$	Uniform	-7.00	5.333	-5.233	-5.438	-5.033
			Monetary Policy Shock			
ρ_1	Uniform*	0.00	0.577	0.367	0.330	0.404
ρ_σ	Beta*	0.90	0.100	0.921	0.897	0.947
η_σ	Gamma	0.50	0.100	0.363	0.331	0.398
$\bar{\sigma}$	Uniform	-7.00	5.333	-6.551	-6.908	-6.168

Notes: ρ denotes the autocorrelation coefficient(s) of the level equation, ρ_σ the one of the volatility equation, $\bar{\sigma}$ is the steady state volatility of the level shocks, η_σ denotes the standard deviation of the volatility shocks, ϕ_d is the debt feedback coefficient, and ϕ_y the output feedback coefficient. Beta* indicates that the parameter divided by 0.999 follows a beta distribution. Uniform* indicates that the roots of the autoregressive process are estimated instead of the autoregressive coefficients and follow the specified prior distribution.

5 Fitting the model to the data

Having obtained the parameter estimates of the stochastic driving processes in the previous section, the next step is now to estimate the deep parameters of the model presented in Section 3.

5.1 Simulated Method of Moments estimation

We use the Simulated Method of Moments (SMM) approach as proposed in Ruge-Murcia (2012). Intuitively, this method minimizes the weighted distance between the empirical moments and the moments resulting from artificial data simulated from the model (details can be found in Online Appendix B.6).

In order to simulate data, one first needs to solve the model non-linearly. Due to the high-dimensional state space of our model, perturbation methods are employed to obtain an approximation of the policy function around the deterministic steady state. Specifically, a third-order approximation is needed to obtain the pure effects of volatility shocks, i.e., when holding the level shocks constant. Loosely speaking, a first-order approximation yields no effects of uncertainty; a second-order approximation yields both a constant effect and an effect mediated through the corresponding level shock. Only in the third-order approximation does time-varying uncertainty play a separate role (for a more detailed explanation, see Online Appendix B.5).

Table 3 presents the values of parameters fixed prior to the estimation. The gross steady state inflation Π is set to 1 and the discount factor β to 0.99. Regarding the depreciation parameters, $\delta_0 = 0.025$ is chosen to imply a 10% annual depreciation rate, $\delta_1 = 0.035$ sets the steady state capital utilization to 1, and the depreciation rate for tax purposes δ_τ is set to twice the rate of physical depreciation (Auerbach, 1989). The fixed-cost parameter $\phi = 0.0865$ implies that firms make zero profit in steady state. Regarding the preference parameters, the parameter governing the intertemporal elasticity of substitution σ_c is set to 2 and σ_G is set to 0.001, the value chosen in Jaimovich and Rebelo (2009).[14] Hence, preferences are close to the GHH-specification and imply a small wealth effect on labor supply, which is consistent with evidence from studies focusing on the effects of news (Schmitt-Grohé and Uribe, 2012) and government spending (Monacelli and Perotti, 2008). The feedback parameter of debt to transfers ϕ_{Td} is set to 3 to assure stability of debt. The elasticity of substitution parameters for differentiated labor services and intermediate goods are set to 10, resulting in a steady state markup of 11%. Thus, we take an intermediate position between the 5% markup argued

[14] When attempting to estimate this parameter, it hit the lower bound of 0. Hence, it is set to a small value that still assures a balanced growth path.

Table 3: Parameters fixed prior to estimation

Parameter	Description	Value	Target/Motivation
Π	Steady state inflation	1.000	Zero infl. steady state
β	Discount factor	0.990	Standard value
δ_0	Steady state depreciation	0.025	10% annual deprec.
δ_1	Capital utilization cost parameter	0.035	$u = 1$
δ_τ	Depreciation rate for tax purposes	0.050	Auerbach (1989)
ϕ	Steady state fixed costs	0.087	0 profits in SS
D/Y	Steady state debt share	1.500	Avg. debt/ann. GDP: 37.5%
σ_c	Risk aversion coefficient	2.000	Standard value
σ_G	Parameter governing wealth effect	0.001	Jaimovich-Rebelo (2009)
η_p	Demand elasticity goods	10.000	11% Markup
η_w	Demand elasticity labor	10.000	11% Markup
ϕ_{Td}	Debt feedback	3.000	Assure stability of debt
τ^n	Steady state labor tax rate	0.226	Sample mean
τ^k	Steady state capital tax rate	0.372	Sample mean
G/Y	Government spending share	0.199	Sample mean
α	Capital share	0.319	Sample mean

for in Altig et al. (2011) and the mean of about 20% estimated in Justiniano et al. (2011, 2013) and Christiano et al. (2005). The capital share α, the steady state tax rates τ^k and τ^n, the steady state share of government spending to output, and the steady state share of debt to GDP are set to their respective sample means.

