Escaping the Great Recession*

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Abstract

We show that policy uncertainty about how the rising public debt will be stabilized accounts for the lack of deflation in the US economy at the zero lower bound. We first estimate a Markov-switching VAR to highlight that a zero-lower-bound regime captures most of the comovements during the Great Recession: a deep recession, no deflation, and large fiscal imbalances. We then show that a micro-founded model that features policy uncertainty accounts for these stylized facts. Finally, we highlight that policy uncertainty arises at the zero lower bound because of a trade-off between mitigating the recession and preserving long-run macroeconomic stability.

JEL Codes: E31, E52, E62, E63, D83

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1 Introduction

The recent financial crisis and the deep recession that followed have led to a substantial change in the conduct of monetary policy, with interest rates stuck at the zero lower bound for the past eight years. A key prediction of the New Keynesian paradigm is that, in this situation, we should have observed deflation. However, this prediction has not materialized. Following Hall's Presidential Address to the American Economic Association, some researchers have labeled this observation "Hall's puzzle" (Hall 2011). Simultaneously, the crisis has triggered a vibrant debate about the best way to deal with the zero lower bound. Two polar views have emerged. The first one advocates a robust fiscal stimulus sometimes even accompanied by a reduced emphasis on inflation stabilization (Romer 2009, Sims 2010a). The second one strongly opposes the idea of abandoning policies that worked in the past (Plosser 2012). This debate has occurred against a background of acute fiscal strain. In 2009, the US deficit-to-GDP ratio was the highest since the Korean war. Furthermore, by 2012 the debt-to-GDP ratio had reached levels unprecedented since the end of World War II and, based on the Congressional Budget Office projections, is expected to continue increasing for the foreseeable future (CBO 2016). It is conceivable that this debate and the severe fiscal imbalance have led to a rise in uncertainty about how debt will be stabilized. In this paper, we show that policy uncertainty can account for the absence of deflation that characterized the Great Recession.

We first establish a series of stylized facts by fitting a Markov-switching VAR to post-World War II data. We include inflation, GDP growth, the federal funds rate, and the deficit-to-debt ratio. The model identifies three distinct regimes. The movements between the first two regimes capture a low frequency relation between the deficit-to-debt ratio and inflation. During the 1960s and 1970s, when Regime 1 is in place, real interest rates are low, the deficit-to-debt ratio trends up, and so does inflation. These dynamics revert once the economy moves to Regime 2 in the early 1980s: Real interest rates increase, inflation falls, and so does the deficit-to-debt ratio. Instead, the third regime captures the bulk of the dynamics during the Great Recession: a large contraction in real activity, a short lasting drop in inflation, a jump in primary deficits, and the zero lower bound. During this zero-lower-bound regime, fiscal shocks have large effects on inflation, providing evidence that fiscal imbalances play a role in explaining inflation dynamics during the Great Recession.

These findings suggest that the following are desirable properties of a structural model whose objective is to study the Great Recession. First, the model should feature three policy regimes in line with the VAR evidence. Second, the model should ideally capture the large inflationary consequences of fiscal imbalances during the zero-lower-bound regime. At the same time, this zero-lower-bound regime should also be inherently different from any other regime to the extent that a policy change is triggered by a large contractionary shock. Third, a successful model should be able to capture the core of the macroeconomic comovements during the Great Recession as the result of this single large initial shock and the associated change in policymakers' behavior.

We construct and estimate a dynamic general equilibrium model that reflects these findings and captures a key policy trade-off that arises at the zero lower bound: choosing between mitigating a large recession and preserving a reputation for fiscal discipline. In the model, when the zero lower bound is not binding, policymakers' behavior is characterized by two very distinct policy combinations. Under the *monetary-led policy mix,* the central bank reacts strongly to deviations of inflation from its target, whereas the fiscal authority passively accommodates the behavior of the monetary authority by adjusting primary surpluses to keep debt on a stable path. If agents expect this regime to prevail for a long time, any fiscal imbalance is backed by future fiscal adjustments and the economy is largely insulated with respect to these disturbances. Under the *fiscally-led policy mix*, the fiscal authority does not react strongly enough to debt fluctuations. It is now the monetary authority that passively accommodates the behavior of the fiscal authority by allowing inflation and real activity to move so as to stabilize debt.[1] Finally, the economy is occasionally hit by a large demand shock that forces policymakers into a *zero-lower-bound regime* in which the central bank sets the interest rate to zero and the fiscal

[1] In the language of Leeper (1991) the monetary-led regime corresponds to active monetary policy and passive fiscal policy, whereas the fiscally-led regime is associated with passive monetary policy and active fiscal policy.

authority temporarily disregards the level of debt.

Agents' beliefs about policymakers' behavior once the economy is out of the zero lower bound play a key role in determining macroeconomic outcomes at the zero lower bound. We model this idea by introducing a parameter that controls agents' beliefs about policymakers' exit strategy. We find that during the recent crisis the probability assigned to a switch to the fiscally-led regime experienced a noticeable increase, even if agents still regard a return to the monetary-led regime as more likely (around 92%). While the estimated probability of a switch to the fiscally-led regime remains relatively low, the inflationary pressure deriving from the large stock of debt is enough to prevent the economy from experiencing deflation. Thus, uncertainty about the future monetary and fiscal policy mix can account for the lack of deflation. To show this, we run a counterfactual simulation in which policy uncertainty is removed. As in the standard New Keynesian model, this counterfactual model predicts a large deflation.

The last part of the paper is devoted to highlighting a policy trade-off that arises at the zero lower bound. To this end, we study the consequences of fully credible announcements about policymakers' future behavior in the aftermath of the large demand shock. If policymakers announce the monetary-led regime, inflation expectations drop, leading to deflation and a severe recession. If instead policymakers announce that they will move to the fiscally-led policy mix, inflation immediately increases because agents expect that debt will be inflated away. This, in turn, leads to a drop in the real interest rate that lifts the economy out of the recession. However, such an announcement would also increase macroeconomic volatility once the economy is out of the recession. This happens because under this regime the macroeconomy is not insulated anymore with respect to fiscal disturbances. Thus, a policy trade-off between mitigating the recession and preserving long-run macroeconomic stability arises at the zero lower bound. As views of the relative importance of the two goals differ, so do the policy prescriptions, with the result that policy uncertainty is likely to arise at the zero lower bound.

Other papers have addressed the Hall's puzzle (King and Watson 2012; Del

Negro et al. 2015) and have proposed resolutions (Christiano et al. 2015 and Coibion and Gorodnichenko 2015). The novelty of this paper is to show that policy uncertainty about the way debt will be stabilized can account for the lack of deflation during the Great Recession. This mechanism also allows us to explain why inflation expectations rose between 2009 and 2011. Accounting for policy uncertainty is important in light of a growing literature that argues that there were in fact changes in policymakers' behavior over the past 60 years (Clarida et al. 2000; Lubik and Schorfheide 2004; and Bianchi 2013). Baker et al. (2016) construct a comprehensive index of policy uncertainty. Fernandez-Villaverde, Guerron-Quintana, et al. (2015) study the role of fiscal volatility in slowing down the recovery during the current crisis. However, fiscal volatility shocks do not provide an explanation for the absence of deflation observed in the data, whereas the uncertainty about future policy rules considered in this paper does.

Our work is related to the vast literature on the zero lower bound.[2] Our work differs from previous contributions in one or more of the following dimensions. First, we conduct a structural estimation of a general equilibrium model and investigate the effects of policy uncertainty at the zero lower bound. In this respect, the paper is related to the literature on the macroeconomic effects of uncertainty (Bloom 2009, Gilchrist et al. 2014, Fernandez-Villaverde et al. 2011, Basu and Bundick 2012). Second, we work in a stochastic environment with a standard New Keynesian model augmented with a fiscal block. This makes our framework suitable for a quantitative assessment of the different exit strategies. Third, zero-lower-bound episodes are recurrent and agents take this into account when forming expectations. In contrast, the literature generally considers situations in which the economy is currently at the zero lower bound and it will never be there again. Moreover, our paper proposes an alternative way for modeling recurrent zero-lower-bound events in dynamic stochastic general equilibrium (DSGE).

Finally, our work is related to the study of the interaction between fiscal and

[2]See Benhabib et al. (2001, 2002), Mertens and Ravn (2014), Fernandez-Villaverde, Gordon, et al. (2015), Fernandez-Villaverde et al. (2014), Coibion et al. (2012), Werning (2012), Correia et al. (2013), Gust et al. (2013), Aruoba and Schorfheide (2013).

monetary policies in determining inflation dynamics (Sargent and Wallace 1981; Leeper 1991; Sims 1994; Woodford 1994, 1995, 2001; Schmitt-Grohe and Uribe 2000; Cochrane 1998, 2001; Reis 2016). In this respect this paper is related to Bianchi and Ilut (2015) and Bianchi and Melosi (2013), but differs from these two papers across several dimensions. First, we here allow for the zero lower bound and show that policy uncertainty can account for the absence of deflation during the Great Recession. Second, we outline that at the zero lower bound a policy trade-off between mitigating a large recession and preserving long-run macroeconomic stability emerges. Finally, we use a Markov-switching VAR to establish a series of stylized facts about the zero lower bound and the 60 years of data that preceded it.

This paper is organized as follows. Section 2 presents the stylized facts based on the Markov-switching VAR. These results are used to motivate the benchmark model presented in Section 3. Section 4 shows that policy uncertainty can account for the lack of deflation. Section 5 compares the benchmark model to a nested model in which policy uncertainty is removed. Section 6 outlines the policy trade-off that arises at the zero lower bound. Section 7 concludes.

2 Motivating Evidence

We introduce a Markov-switching VAR (MS-VAR) to motivate the key mechanism studied in this paper; that is, the growing US fiscal imbalances can account for why inflation did not persistently drop during the Great Recession. With respect to the seminal contribution by Sims and Zha (2006), our MS-VAR includes a measure of the US fiscal stance. This reduced-form analysis will also be valuable for designing a structural model to study the last eight years of data.

Estimating Bayesian VAR models with Markov-switching parameters proves to become quickly computationally challenging as the number of observables and lags grows. We therefore opt for a parsimonious specification with two lags, four observables, and quarterly data. This is in line with the literature that allows for smoothly time-varying parameters in VARs (Primiceri 2005, Cogley and Sargent 2006). We include GDP growth, inflation, and the federal funds

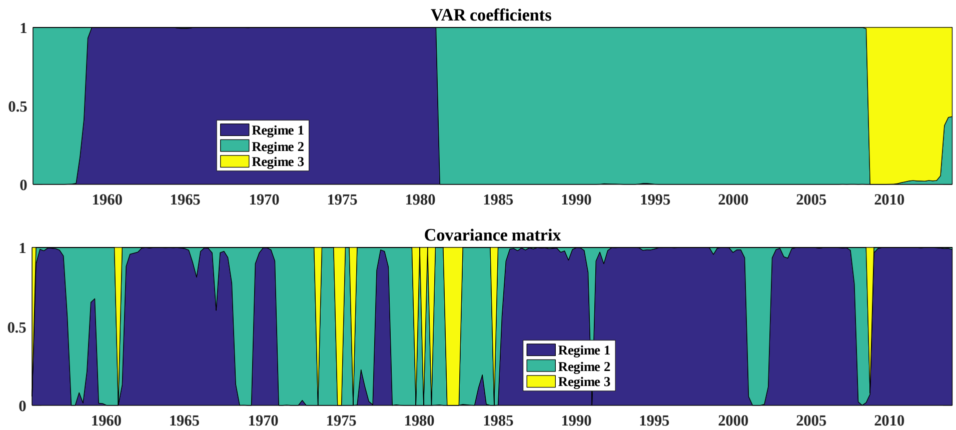

Figure 1: **Smoothed Probabilities of Regimes of MS-VAR.** The top panel reports the probabilities for the three regimes characterizing the VAR coefficients, whereas the lower panel reports the probabilities for the three regimes of the covariance matrix.

rate (FFR) to capture the behavior of the macroeconomy. We then add the ratio of primary deficit-to-debt as a parsimonious observable that captures the fiscal stance of the US government over time. In order for debt to be fiscally sustainable, this ratio needs to be negative on average, as the fiscal authority needs to run primary surpluses.[3] We allow for three Markov-switching regimes for the constants and the autoregressive parameters and three Markov-switching regimes for the volatility of the innovations:

$$Z_t = c_{\xi_t^\Phi} + A_{\xi_t^\Phi,1} Z_{t-1} + A_{\xi_t^\Phi,2} Z_{t-2} + \Sigma_{\xi_t^\Sigma}^{1/2} \omega_t \tag{1}$$

$$\Phi_{\xi_t^\Phi} = \left[c_{\xi_t^\Phi}, A_{\xi_t^\Phi,1}, A_{\xi_t^\Phi,2} \right], \ \omega_t \sim N(0, I) \tag{2}$$

where Z_t is an $(n \times 1)$ vector of data. The unobserved states ξ_t^Φ and ξ_t^Σ control the regimes in place for the VAR coefficients and the covariance matrix, respectively. The regimes evolve according to two transition matrices, H^Φ and H^Σ. Since we want to keep this analysis as agnostic as possible, we do not impose any ex-ante restrictions on the property of these regimes. Therefore, we estimate the MS-VAR model by using Bayesian techniques with flat priors.

[3]Other VAR studies have used this ratio as an observable. See Sims (2010b) and Kliem et al. (2016). Appendix A contains details about the model, the dataset, and the estimation.

Conditional Steady States						
	Regime 1			Regime 2		
	Median	16%	84%	Median	16%	84%
Deficit/Debt	2.99	1.44	6.21	−3.63	−8.72	−0.49
GDP Growth	3.45	1.91	4.25	3.00	2.69	3.28
Inflation	5.11	3.45	8.61	2.48	2.06	2.81
Interest Rate	6.15	4.87	8.89	4.68	3.53	5.83
Real Interest Rate	1.07	0.23	1.48	2.21	1.27	3.21

Table 1: Conditional steady states implied by the MS-VAR. For each draw of the VAR coefficients we compute the implied conditional steady states. These represent the values to which the observable converge once a regime is in place for a prolonged period of time.

Figure 1 reports the smoothed probabilities at the posterior mode for the three regimes controlling the VAR coefficients and the three regimes of the covariance matrix. As far as the covariance matrix, Appendix A shows that the three regimes imply increasing levels of volatility. Regime 2 can be thought of as a regime associated with recessions and the turbulent periods of the 1970s until the beginning of the Great Moderation, which is instead dominated by the low volatility Regime 1. The volatility Regime 3 captures exceptional events, like the acceleration of the Great Recession in 2008Q3. However, we are mostly interested in the dynamics captured by the regimes for the VAR coefficients. Regime 1 dominates the 1960s and the 1970s. The switch from Regime 1 to Regime 2 occurs in 1981Q2. In order to understand what distinguishes these two regimes, Table 1 reports their conditional steady states. These are the values to which the variables converge if a regime is in place for a prolonged period of time. Regime 1 is characterized by primary deficits, as opposed to primary surpluses under Regime 2, higher inflation, and a lower real interest rate.

