

# Escaping the Great Recession\*

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## Abstract

We show that policy uncertainty about how the rising public debt will be stabilized empirically accounts for the lack of deflation in the US economy during the zero-lower-bound period. Announcing fiscal austerity is detrimental in the short run, but it preserves macroeconomic stability. On the other hand, a recession can be mitigated by abandoning fiscal discipline, at the cost of increasing macroeconomic instability. This policy trade-off can be resolved by committing to inflating away only the portion of debt accumulated during the recession.

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# 1 Introduction

The recent financial crisis and the deep recession that followed led to a substantial change in the conduct of monetary policy, with interest rates stuck at the zero lower bound for the past seven years. While in a Keynesian framework the zero lower bound and the associated large contraction in economic activity are associated with persistent deflation, inflation in the data has remained remarkably close to its target value. Following Hall's Presidential Address to the American Economic Association, some researchers have labeled this observation the "Bob Hall's puzzle" (Hall 2011). At the same time, the crisis has triggered a widespread policy debate about the best way to mitigate the consequences of a deep recession once monetary policy is constrained by the zero lower bound. While this debate is animated by a wide spectrum of opinions, there seem to be two popular polar views. The first one advocates a discontinuity with respect to the policies of the past, calling for a robust fiscal intervention, perhaps associated with a reduction on the focus on inflation stabilization. The second one strongly opposes the idea of explicitly abandoning policies that have arguably led to a stable macroeconomic environment since the Volcker disinflation. In this paper, we will show that policy uncertainty about the way policy makers will behave in the future can account for the absence of deflation that has characterized the Great Recession.

We construct and estimate a dynamic general equilibrium model that captures the policy trade-off that seems to arise 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 fiscal authority adjusts primary surpluses in response to fluctuations in the ratio of public debt to gross domestic product (GDP), while the central bank reacts strongly to deviations of inflation from its target. If agents expect this regime to prevail for a long time, any fiscal imbalance is backed by future fiscal adjustments and reputation for fiscal discipline is strong. Under the *Fiscally led policy mix*, the fiscal authority does not react strongly enough to debt fluctuations and the central bank disregards the Taylor principle. In this second case, agents understand that policymakers are unlikely to implement the fiscal adjustments necessary to preserve debt stability.<sup>1</sup> Finally, the economy can be hit by a large swing in preferences that induces agents to substantially reduce consumption. In this case, a standard Taylor rule would imply a negative nominal interest rate. This forces policymakers into a *zero lower bound regime* in which the federal funds rate is restricted to zero and the fiscal authority disregards the level of debt in an attempt to mitigate the resulting deep recession. As in Krugman (1998), Eggertsson and Woodford (2003), and Christiano et al. (2011), the real interest rate is now too high with respect to what would be desirable. Policymakers would then find it beneficial to induce a jump in inflation expectations in order to cause a drop in real interest rates and push the economy out of the recession.

Given that at the zero lower bound policymakers' behavior is constrained, 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

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<sup>1</sup>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.

that controls agents' beliefs about policymakers' exit strategy. We estimate the model and we find that during the recent crisis the probability assigned to a switch to the Fiscally led regime experienced a discrete increase, even if agents still regard a return to the Monetary led regime as more likely (around 92%). Even if the estimated probability of a switch to the Fiscally led regime is relatively low, the inflationary pressure deriving from the large stock of debt is enough to prevent the economy from entering a deflationary state.

In order to highlight the importance of policy uncertainty, we first use a counterfactual simulation to point out that the US economy would have experienced large deflation if the Monetary led regime had been the only possible one. In other words, absent policy uncertainty, the consequences of the current recession would have been much more severe because the increase in debt would not have implied any inflationary pressure. We then show that the estimated model is able to explain the behavior of inflation expectations as measured by the Michigan survey. In other words, agents' expectations are consistent with the mechanism implied by our model. This is an important external validation because we do not use inflation expectations in our estimates. We show that a model that excludes fiscal uncertainty cannot account for the joint dynamics of inflation and output and the behavior of inflation expectations at the zero lower bound.