The empirical moments to be matched are the standard deviations and first- and second-order autocovariances of output, consumption, investment, inflation, the real wage, hours worked, and the nominal interest rate. Moreover, the covariance of output with the other variables and the mean of hours worked are targeted.[15] All growing variables are logged and in first differences, while gross inflation, the gross federal funds rate, and hours worked enter in log-levels. Measurement error in wages is included following the evidence in Justiniano et al. (2013). The even-numbered columns of Table 5 display the respective sample moments.

5.2 Parameter estimates

The parameter estimates are shown in Table 4. All parameters except for the capital utilization costs δ_2/δ_1 are precisely estimated as seen in columns 4 and 5. Consumers have moderate habits in consumption with $\phi_c = 0.54$, which is at the lower end of the range of values generally found in estimated DSGE models (see, e.g., Christiano et al., 2005; Smets and Wouters,

[15]Due to the use of third-order perturbation techniques, the mean of the ergodic distribution is targeted and not the deterministic steady state.

Table 4: Parameters estimated by SMM

Parameter	Description	Mean	-1 stdev.	+1 stdev.
ϕ_c	Consumption habits	0.540	0.468	0.612
δ_2/δ_1	Capital utilization costs	0.101	0.000	0.372
ρ_R	Interest smoothing	0.836	0.796	0.876
θ_p	Calvo parameter prices	0.656	0.583	0.728
θ_w	Calvo parameter wages	0.786	0.720	0.852
χ_p	Price indexation	0.467	0.269	0.665
χ_w	Wage indexation	0.514	0.306	0.722
σ_l	Frisch elasticity parameter	0.976	0.822	1.131
ϕ_{R_π}	Taylor rule inflation	1.777	1.525	2.028
ϕ_{R_y}	Taylor rule output growth	0.319	0.211	0.428
γ	Labor disutility	6.650	5.514	7.787
κ	Capital adjustment costs	1.632	1.078	2.185
σ_{me}	Log Stdev. Meas. Error Wages	-7.129	-7.290	-6.968

Notes: The confidence bands rely on the asymptotic normality of the estimator as shown in equation (B.18) in the online appendix. However, this is only a rough approximation as most parameters, e.g., the Calvo parameters, have bounded support.

2007). Capital utilization costs show little convexity with $\delta_2/\delta_1 = 0.101$, while investment adjustment is moderately costly as indicated by $\kappa = 1.632$, ensuring that investment is not excessively volatile. Prices are estimated to be somewhat sticky with $\theta_p = 0.656$, implying that on average a firm optimally resets its price every three quarters. Due to the presence of price indexation ($\chi_p = 0.467$) actual prices change more often. The high degree of wage stickiness is consistent with micro evidence (Barattieri et al., 2014) with an average duration of a little more than a year and an indexation to past wage inflation similar to that for prices. In the Taylor rule, there is evidence for interest rate smoothing. The reaction coefficients of monetary policy are in line with values found in the literature. Finally, an estimated value of $\sigma_l = 0.976$ implies a Frisch elasticity of $\sigma_l^{-1} = 1.0246$ in the GHH case, which is in the range considered plausible, e.g. in Ríos-Rull et al. (2012).

Table 5 shows that the model fits the data well. Output is 93% as volatile in the simulated model as in the data, while consumption is somewhat too volatile. The volatility of investment is well-matched, while its correlation with output is a bit too high. Our model does somewhat less well in matching the cyclical behavior of the real wages. The problem in matching the labor market part is a weakness our model shares with many less-tightly parameterized macro models that do not feature an explicitly modeled search and matching labor market as in, e.g., Christiano et al. (2011a). For example, prototypical models (e.g., Smets and Wouters, 2007) typically require a much larger Frisch elasticity than implied by micro studies