In order to understand the role of regime changes in capturing the properties of the data, Figure 2 presents a simulation in which all Gaussian shocks are set to zero and only regime changes occur. The light gray area and the dark gray area correspond to the periods during which Regime 1 and Regime 3 were in place, respectively. The early switch from Regime 2 to Regime 1 captures the low frequency increase in inflation that occurred starting in the late 1960s and that lasted until the Volcker disinflation of the early 1980s. This low frequency increase in inflation is associated with a similar low frequency movement in the

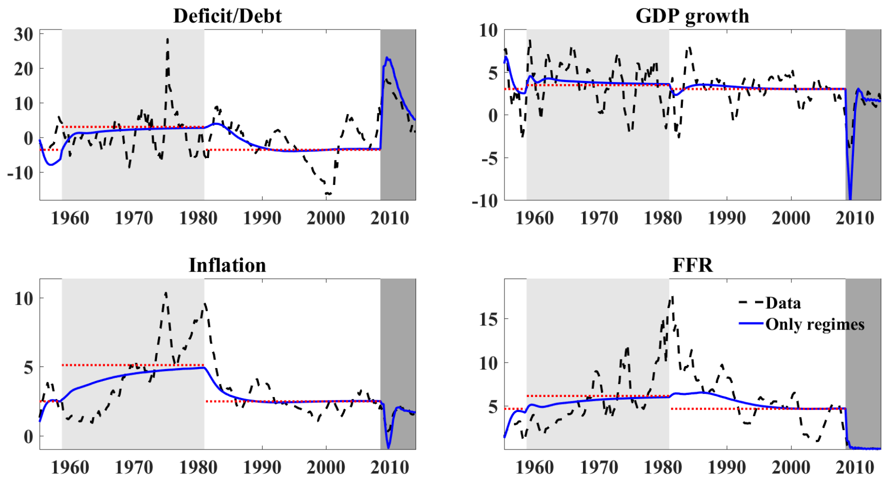

Figure 2: **Effects of regime changes.** The figure presents a simulation in which all Gaussian shocks are set to zero and only regime changes occur. The light gray area and the dark gray area correspond to the periods during which Regime 1 and Regime 3 were in place, respectively. The dashed line corresponds to the data, whereas the dotted line corresponds to the conditional steady states for Regime 1 and Regime 2.

deficit-to-debt ratio that stabilizes around a positive value. The increase in the federal funds rate is visibly smaller than the increase in inflation. This is in line with the drop in the conditional steady state of the real interest rate presented in Table 1. As will become clear when considering the structural model, these stylized facts can be rationalized in light of a change in the monetary-fiscal policy mix from fiscally-led to monetary-led. Under Regime 1, higher deficits lead to higher average inflation. Real interest rates remain low because the monetary authority does not react aggressively to inflation. We refer to Regime 1 as the fiscally-led regime and Regime 2 as the monetary-led regime.[4]

Regime 3 dominates the last part of the sample starting in 2008Q3. This quarter marks the acceleration of the financial crisis and the worst period of the Great Recession. The large contraction in real activity prompted policymakers to take extraordinary actions on both the monetary and the fiscal sides. The

[4]This interpretation of the data is consistent with Bianchi and Ilut (2015), who find a similar sequence of regime changes for the pre-crisis period when estimating a microfounded model. They identify a switch from a fiscally-led regime, which characterized the 1960s and 1970s, to a monetary-led regime exactly in 1981:Q2, after the appointment of Volcker as Fed Chairman and Reagan's election as President of the United States.

fiscal authority swiftly introduced massive measures of fiscal stimulus that raised the deficit-to-debt ratio by 11 percentage points within the next three quarters. The Federal Reserve cut the FFR aggressively to reach the zero lower bound. Consequently, we label Regime 3 the zero-lower-bound regime. At the end of the sample, we observe an increase in the probability of Regime 2, which we interpret as the monetary-led regime. However, Regime 3 is still the most likely regime. Furthermore, this result is in part driven by end-of-sample uncertainty.

Our MS-VAR model explains the key macroeconomic dynamics during the Great Recession and the ensuing slow recovery as a result of the shock that pushed the economy from the monetary-led regime to the zero-lower-bound regime in 2008:Q3. To highlight this point, Figure 3 extends the previous analysis by focusing on the effects of entering the zero-lower-bound regime in 2008:Q3. All Gaussian shocks are still shut down in this simulation and the starting point is 2008:Q3. The 70% posterior bands (gray areas) for the effects of this discrete shock capture remarkably well the dynamics of the data (solid line). This result suggests that the dynamics of the macroeconomy during the Great Recession can in principle be explained by only one adverse discrete shock. This shock lowered both output growth and inflation for a few quarters while it triggered radical and persistent changes in the conduct of fiscal and monetary policies. The switch to the zero-lower-bound regime seems to capture all of these stylized facts.

Of particular interest is the quick deterioration of the fiscal position as the Great Recession started. A crucial question for this paper is whether these fiscal imbalances had noticeable effects on price dynamics during the zero-lower-bound period. The following exercise serves the purpose of providing evidence of the key mechanism studied in this paper and hence motivates our ensuing structural analysis. We compute the response of inflation to fiscal shocks in the estimated MS-VAR so as to assess the inflationary consequences (if any) of the quickly deteriorating fiscal position during the Great Recession. We identify fiscal shocks as those shocks that raise the deficit-to-debt ratio upon impact while stimulating the economy for at least 5 quarters.[5] The positive comovement

[5]We restrict the deficit-to-debt ratio to respond positively *only upon impact* to accommodate the fact that primary deficits tend to be countercyclical and that fiscal rules, whose

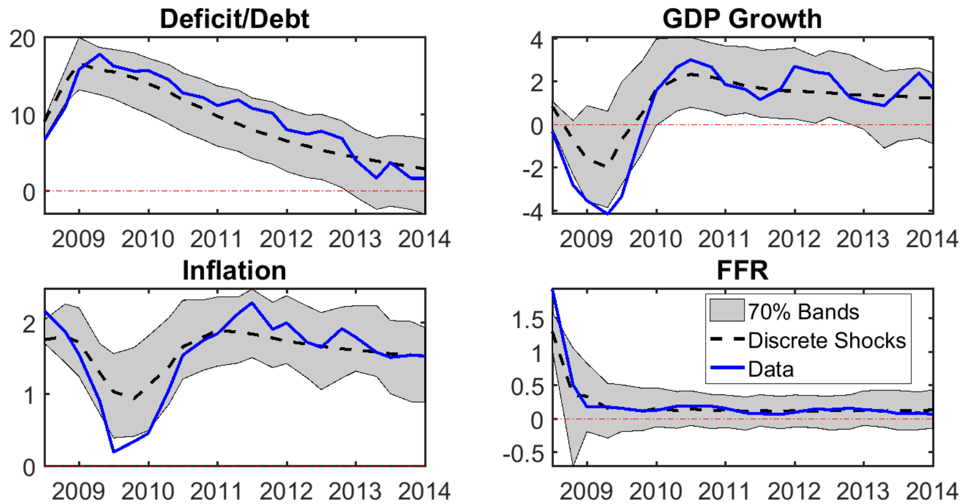

Figure 3: **Entering the zero-lower-bound regime.** The blue solid line reports the actual data. The black dashed line denotes the posterior median of the variables simulated from the MS-VAR by using only the dynamics implied by the VAR coefficients under Regime 3 starting in 2008:Q3. We initialize the simulations by using the actual value of the observables in 2008Q2. The gray areas capture the 70% posterior set of the simulated variables.

between deficit dynamics and GDP growth is the salient identifying feature of fiscal shocks. Non-fiscal shocks that affect economic activity, such as technology shocks, should arguably lead to a negative comovement between deficit and GDP growth, given that tax revenues go down during recession, while transfers tend to increase.

The results are reported in Figure 4, which shows three snapshots of the macroeconomic effects of fiscal shocks before, at, and after the onset of the Great Recession. These findings suggest that the inflationary effects of a growing fiscal imbalance due to the Great Recession may have been fairly sizable. The plots report a fiscal shock that raises the deficit-to-debt ratio by slightly more than one percentage point in 2008:Q3. In the data this ratio went up by more than four percentage points in 2008:Q3 and 11.20 percentage points from 2008:Q3 through 2009:Q2 (peak). Consequently, it is conceivable that the deterioration

objectives are to stabilize the business cycles, feature feedbacks to the real economy. Also, a higher deficit today will imply a higher stock of debt tomorrow, making the impact of fiscal shocks on this observable variable ambiguous ex-ante. As is standard in the structural VAR literature, this identification scheme is consistent with our DSGE model.

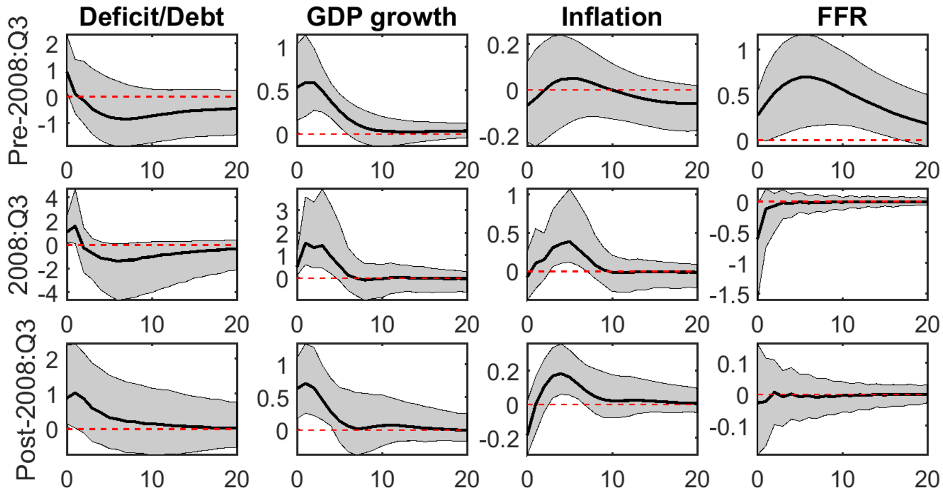

Figure 4: **Fiscal shocks before and at the zero lower bound.** The solid line denotes the posterior median of the response of the observable variables to a one-standard-deviation fiscal shock that raises the deficit-to-debt ratio upon impact and GDP growth within the next five quarters. Gray areas denote the 70% posterior set for the responses.

in the government's fiscal position observed in the data contributed to raising inflation quite substantially in the first quarters of the Great Recession.

Another interesting finding is that fiscal imbalances started to have inflationary consequences only in 2008:Q3, that is, when the zero-lower-bound regime arises. Before that period, the inflationary implications of fiscal imbalances are found to be statistically not significant (see upper panel in Figure 4). Before the Great Recession, the Federal Reserve was used to raising the rate relatively aggressively in response to fiscal shocks and in doing so kept a firm control over price dynamics. Furthermore, when the zero lower bound becomes binding in post-2008:Q3, the impact of fiscal imbalances on inflation was reduced as the Federal Reserve could not lower the rate further as it did in 2008:Q3.

The findings presented in this section suggest that the following are desirable properties for a structural model whose objective is to study the Great Recession. First, a successful model should be able to explain the dynamics of macro aggregates during the Great Recession as the result of a single large initial shock. Second, the model should feature three policy regimes as the VAR clearly identifies a switch to a third regime once the Great Recession began and two distinct periods before that. Third, the model should ideally capture the large inflationary consequences of fiscal imbalances during the zero-lower-bound regime. This third regime should be characterized by extremely low variability in the policy rate and hence must be different from the regimes that were in place before the crisis. Even if this third regime should feature an important role for fiscal imbalances, it should be associated with the realization of a large negative demand shock, unlike the fiscally-led regime that arose in the 1960s and 1970s. In the next section, we build a model in line with these key properties.

3 A Model with Policy Uncertainty

In this section we introduce the model that we will fit to US data in order to quantify the importance of policy uncertainty. The model is obtained by augmenting the prototypical New Keynesian model with a fiscal block and a discrete shock that can push the economy to the zero lower bound (ZLB).

3.1 A New Keynesian model

Households. The representative household maximizes expected utility:

$$E_0 \left[\sum_{s=0}^{\infty} \beta^t \exp\left(\zeta_t^d\right) \left[\log\left(C_t - \Phi C_{t-1}^A\right) - h_t \right] \right] \tag{3}$$

subject to the budget constraint:

$$P_t C_t + P_t^m B_t^m + P_t^s B_t^s = P_t W_t h_t + B_{t-1}^s + \left(1 + \rho P_t^m\right) B_{t-1}^m + P_t D_t - T_t + TR_t$$

where D_t stands for real dividends paid by the firms, C_t is consumption, h_t is hours, W_t is the real wage, T_t is taxes, TR_t stands for transfers, and C_t^A represents the average level of consumption in the economy. The parameter Φ captures the degree of external habit. Following Woodford (2001), we assume that there are two types of government bonds: one-period government debt, B_t^s, in zero net supply with price P_t^s and a more general portfolio of government debt, B_t^m, in non-zero net supply with price P_t^m. The former debt instrument satisfies $P_t^s = R_t^{-1}$. The latter debt instrument has payment structure $\rho^{T-(t+1)}$

for $T > t$ and $0 < \rho < 1$. The asset can be interpreted as a portfolio of infinitely many bonds with average maturity controlled by the parameter ρ. The value of such an instrument issued in period t in any future period $t+j$ is $P_{t+j}^{m-j} = \rho^j P_{t+j}^m$.

The preference shock ζ_d is the sum of a continuous and discrete component: $\zeta_d = d_t + \overline{d}_{\xi_t^d}$. The continuous component d_t follows an AR(1) process: $d_t = \rho_d d_{t-1} + \sigma_d \varepsilon_{d,t}$. The discrete component $\overline{d}_{\xi_t^d}$ can assume two values: high or low ($\overline{d}_h$ or $\overline{d}_l$). The variable ξ_t^d controls the regime in place and evolves according to the transition matrix H^d:

$$H^d = \begin{bmatrix} p_{hh} & 1 - p_{ll} \\ 1 - p_{hh} & p_{ll} \end{bmatrix},$$

where $p_{ji} = P\left(\xi_{t+1}^d = j | \xi_t^d = i\right)$. The values of H^d, $\overline{d}_h$, and $\overline{d}_l$ are such that the unconditional mean of the discrete shock $\overline{d}_{\xi_t^d}$ is zero. This specification is in the spirit of Christiano et al. (2011). However, in the current setup shocks to preferences that are able to trigger the ZLB are assumed to be recurrent, and agents take into account that these episodes can lead to unusual policymakers' responses, as discussed later on.

Firms. The representative firm j faces a downward-sloping demand curve, $Y_t(j) = (P_t(j)/P_t)^{-1/\upsilon_t} Y_t$, where the parameter $1/\upsilon_t$ is the elasticity of substitution between two differentiated goods. Firms take as given the general price level, P_t, and the level of real activity, Y_t. Whenever a firm changes its price, it faces a quadratic adjustment cost:

$$AC_t(j) = .5\varphi \left(P_t(j)/P_{t-1}(j) - \Pi\right)^2 Y_t(j) P_t(j)/P_t \tag{4}$$

where $\Pi_t = P_t/P_{t-1}$ is gross inflation at time t and Π is the corresponding deterministic steady state. Shocks to the elasticity of substitution imply shocks to the markup $\aleph_t = 1/(1-\upsilon_t)$. We assume that the rescaled markup $\mu_t = \kappa \log(\aleph_t/\aleph)$ follows an autoregressive process, $\mu_t = \rho_\mu \mu_{t-1} + \sigma_\mu \epsilon_{\mu,t}$, where $\kappa \equiv \frac{1-\upsilon}{\upsilon\varphi\Pi^2}$ is the slope of the Phillips curve. The firm chooses the price $P_t(j)$ to maximize the present value of future profits:

$$E_t \left[\sum_{s=t}^{\infty} Q_s \left(\left[P_s(j)/P_s\right] Y_s(j) - W_s h_s(j) - AC_s(j)\right)\right]$$

where Q_s is the marginal value of a unit of consumption good. Labor is the only input in the firm production function, $Y_t(j) = A_t h_t^{1-\alpha}(j)$, where total factor productivity A_t evolves according to an exogenous process: $\ln(A_t/A_{t-1}) = \gamma + a_t$, $a_t = \rho_a a_{t-1} + \sigma_a \varepsilon_{a,t}$, $\epsilon_{a,t} \sim N(0,1)$.

Government. Imposing the restriction that one-period debt is in zero net supply, the flow budget constraint of the federal government is given by:

$$P_t^m B_t^m = B_{t-1}^m (1 + \rho P_t^m) - T_t + E_t + TP_t$$

where $P_t^m B_t^m$ is the market value of debt and T_t and E_t represent federal tax revenues and federal expenditures, respectively. Government expenditure is the sum of federal transfers and goods purchases: $E_t = P_t G_t + TR_t$. The term TP_t is a shock that is meant to capture a series of features that are not explicitly modeled here, such as changes in the maturity structure and the term premium. This shock is necessary because we treat all the components of the government budget constraint as observables. We rewrite the federal government budget constraint in terms of debt-to-GDP ratio $b_t^m = (P_t^m B_t^m)/(P_t Y_t)$:

$$b_t^m = \left(b_{t-1}^m R_{t-1,t}^m\right) / (\Pi_t Y_t / Y_{t-1}) - \tau_t + e_t + tp_t$$

where $R_{t-1,t}^m = (1 + \rho P_t^m)/P_{t-1}^m$ is the realized return of the maturity bond, all the variables are expressed as a fraction of GDP, and we assume $tp_t = \rho_{tp} tp_{t-1} + \sigma_{tp} \varepsilon_{tp,t}$, $\epsilon_{tp,t} \sim N(0,1)$.

The linearized transfers as a fraction of GDP, $\widetilde{tr}_t$, follow the following process:

$$\begin{aligned} \left(\widetilde{tr}_t - \widetilde{tr}_t^*\right) &= \rho_{tr}\left(\widetilde{tr}_{t-1} - \widetilde{tr}_t^*\right) + (1-\rho_{tr})\,\phi_y\left(\widehat{y}_t - \widehat{y}_t^*\right) + \sigma_{tr}\epsilon_{tr,t} \\ \widetilde{tr}_t^* &= \rho_{tr^*}\widetilde{tr}_{t-1}^* + \sigma_{tr^*}\epsilon_{tr^*,t},\ \ \epsilon_{tr^*,t} \sim N(0,1)\,,\ \ \epsilon_{tr,t} \sim N(0,1) \end{aligned}$$

where $\widetilde{tr}_t^*$ represents a long-term component that is meant to capture the large programs that arise as the result of a political process that is not modeled here.[6] Transfers move around this trend component as a result of business cycle

[6] In what follows, $\widehat{x}_t$ denotes the percentage deviation of a detrended variable from its own steady state. For all the variables normalized with respect to GDP (debt, expenditure, and taxes) $\widetilde{x}_t$ denotes a linear deviation, while for all the other variables $\widetilde{x}_t$ denotes a percentage

fluctuations captured by the log-linearized output gap $(\widehat{y}_t - \widehat{y}_t^*)$, where $\widehat{y}_t^*$ is potential output. The government also buys a fraction G_t/Y_t of total output. We define $g_t = 1/(1 - G_t/Y_t)$ and we assume that $\widetilde{g}_t = \ln(g_t/g)$ follows an autoregressive process: $\widetilde{g}_t = \rho_g \widetilde{g}_{t-1} + \sigma_g \epsilon_{g,t}$, $\epsilon_{g,t} \sim N(0,1)$.