Policy uncertainty about the way debt will be stabilized prevents deflation at the zero lower bound because it induces inflationary pressure. To inspect this mechanism, we study the consequences of removing policy uncertainty and introducing explicit announcements about future policymakers' behavior in the aftermath of a large shock. If policymakers announce that as the economy exits the zero lower bound, a prolonged period of fiscal discipline will follow, inflation expectations drop, leading to deflation and a severe recession. If instead policymakers announce a prolonged deviation from the Monetary 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 pushes the economy out of the recession and the economy is able to avoid the zero lower bound. Finally, if policymakers do not make any explicit announcements about the way debt will be stabilized, the estimated benchmark case in which agents form expectations by taking into account the two alternative scenarios arise and the model is able to rationalize why, despite the time spent at the zero lower bound, we have not observed deflation in the United States. Therefore, if deflation occurs or not at the zero lower bound depends on the relative weight assigned to the two exit strategies.

A clear announcement of a switch to the Fiscally led regime would push the economy out of the zero lower bound. However, such an announcement would also result in an increase in macroeconomic volatility once the economy is out of the zero lower bound. The two results go together. The announcement is effective if and only if it is able to convince agents that the Fiscally led policy mix will prevail for a long time. In this situation the macroeconomy is not insulated with respect to fiscal disturbances. When policymakers are expected to follow the Monetary led rule for many periods ahead, all the shocks that hit the debt-to-GDP ratio are neutralized by the fiscal authority and the economy is therefore insulated with respect to fiscal disturbances. However, if the Fiscally led regime is expected to be in place most of the time, agents realize that inflation, not taxation, will be used to keep debt on a stable

path. Therefore, all the fiscal imbalances that are systematically neutralized under the Monetary led regime will now affect inflation. In the presence of nominal rigidities, inflation volatility translates into output volatility, resulting in a more uncertain macroeconomic environment.

Entering the zero lower bound also implies an increase in macroeconomic uncertainty. This is because of three reasons. First, given that the timing of the end of the recession is unknown, the possibility of a swing in real activity creates uncertainty. Second, the fact that the federal funds rate (FFR) is stuck at zero implies that policymakers cannot immediately mitigate the consequences of the shocks hitting the macroeconomy. Finally, fiscal shocks have potentially large effects on the macroeconomy because of the increase in policy uncertainty. Modest changes in the relative probability of the different exit strategies do not get rid of macroeconomic uncertainty and can cause large swings in expected inflation. These findings square well with recent contributions by Kitsul and Wright (2013) and Longstaff et al. (2013) that point out that during the most recent recession market based inflation expectations presented large fluctuations between fears of inflation and fears of deflation.

In summary, a policy trade-off arises the moment that a large negative preference shock pushes monetary policy to the zero lower bound. The fact that the Monetary led regime results in a more stable macroeconomic environment in the long run provides support to those who are reluctant to explicitly abandon the policies that prevailed from the Volcker disinflation to the recent crisis. Yet, the possibility of mitigating the recession by moving to the Fiscally led regime can explain why some policymakers and economists have suggested discontinuity with respect to the past.

We show that the policy trade-off between mitigating the recession and preserving long run macroeconomic stability can be resolved by committing to inflating away only the portion of debt resulting from the exceptionally large recession.<sup>2</sup> This *shock specific rule* provides a sort of *automatic stabilizer*: The large negative preference shock can lead to a deep recession and a corresponding large increase in the debt-to-GDP ratio. The expectation that this extra fiscal burden is going to be inflated away determines a drop in the real interest rate that stimulates demand, reducing the size of the output contraction and the amount of debt that needs to be inflated away. This mechanism can be strong enough to prevent the economy from hitting the zero lower bound. Furthermore, given that the recession is now largely mitigated, the resulting increase in the debt-to-GDP ratio is small and so is the increase in inflation necessary to stabilize it.

At the same time, policymakers never changed their behavior with respect to the pre-crisis stock of debt and in response to other exogenous business cycle disturbances that are unlikely to push the economy to the zero lower bound. This has two very important consequences. First, the level of debt that existed before the crisis is irrelevant for the amount of inflation that is generated because it is still backed by future fiscal adjustments. Second, agents expect that all future fiscal imbalances will still be taken care of by the fiscal authority. Therefore, the proposed policy is successful in mitigating the recession and preserving long-run stability.