Table 5: Simulated and empirical moments

	Model	Data	Model	Data	Model	Data	Model	Data	Model	Data
	$\sigma(x_t)$		$\sigma_{x_t}/\sigma_{y_t}$		$\rho(x_t, y_t)$		$\rho(x_t, x_{t-1})$		$\rho(x_t, x_{t-2})$	
					a) Baseline					
Δy	0.79%	0.85%	1.00	1.00	1.00	1.00	0.56	0.29	0.24	0.24
Δc	0.64%	0.55%	0.81	0.64	0.85	0.58	0.50	0.43	0.14	0.22
Δi	2.47%	2.44%	3.10	2.86	0.88	0.69	0.66	0.62	0.36	0.46
π	0.78%	0.62%	0.99	0.72	-0.13	-0.20	0.84	0.88	0.62	0.84
Δw	0.20%	0.64%	0.26	0.75	0.32	-0.00	0.48	0.03	0.26	0.03
r	0.68%	0.94%	0.86	1.10	-0.68	-0.11	0.90	0.94	0.72	0.89
l	2.54%	1.64%	3.20	1.91	0.13	0.33	0.84	0.93	0.67	0.82
					b) Volatile Counterfactual					
Δy	1.81%	0.85%	1.00	1.00	1.00	1.00	0.59	0.29	0.27	0.24
Δc	1.15%	0.55%	0.64	0.64	0.93	0.58	0.65	0.43	0.32	0.22
Δi	6.49%	2.44%	3.59	2.86	0.96	0.69	0.58	0.62	0.27	0.46
π	1.04%	0.62%	0.57	0.72	0.34	-0.20	0.76	0.88	0.58	0.84
Δw	0.30%	0.64%	0.17	0.75	0.69	-0.00	0.65	0.03	0.39	0.03
r	0.44%	0.94%	0.24	1.10	-0.72	-0.11	0.87	0.94	0.67	0.89
l	4.72%	1.64%	2.61	1.91	0.18	0.33	0.90	0.93	0.73	0.82

Notes: Time series x_t are output (y_t), consumption (c_t), investment (i_t), inflation (π_t), the real wage (w_t), the nominal interest rate (r_t), and hours worked l_t. Lowercase letters denotes variables that are logged. The columns show the standard deviation $\sigma(x_t)$, the relative standard deviation compared to output volatility $\sigma_{x_t}/\sigma_{y_t}$, the correlation with output $\rho(x_t, y_t)$, and the first two autocorrelations $\rho(x_t, x_{t-1})$ and $\rho(x_t, x_{t-2})$. Some of the target moments are transformed to correlations for better interpretation. The relative standard deviations with respect to the standard deviation of output are only implicitly targeted through the standard deviations of the respective series.

(see the discussions in Chetty et al. (2011) and Reichling and Whalen (2012)). Below, the robustness of our results to different parameterizations of the labor market is explored. The autocorrelations are in general well-matched. Only the real wage exhibits a somewhat too high autocorrelation. The first moment of hours is also well matched at 0.3387 compared to 0.3386 in the data.

A simple counterfactual experiment demonstrates the importance of accounting for time-varying volatility. Time-varying volatility is completely shut off by setting the uncertainty shocks to zero and simulating the model again. Compared to the actual data, such an economy fails to generate sufficient volatility: output, consumption, and investment are only about 59%, 78%, and 68% as volatile as the data, respectively (see Table D.1 in the online appendix). These results clearly indicate the importance of time-varying volatility in explaining U.S. macroeconomic time series (see, e.g., Justiniano and Primiceri, 2008; Primiceri, 2005).

6 Impulse response analysis

The estimated model now allows us to analyze the effects of aggregate uncertainty on business cycle fluctuations. First, policy experiments are conducted to trace out the effects of uncertainty shocks. Then the transmission of uncertainty shocks into the economy is studied and the underlying amplification mechanisms are analyzed in order to find out why the effects of uncertainty are not larger.

6.1 The aggregate effects of policy risk

First, the pure uncertainty effect resulting from time-varying volatility is analyzed by separating it from the ex-post effect of more extreme shock realizations. This is done by computing impulse response functions (IRFs) to uncertainty shocks while keeping the realizations of the level shocks constant.[16] As is common in the uncertainty literature, an uncertainty shock is defined as a two-standard deviation increase in the respective variable's volatility.

The historical volatility estimates shown in Figure 1 indicate that uncertainty about the future path of economic policy increased for all policy instruments during the Great Recession. Such a situation is simulated in the form of a simultaneous two-standard deviation increase in policy risk.[17] Results are shown in Figure 2.

[16]For details on the computation of IRFs, see Online Appendix B.7.

[17]The separate IRFs to each *single* policy risk shock are qualitatively very similar, with capital tax risk and monetary policy risk inducing the strongest output response (see Figure D.2 in the online appendix). Concerning technological uncertainty, the impact of TFP uncertainty is negative while that of investment-specific uncertainty is expansionary. The IRFs to the corresponding level shocks are shown in Figure D.1. They conform to the conventional wisdom. A recession diagnostic is also conducted by feeding the smoothed