Policy Rules. When the high value for the preference shock is realized $(\xi_t^d = h)$, the economy is out of the ZLB and monetary and fiscal policies are not constrained. In this case, the central bank follows a standard Taylor rule and the evolution of the policy mix can be described by a two-regime Markov switching process ξ_t^p, whose properties will be described in the next section. When the low value for the preference shock is realized $(\xi_t^d = l)$, the central bank lowers the FFR until the ZLB is reached and the fiscal authority focuses on stabilizing the economy as opposed to trying to stabilize the stock of debt.

Specifically, the monetary policy rule reads as follows:

$$
\begin{aligned}
R_t/R \; = \; & \left(1 - Z_{\xi_t^d}\right) (R_{t-1}/R)^{\rho_{R,\xi_t^p}} \left[(\Pi_t/\Pi)^{\psi_{\pi,\xi_t^p}} (Y_t/Y_t^*)^{\psi_{y,\xi_t^p}} \right]^{\left(1-\rho_{R,\xi_t^p}\right)} e^{\sigma_R \epsilon_{R,t}} \\
& + Z_{\xi_t^d} (R_{t-1}/R)^{\rho_{R,Z}} (1/R)^{\left(1-\rho_{R,Z}\right)\psi_Z} e^{\sigma_Z \epsilon_{R,t}} \qquad (5)
\end{aligned}
$$

where $\epsilon_{R,t} \sim N(0,1)$, R is the steady-state gross nominal interest rate, Y_t^* is the output target, and Π is the deterministic steady-state level for gross inflation. The parameters ψ_{π,ξ_t^p} and ψ_{y,ξ_t^p} capture the central bank's response to inflation and output gap, which depends on the policy mix ξ_t^p in place at time t. The dummy variable $Z_{\xi_t^d}$ is zero when the value of the preference shock is high $(\xi_t^d = h)$ and one when it is low $(\xi_t^d = l)$. To match the behavior of the FFR in the data during the zero-lower-bound period, we need to allow for small disturbances and a gradual decline toward a value close, but not exactly equal, to zero. The size of the monetary policy shocks at the ZLB, σ_Z, is assumed to be a tenth of the standard deviation of the monetary policy shocks when out of the ZLB: $\sigma_Z = \sigma_R/10$. The persistence of changes in the federal funds rate at the ZLB is controlled by $\rho_{R,Z}$ and fixed to .2. Finally, the parameter $0 < \psi_Z \leq 1$ controls the average level of the FFR when at the ZLB. It can be thought of as the fraction of the steady-state net interest rate. Notice that if

deviation.

we set $\sigma_Z = 0$, $\rho_{R,Z} = 0$, and $\psi_Z = 1$, we would obtain $R_t = 1$ at the ZLB and the net nominal interest rate would be exactly zero.[7]

The fiscal authority moves taxes according to the following rule:

$$\begin{aligned}\widetilde{\tau}_t &= \left(1 - Z_{\xi_t^d}\right)\left[\rho_{\tau,\xi_t^p}\widetilde{\tau}_{t-1} + \left(1 - \rho_{\tau,\xi_t^p}\right)\left[\delta_{b,\xi_t^p}\widetilde{b}_{t-1}^m + \delta_e\widetilde{e}_t^* + \delta_y\left(\widehat{y}_t - \widehat{y}_t^*\right)\right]\right] \\ &\quad + Z_{\xi_t^d}\left[\rho_{\tau,Z}\widetilde{\tau}_{t-1} + \left(1 - \rho_{\tau,Z}\right)\left[\delta_e\widetilde{e}_t^* + \delta_y\left(\widehat{y}_t - \widehat{y}_t^*\right)\right]\right] + \sigma_\tau\epsilon_{\tau,t} \qquad (6)\end{aligned}$$

where $\widetilde{e}_t^* \equiv \widetilde{tr}_t^* + g^{-1}\widetilde{g}_t$, $\epsilon_{\tau,t} \sim N(0,1)$, and $\widetilde{\tau}_t$ is the level of tax revenues with respect to GDP in deviations from the steady state. When the economy is in the high state of demand ($Z_{\xi_t^d} = 0$), tax revenues respond to the state of the economy, captured by the output gap, to the sum of the long-run level of transfers and government purchases, and to the level of debt. The parameter δ_{b,ξ_t^p} captures the fiscal authority's attitude toward debt stabilization, which depends on the type of policy mix ξ_t^p in place at time t. When the large negative preference shock hits ($Z_{\xi_t^d} = 1$), the fiscal authority temporarily disregards the level of debt to focus on stabilizing the economy. However, the fiscal authority still responds to the level of spending.

3.2 Policy changes

To characterize policymakers' behavior out of the ZLB, we will make use of the partition of the parameter space introduced by Leeper (1991). For the sake of the exposition, we will assume that the Taylor rule reacts only to inflation, whereas the fiscal rule reacts only to debt. In this simplified version of the model, we can distinguish four regions based on the properties of the model under fixed coefficients. When the values of model parameters are fixed, the two policy rules are key in determining the existence and uniqueness of a solution. There are two determinacy regions. The first region, Active Monetary/Passive

[7] When estimating the model we verify that the ZLB would be binding in response to the large negative preference shock. Our approach to modeling the ZLB differs from the conventional one, which implies $R_t = \max(0, R_t^*)$, where R_t^* is the interest rate implied by the Taylor rule. While our approach cannot rule out the possibility of states of the world in which the nominal rate R_t assumes negative values, it has the advantage of keeping the model tractable while it allows us to study the consequences of policy uncertainty.

Fiscal (AM/PF), is the most familiar one: The Taylor principle is satisfied and the fiscal authority moves taxes to keep debt on a stable path: $\psi_{\pi}^{AM} > 1$ and $\delta_b^{PF} > \beta^{-1} - 1$. We refer to this policy combination as the monetary-led regime.

The second determinacy region, Passive Monetary/Active Fiscal (PM/AF), corresponds to the case in which the fiscal authority is not committed to stabilizing the process for debt: $\delta_b^{AF} < \beta^{-1} - 1$. Now it is the monetary authority that passively accommodates the behavior of the fiscal authority, disregarding the Taylor principle and allowing inflation to move in order to stabilize the process for debt: $\psi_{\pi}^{PM} < 1$. Under this regime, even in the absence of distortionary taxation, shocks to net taxes can have an impact on the macroeconomy as agents understand that they will not be followed by future offsetting changes in the fiscal variables. We label this policy combination the fiscally-led regime. Finally, when both authorities are active, no stationary equilibrium exists, whereas when both of them are passive, the economy is subject to multiple equilibria.

In the benchmark model, when the preference shock is high ($\xi_t^d = h$), the economy is out of the ZLB ($Z_{\xi_t^d} = 0$) and the evolution of policymakers' behavior is captured by a two-regime Markov chain that evolves according to the transition matrix H^p:

$$H^p = \begin{bmatrix} p_{MM} & 1 - p_{FF} \\ 1 - p_{MM} & p_{FF} \end{bmatrix},$$

where $p_{ji} = P\left(\xi_{t+1}^p = j | \xi_t^p = i\right)$. This transition matrix is supposed to capture the stochastic outcome of a game between the monetary and fiscal authorities that is not explicitly modeled in this paper. Regime M is the *monetary-led regime*: $\psi_{\pi,M} = \psi_{\pi}^{AM} > 1$ and $\delta_{b,M} = \delta_b^{PF} > \beta^{-1} - 1$. Regime F is the *fiscally-led regime*: $\psi_{\pi,F} = \psi_{\pi}^{PM} < 1$ and $\delta_{b,F} = \delta_b^{AM} < \beta^{-1} - 1$.

When the low value for the preference shock occurs ($\xi_t^d = l$), the ZLB becomes binding ($Z_{\xi_t^d} = 1$), and policymakers' behavior is now constrained. In this third regime, the central bank lowers the FFR until it hits the ZLB and the fiscal authority temporarily disregards the level of debt in order to focus on stabilizing the economy.[8] Notice that the zero-lower-bound policy mix can

[8]Our results are robust to relaxing the assumption regarding the behavior of the fiscal

be considered as an extreme version of the fiscally-led policy mix. However, while out of the ZLB, switches to the fiscally-led regime capture the deliberate choices of policymakers, the zero-lower-bound regime is triggered by an exogenous negative preference shock that prompts the fiscal authority to forgo fiscal adjustments to counter the effects of a deep recession. Once the preference shock is back to its high value, policymakers' behavior is not constrained anymore.

Even if the ZLB imposes a constraint on policymakers' behavior, agents' beliefs are not constrained. Therefore, beliefs about the exit strategy and policy uncertainty are going to be key to understanding the macroeconomic dynamics at the ZLB. To capture this feature, we introduce a parameter controlling the expected exit strategy from the ZLB. The parameter p_{ZM} represents the probability that once the discrete preference shock is reabsorbed, the economy will move to the the monetary-led regime.

The joint evolution of policymakers' behavior and the discrete preference shock is controlled by the combined chain $\xi_t \equiv \left[\xi_t^p, \xi_t^d\right] = \{[M, h], [F, h], [Z, l]\}$. The corresponding transition matrix H is obtained by combining the transition matrices H^d and H^p with the parameter p_{ZM}:

$$H = \left[\begin{array}{cc} p_{hh} H^p & (1 - p_{ll}) \left[\begin{array}{c} p_{ZM} \\ 1 - p_{ZM} \end{array} \right] \\ (1 - p_{hh}) [1, 1] & p_{ll} \end{array} \right].$$

3.3 Solving the MS-DSGE model

The technology process A_t is assumed to have a unit root. The model is then rescaled and linearized around the unique deterministic steady state. The model can be solved with any of the solution methods developed for Markov–switching DSGE models. We use the solution method of Farmer et al. (2009). It is worth emphasizing that in our model, agents form expectations while taking into account the possibility of entering the ZLB and of changes in policymakers' behavior. Furthermore, they understand that entering the ZLB is an event induced by an exogenous shock that can modify policymakers' behavior even

authority because the dynamics at the zero lower bound mostly depend on the exit strategy.

once the constraint stops being binding. In other words, our approach allows us to model *recurrent* zero-lower-bound episodes and to capture the impact of different exit strategies for policymakers' behavior at the ZLB. The solution can be characterized as a MS-VAR:

$$S_t = c(\xi_t, \theta, H) + T(\xi_t, \theta, H) S_{t-1} + R(\xi_t, \theta, H) Q(\theta^v) \varepsilon_t \tag{7}$$

where θ, θ^v, and S_t are vectors that contain the structural parameters, the stochastic volatilities, and all the variables of the model, respectively. Appendix B provides more details about the linearization and the solution algorithm.

It is worth emphasizing that the law of motion of the model depends on the structural parameters (θ), the regime in place (ξ_t), and the probability of moving across regimes (H). This notation highlights that the properties of one regime depend not only on the structural parameters describing that particular regime, but also on what agents expect is going to happen under alternative regimes and on how likely it is that a regime change will occur in the future (see also Davig and Leeper 2007). In other words, agents' beliefs about future regime changes matter for the law of motion governing the economy.

4 The Effects of Policy Uncertainty

The model solution is combined with a system of observation equations. We estimate the model with Bayesian methods. We include seven observables spanning the sample 1954:Q4-2014:Q1: real GDP growth, annualized GDP deflator inflation, annualized FFR, annualized debt-to-GDP ratio, federal tax revenues to GDP ratio, federal expenditure to GDP ratio, and a transformation of government purchases to GDP ratio. All variables are expressed in percentage points when reporting the results. For tractability, we fix the regime sequence for the out-of-the-zero-lower-bound regimes based on the VAR evidence presented in Section 2. The zero-lower-bound regime is assumed to start in 2008:Q4 and remains in place until the end of the sample.[9]

[9] As the starting date of the ZLB we choose 2008:Q4, instead of 2008:Q3 as implied by the MS-VAR, in light of a model comparison exercise in which we considered all quarters between

	Mean	5%	95%	Type	Mean	Std
$\psi_{\pi,M}$	1.6019	1.1758	2.0207	N	2.5	0.3
$\psi_{y,M}$	0.5065	0.2980	0.7688	G	0.4	0.2
$\rho_{R,M}$	0.8652	0.8135	0.9108	B	0.5	0.2
$\delta_{b,M}$	0.0712	0.0457	0.1041	G	0.07	0.02
$\rho_{\tau,M}$	0.9652	0.9439	0.9816	B	0.5	0.2
$\psi_{\pi,F}$	0.6356	0.5007	0.7546	G	0.8	0.3
$\psi_{y,F}$	0.2709	0.2005	0.3458	G	0.15	0.1
$\rho_{R,F}$	0.6663	0.5927	0.7401	B	0.5	0.2
$\rho_{\tau,F}$	0.6874	0.5358	0.8438	B	0.5	0.2
$\bar{d}_l$	-0.3662	-0.4827	-0.2789	N	-0.3	0.1
p_{hh}	0.9995	0.9984	0.9999	D	0.96	0.03
p_{ll}	0.9306	0.8936	0.9599	D	0.83	0.10
p_{MM}	0.9923	0.9872	0.9965	D	0.96	0.03
p_{FF}	0.9923	0.9888	0.9951	D	0.96	0.03
p_{ZM}	0.9225	0.8108	0.9861	D	0.50	0.22
ψ_Z	0.9678	0.9596	0.9761	B	0.95	0.02
κ	0.0073	0.0052	0.0098	G	0.3	0.15
ρ_{tr}	0.4599	0.3677	0.5537	B	0.2	0.05
δ_y	0.2766	0.1899	0.3707	N	0.4	0.2
δ_e	0.3661	0.2096	0.5137	N	0.5	0.2
ϕ_y	-0.2910	-0.3433	-0.2435	N	-0.4	0.2
Φ	0.8628	0.8299	0.8928	B	0.5	0.2
ρ_g	0.9796	0.9742	0.9839	B	0.5	0.2
ρ_a	0.4053	0.1522	0.6480	B	0.5	0.2
ρ_d	0.3944	0.2881	0.4963	B	0.5	0.2
ρ_{tp}	0.3267	0.2276	0.4218	B	0.5	0.2
ρ_μ	0.4784	0.4053	0.5513	B	0.5	0.2
$100\sigma_R$	0.1934	0.1767	0.2115	IG	0.5	0.5
$100\sigma_g$	0.2826	0.2614	0.3049	IG	1.00	1.00
$100\sigma_a$	0.7708	0.4713	1.1552	IG	1.00	1.00
$100\sigma_\tau$	0.4547	0.4174	0.4951	IG	2.00	2.00
$100\sigma_d$	7.6949	6.3336	9.3354	IG	10.00	2.00
$100\sigma_{tr}$	0.3007	0.2750	0.3282	IG	2.00	2.00
$100\sigma_{tp}$	2.8511	2.6336	3.0922	IG	1.00	1.00
$100\sigma_\mu$	0.1774	0.1530	0.2037	IG	1.00	1.00
100π	0.4631	0.3955	0.5369	G	0.5	0.05
100γ	0.4185	0.3523	0.4849	G	0.4	0.05
$.25b^m$	0.2672	0.2342	0.2995	N	0.25	0.05
g	1.0865	1.0779	1.0960	N	1.06	0.04
$.25\tau$	0.0430	0.0417	0.0445	N	0.045	0.0025

Table 2: Posterior means, 90% posterior error bands and priors of the model parameters. For the structural parameters, M stands for the monetary-led regime, and F stands for the fiscally-led regime. The letters in the column "Type" indicate the prior density function: N, G, B, D, and IG stand for Normal, Gamma, Beta, Dirichlet, and Inverse Gamma, respectively.

4.1 Parameter estimates

Table 2 reports priors and posterior parameter estimates. The priors for the parameters that do not move across regimes are in line with previous contributions in the literature and are relatively loose. As for the parameters of the Taylor rule, the prior for the autoregressive component is symmetric across regimes, whereas we have chosen asymmetric and truncated priors for the responses to inflation and the output gap in line with the theoretical restrictions outlined above: Under the monetary-led regime (M) monetary policy is active, whereas under the fiscally-led regime (F), monetary policy is passive. In a similar way, the priors for the response of taxes to government debt are asymmetric across the two regimes: Under the fiscally-led regime and the ZLB regime, this parameter is restricted to zero, whereas under the monetary-led regime it is expected to be fairly large. In order to separate the short- and long-term components of transfers, we restrict the persistence of the long-term component ($\rho_{e^L} = .99$) and the standard deviation of its innovations ($\sigma_{e^L} = .1\%$). We fix the discount factor β to .9985, a value broadly consistent with an annualized 2% real interest rate, and the average maturity to 5 years (this is controlled by the parameter ρ). We assume that the persistence of the fiscal rule at the ZLB coincides with its value in the fiscally-led regime: $\rho_{\tau,Z} = \rho_{\tau,F}$.