This paper is organized as follows. Section 2 reviews the related literature. Section 3 uses a Markov-

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<sup>2</sup>This policy has been advocated by Krugman (2013) and Rogoff (2008) among several others. Furthermore, during the recession, the then Fed Chairman Ben Bernanke has often insisted on the importance of distinguishing between long run fiscal sustainability and the need to stimulate the economy in the short run. See, for example, Bernanke (2011).

switching VAR to present some stylized facts about the zero lower bound with a focus on the role of fiscal imbalances. These stylized facts will then be used to motivate the structure of the benchmark model. Section 4 presents the benchmark model. Section 5 shows that policy uncertainty can account for the lack of deflation and high macroeconomic uncertainty. Section 6 considers an alternative model without the fiscal block to show that once fiscal uncertainty is removed the traditional -Keynesian model cannot account for the joint dynamics of inflation and output as the result of a single shock. Section 7 outlines the policy trade-off that arises at the zero lower bound: Mitigating a recession at the cost of losing long run macroeconomic stability. Section 8 proposes the shock-specific policy response. Section 9 concludes.

## 2 Related Literature

Our work is related to the vast theoretical literature on the zero lower bound. Wolman (1998), Fuhrer and Madigan (1994), Krugman (1998), and Orphanides and Wieland (1998, 2000) are among the first to study the zero lower bound and monetary policy in an intertemporal framework. Eggertsson and Woodford (2003) show that optimal monetary policy at the zero lower bound involves a commitment to generate future inflation. Eggertsson (2006) argues that such a policy can suffer from a time-inconsistency problem, while Eggertsson (2008), using a model in which taxation is costly, shows that President Franklin Delano Roosevelt was able to make the promise of future inflation credible by expanding fiscal deficits. Sims (2010a) makes a similar point in the context of the recent crisis, arguing that a large debt accumulation could create credible expectations of high inflation at the zero lower bound. Benhabib et al. (2001b) show that active monetary policy rules can lead to a liquidity trap, while Benhabib et al. (2002) explain how fiscal and monetary policies can be designed in order to rule out deflationary spirals. Correia et al. (2012) show how distortionary taxes can be used to replicate the effects of negative nominal interest rates and completely circumvent the zero lower bound problem. Werning (2012) works in a deterministic environment and shows that the effectiveness of policies at the zero lower bound crucially depends on what agents expect after the constraint is not binding anymore. Fernandez-Villaverde et al. (2011) show how supply-side policies may play a role in preventing an economy from hitting the zero lower bound. Galí (2014) studies the effects of a money-financed fiscal stimulus. Schmitt-Grohe and Uribe (2012) present a model that can account for a recession associated with a protracted liquidity trap and a jobless recovery. Coibion et al. (2012) study the optimal inflation target in a Keynesian model in which the policy rate occasionally gets constrained by the zero lower bound.

Our work differs from each of these papers 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. 2012; Williams 2012; and Basu and Bundick 2012). Second, we work in a stochastic environment (not perfect foresight/deterministic) with a standard 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 microfounded dynamic stochastic general equilibrium (DSGE) models to those of Gust et al. (2013) and Aruoba and Schorfheide (2013). Finally, our results are based on the possibility of generating an increase in inflation expectations through a change in the monetary/fiscal policy mix and do not require the use of distortionary taxation.

Other papers have addressed Bob Hall's puzzle (Ball and Mazumder 2011 and King and Watson 2011). While some papers explain the lack of deflation at the ZLB as a result of non-policy exogenous innovations (financial shocks in Del Negro et al. 2015; oil shocks in Coibion and Gorodnichenko 2015; a combination of a negative shock to total factor productivity and a positive shock to the cost of working capital in Christiano et al. 2015), our paper provides an explanation based on the observed change in the conduct of monetary and fiscal policies induced by the Great Recession. We show that once one takes into account the effects of fiscal imbalances on price dynamics, a single demand shock can jointly explain the dynamics of real activities and inflation during the Great Recession and the ensuing slow economic recovery. The slow-moving endogenous dynamics of government debt plays a crucial role in explaining why the decoupling between real activity and price dynamics has been so persistent.