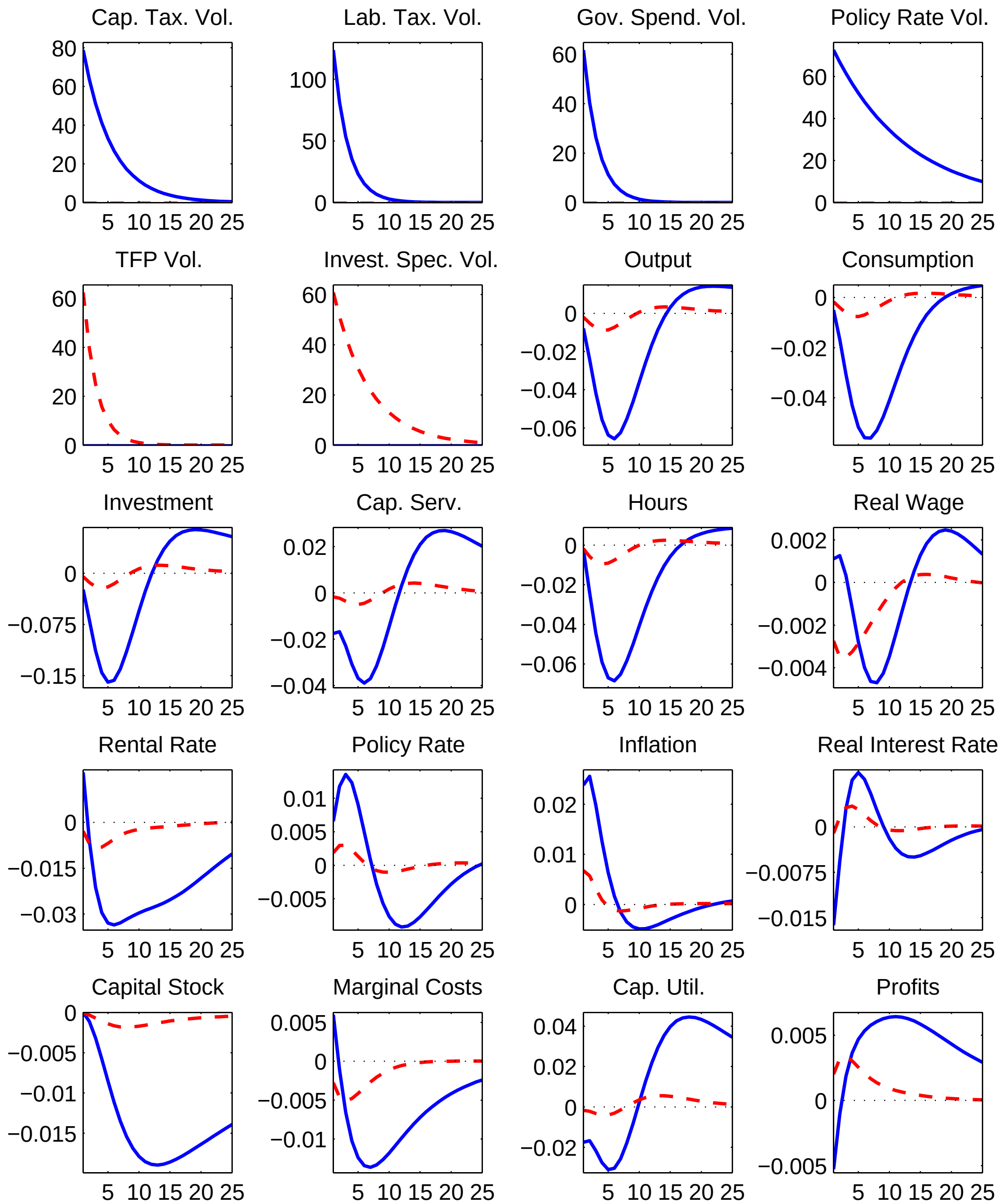

Figure 2: IRFs to a joint two-standard deviation policy risk shock (blue solid line) and to a joint technology risk shock of the same size (red dashed line).
Notes: Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent, except for inflation and the interest rates which are in percentage points. The real interest rate is computed as the difference between the policy rate and expected inflation.

A simultaneous two-standard deviation policy risk shock (solid lines) leads to a quick decrease in output of 0.065%, before output returns to its initial level after 15 quarters and then overshoots. The decrease in output results from a fall in both consumption and investment, with investment dropping by more than 0.15%. Thus, initially the capital stock falls and needs to be replenished when the shock subsides, resulting in the typical overshooting visible in the figure.

The drop in output is driven by the interaction of two effects. When uncertainty increases, households desire to consume less and work more due to the precautionary motive. This increase in labor supply ceteris paribus lowers wages and firms' marginal costs and would translate into a drop in prices if markups stayed constant. But as prices are sticky and not fully indexed, prices do not fall as much as marginal costs, which leads to an increase in markups (see Basu and Bundick, 2012, on this mechanism). At the same time, firms also face increased uncertainty about future marginal costs and demand conditions. This increased risk has asymmetric effects due to the convexity of the marginal profit curve ("inverse Oi-Hartman-Abel effect"). If the future relative price of a firm is set too high, it will sell fewer goods, but at a larger markup over marginal costs. In contrast, if the price is set too low, the firm sells more at a lower or even negative markup, thereby incurring losses. Thus, if uncertainty increases, firms will try to increase their prices to self-insure against being stuck with too low a price. This pricing behavior also tends to increase markups. The same effect is present in the labor market due to the presence of monopolistically competitive unions. Due to precautionary pricing, the markup over the marginal rate of substitution increases, leading to a decrease in labor demand. In case of an uncertainty shock without subsequent realizations of corresponding level shocks, those two effects together lead to a significant increase in markups as visible by the simultaneous increase in prices and decrease in marginal costs as well as the increase in firm profits. In an economy that is fundamentally demand driven in the short run, this increase in markups is strongly contractionary. At the same time, through the increase in markups, inflation rises.