We choose priors for the persistence of the policy regimes in line with the persistence of the two regimes implied by the regime sequence recovered when estimating the MS-VAR. Finally, we choose a loose and symmetric prior for the parameter p_{ZM}, which captures the uncertainty about the policy that will be carried out after the liftoff of the interest rate from the ZLB. Our symmetric and broad prior implies that we maintain an agnostic view with respect to which exit strategy agents regard as most likely.

Regarding the parameters of the Taylor rule, under the monetary-led regime the federal funds rate reacts strongly to both inflation and the output gap. The opposite occurs under the fiscally-led regime. Under the fiscally-led and ZLB regimes the response of taxes to debt is restricted to zero, while under the

2008:Q1 and 2009:Q3 as possible starting dates. The results of this exercise, the dataset, and evidence for convergence of the MCMC algorithm can be found in Appendix C.

monetary-led regime it turns out to be significantly larger than the threshold value described in Subsection 3.2 ($\beta^{-1} - 1 = .0015$).

Since we fixed the regime sequence, the estimates of the transition matrix are determined by the model dynamics across the different regimes and not by the frequency of regime changes. Both the monetary-led regime and the fiscally-led regime turn out to be quite persistent, implying that when one of the two regimes is in place, agents expect to spend a significant amount of time under such a regime. The persistence of the high state for the discrete preference shock is also very high. This implies that when out of the ZLB, agents attach a small weight to the possibility of a large contraction in real activity deriving from the negative preference shock. This result is consistent with the fact that before the recent crisis, the US economy had always been able to avoid the ZLB. When at the ZLB, agents regard it as more likely that once the negative preference shock is reabsorbed, policymakers will move to the monetary-led regime ($p_{ZM} = 92\%$ at the posterior mean). However, this probability is smaller than the estimated persistence of the monetary-led regime (p_{MM} is around 99%). Therefore, when the economy entered the ZLB, the probability attached to switching to the fiscally-led regime increased and agents' uncertainty about the future policy mix rose.

It is worth clarifying the importance of estimating the model over the whole sample, as opposed to focusing exclusively on the zero-lower-bound period. For the sake of argument, we can think that the properties of the fiscally-led regime are mostly identified by the study of the effects of fiscal imbalances during the 1960s and 1970s.[10] Similarly, the properties of the monetary-led regime are mostly pinned down by the behavior of the economy during the post-Volcker disinflation period. As we shall explain in greater detail in Section 6, for given properties of the monetary-led and fiscally-led regimes, the parameter p_{ZM} highly influences the effects of fiscal imbalances on the macroeconomy at the ZLB. Thus, this key parameter is identified by the joint dynamics of fiscal variables, inflation, and real activity during the ZLB period.

[10] The discussion here is simplified to the extent that the properties of one regime depend in part on the properties of the other regimes. Furthermore, there are feedback effects from the macroeconomy to the fiscal variables.

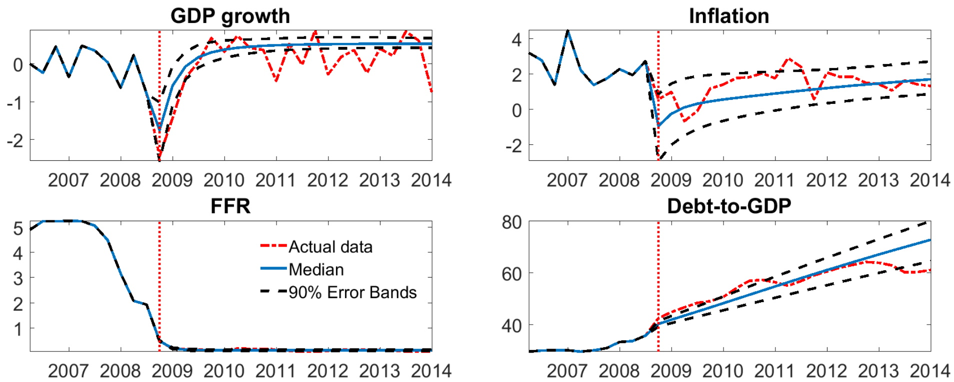

Figure 5: **Macroeconomic dynamics at the zero lower bound.** Response of GDP growth, inflation, FFR, and debt-to-GDP ratio to a discrete negative preference shock. The red dashed line reports actual data.

4.2 Dynamics at the zero lower bound

Figure 5 reports the estimated impulse response to a discrete negative preference shock $\overline{d}_l$. To compute the impulse response, we use the actual data in 2008:Q3. The shock occurs in 2008:Q4 and is marked by a vertical line.[11] The model is able to replicate the key changes that occurred starting with the 2008 crisis as a result of the single discrete negative preference shock, in line with the VAR evidence. The economy experiences a drop in real activity and a large increase in the debt ratio, monetary policy enters the ZLB, but inflation remains relatively stable. It is also interesting to notice that the model is able not only to replicate the absence of deflation, but also the fact that inflation has been trending up. The model rationalizes this behavior as a result of increasing inflationary pressure coming from the large debt accumulation.

The absence of deflation is tightly linked to uncertainty about policymakers' future behavior. To show this, Figure 6 compares the effects of the discrete negative preference shock under the benchmark estimated model with its effects in a counterfactual economy in which the monetary-led policy mix is the only possible regime when out of the ZLB (dashed line). Thus the vertical distance

[11] Using actual data is important because the impulse response is not invariant with respect to the state of the economy, namely the observed fiscal imbalances. This is because the negative preference shock affects agents' beliefs about policymakers' future behavior.

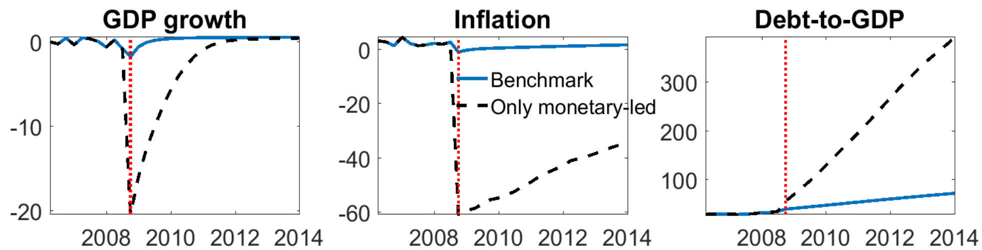

Figure 6: **Actual and counterfactual impulse responses to a discrete negative preference shock.** The solid blue line corresponds to the estimated model, whereas the black dashed line corresponds to a counterfactual economy in which the monetary-led policy mix is the only possible policy mix.

between the two lines captures the effects of uncertainty about the exit strategy on the output gap, inflation, and the debt-to-GDP ratio. Notice that under the counterfactual economy, the negative preference shock has now a much larger impact on inflation and real activity. The economy experiences a very large and persistent deflation and a much larger contraction in output. Furthermore, the massive increase in the debt-to-GDP ratio does not have any mitigating effect on inflation: Agents expect that the entire debt-to-GDP ratio will eventually be repaid with an increase in taxation. Thus, paradoxically, the uncertainty about future policy was beneficial, rather than harmful, to macroeconomic performance. This does not mean that policy uncertainty is beneficial in itself, but it implies that when monetary policy becomes constrained by the ZLB, the resulting policy uncertainty mitigates the consequences of the ZLB by creating inflationary pressure.

Note that in the counterfactual economy the contraction in output and the drop in inflation are unrealistically large because we are removing the key mechanism of the estimated model. In Section 5, we will formally compare our benchmark model to an estimated nested model that removes policy uncertainty in a way that puts the two models on the same ground. The goal in this section is instead to isolate the key mechanism that prevents deflation in the estimated model. In this respect, the fact that the model can in principle reproduce the standard features of the ZLB is important: The data could have rejected the role played by policy uncertainty in explaining inflation dynamics. For example, the estimates could have suggested a very small probability of ever moving to the fiscally-led regime and a counteracting mark-up shock that keeps inflation positive. Instead, a large preference shock is found to explain the sharp decline in real activity. The absence of deflation is then rationalized in light of the possibility of a change in the monetary/fiscal policy mix.[12]

It is also important to emphasize that the amount of policy uncertainty required to explain the absence of deflation during the Great Recession is quite moderate. As shown in Table 2, the posterior mean of the probability of moving to the monetary-led policy mix once out of the ZLB regime is $p_{ZM} = 92.25\%$. This implies that at the ZLB agents mostly believe that policymakers will eventually resume the same policy mix observed before the Great Recession. Such a belief is plausible for the US in light of the long spell of monetary-led policy mix observed between the Volcker disinflation and the onset of the Great Recession. However, as noted earlier, this value implies a higher probability of moving to the fiscally-led regime than that in the pre-crisis period. Finally, in the estimated model, the magnitude of the inflationary effects of uncertainty about the exit strategy largely depend on the pre-crisis level of government debt, which is observed to be above its estimated steady-state value (around 42.5%).

Figure 7 provides further corroborating evidence in favor of the mechanism proposed in this paper. The figure reports the evolution of the one-year-ahead and five-year-ahead inflation expectations as implied by the model and compares them with the Michigan surveys. The error bands reflect parameter uncertainty. Even though we do not use inflation expectations for estimation, the model is able to replicate the salient features of the Michigan surveys. First, the model captures the upward trend in inflation expectations that is visible right before the recession started. This pattern can be partially explained by the increase in the US fiscal burden during those years. Second, the model captures remarkably well the swing in inflation expectations that occurred once the crisis started. From above trend, inflation expectations quickly moved below trend. However, they never became negative and they quickly recovered. Finally, at the ZLB inflation expectations exhibit an upward trend. The model explains this pattern

[12] In Appendix D we show that our results do not depend on the shock that triggers the zero lower bound. To that end, we consider a prototypical New Keynesian model in which we can directly shock the natural rate as in Eggertsson and Woodford (2003).

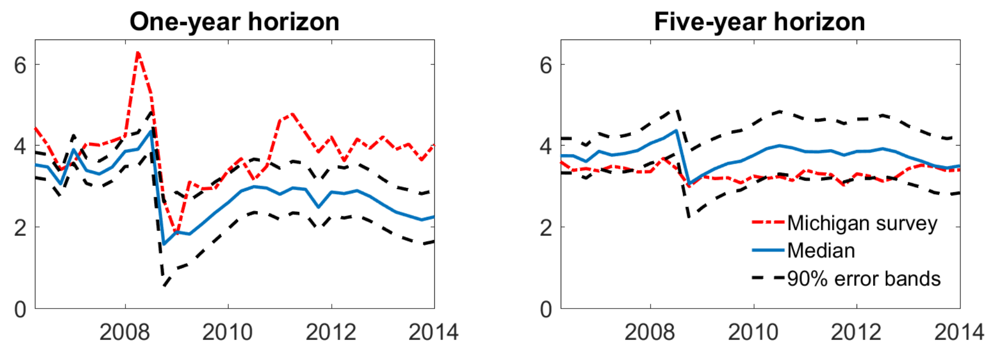

Figure 7: **Inflation expectations.** The figure reports the evolution of the model-implied one-year-ahead and five-year-ahead inflation expectations together with the Michigan surveys (red dashed dotted line).

as a result of the large debt accumulation.

We find it reassuring that the model is able to replicate these key facts even if inflation expectations are not used for estimating the model. This result shows that the inflationary pressure coming from the fiscal burden delivers inflation expectations that are very much in line with the data. It is important to emphasize that inflation expectations moved down, as predicted by our model, when the ZLB was encountered, but they never entered negative territory. In other words, agents were confident that deflation would not have occurred. Instead, in the baseline New Keynesian model, where the monetary-led policy mix is the only possible regime, agents should expect deflation once the economy enters the ZLB. The fact that inflation expectations, and not just inflation, behave in a way that is not consistent with the baseline New Keynesian model suggests that the absence of deflation in the United States cannot be easily rationalized ex-post with a series of lucky realizations of inflationary shocks.

4.3 Inspecting the fiscal mechanism

In our model, how shocks propagate depends on the policy regime in place as well as the state variables of the economy. This property is key for the model to rationalize the absence of deflation at the ZLB. Figure 8 reports the impulse responses to an increase in the long-term component of transfers under the three different regimes. This shock has a direct impact on the debt-to-GDP ratio

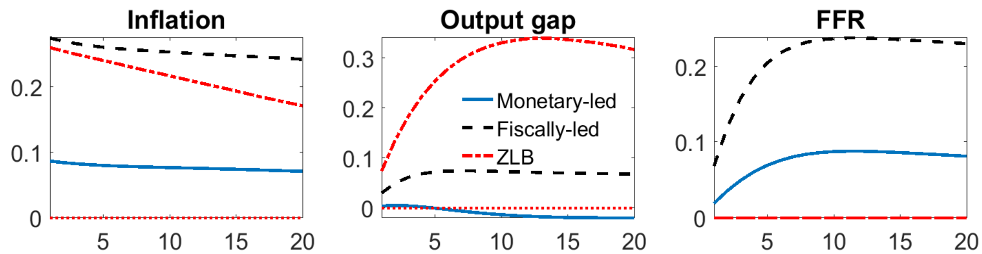

Figure 8: **Impulse responses to a shock to transfers.** The impulse responses are computed assuming a regime in place over the the relevant horizon. However, agents form expectations taking into account the possibility of regime changes.

and, consequently, on the amount of spending that would have to be financed with future taxes. Impulse responses are computed conditionally on each policy regime being in place over the entire horizon. Nevertheless, model dynamics reflect the possibility of regime changes.

When the fiscally-led regime is in place, agents understand that in the near future the probability of a fiscal adjustment in response to the current increase in the primary deficit is fairly low. This determines an increase in inflation that is made possible by the accommodating behavior of the monetary authority that adjusts the interest rate less than one-to-one to inflation. The resulting decline in the real interest rate determines an increase in real activity. The debt-to-GDP ratio is then stabilized because of the fall in the real interest rate and the faster GDP growth.

Under the monetary-led regime the primary deficit shock triggers a much smaller increase in inflation because the fiscal authority is expected to implement the necessary fiscal adjustments. However, the response of inflation is not zero because agents form expectations taking into account the small possibility of moving to the fiscally-led regime. As a result, a high level of spending determines some inflationary pressure even when the monetary-led regime is in place. However, the rise in inflation is moderate compared to the case in which the fiscally-led policy mix is in place. Given that the Taylor principle holds, the central bank reacts more than one-to-one to the increase in inflation. The result is a prolonged period of slightly negative output gaps that last as long as the fiscal imbalance is not fully reabsorbed.

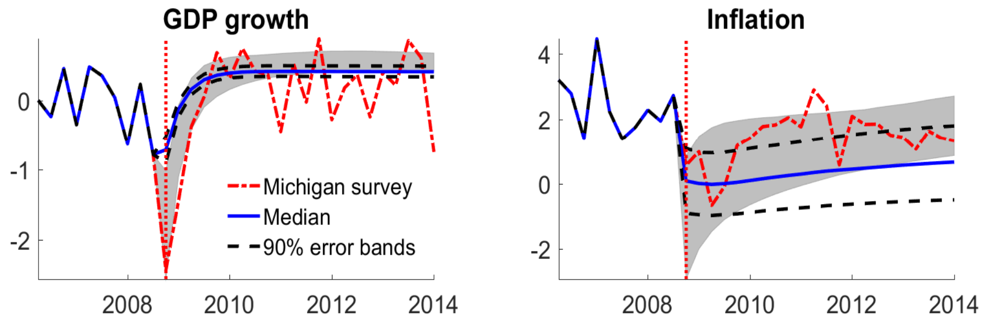

Figure 9: **Macroeconomic dynamics at the zero lower bound for a model without the fiscal block.** Response of GDP growth and inflation to a discrete negative preference shock based on a model that excludes the fiscal block. The red dashed line reports actual data, while the shaded areas report the 90% error bands for the benchmark model.

Under the zero-lower-bound regime the effects of the fiscal shock are quite similar to those that characterize the fiscally-led regime even though the probability to a return to the monetary-led regime (p_{ZM}) is quite large. The increase in spending triggers a large increase in inflation. Given that the FFR is stuck at zero, the resulting drop in the real interest rate is amplified with a consequent large increase in the output gap. However, inflation is slightly smaller than under the fiscally-led policy mix because the faster output growth ends up ameliorating the fiscal imbalance.