Figure 2 also shows the impulse responses to a joint technology risk shock of the type occurring in the middle of the 1970s. The comparison of technology risk (red dashed lines) with policy risk (blue solid lines) shows that while policy risk generates responses that are about seven times larger than technological risk, the qualitative mechanism underlying both responses is very similar.

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shocks into the model and looking at the implied filtered time series. Most recessions in our model are driven by TFP and tax shocks (results not reported).

6.2 Dissecting the transmission channels of uncertainty

The previous section has shown that the response of the economy to policy risk is mostly driven by the precautionary motive of households and firms combined with the presence of nominal rigidities. This combination leads to significant increases in markups, which, due to their depressing effect on demand, leads to a drop in output.

A deeper insight into the transmission of uncertainty can be gained by shutting off various features of the model. The consequences for the output response to a policy risk shock when doing this are shown in the panels of Figure 3, where for comparison the blue solid line depicts the output response under our baseline parametrization.[18] We start with parameters influencing the behavior of the household and perturb one (set of) parameter(s) at a time, keeping all other parameters at their baseline value.

First, increasing the habit persistence parameter ϕ_c to 0.9 reduces the output response by making consumption react only sluggishly to risk shocks (see Panel A). On the other hand, without habit formation in consumption ($\phi_c = 0$), the precautionary adjustment of consumption is less costly in terms of utility and hence an increase in uncertainty generates a bigger drop in output due to the stronger reaction of consumption demand.

Increasing σ_l to 2, and therefore lowering the Frisch elasticity, increases the fall in output in response to a policy risk shock (see Panel B) through a stronger response of hours worked, which is now necessary to equilibrate the labor market. Linear labor, i.e., an infinite Frisch elasticity of labor supply, in contrast requires a weaker drop of labor and, due to this, results in a smaller output drop. The low wealth effect on the labor supply implied by the preferences being close to the GHH-form ($\sigma_G \approx 0$) has hardly any effect on the responses to uncertainty. They are only a bit less persistent compared to the King et al. (1988) preferences case, $\sigma_G = 1$ (Panel C).

On the investment side of the model, fixing the relative price of investment to consumption at $z^I = 1$ shows that the real option effect embedded in the depreciation allowances via the stochastic resale price of capital hardly plays a role (not reported here). However, while their role in providing current investment with a tax shield at historical investment prices does not seem to create strong real option effects in our model, this does not mean that depreciation allowances do not play an important role. With their effect on Tobin's marginal q and the capital utilization decision, they have an important amplifying effect on the investment response and hence on output. When lowering δ_τ from 0.05 to 0.01, as Panel D shows, output drops less, which is driven by a smaller investment response (see Figure D.6 in the online appendix).

Decreasing the costs of adjusting investment and of using capital with an intensity higher

[18] Detailed figures showing the responses of other model variables can be found in Online Appendix D.

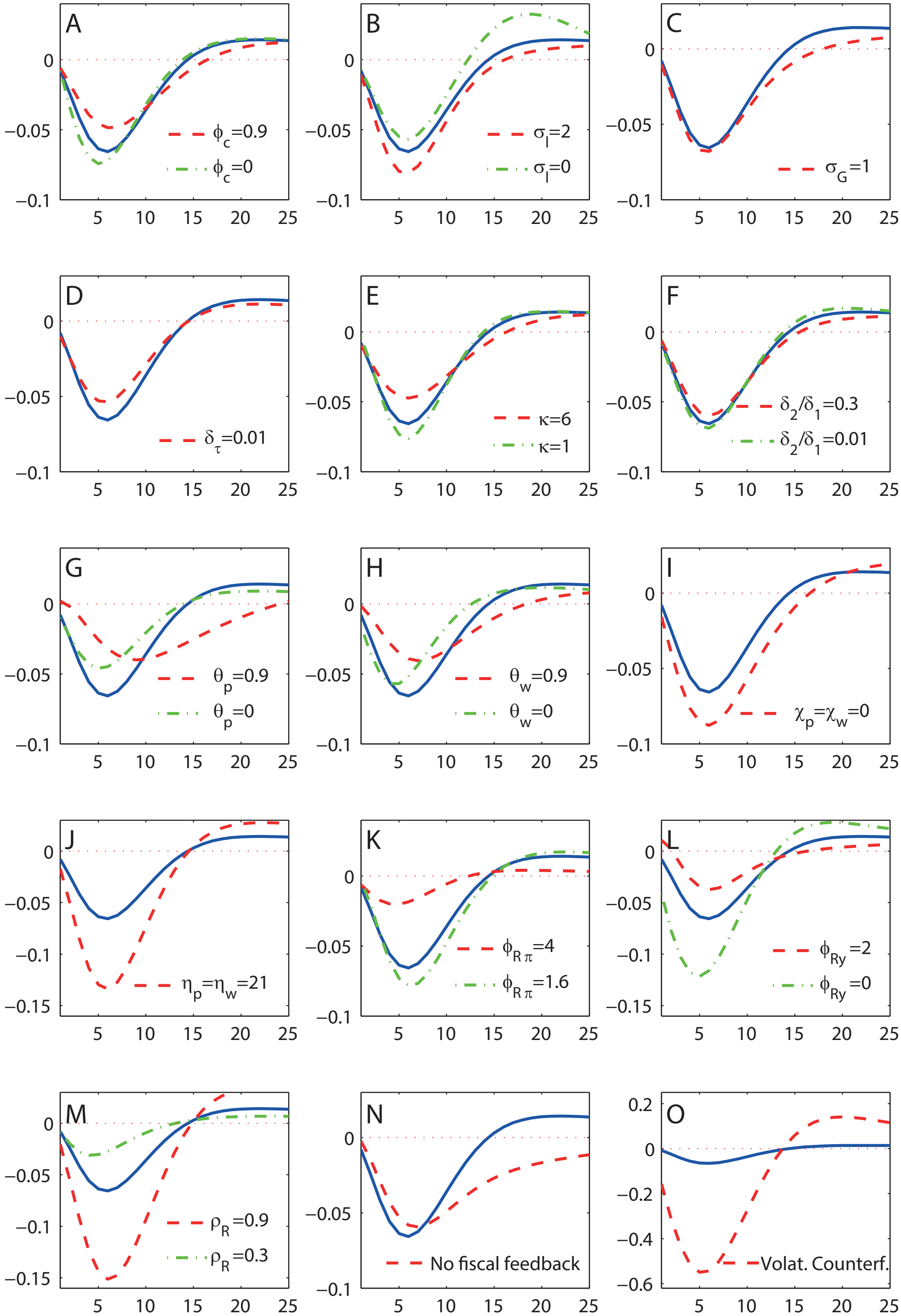

Figure 3: Output IRFs to a joint two-standard deviation policy risk shock. The blue solid line always depicts the output response under the baseline parametrization.
Notes: Level shocks are held constant. Horizontal axes indicate quarters. All responses are in percent.

than normal (κ and δ_2/δ_1 in equation (6)) makes the model more volatile and increases the response of output (see Panels E and F). This indicates that the first-order effect of lower adjustment costs dominates the reduced second-order real option effect arising from lower costly adjustment. Thus, while stronger nominal rigidities amplify the response to uncertainty shocks, larger real rigidities tend to dampen it.

As shown in the previous section, nominal rigidities are key to understand the model response to a policy risk shock due to their effect on markups. Setting price stickiness to zero ($\theta_p = 0$) and only keeping wage stickiness yields an output response that is only two thirds of the baseline response (see Panel G). Similarly, shutting off wage rigidities and only keeping price stickiness also results in a smaller output drop (see Panel H). As both panels show, the effect of price rigidities is not monotonic in our model. The reason is the relatively strong estimated output feedback in the Taylor rule. With price stickiness increasing above a certain threshold, uncertainty shocks would ceteris paribus be associated with relatively large changes in output compared to inflation so that the output feedback of the Taylor rule becomes more important. This output feedback has a stabilizing effect that in equilibrium is associated with a muted output response that is more drawn out.[19] Conforming to our intuition about the importance of nominal rigidities, Panel I shows that shutting off price and wage indexation amplifies the output drop, because indexation decreases the exposure to unwanted deviations of relative prices from their target.

Increasing the steady state demand elasticity to imply a steady state markup of 5%, the value used in Fernández-Villaverde et al. (2012), leads to a doubling (-0.13%) of the trough output drop to a policy risk shock (Panel J). This is due to the higher demand elasticity increasing the convexity of the marginal profit function and hence the "inverse Oi-Hartman-Abel effect": for every additional cent the price is set too low, demand increases more and results in selling more goods at a loss. Firms will thus choose larger markups in response to uncertainty shocks to avoid this scenario, thereby increasing the amplification. However, Justiniano et al. (2011, 2013) find a 90% highest posterior density interval of about 10 to 30% for the steady state markup, while Christiano et al. (2005) estimate a 95% confidence interval in the same range. Thus, we think that a markup of 11% as used in our study already presents an upper bound on the amplification through this channel.