5 No Policy Uncertainty

In the previous section, we used a counterfactual simulation to isolate the role of policy uncertainty in accounting for the absence of deflation. In such an exercise, since it is a counterfactual simulation, all shocks and non-policy parameters of the model are kept fixed. In this section, we go one step further and formally compare the benchmark model with an estimated nested model that does not feature policy uncertainty about the way debt will be stabilized. Given that both models are now estimated, we can conduct a formal assessment of the role played by the fiscal block in explaining the joint dynamics of GDP and inflation as well as inflation expectations at the ZLB.

The nested model is similar to the traditional New Keynesian model used by

Benchmark Model					
Variable	*Median*	5%	95%	16%	84%
GDP growth	0.2997	0.2324	0.4172	0.2552	0.3595
Inflation	0.0638	0.0312	0.1897	0.0351	0.1338
Model without Fiscal Block					
Variable	*Median*	5%	95%	16%	84%
GDP growth	0.4134	0.3607	0.4723	0.3807	0.4485
Inflation	0.1042	0.0331	0.3075	0.0461	0.2066

Table 3: Mean squared distance between the actual data and the path implied by the discrete preference shock. The top panel refers to the benchmark model, and the lower panel refers to a nested New Keynesain model that excludes the fiscal block. The period considered is 2008:Q4-2014:Q1.

Clarida et al. (2000) and Lubik and Schorfheide (2004) and it does not feature any uncertainty about the way debt will be financed. We still allow for the possibility of changes in policymakers' behavior, but now such changes only concern the behavior of the monetary authority. As observables, we use four of the seven series used to estimate the benchmark model: GDP growth, inflation, federal funds rate, and government expenditure.[13] Figure 9 reports the impulse responses to the discrete negative preference shock based on this alternative model. The figure is analogous to Figure 5 shown above for the benchmark model. To ease the comparison, the shaded areas report the bands for the benchmark model. As before, we use the actual data until 2008:Q3 and we then have the discrete shock occurring in 2008:Q4. Unlike the benchmark model, the model without the fiscal block is not able to account for the joint dynamics of inflation and output growth as a result of the single discrete preference shock. The model is able to track relatively well the behavior of inflation, even if inflation is often outside the 90% error bands. On the other hand, it clearly misses the magnitude of the contraction in growth.

To formalize this visual impression, Table 3 reports the mean squared distance between the actual data and the path in response to the discrete demand shock implied by the two models. The benchmark model delivers better results both for inflation and output growth. However, in line with what could already

[13]Including the remaining fiscal series would be irrelevant for the dynamics of the macroeconomy because Ricardian equivalence applies when assuming that fiscal policy is always passive. Details about the model and the parameter estimates can be found in Appendix E.

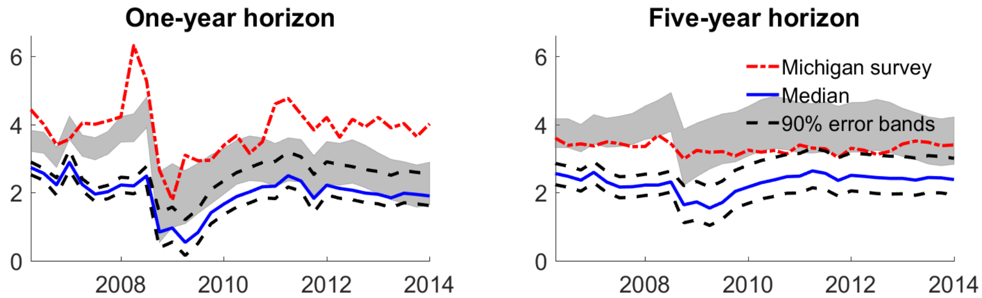

Figure 10: **Inflation expectations for a model without the fiscal block.** The figure reports the evolution of the one-year-ahead and five-year-ahead inflation expectations implied by a model that excludes the fiscal block. The red dashed lines correspond to the Michigan surveys inflation expectations. The shaded areas report the 90% error bands for the benchmark model.

be inferred by the picture, the gains are particularly large for output growth. Not only is the median of the mean squared distance significantly smaller, but also the 68% bands do not overlap. As shown in Appendix E, the model without the fiscal block uses the discrete shock to fit inflation dynamics, leaving the behavior of output to be explained by a contemporaneous TFP shock. Therefore, when excluding the fiscal block we obtain the standard result of the literature: A combination of shocks is necessary in order to explain the joint dynamics of inflation and output following the recent recession.

As further evidence in favor of the mechanism proposed in this paper, Figure 10 reports the evolution of inflation expectations implied by the model without the fiscal block. Once again, we use shaded areas to denote the 90% error bands for the benchmark model. Even in this case, we find that the alternative model performs worse than the benchmark model. The model without a fiscal block tends to constantly underestimate inflation expectations, which lie outside the 90% error bands most of the time. This is true for both the one-year-ahead and the five-year-ahead expectations. Furthermore, the alternative model does worse both before and after the economy entered the ZLB.

Table 4 formally compares the two models with respect to their ability to replicate the dynamics of inflation expectations. For each model, we compute the mean squared distance between the model-implied inflation expectations and the actual inflation expectations. It is important to check that the im-

Benchmark Model

Variable	$Median$	5%	95%	16%	84%
Whole sample: 1-year	0.0569	0.0374	0.0857	0.0440	0.0733
Whole sample: 5-year	0.0451	0.0345	0.0641	0.0378	0.0557
Pre-ZLB: 1-year	0.0424	0.0317	0.0615	0.0349	0.0529
Pre-ZLB: 5-year	0.0493	0.0383	0.0734	0.0415	0.0625
Post-ZLB: 1-year	0.1001	0.0368	0.2067	0.0551	0.1595
Post-ZLB: 5-year	0.0181	0.0037	0.0958	0.0066	0.0532

Model without Fiscal Block

Variable	$Median$	5%	95%	16%	84%
Whole sample: 1-year	0.1675	0.1399	0.1955	0.1510	0.1840
Whole sample: 5-year	0.1563	0.1106	0.2141	0.1307	0.1894
Pre-ZLB: 1-year	0.1496	0.1241	0.1880	0.1349	0.1696
Pre-ZLB: 5-year	0.1836	0.1281	0.2557	0.1510	0.2229
Post-ZLB: 1-year	0.2309	0.1005	0.3008	0.1577	0.2778
Post-ZLB: 5-year	0.0656	0.0139	0.1369	0.0298	0.1058

Table 4: Mean squared distance between model-implied and actual inflation expectations for the 1-year and 5-year horizons. The top panel refers to the benchmark model, and the lower panel refers to a nested New Keynesain model that excludes the fiscal block. We report results for the whole sample for which expectations are available (1978:Q1-2014:Q1), for the subsample before the economy entered the zero lower bound (1978:Q1-2008:Q3), and for the subsample after the economy entered the zero lower bound (1978:Q4-2014:Q4).

provement in the ability to match the behavior of inflation expectations does not occur only at the ZLB, because this could be just a lucky coincidence. We therefore take the mean squared distance over the whole sample for which inflation expectations are available (1978:Q1-2014:Q1) and for two subsamples: before and after entering the ZLB. The benchmark model performs better than the alternative model over all subsamples and for both horizons.

6 Policy Trade-off

In this section, we are interested in assessing why policy uncertainty is likely to increase once the economy enters the ZLB. We will show that while the monetary-led regime leads to a more stable macroeconomic environment during regular times, a policy trade-off characterizes the ZLB: mitigating a large recession or preserving long-run macroeconomic stability. Policy uncertainty rises when policymakers do not offer a clear resolution of this policy trade-off.

Let us revisit the effects of the large negative preference shock $\overline{d}_l$ under three different scenarios concerning policymakers' behavior. In the first scenario, we consider the benchmark model in which no announcement is made. In the second and third scenarios policymakers make credible announcements about the exit strategy. Specifically, in the second scenario, policymakers announce that fiscal discipline will be abandoned and that the economy will move to the fiscally-led regime. In the third scenario, policymakers announce that once the economy is out of the zero-lower-bound period, fiscal discipline will be restored, implying that the economy will move back to the monetary-led regime.[14]

Figure 11 reports the results. If policymakers announce that fiscal discipline will be abandoned (dashed line), agents expect that the rising stock of debt will be inflated away. Therefore, they revise upward their inflation expectations and, consequently, inflation increases today through the expectation channel. Notice that the recession is in this case substantially mitigated and the economy is effectively avoiding the ZLB. If instead policymakers explicitly announce fiscal discipline, the economy enters a recession and deflation arises (dashed-dotted line). Compared to the case in which no announcement is made (solid line), announcing fiscal discipline worsens the recession and brings about a larger drop in prices. This is because this announcement lowers the probability that the growing stock of debt will be inflated away, which raises the real interest rate and consequently leads to a recession deeper than the one we actually observed. The outcomes for this case are qualitatively in line with the traditional view about the ZLB. However, the drops in real activity and inflation are substantially mitigated compared to the counterfactual economy presented in Subsection 4.2, in which the monetary-led policy mix is the only possible regime. The reason is that when policymakers announce fiscal discipline, rational agents understand that a switch to the fiscally-led regime can still occur in the more distant future.

Figure 12 illustrates the evolution of uncertainty for the three scenarios presented above. We consider three horizons: 1 quarter, 1 year, and 2 years. Uncertainty is computed taking into account the possibility of regime changes and future Gaussian shocks (Bianchi 2016). For a variable X_t and a horizon q,

[14] Appendix B.3 presents the transition matrix for the economy with announcements.

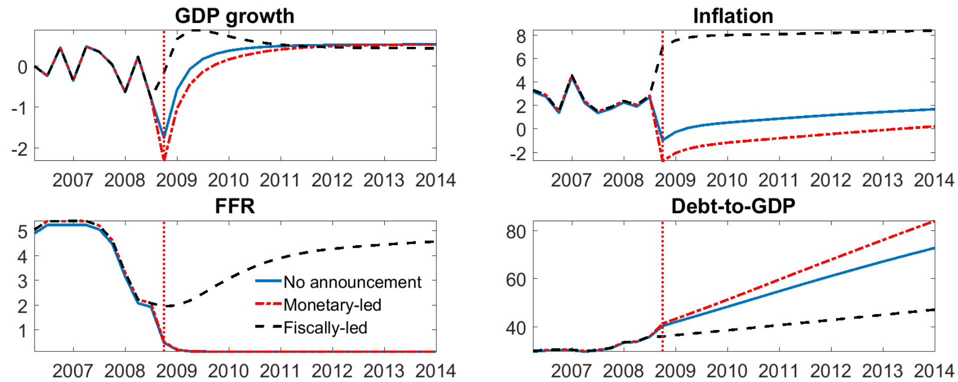

Figure 11: **Effects of policy announcements following the discrete negative preference shock.** Three cases are considered. The first case corresponds to the benchmark model with no announcement; in the second case, policymakers announce a return to the monetary-led regime; in the third case, a switch to the fiscally-led regime is announced.

it corresponds to the conditional standard deviation $sd_t\left(X_{t+q}\right)$. At the ZLB, uncertainty is higher than in the pre-crisis period because of the uncertainty about the end of the recession and the lack of a systematic monetary policy response to shocks hitting the macroeconomy. When policymakers announce the fiscally-led regime as the exit strategy, the economy avoids hitting the ZLB and consequently macroeconomic uncertainty remains very close to the pre-crisis levels. Hence, promising to follow the fiscally-led policy mix has the effects of mitigating the recession and of lowering macroeconomic uncertainty in the short run.

Longstaff et al. (2013), following Kitsul and Wright (2013), extract the objective distribution of inflation from the market prices of inflation swaps and options by using data at daily frequency. They find substantial swings between fears of inflation and fears of deflation. Such a large level of uncertainty about inflation is consistent with our findings. We regard the study of the link between policy uncertainty and macroeconomic uncertainty in the context of asset pricing as an interesting and promising venue for future research.

The measure of uncertainty reported here reflects the level of uncertainty faced by the agent in the model, taking into account the possibility of regime changes, along the simulations presented above. Therefore, they cannot be immediately compared with measures of uncertainty based on reduced-form sta-

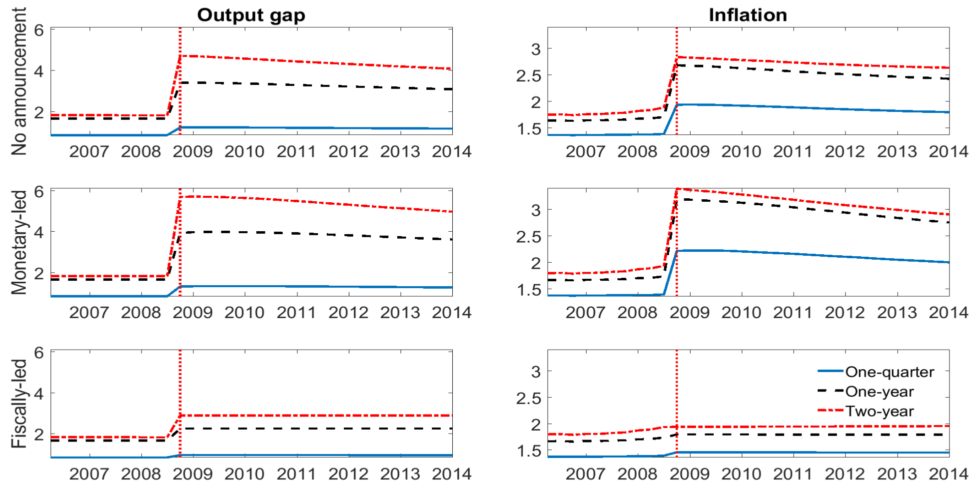

Figure 12: **Evolution of uncertainty under policy announcements.** The graphs report the evolution of uncertainty at different horizons following an adverse discrete preference shock and different announcements about policymakers' future behavior.

tistical models such as the ones presented by Jurado et al. (2015). If we were to estimate a reduced-form model with time-varying parameters and heteroskedasticity on the economy simulated above, we would find that uncertainty spikes when the economy enters the ZLB. Nevertheless, uncertainty would stay low while the economy remains at the ZLB because no large changes in real activity or inflation occur.[15] Such a measure of uncertainty would be in line with the evidence presented in Jurado et al. (2015). Therefore, our results should be interpreted as showing that the ZLB implies an increase in uncertainty for a given level of volatility of the exogenous shocks.

While moving to the fiscally-led regime would largely mitigate the recession and reduce uncertainty in the short run, it would also imply an increase in macroeconomic uncertainty in the long run. Figure 13 reports the evolution of uncertainty at different horizons, from 1 quarter to 10 years, when the monetary-led and the fiscally-led regime are in place. When policymakers follow the monetary-led policy mix, agents anticipate that with high probability future fiscal imbalances will be neutralized through the actions of the fiscal authority. This leads to a reduction in macroeconomic uncertainty. At the same time,

[15]See Justiniano and Primiceri (2008), Bianchi (2013), Fernandez-Villaverde et al. (2010), and Bianchi and Ilut (2015) for examples of DSGE models that allow for heteroskedasticity.

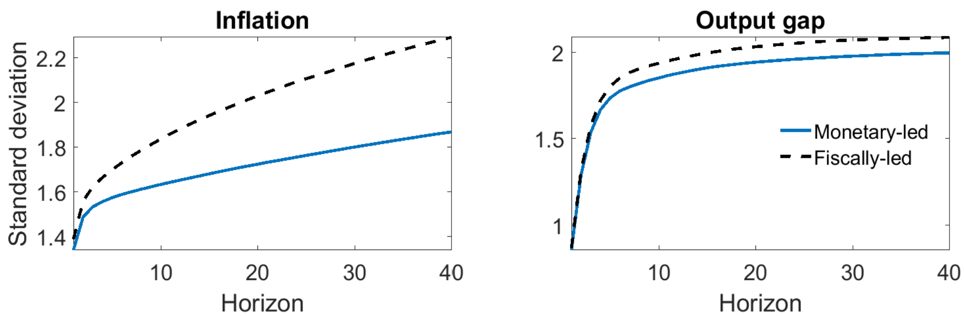

Figure 13: **Evolution of uncertainty when out of the zero lower bound.** Evolution of uncertainty at different horizons conditional on being in a specific regime today, taking into account the possibility of future regime changes.

the central bank responds strongly to inflation, leading to a further reduction in volatility. If instead policymakers follow the fiscally-led regime, uncertainty increases at all horizons. This is because the central bank reacts less aggressively to economic fluctuations and agents anticipate that all fiscal imbalances will now strongly affect inflation and real economic activity.

Mitigating a large recession by pledging to abandon fiscal discipline and the rise in uncertainty as the economy exits the ZLB are two sides of the same coin. The announcement effectively softens the recession if and only if it is able to convince agents that the fiscally-led policy mix will prevail for a long time. Only under these circumstances do agents expect that debt will be inflated away. If the fiscally-led regime had low persistence, the announcement would fail to mitigate the recession because inflation would not rise. In fact, agents would simply expect a change in the timing of fiscal adjustments. The existence of this trade-off between short-run benefits and long-run costs provides an explanation for the ample spectrum of opinions about the best path of action at the zero lower bound and the consequent increase in policy uncertainty.

7 Conclusions

The US is arguably facing uncertainty about the way policymakers will handle the large stock of debt that was accumulated during the Great Recession. Part of the debt is expected to be absorbed by higher growth once the economy fully recovers. However, it is quite unlikely that this factor alone will be enough to correct the dynamics of US sovereign debt in the absence of substantial fiscal adjustments. A large stock of debt, combined with no clear plan for fiscal stabilization, is likely to create uncertainty about the future policy course because the monetary authority cannot control inflation without the necessary fiscal backing (Sims 2010a). We have shown that this type of policy uncertainty can explain why the US economy has not experienced deflation despite the several years spent at the zero lower bound.

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Online Appendix

A Markov-switching VAR

In this appendix, we describe the MS-VAR used in Section 2.

A.1 Model setup

The variables of interest are assumed to evolve according to a Markov-switching VAR with two lags:

$$Z_t = c_{\xi_t^\Phi} + A_{\xi_t^\Phi,1} Z_{t-1} + A_{\xi_t^\Phi,2} Z_{t-2} + \Sigma_{\xi_t^\Sigma}^{1/2} \omega_t \tag{8}$$

$$\Phi_{\xi_t^\Phi} = \left[c_{\xi_t^\Phi}, A_{\xi_t^\Phi,1}, A_{\xi_t^\Phi,2} \right], \ \omega_t \sim N(0, I) \tag{9}$$

where Z_t is a $(n \times 1)$ vector of data. The unobserved states ξ_t^Σ and ξ_t^Φ can take on a finite number of values, $j^\Phi = 1, \ldots, m^\Phi$ and $j^\Sigma = 1, \ldots, m^\Sigma$, and follow two independent Markov chains. This represents a convenient way to model heteroskedasticity and to allow for the possibility of changes in the dynamics of the state variables. The probability of moving from one state to another is given by $P[\xi_t^\Phi = i | \xi_{t-1}^\Phi = j] = h_{ij}^\Phi$ and $P[\xi_t^\Sigma = i | \xi_{t-1}^\Sigma = j] = h_{ij}^\Sigma$. Given $H^\Phi = [h_{ij}^\Phi]$ and $H^\Sigma = [h_{ij}^\Sigma]$ and a prior distribution for the initial state, we can compute the likelihood of the parameters of the model, conditional on the initial observation Z_0. We impose flat priors on all parameters of the models, implying that the posterior coincides with the likelihood.

A.2 Likelihood and regime probabilities

Define the combined regime $\xi_t \equiv \left(\xi_t^\Phi, \xi_t^\Sigma\right)$, the associated transition matrix $H \equiv H^\Phi \otimes H^\Sigma$, and vector $\theta_{\xi_t} \equiv \left(\Phi_{\xi_t^\Phi}, \Sigma_{\xi_t^\Sigma}\right)$ with the corresponding set of parameters. For each draw of the parameters θ_{ξ_t} and H, we can then compute the filtered probabilities $\pi_{t|t}$, or smoothed probabilities $\pi_{t|T}$, of the regimes conditional on the model parameters. The filtered probabilities reflect the probability of a regime conditional on the data up to time t, $\pi_{t|t} = p(\xi_t | Y^t; H, \theta_{\xi_t})$, for $t =$

$1, ..., T$, and are part of the output obtained computing the likelihood function associated with the parameter draw H, θ_{ξ_t}. The filtered probabilities can be obtained using the following recursive algorithm:

$$\pi_{t|t} = \frac{\pi_{t|t-1} \odot \eta_t}{\mathbf{1}' \left(\pi_{t|t-1} \odot \eta_t\right)} \tag{10}$$

$$\pi_{t+1|t} = H\pi_{t|t} \tag{11}$$

$$p(Z_t|Z^{t-1}) = \mathbf{1}' \left(\pi_{t|t-1} \odot \eta_t\right) \tag{12}$$

where η_t is a vector whose jth element contains the conditional density $p(Z_t|\xi_t = i, Z^{t-1}; H, \theta_{\xi_t})$, the symbol $\odot$ denotes element by element multiplication, and $\mathbf{1}$ is a vector with all elements equal to 1. To initialize the recursive calculation, we need an assumption on the distribution of ξ_0. We assume that the nine regimes have equal probabilities $p(\xi_0 = i) = 1/9$ for $i = 1...m$. The likelihood for the entire data sequence Z^T is obtained multiplying the one-step-ahead conditional likelihoods $p(Z_t|Z^{t-1})$:

$$p\left(Z^T|\theta\right) = \prod_{t=1}^{T} p\left(Z_t|Z^{t-1}\right)$$

The smoothed probabilities reflect all the information that can be extracted from the whole data sample, $\pi_{t|T} = p(\xi_t|Z^T; H, \theta_{\xi_t})$. The final term $\pi_{T|T}$ is returned with the final step of the filtering algorithm. Then a recursive algorithm can be implemented to derive the other probabilities:

$$\pi_{t|T} = \pi_{t|t} \odot \left[H' \left(\pi_{t+1|T} \left(\div\right) \pi_{t+1|t}\right)\right]$$

where $(\div)$ denotes element by element division.

Finally, it is possible to obtain the filtered and smoothed probabilities for each of the two independent chains by integrating out the other chain. For example, if we are interested in $\pi^{\Phi}_{t|t} = p(\xi^{\Phi}_t|Y^t; H, \theta_{\xi_t})$ we have:

$$\pi^{\Phi,i}_{t|t} = p(\xi^{\Phi}_t = i|Y^t; H, \theta_{\xi_t}) = \sum_{j=1}^{m} p(\xi_t = \{i, j\}|Y^t; H, \theta_{\xi_t})$$

Similarly, the smoothed probabilities are obtained as:

$$\pi_{t|T}^{\Phi,i} = p(\xi_t^{\Phi} = i|Y^T; H, \theta_{\xi_t}) = \sum_{j=1}^{m} p(\xi_t = \{i,j\}|Y^T; H, \theta_{\xi_t}).$$

A.3 Posterior Mode and Gibbs sampling algorithm

We first find the posterior mode by using a minimization algorithm on the negative of the posterior. Given that we have flat priors, our point estimates coincide with the maximum likelihood estimates. Once we have found the posterior mode, we compute the most likely regime sequence and then proceed to characterize uncertainty around the parameter values conditional on this regime sequence by using a Gibbs sampling algorithm. Alternatively, we could have imposed some identifying restrictions based on the properties of the regimes at the posterior mode, but we preferred to take this more agnostic approach. This makes the interpretation of the results more immediate because the properties of the regimes can be immediately associated with the periods during which they were in place.

Both the VAR coefficients and the covariance matrix can switch and the regimes are assumed to be independent. Draws for the parameters of the model can be made following the following Gibbs sampling algorithm:

1. Sampling $\Sigma_{\xi_t^{\Sigma}}$ given $\Phi_{\xi_t^{\Phi}}, \xi_t^{\Phi}, \xi_t^{\Sigma}$: Given $\Phi_{\xi_t^{\Phi}}$ and $\xi^{\Phi,T}$, we can compute the residuals of the MS-VAR at each point in time. Then, given ξ_t^{Σ}, we can group all the residuals that pertain to a particular regime. Therefore, $\Sigma_{\xi_t^{\Sigma}}$ can be drawn from an inverse Wishart distribution for $\xi_t^{\Sigma} = 1...m^{\Sigma}$.

2. Sampling $\Phi_{\xi_t^{\Phi}}$ given $\Sigma_{\xi_t^{\Sigma}}, \xi_t^{\Phi}, \xi_t^{\Sigma}$: When drawing the VAR coefficients, we need to take into account the heteroskedasticity implied by the switches in $\Sigma_{\xi_t^{\Sigma}}$. This can be done following the following steps for each $i = 1...m^{\Phi}$:

   (a) Based on $\xi^{\Phi,T}$, collect all the observation such that $\xi_t^{\Phi} = i$.

   (b) Divide the data that refer to $\xi_t^{\Sigma} = j$ based on $\xi^{\Sigma,T}$. We now have a series of subsamples for which VAR coefficients and covariance matrices are fixed: $\left(\xi_t^{\Phi} = i,\ \xi_t^{\Sigma} = 1\right), ..., \left(\xi_t^{\Phi} = i,\ \xi_t^{\Sigma} = m^{\Sigma}\right)$. Denote these subsamples with $\left(y_{i,\xi_t^\Sigma},\ x_{i,\xi_t^\Sigma}\right)$, where the y_{i,ξ_t^Σ} and x_{i,ξ_t^Σ} denote left-hand-side and right-hand-side variables in the MS-VAR. Notice that some of these subsamples might be empty.

(c) Apply recursively the formulas for the posterior of VAR coefficients conditional on a known covariance matrix. Therefore, for $j = 1...m^\Sigma$ the following formulas need to be applied recursively:

$$\begin{aligned} P_T^{-1} &= P_L^{-1} + \Sigma_{\xi_t^\Sigma}^{-1} \otimes (x'_{i,\xi_t^\Sigma} x_{i,\xi_t^\Sigma}) \\ B_T &= B_L + (\Sigma_{\xi_t^\Sigma}^{-1} \otimes x'_{i,\xi_t^\Sigma}) vec(y_{i,\xi_t^\Sigma}) \\ P_L^{-1} &= P_T^{-1}, B_L = B_T \end{aligned}$$

where the algorithm is initialized using the priors for the VAR coefficients $B_L = B_0$ and $P_L^{-1} = P_0^{-1} = \left(S_0 \otimes N_0^{-1}\right)^{-1}$. Notice that this implies that if there are not any observations for a particular regime, then the posterior will coincide with the priors. With proper priors, this is not a problem.

(d) Make a draw for the VAR coefficients $vec\left(\Phi_{\xi_t^\Phi}\right) \sim N\left(P_T B_T, P_T\right)$ with $\xi_t^\Phi = i$.

3. Sampling H^Φ and H^Σ: Given the draws for the state variables $\xi^{\Phi,T}$ and $\xi^{\Sigma,T}$, the transition probabilities are independent of Y_t and the other parameters of the model and have a Dirichlet distribution. For each column of H^Φ and H^Σ, the posterior distribution is given by:

$$H^s(:,i) \sim D(a_{ii}^s + \eta_{ii}^s, a_{ij}^s + \eta_{ij}^s),\ \ s = \Phi, \Sigma$$

where η_{ij}^Φ and η_{ij}^Σ denote respectively the numbers of transitions from state i^Φ to state j^Φ and from state i^Σ to state j^Σ.

A.4 Data

We use four observables to estimate the Markov-switching VAR: (i) inflation; (ii) real GDP growth; (iii) federal funds rate; (iv) deficit-to-debt ratio. Inflation and

$\xi_t^{\Sigma}=1$	u_{ER}	u_{TY}	u_{PE}	u_{VS}
u_{ER}	1.2377 (1.1183,1.3693)			
u_{TY}	−0.2235 (−0.3623,−0.0824)	0.7015 (0.6319,0.7784)		
u_{PE}	0.0378 (−0.1003,0.1817)	−0.1778 (−0.3119,−0.0366)	0.2516 (0.2278,0.2788)	
u_{VS}	−0.4275 (−0.5414,−0.3041)	0.1983 (0.0452,0.3362)	0.2672 (0.1323,0.3996)	0.2688 (0.2425,0.2981)
$\xi_t^{\Sigma}=2$	u_{ER}	u_{TY}	u_{PE}	u_{VS}
u_{ER}	3.7397 (3.2247,4.3585,)			
u_{TY}	−0.2054 (−0.4038,0.0044)	1.3657 (1.1625,1.6117)		
u_{PE}	−0.2112 (−0.4120,0.0055)	−0.1114 (−0.3284,0.1069)	0.0369 (0.2753,0.3726)	
u_{VS}	−0.2157 (−0.4057,−0.0112)	0.1558 (−0.0649,0.3668)	0.1837 (−0.0400,0.3989)	0.0279 (0.6139,0.8324)
$\xi_t^{\Sigma}=3$	u_{ER}	u_{TY}	u_{PE}	u_{VS}
u_{ER}	4.4369 (3.1092,6.3281)			
u_{TY}	−0.4984 (−0.8002,−0.0732)	1.9303 (1.3216,2.7927)		
u_{PE}	−0.3404 (−0.7160,0.1282)	0.2079 (−0.3043,0.6676)	0.6111 (0.3993,0.9047)	
u_{VS}	−0.9854 (−0.9966,−0.9646)	0.5879 (0.216,0.8439)	0.241 (−0.2430,0.6507)	3.4718 (2.4454,4.9064)

Table 5: Parameter estimates for the covariance matrix. The three sets of tables contain means and 90% error bands for the posterior distribution of the parameters of the covariance matrices. The standard deviations of the shocks are on the main diagonal, whereas the correlations of the shocks are below the main diagonal.

real output growth are defined as year-to-year first differences of the logarithm of the GDP price deflator and real GDP, respectively. Inflation, real GDP, and the federal funds rate are taken from the FRED II database of the Federal Reserve Bank of St. Louis. The primary deficit is constructed from the NIPA tables (Table 3.2. Federal Government Current Receipts and Expenditures) as detailed in Appendix C. As a measure of the fiscal stance, we consider the variable deficits over debt. The government debt series is the market value of the US government debt available on the Dallas Fed website. The sample period ranges from 1954:Q4-2014:Q1.

A.5 Volatility regimes

Table 5 reports the estimates of the covariance matrix across different volatility regimes.

B Benchmark Model

In what follows, we provide the details for the solution and estimation of the model.

B.1 System of equations

1. Linearized Euler equation:

$$\begin{aligned}\left(1+\Phi M_a^{-1}\right)\widehat{y}_t &= -\left(1-\Phi M_a^{-1}\right)\left[\widehat{R}_t - E_t\widetilde{\pi}_{t+1} - (1-\rho_d)\, d_t - \overline{d}_{\xi_t^d} + E_{\xi_t^d}\overline{d}_{\xi_{t+1}^d}\right] \\ &\quad -\left(\Phi M_a^{-1} - \rho_a\right) a_t + E_t\widehat{y}_{t+1} + \left(1-\rho_g + M_a^{-1}\Phi\right)\widetilde{g}_t \\ &\quad + M_a^{-1}\Phi\left(\widehat{y}_{t-1} - \widetilde{g}_{t-1}\right)\end{aligned}$$

where $M_a = \exp(\gamma)$ and $\overline{d}_{\xi_t^d}$ follows a Markov-switching process governed by the transition matrix H^d. Please refer to the next subsection for details about how to handle the discrete shock.