A stronger inflation response of the central bank ($\phi_{R\pi} = 4$ in Panel K) tends to dampen the effects of uncertainty as the central bank decreases expectations about future inflation and thus the risk of having an undesirably low price relative to other firms that are able to reset prices. With a stronger response to inflation, the central bank comes closer to replicating

[19] When shutting off the output feedback of the Taylor rule, the output response to policy risk is monotonically increasing in nominal rigidities.

the flex-price output and allowing firms to have set the desired price. A stronger output feedback ceteris paribus also helps to dampen the output response to uncertainty shocks ($\phi_{Ry} = 2$ in Panel L). As shown in Figure D.14 in the online appendix, this effect comes from the interaction between price and wage rigidities as real wages increase after an uncertainty shock so that aggregate demand does not drop as much, thereby providing insurance against unwanted demand shifts. Panel M displays the effect of different interest smoothing of the central bank. The stronger the smoothing, the less the central bank is able to react to current economic circumstances and the less stabilizing its policy response is. As a result, for $\rho_R = 0.9$ the output fall almost triples compared to the baseline. Summarizing, the importance of the central bank reaction function shows that general equilibrium effects may considerably dampen the output effects of uncertainty shocks (see also Bachmann and Bayer, 2013).

Shutting off the reaction of government spending and taxes to the state of the economy and the government's debt situation prolongs the drop in output, as shown in Panel N of Figure 3. The reason is the estimated persistence of the labor tax rate. This persistence is usually dampened by the stabilizing feedback from debt and output. Shutting off this stabilizing effect increases the persistence and thus makes stronger and longer-lasting adjustments necessary.

6.3 Why are the effects of uncertainty not larger?

There are two reasons why the output effects of policy risk are not larger, which are essentially two sides of the same coin: the aggregate policy risk shocks are *i)* too small and *ii)* not sufficiently amplified.

The parameter perturbations in Section 6.2 have shown that the model is in principle capable of generating larger business cycle effects of uncertainty. A natural counterfactual experiment therefore is to simultaneously change a number of estimated parameters at the same time to values that yield more "bang for the buck" in response to an uncertainty shock. Specifically, we lower the monetary policy response to output to $\phi_{Ry} = 0.1$, increase the interest rate smoothing to $\rho_R = 0.9$, shut off price and wage indexation, $\chi_p = \chi_w = 0$, and lower the real frictions to $\kappa = 1$ and $\delta_1/\delta_2 = 0.001$. This new calibration indeed yields a larger output drop of -0.55%, about one order of magnitude larger than in our baseline parametrization. However, looking at the implied moments, this model is much too volatile (see Panel b of Table 5). The reason is that the parameter changes do not only amplify the (second moment) risk shocks, but also the level shocks. Given the estimated parameter values and the resulting amplification, the risk shocks are too small relative to the level shocks.

Our results suggest that for policy risk shocks to matter, one needs an extraordinarily large uncertainty shock. Was such a large shock that exceeded the two standard deviations of our experiments present during the Great Recession? Both the historical smoothed volatilities of the policy variables in our model (see Figure 1) and the Baker et al. (2013)-index of economic policy uncertainty increased by 3 to 4 standard deviations. But even such a large shock is not capable of generating a major drop in output. A four-standard deviation policy risk shock results in a trough response of -0.13%, roughly twice the baseline size (not shown here).

The flipside of this is that given the relative sizes of the level and risk shocks, the propagation of risk shocks is not strong enough compared to that of the level shocks. One way to generate such an asymmetric amplification in the context of a standard New Keynesian business cycle model is the use of a larger demand elasticity/smaller steady state markup, which increases the curvature of the firms' revenue function and thus has a stronger effect on risk than on level shocks. However, as discussed in Section 6.2, we think that a markup of 11% as used in our study already presents an upper bound on the amplification through this channel. Chugh (2011) has taken a different approach in the context of TFP risk by integrating uncertainty about technology in a financial accelerator model, thereby upgrading uncertainty shocks from a second to a first order shock. However, even in this case uncertainty shocks have only very muted output effects. Thus, future work should focus on identifying potential channels of *asymmetric* amplification.

One amplification mechanism that could potentially be relevant for the Great Recession is the zero lower bound (ZLB). As shown in the previous section, when the central bank *does not* counteract nominal rigidities by strongly reacting to inflation and thus replicating the flex-price output after an uncertainty shock, the negative output effects of a policy risk shock increase significantly. This also suggests strong effects when the central bank *cannot* react strongly to movements in the price level. This conjecture is corroborated by recent work of Basu and Bundick (2012) using a stylized New Keynesian model solved with global solution techniques. In their model, if the central bank is constrained by the ZLB, it is unable to replicate the flex-price outcome and hence unable to undo the negative effects of uncertainty shocks. Even after controlling for the "contractionary bias" arising from the interaction of uncertainty and the ZLB, i.e., the fact that expected real interest rates increase after an uncertainty shock due to the left truncation of nominal interest rates, being at the ZLB doubles the effects of the discount factor uncertainty shock they consider.

Johannsen (2013) explicitly analyzes the effects of fiscal policy uncertainty and shows that the amplification effects of the ZLB are also true for policy uncertainty. The reason is the strongly asymmetric response of the economy to fiscal policy. As shown in, e.g., Christiano et al. (2011b), fiscal multipliers at the ZLB may be large. It follows that the downside risk part of increased uncertainty about government spending consists of a very large contraction due to the ZLB continuing to bind and multipliers being very high for the whole left tail of the distribution. In contrast, the upside risk consists of fiscal policy pushing the economy to regions where the ZLB stops to bind and multipliers will be at a normal level. Thus, the left tail is associated with catastrophic downturns, while the right tail only leads to moderate expansions. Households would like to insure against this downside risk by saving and working more, thereby decreasing inflation and increasing the real interest rate, given that the nominal rate is stuck at zero. This increase in the real rate, which would not occur if the general equilibrium response of the central bank were operational, considerably increases the contractionary effect of policy risk.

While the theoretical possibility that catastrophic tail events as in Johannsen (2013) have significant macroeconomic effects cannot be ruled out, there are important arguments against policy uncertainty being the main culprit for the prolonged slump. While increasing the *absolute* effect of uncertainty shocks on output, the ZLB tends to leave their *relative* importance unaltered, because level shocks experience a similar amplification. Thus, to explain the Great Recession, extraordinarily large policy uncertainty shocks compared to other shocks like government spending or wealth shocks are needed. This seems at odds with the evidence on large level shocks presented in Stock and Watson (2012) and measures of policy uncertainty (e.g., Baker et al., 2013), which suggest significant but not extreme increases in uncertainty ($\approx 4\, stdev$). However, there remains the possibility that an increased possibility of small tail events is not picked up by our (or other) measures of uncertainty.

At the same time, our results suggest that unconventional monetary policy may have an important effect on the amplification of policy uncertainty shocks at the ZLB. On the one hand, it might be effective in counteracting the negative output effect by undoing some of the effects of nominal rigidities by restoring the Taylor rule feedback. On the other hand, our results suggest that a credible commitment of the central bank to higher *future* inflation ("forward guidance") to stimulate output today may actually increase the negative effects of uncertainty shocks through firms and workers today setting higher markups over marginal costs. However, at the same time increasing markups and prices in the short run might be inflationary and lower the real interest rate, exactly what the central bank desires to achieve. This suggests that future research using a formal quantitative model incorporating the ZLB is needed in order to trace out the general equilibrium effects for policy risk shocks at the ZLB.

7 Conclusion

Analyzing the aggregate effects of policy risk on the business cycle, we find them to be minor. Although the effects of uncertainty about fiscal and monetary policy are seven times larger than those of technological uncertainty, a two-standard deviation policy risk shock still only generates a -0.065% drop in output.

As shown, the negative effect on output is mainly driven by the price and wage setting behavior of firms and unions constrained by nominal rigidities. Markups rise when uncertainty increases and, given that output is demand-determined in the short run, this results in a drop in output. However, in our estimated model, this drop is relatively small.

The reason for this small effect is that, given the estimated parametrization of the model, the size of the policy risk shocks is too small to cause a more significant drop of output. Even considering the case of the Great Recession, the upper bound of the estimated joint increase in fiscal and monetary uncertainty in our sample, results only in an output drop of -0.13%. The flipside of this is that the estimated model does not feature a strong enough amplification to transform these uncertainty shocks into large output effects. In principle, a different parametrization like decreasing the output feedback in the Taylor rule would allow for a bigger effect of risk shocks. However, such a calibration would imply unrealistically large business cycle fluctuations due to its relatively symmetric amplification of level shocks. This is the reason that the amplification of uncertainty shocks was estimated to be rather low.

Thus, our results also suggest a potential issue for studies using a “proof-of-concept”-approach. Such studies typically show that uncertainty may matter by putting one source of uncertainty along one level shock into a model and then designing a transmission mechanism that enables this source to explain the whole business cycle. Our findings indicate that more attention needs to be devoted to what happens if other shocks, both uncertainty and level, are present. Moreover, it does not seem sufficient to consider amplification mechanisms that affect level and uncertainty shocks symmetrically.

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