2. New Keynesian Phillips curve:

$$\begin{aligned}\widetilde{\pi}_t &= \kappa\left(\begin{array}{c}\left[\frac{1}{1-\Phi M_A^{-1}} + \frac{\alpha}{1-\alpha}\right]\widehat{y}_t - \frac{1}{1-\Phi M_A^{-1}}\widetilde{g}_t \\ -\frac{\Phi M_A^{-1}}{1-\Phi M_A^{-1}}\left(\widehat{y}_{t-1} - \widetilde{g}_{t-1} - a_t\right)\end{array}\right) \\ &\quad + \beta E_t\left[\widetilde{\pi}_{t+1}\right] + \widetilde{\mu}_t\end{aligned}$$

where we have used the rescaled markup $\widetilde{\mu}_t = \kappa\left(\frac{v}{1-v}\right)\widetilde{v}_t$

3. No arbitrage condition

$$\widetilde{R}_t = E_t\left[\widetilde{R}^m_{t,t+1}\right]$$

4. Return long term bond

$$\widetilde{R}^m_{t-1,t} = R^{-1}\rho\widetilde{P}^m_t - \widetilde{P}^m_{t-1}$$

5. Government budget constraint:

$$\begin{aligned}\widetilde{b}^m_t &= \beta^{-1}\widetilde{b}^m_{t-1} + b^m\beta^{-1}\left(\widehat{R}^m_{t-1,t} - \widehat{y}_t + \widehat{y}_{t-1} - a_t - \widetilde{\pi}_t\right)\\ &\quad -\widetilde{\tau}_t + \widetilde{tr}_t + g^{-1}\widetilde{g}_t + \widetilde{tp}_t\end{aligned}$$

6. Monetary policy rule

$$\begin{aligned}\widetilde{R}_t &= \left[1 - Z_{\xi^d_t}\right]\left[\rho_{R,\xi^p_t}\widetilde{R}_{t-1} + (1-\rho_R)\left(\psi_{\pi,\xi^p_t}\widetilde{\pi}_t + \psi_{y,\xi^p_t}\left[\widehat{y}_t - \widehat{y}^*_t\right]\right) + \sigma_R\epsilon_{R,t}\right]\\ &\quad + Z_{\xi^d_t}\left[\rho_{R,Z}\widetilde{R}_{t-1} - \left(1-\rho_{R,Z}\right)\psi_Z\log(R) + \sigma_Z\epsilon_{R,t}\right]\end{aligned}$$

7. Fiscal rule

$$\widetilde{\tau}_t = \rho_{\tau,\xi^p_t}\widetilde{\tau}_{t-1} + \left(1-\rho_{\tau,\xi^p_t}\right)\left[\delta_{b,\xi^p_t}\widetilde{b}^m_{t-1} + \delta_e\left(\widetilde{tr}^*_t + g^{-1}\widetilde{g}_t\right) + \delta_y\left(\widehat{y}_t - \widehat{y}^*_t\right)\right] + \sigma_\tau\epsilon_{\tau,t}$$

8. Transfers

$$\left(\widetilde{tr}_t - \widetilde{tr}^*_t\right) = \rho_{tr}\left(\widetilde{tr}_{t-1} - \widetilde{tr}^*_t\right) + (1-\rho_{tr})\phi_y\left(\widehat{y}_t - \widehat{y}^*_t\right) + \sigma_{tr}\epsilon_{tr,t},\ \ \epsilon_{tr,t} \sim N(0,1)$$

9. Long term component of transfers

$$\widetilde{tr}^*_t = \rho_{tr^*}\widetilde{tr}^*_{t-1} + \sigma_{tr^*}\epsilon_{tr^*,t}, \epsilon_{tr^*,t} \sim N(0,1)$$

10. Government purchases ($\widetilde{g}_t = \ln(g_t/g)$):

$$\widetilde{g}_t = \rho_g\widetilde{g}_{t-1} + \sigma_g\epsilon_{g,t},\ \ \epsilon_{g,t} \sim N(0,1).$$

11. TFP growth

$$a_t = \rho_a a_{t-1} + \sigma_a\varepsilon_{a,t}$$

12. Term premium

$$tp_t = \rho_{tp} tp_{t-1} + \sigma_{tp} \varepsilon_{tp,t}$$

13. The rescaled markup $\mu_t = \kappa \log(\aleph_t / \aleph)$, where $\aleph_t = 1/(1-\upsilon_t)$, follows an autoregressive process,

$$\mu_t = \rho_\mu \mu_{t-1} + \sigma_\mu \epsilon_{\mu,t}$$

14. Output target

$$\left[\frac{1}{1-\Phi M_a^{-1}} + \frac{\alpha}{1-\alpha}\right] \widehat{y}_t^* = \frac{1}{1-\Phi M_a^{-1}} \widetilde{g}_t + \frac{\Phi M_a^{-1}}{1-\Phi M_a^{-1}} \left(\widehat{y}_{t-1}^* - \widetilde{g}_{t-1} - a_t\right)$$

B.2 Model solution

As explained in the main text, the Markov-switching process for the discrete preference shock $\overline{d}_{\xi_t^d}$ is defined in a way that its steady state is equal to zero. In order to solve the model we implement the following steps:

1. Introduce a dummy variable $e_{\xi_t^d}$ controlling the regime that is in place for the discrete preference shock. Augment the DSGE state vector with this dummy variable.

2. Use the aforementioned dummy variable to rewrite all the equations linked to the discrete preference shock. These are the linearized Euler equation and the linearized Taylor rule.

3. Solve the model using Farmer et al. (2009). This returns a MS-VAR:

$$\widetilde{S}_t = \widetilde{T}(\xi_t, H, \theta) \widetilde{S}_{t-1} + \widetilde{R}(\xi_t, H, \theta) Q \varepsilon_t$$

in the augmented state vector $\widetilde{S}_t$.

4. Extract the column corresponding to the dummy variable $e_{\xi_t^d}$ from the matrix $\widetilde{T}$ and redefine the matrices and the DSGE state vector accordingly.

This will return a MS-VAR with a MS constant:

$$S_t = c(\xi_t, H, \theta) + T(\xi_t, H, \theta) S_{t-1} + R(\xi_t, H, \theta) Q\varepsilon_t$$

where Q is a diagonal matrix that contains the standard deviations of the structural shocks and S_t is a vector with all variables of the model.

Unlike other papers that have used the technique described here, our model allows for non-orthogonality between policymakers' behavior and a discrete shock. This allows us to solve a model in which agents take into account that a large preference shock leads to an immediate change in policy, the zero lower bound, and, potentially, to further changes. This proposed method is general and can be applied to other cases in which a shock induces a change in the structural parameters.

B.3 Matrices used in the counterfactual simulations

We here describe the matrices used in the simulations reported in the paper.

B.3.1 Textbook New Keynesian model: Always monetary-led

In the first counterfactual simulation, policymakers always follow the monetary-led regime when out of the zero lower bound. Furthermore, there is only one zero-lower-bound regime from which agents expect to return to the monetary-led regime. Therefore, the transition matrix used to solve this counterfactual economy is given by:

$$H^p = 1, \; H^d = \begin{bmatrix} p_{hh} & 1 - p_{ll} \\ 1 - p_{hh} & p_{ll} \end{bmatrix}, \; H = H^d.$$

where p_{hh} and p_{ll} are the estimated parameter values.

B.3.2 Announcements

In the counterfactual economy with announcements, at the zero lower bound we distinguish two cases, based on the exit strategy:

1. Policymakers announce that they will move to the monetary-led regime once the economy out of the zero lower bound.

2. Policymakers announce that they will *immediately* move to the fiscally-led regime.

We assume that the probability of the first scenario is equal to the estimated probability of switching to the monetary-led regime in the benchmark model. In other words, the first scenario is more likely than the second scenario and it has a probability equal to p_{ZM}. Furthermore, their probabilities do not depend on the regime that was in place when the negative preference shock occurred. We then have a total of four regimes $\xi_t = \{[M,h],[F,h],[Z,l],[F,l]\}$ and the corresponding transition matrix is given by:

$$H = \begin{bmatrix} p_{hh}H^p & (1-p_{ll})\,H^o \\ (1-p_{hh})\,H^i & p_{ll}H^z \end{bmatrix}$$

$$H^p = \begin{bmatrix} p_{MM} & 1-p_{FF} \\ 1-p_{MM} & p_{FF} \end{bmatrix},\ H^o = \begin{bmatrix} 1 & \\ & 1 \end{bmatrix},$$

$$H^i = \begin{bmatrix} p_{ZM} & p_{ZM} \\ 1-p_{ZM} & 1-p_{ZM} \end{bmatrix},\ H^z = \begin{bmatrix} 1 & \\ & 1 \end{bmatrix},$$

$$H^d = \begin{bmatrix} p_{hh} & 1-p_{ll} \\ 1-p_{hh} & p_{ll} \end{bmatrix}.$$

C Estimation of the DSGE model

This appendix describes the dataset and provides details for the benchmark model.

C.1 Dataset

Real GDP, the GDP deflator, and the series for fiscal variables are obtained from the Bureau of Economic Analysis. The fiscal series are built using NIPA Table 3.2. (Federal Government Current Receipts and Expenditures). Government purchases (G) are computed as the sum of consumption expenditure (L24), gross government investment (L44), net purchases of non-produced assets (L46), minus consumption of fixed capital (L47). Transfers are given by the sum of net current transfer payments (L25-L18), subsidies (L35), and net capital transfers (L45-L41). Tax revenues are given by the difference between current receipts (L40) and current transfer receipts (L18). All variables are then expressed as a fraction of GDP. Government purchases are transformed in a way to obtain the variable g_t defined in the model. The series for the federal funds rate is obtained averaging monthly figures downloaded from the St. Louis Fed web-site.

C.2 MCMC algorithm and convergence

Draws from the posterior are obtained using a standard Metropolis-Hastings algorithm initialized around the posterior mode. When working with models whose posterior distribution is very complicated in shape it is very important to find the posterior mode. In a MS-DSGE model, this search can turn out to be an extremely time-consuming task, but it is a necessary step to reduce the risk of the algorithm getting stuck in a local peak. Here are the key steps of the Metropolis-Hastings algorithm:

- Step 1: Draw a new set of parameters from the proposal distribution: $\vartheta \sim N\left(\theta_{n-1}, c\overline{\Sigma}\right)$
- Step 2: Compute $\alpha\left(\theta^m; \vartheta\right) = \min\left\{p\left(\vartheta\right)/p\left(\theta^{m-1}\right), 1\right\}$ where $p\left(\theta\right)$ is the posterior evaluated at θ.
- Step 3: Accept the new parameter and set $\theta^m = \vartheta$ if $u < \alpha\left(\theta^m; \vartheta\right)$ where $u \sim U\left([0,1]\right)$, otherwise set $\theta^m = \theta^{m-1}$
- Step 4: If $m \leq n^{sim}$, stop. Otherwise, go back to step 1

The matrix $\overline{\Sigma}$ corresponds to the inverse of the Hessian computed at the posterior mode $\overline{\theta}$. The parameter c is set to obtain an acceptance rate of around 35%. Table 6 reports results based on the Brooks-Gelman-Rubin potential reduction scale factor using within and between variances based on the five multiple chains used in the paper. The eight chains consist of $2,100,000$ draws each

Parameter	PSRF	Parameter	PSRF	Parameter	PSRF	Parameter	PSRF
$\psi_{\pi,M}$	1.01	ψ_Z	1	ρ_d	1	$100\sigma_R$	1
$\psi_{y,M}$	1.05	κ	1.15	ρ_{tp}	1	$100\sigma_g$	1
$\rho_{R,M}$	1.01	$\delta_{b,M}$	1	ρ_μ	1.01	$100\sigma_a$	1
$\rho_{\tau,M}$	1	ρ_{tr}	1.01	100π	1	$100\sigma_\tau$	1
$\psi_{\pi,F}$	1.06	δ_y	1.03	100γ	1	$100\sigma_d$	1.04
$\psi_{y,F}$	1.05	Φ	1.04	b^m	1.01	$100\sigma_{tr}$	1
$\rho_{R,F}$	1	δ_e	1.07	g	1	$100\sigma_{tp}$	1
$\rho_{\tau,F}$	1.02	ρ_g	1	τ	1.02	$100\sigma_\mu$	1
d_l	1.01	ρ_a	1.01	ϕ_y	1.01	p_{FF}	1.02
p_{hh}	1.09	p_{ll}	1.02	p_{MM}	1.01	p_{ZM}	1.01

Table 6: The table reports the Gelman-Rubin Potential Scale Reduction Factor (PSRF) for eight chains of 540,000 draws each (1 every 200 is stored). Values below 1.2 are regarded as indicative of convergence.

(1 every 3000 draws is saved). The numbers are well below the 1.2 benchmark value used as an upper bound for convergence.

C.3 Determining the time of the ZLB Regime

For tractability, we fix the sequence of Markov-switching regimes to estimate the model. To select the date at which the ZLB regime has started, we compute the posterior modes associated with a number of candidate dates. As shown in Table 7, the fourth quarter of 2008 (2008:Q4) attains the highest posterior mode and hence is selected as the date at which the ZLB regime has started (recall that all models only differ in terms of the starting date for the ZLB regime, so they present the same number of parameters).

D A Prototypical New Keynesian Model with a Fiscal Block

The objective of this appendix is to show that the results of Section 4.2 are robust when one considers models that has less bells and whistles and are more agnostic about the nature of shocks than the model we estimated in the pa-

Starting date of ZLB Regime	Likelihood	Posterior
2008:Q1	6,428.5	6,374.2
2008:Q2	6,370.0	6,376.0
2008:Q3	6,407.4	6,415.1
2008:Q4	**6,522.4**	**6,521.1**
2009:Q1	6,496.5	6,497.7
2009:Q2	6,490.0	6,487.9
2009:Q3	6,475.8	6,476.6

Table 7: The table shows the value of the posterior and the likelihood at the posterior mode as the starting date of the ZLB regime changes. The results associated with the highest posterior mode are in bold.

per. Let us a consider a prototypical New Keynesian DSGE model of the type studied in Eggertsson and Woodford (2003). This modeling framework is purposely very stylized and follows Eggertsson and Woodford (2003) in considering unanticipated shocks to the natural rate of interest as the cause of ZLB episodes.

The loglinearized equations of the model are as follows. All the variables henceforth are expressed in log-deviations from their steady-state values with the only exception of the debt-to-output ratio b_t, which is defined in deviation from its steady-state value. The IS equation reads:

$$x_t = E_t x_{t+1} - \sigma^{-1} \left(R_t - E_t \pi_{t+1} - r_t^n \right) \tag{13}$$

where x_t denotes the gap between the actual output and its flexible-price level (henceforth, the output gap), π_t denotes inflation, R_t denotes the nominal interest rate, and r_t^n stands for the natural rate of interest, which is the real interest rate that would be realized if prices were perfectly flexible.

The New Keynesian Phillips curve is

$$\pi_t = \kappa x_t + \beta E_t \pi_{t+1} \tag{14}$$

The monetary policy reaction function is:

$$R_t = \left[1 - Z_{\xi_t^d}\right] \left[\rho_R R_{t-1} + (1 - \rho_R) \left(\psi_{\pi,\xi_t^p} \pi_t + \psi_x x_t\right)\right] - Z_{\xi_t^d} \ln(R) \tag{15}$$

where R is the steady-state value of the nominal interest rate R_t. Note that the monetary authority follows the Taylor rule when $Z_{\xi_t^d} = 0$ or set its (net) nominal rate equal to its *zero lower bound* when $Z_{\xi_t^d} = 1$. It should be noted that $Z_{\xi_t^d}$ is a dummy variable assuming value 0 and 1 depending on the realization of an exogenous discrete Markov-switching process ξ_t^d. As we shall discuss below, this process determines the natural rate of interest r_t^n, implying that ZLB episodes are caused by unanticipated and recurrent, exogenously-driven falls in the natural rate of interest. Furthermore, when the economy is *out of the ZLB*, the value of the policy parameter ψ_{π,ξ_t^p}, which controls how strongly the central bank adjusts the nominal interest rate to inflation, are affected by the exogenous discrete Markov-switching process ξ_t^p.

The natural rate of interest is linked to the (exogenous) dynamics of the natural output though the IS equation under flexible prices:

$$r_t^n = \sigma\left(E_t \Delta y_{t+1}^n\right) \tag{16}$$

where Δy_t^n stands for the growth rate of natural output, whose value at any time is assumed to depend on the realization of a discrete Markov-switching process ξ_t^d.

The fiscal rule that determines the primary surplus τ_t

$$\tau_t = \delta_{b,\xi_t^p} b_{t-1} + \delta_x x_t \tag{17}$$

where b_t stands for the government debt-to-output ratio. Note that the response of the primary surplus to the last period's debt-to-output ratio is given by δ_{b,ξ_t^p} whose value depends on the realization of the Markov-switching process ξ_t^p that also determines the central bank's response to inflation in the Taylor rule. Hence, the process ξ_t^p captures the monetary-fiscal policy mix *out of the zero lower bound*

The government's budget constraint is driven by

$$b_t = \beta^{-1} b_{t-1} + b\beta^{-1}\left(R_{t-1} - \pi_t - \Delta x_t - \Delta y_t^n\right) - \tau_t \tag{18}$$

There are two exogenous Markov-switching processes: ξ_t^p and ξ_t^d. The former captures monetary and fiscal authority's response to their targets *out of the zero lower bound*. More specifically we assume that there are two monetary and fiscal policy mix: a monetary-led regime ($\xi_t^p = M$) and a Fiscally-led regime ($\xi_t^p = F$). Under the monetary-led regime the monetary authority responds strongly to inflation $\psi_{\pi,\xi_t^p} > 1$ and the fiscal authority promptly adjusts the primary surplus to changes in the debt-to-output ratio $\delta_{b,\xi_t^p} > \left(\beta^{-1} - 1\right)$.[16] Under the fiscally-led policy regime the monetary authority adjusts the nominal interest rate R_t less vigorously to inflation $\psi_{\pi,\xi_t^p} \leq 1$ and the fiscal authority pays less attention to the dynamics of its debt-to-output ratio $\delta_{b,\xi_t^p} \leq \left(\beta^{-1} - 1\right)$. The transition matrix driving the policy regime out of the zero lower bound ξ_t^p is given by the following matrix

$$H^p = \begin{bmatrix} p_{MM} & 1 - p_{FF} \\ 1 - p_{MM} & p_{FF} \end{bmatrix}$$

The non-Gaussian process ξ_t^d determines the growth rate of natural output and hence the natural interest rate through equation (16). The growth rate of natural output $\Delta y_t^n \in \{\Delta y_H^n, \Delta y_L^n\}$, where $\Delta y_H^n > \Delta y_L^n$, and these two states evolve according to the transition matrix:

$$H^d = \begin{bmatrix} p_{hh} & 1 - p_{ll} \\ 1 - p_{hh} & p_{ll} \end{bmatrix}$$

When the growth rate of natural output is low, the natural rate is low, and the policymakers are assumed to engage in the *ZLB policy regime*, which is characterized by a nominal interest rate set to zero and no adjustment of primary surplus to changes in the debt-to-output ratio.

In summary, the joint evolution of policymakers' behavior and the shock to the natural rate is captured by the regime obtained combining the two chains $\xi_t = \left[\xi_t^p, \xi_t^d\right]$. The combined chain can assume three values: $\xi_t = \{[M,h], [F,h], Z, l\}$. The corresponding transition matrix H is obtained by combining the transition matrix H^d, which describes the evolution of the pref-

[16] See Leeper (1991) for the derivation of this cut-off values for the policy parameters defining the monetary-led and the fiscally-led policy regimes.

Parameters	Values	Parameters	Values
$\psi_{\pi,M}$	2.00	p_{hh}	0.98
$\delta_{b,M}$	0.03	p_{ll}	0.95
$\psi_{\pi,F}$	0.80	p_{MM}	0.99
$\delta_{b,F}$	0.00	p_{FF}	0.99
$\delta_{b,Z}$	0.00	p_{ZM}	0.50
κ	0.03	100π	0.5
σ	1.00	b	0.30
ψ_x	0.10	β	0.995
ρ_i	0.85	$\Delta y_t^n\left(\xi_t^d = h\right)$	5.30
δ_x	0.5	$\Delta y_t^n\left(\xi_t^d = l\right)$	-21.33

Table 8: Parameters used for the prototypical New Keynesian model.

erence shock; the transition matrix H^p, which describes policymakers' behavior out of the zero lower bound, and the parameter p_{ZM} that controls the probability of moving to the monetary-led regime once the negative preference shock is reabsorbed:

$$H = \begin{bmatrix} p_{hh}H^p & (1-p_{ll})\begin{bmatrix} p_{ZM} \\ 1-p_{ZM} \end{bmatrix} \\ (1-p_{hh})\cdot[1,1] & p_{ll} \end{bmatrix}$$

Table 8 reports the parameter values we will use to study the property of this stylized model. The parameters π, and b denote the steady-state inflation and the steady-state value of the government debt-to-output ratio.

The exogenous drop in the growth rate of natural output is chosen so that to induce an annualized natural rate of -20% during the ZLB periods. In the benchmark calibration, we set the probability of moving to the monetary-led policy mix after the ZLB episode equal to $p_{ZM} = 50\%$ so as to capture a situation of sizable uncertainty about the policymakers' behaviors when the economy will exit the ZLB.

Figure 14 shows the dynamics of the output gap, inflation, and debt-to-GDP ratio in the aftermath of a discrete shock to the natural rate. We consider the benchmark case with parameter values reported in Table 8 and a counterfactual case in which agents are much more certain that the policy mix out of the ZLB

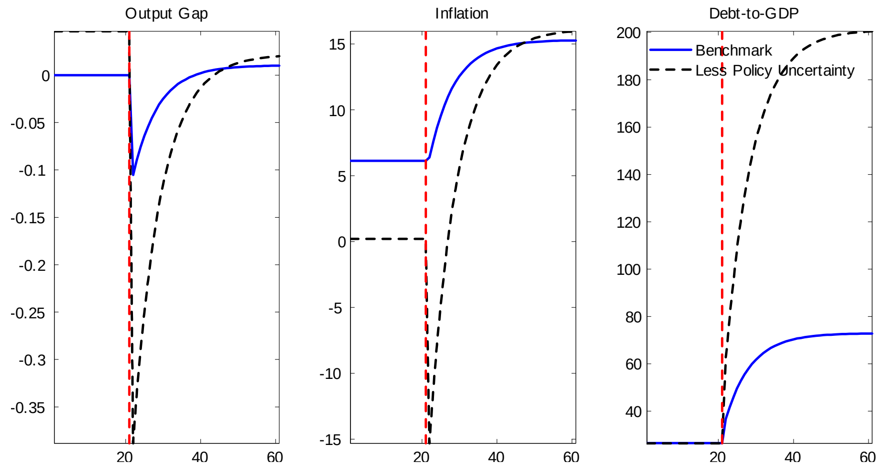

Figure 14: **Prototypical New Keynesian model.** The figure reports the impulse responses to a discrete shock to the natural interest rate. In the Benchmark model there is high policy uncertainty, while in the counterfactual economy agents think that they are more likely to move to the Monetary led regime.

will be monetary-led ($p_{ZM} = 85\%$). Both economies are hit by a negative shock to the natural rate at time 6.[17]

It should be observed that larger policy uncertainty causes absence of deflation in presence of a negative output gap as the economy hits the ZLB. Furthermore, policy uncertainty about policymakers' future behavior largely mitigates the output gap. These results are qualitatively in line with the ones obtained from our estimated model in Section 4.2. The exercise made in this section makes it clear that the results analyzed in the paper are not driven by the type of shock we chose to trigger the ZLB episode or by the more articulated nature of the model used for estimation.

E Model without the fiscal block

In what follows, we provide the details for the model that removes the fiscal block. As explained in the main text, this model is nested in the benchmark model and it does not feature any uncertainty about the way debt will be

[17] Both economies are assumed to be at their respective out-of-ZLB steady-state equilibrium. However, the starting level of the debt-to-GDP ratio in the counterfactual economy is set to be equal to that in the benchmark so as to ease the comparison.

financed. For this reason, debt and non-distortionary taxation become irrelevant for macroeconomic dynamics.

E.1 System of equations

1. Linearized Euler equation:

$$\begin{aligned}\left(1+\Phi M_a^{-1}\right)\widehat{y}_t &= -\left(1-\Phi M_a^{-1}\right)\left[\widehat{R}_t - E_t\widetilde{\pi}_{t+1} - (1-\rho_d)\,d_t - \overline{d}_{\xi_t^d} + E_{\xi_t^d}\overline{d}_{\xi_{t+1}^d}\right] \\ &\quad -\left(\Phi M_a^{-1}-\rho_a\right)a_t + E_t\widehat{y}_{t+1} + \left(1-\rho_g+M_a^{-1}\Phi\right)\widetilde{g}_t + M_a^{-1}\Phi\left(\widehat{y}_{t-1}-\widetilde{g}_{t-1}\right)\end{aligned}$$

   where $M_a = \exp(\gamma)$ and $\overline{d}_{\xi_t^d}$ follows a Markov-switching process governed by the transition matrix H^d. Please refer to the next subsection for details about how to handle the discrete shock.

2. New Keynesian Phillips curve:

$$\begin{aligned}\widetilde{\pi}_t &= \kappa\left(\left[\frac{1}{1-\Phi M_A^{-1}}+\frac{\alpha}{1-\alpha}\right]\widehat{y}_t - \frac{1}{1-\Phi M_A^{-1}}\widetilde{g}_t - \frac{\Phi M_A^{-1}}{1-\Phi M_A^{-1}}\left(\widehat{y}_{t-1}-\widetilde{g}_{t-1}-a_t\right)\right) \\ &\quad +\beta E_t\left[\widetilde{\pi}_{t+1}\right]+\widetilde{\mu}_t\end{aligned}$$

   where we have used the rescaled markup $\widetilde{\mu}_t = \kappa\left(\frac{\upsilon}{1-\upsilon}\right)\widetilde{\upsilon}_t$

3. No arbitrage condition

$$\widetilde{R}_t = E_t\left[\widetilde{R}^m_{t,t+1}\right]$$

4. Return long term bond

$$\widetilde{R}^m_{t-1,t} = R^{-1}\rho\widetilde{P}^m_t - \widetilde{P}^m_{t-1}$$

5. Monetary policy rule

$$\begin{aligned}\widetilde{R}_t &= \left[1-Z_{\xi_t^d}\right]\left[\rho_{R,\xi_t^p}\widetilde{R}_{t-1}+(1-\rho_R)\left(\psi_{\pi,\xi_t^p}\widetilde{\pi}_t+\psi_{y,\xi_t^p}\left[\widehat{y}_t-\widehat{y}_t^*\right]\right)+\sigma_R\epsilon_{R,t}\right] \\ &\quad +Z_{\xi_t^d}\left[\rho_{R,Z}\widetilde{R}_{t-1}-\left(1-\rho_{R,Z}\right)\psi_Z\log(R)+\sigma_Z\epsilon_{R,t}\right]\end{aligned}$$

6. Government purchases ($\widetilde{g}_t = \ln(g_t/g)$):

$$\widetilde{g}_t = \rho_g \widetilde{g}_{t-1} + \sigma_g \epsilon_{g,t},\ \ \epsilon_{g,t} \sim N(0,1).$$

7. TFP growth

$$a_t = \rho_a a_{t-1} + \sigma_a \varepsilon_{a,t}$$

8. The rescaled markup $\mu_t = \kappa \log(\aleph_t/\aleph)$, where $\aleph_t = 1/(1-\upsilon_t)$, follows an autoregressive process,

$$\mu_t = \rho_\mu \mu_{t-1} + \sigma_\mu \epsilon_{\mu,t}$$

9. Output target

$$\left[\frac{1}{1-\Phi M_a^{-1}} + \frac{\alpha}{1-\alpha}\right]\widehat{y}_t^* = \frac{1}{1-\Phi M_a^{-1}}\widetilde{g}_t + \frac{\Phi M_a^{-1}}{1-\Phi M_a^{-1}}\left(\widehat{y}_{t-1}^* - \widetilde{g}_{t-1} - a_t\right)$$

E.2 Parameter estimates

Table 9 reports the parameter estimates for the model that excludes the fiscal block. As observables, we use four of the seven series used to estimate the benchmark model: GDP growth, inflation, federal funds rate, and government expenditure. Note that including the remaining fiscal series would be irrelevant for the dynamics of the macroeconomy because Ricardian equivalence applies when imposing that fiscal policy is always passive.

E.3 Dynamics at the zero lower bound

Figure 15 shows that the model without the fiscal block needs to use a combination of shocks in order to explain the absence of deflation during the zero lower bound. The figure reports the dynamics of inflation and output starting from 2008:Q4 in response to *two* shocks. The discrete preference shock and a large negative TFP shock. To ease the comparison with the results reported in Section 5, we also report the 90% error bands for the impulse response to the

	Mean	5%	95%	Type	Mean	Std
$\psi_{\pi,1}$	2.2157	1.7523	2.6568	N	2.5	0.3
$\psi_{y,1}$	0.3334	0.1542	0.5421	G	0.4	0.2
$\rho_{R,1}$	0.8641	0.8170	0.9118	B	0.5	0.2
$\psi_{\pi,2}$	1.1032	0.8242	1.3961	G	0.8	0.3
$\psi_{y,2}$	0.2678	0.1388	0.4414	G	0.15	0.1
$\rho_{R,2}$	0.8361	0.7811	0.8874	B	0.5	0.2
$\bar{d}_l$	-0.2592	-0.4124	-0.1272	N	-0.3	0.1
p_{hh}	0.9610	0.9204	0.9886	D	0.96	0.03
p_{ll}	0.8958	0.7792	0.9711	D	0.83	0.10
p_{MM}	0.9613	0.9072	0.9923	D	0.96	0.03
p_{FF}	0.9595	0.9075	0.9914	D	0.96	0.03
p_{ZM}	0.5009	0.1478	0.8451	D	0.50	0.22
ψ_Z	0.9698	0.9608	0.9781	B	0.95	0.02
κ	0.0707	0.0467	0.1025	G	0.3	0.15
Φ	0.8601	0.8147	0.8996	B	0.5	0.2
ρ_g	0.9919	0.9847	0.9971	B	0.5	0.2
ρ_a	0.1608	0.0583	0.2786	B	0.5	0.2
ρ_d	0.9358	0.9083	0.9599	B	0.5	0.2
ρ_μ	0.3291	0.1082	0.6432	B	0.5	0.2
$100\sigma_R$	0.2118	0.1958	0.2295	IG	0.5	0.5
$100\sigma_g$	0.2775	0.2568	0.2997	IG	1.00	1.00
$100\sigma_a$	1.4785	1.3037	1.6729	IG	1.00	1.00
$100\sigma_d$	13.8890	9.8559	19.2040	IG	10.00	2.00
$100\sigma_\mu$	0.2274	0.1965	0.2715	IG	1.00	1.00
100π	0.5678	0.4800	0.6607	G	0.5	0.05
100γ	0.4100	0.3352	0.4912	G	0.4	0.05
g	1.0758	1.0604	1.0942	N	1.06	0.04

Table 9: Posterior means, 90% posterior error bands and priors of thel parameters for the model that exludes the fiscal block. For the structural parameters, the suffix denotes the regime. The letters in the column "Type" indicate the prior density function: N, G, B, D, and IG stand for Normal, Gamma, Beta, Dirichlet, and Inverse Gamma, respectively.

discrete preference shock only. While the discrete preference shock accounts for the bulk of the decline of inflation, the fall in output growth is mostly explained by the negative preference shock. As explained in the paper, the result shows that fiscal uncertainty plays a key role in explaining the joint dynamics of inflation and output. Once the fiscal block in removed, a combination of shocks is necessary to explain the joint dynamics of output and inflation.

Figure 16 examines the properties of the traditional New Keynesian model to match the joint behavior of output growth and inflation from a different angle. This exercise is based on the estimates for the benchmark model, but removing

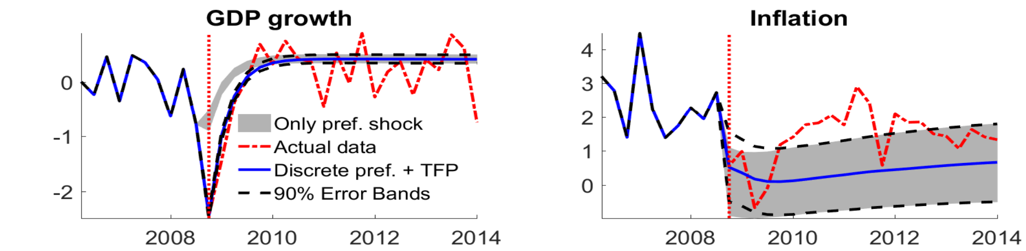

Figure 15: **Macroeconomic dynamics at the zero lower bound without fiscal block: The role of TFP shocks.** Response of GDP growth and inflation to a discrete negative preference shock and a contemporaneous negative TFP shock based on a model that excludes the fiscal block. The red dashed line reports actual data, while the shaded areas report the 90% error bands when only the discrete prefence shock occurs.

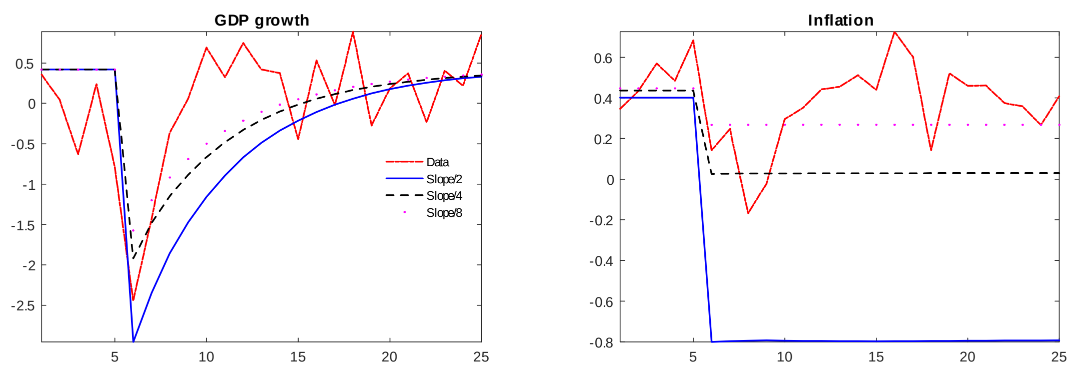

Figure 16: **Macroeconomic dynamics at the zero lower bound without fiscal block: The role of nominal rigidities.** Response of GDP growth and inflation to a large discrete negative preference shock for different values of the slope of the Phillips curve, κ.

the fiscally-led regime. We chose the estimated benchmark model as a starting point because the size of the discrete shock is in fact able to generate a realistic contraction in real activity. We then ask what slope of the Phillips curve can deliver a behavior of inflation and output growth in line with what observed in the data. The solid blue line corresponds to the case in which the slope of the Phillips curve is divided by two, implying that in average the slope is around .0036. Clearly in this case the model can generate a sizeable recession, but a the cost of generating deflation. Dividing the estimates slope by four, things slightly improve, but inflation is still too low. Finally, with a mean of the slope around .0009 and ranging from .0006 to .0024 we can obtain a behavior of inflation more in line of the data, at the cost of a smaller recession.

Summarizing, we can highlight three conclusions based on the analysis of a model that excludes the fiscal block. First, in order to rationalize the joint dynamics of inflation and output, a very large level of nominal rigidities are necessary. Second, when using both data before and at the zero lower bound, this high level of nominal rigidities is rejected by the estimates. Instead, the model explains the zero lower bound dynamics as a result of two combined shocks: A discrete preference shock and contemporaneous negative TFP shock. This is because we do not ask the model to simply match the zero lower bound events, but also what happened before this event. Finally, the standard New Keynesian model cannot generate the drop followed by the slight upward of inflation observed in the data. In the model this is caused by the fact that as more time is spent at the zero lower bound, the fiscal burden increases, generating inflationary pressure.