Baker et al. (2013) construct a comprehensive index of policy uncertainty. We focus on policy uncertainty about the way policy makers are going to stabilize a rising stock of debt. Fernandez-Villaverde et al. (2013) and Johannsen (2013) use higher order approximations to study the role of fiscal volatility in slowing down the recovery during the current crisis, but they assume that government debt is always backed by future fiscal surpluses while agents face uncertainty regarding the magnitude of the innovations to the fiscal instruments. In our model, agents instead are uncertain about the rules governing policymakers' behavior. We will show that this kind of policy uncertainty, while detrimental during regular times, can prevent deflation and mitigate the fall in output at the zero lower bound, when monetary policy becomes ineffective. Instead, fiscal volatility shocks do not provide an explanation for the absence of deflation observed in the data.

Our choice of working with regimes gives us the possibility of capturing the consequences of policy uncertainty and to compare different scenarios. Other authors have approached the problem of the zero lower bound from a different angle, i.e., by solving for optimal policies. While such an approach has provided the theoretical foundations of our understanding of the zero lower bound, it does not leave space for comparative analysis or the possibility of allowing for policy uncertainty in the moment that one optimal policy emerges. 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; Davig and Doh 2013; Fernandez-Villaverde et al. 2010; and Bianchi 2013).

This paper is related to a research agenda that aims to understand the role of fiscal policy in explaining changes in the reduced form properties of the macroeconomy. Using a Markov-switching DSGE model, Bianchi and Ilut (2015) show that the rise and fall of US inflation can be explained in

light of a change in the monetary/fiscal policy mix that occurred a few years after the appointment of Paul Volcker as Federal Reserve Chairman. Bianchi and Melosi (2013) introduce the notion of *dormant shocks*, showing that a fiscal imbalance can lead to an increase in inflation many years after it occurred. This paper differs from the two aforementioned contributions across several dimensions. First, we here allow for the zero lower bound and show that policy uncertainty can account for the absence of deflation. 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 show how policymakers can resolve this trade-off by using a *shock-specific* rule.

Our work is then related to the study of the interaction between fiscal and 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; Bassetto 2002; among many others) and to the vast literature on fiscal multipliers (Blanchard and Perotti 2002; Mountford and Uhlig 2009; Uhlig 2010; Romer and Romer 2010; Mertens and Ravn 2011, 2013; Leeper et al. 2013; Misra and Surico 2013). Mertens and Ravn (2014) and Drautzburg and Uhlig (2011) use a DSGE model to study the fiscal multiplier when interest rates are stuck at the zero bound.

### 3 Motivating Evidence

We introduce a Markov-switching VAR (MS-VAR) model to motivate the key mechanism studied in this paper; that is, the growing U.S. fiscal imbalances can account for why inflation did not persistently dropped during the Great Recession. This reduced-form analysis also turns out to be quite valuable for designing a structural model to study the last eight years of data.

The model is a VAR with two lags, three Markov-switching regimes for the constants and the autoregressive parameters, and three Markov-switching regimes for the volatility of innovations:

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

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

where  $Z_t$  is a  $(n \times 1)$  vector of data. The unobserved states  $\xi_t^\Sigma$  and  $\xi_t^\Phi$  control the regimes in place for the VAR coefficients and the covariance matrix, respectively. The regimes evolve according to two transition matrices,  $H^\Phi$  and  $H^\Sigma$ . 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. We estimate the MS-VAR model by using Bayesian techniques and four variables: the ratio of primary deficit to government debt, GDP growth, inflation, and the federal funds rate.<sup>3</sup> We use the ratio of primary deficit to debt as a parsimonious observable that captures the fiscal stance of the U.S. government over time.<sup>4</sup> Estimating Bayesian VAR models with Markov-switching parameters proves to become quickly computationally unmanageable as

<sup>3</sup>The details about the model, the data set, and the estimation procedure are in the Appendix A.

<sup>4</sup>Other VAR studies have used this ratio as an observable. See Sims (2010b) for a fixed coefficient VAR and Kliem et al. (2013) for a time-varying VAR.

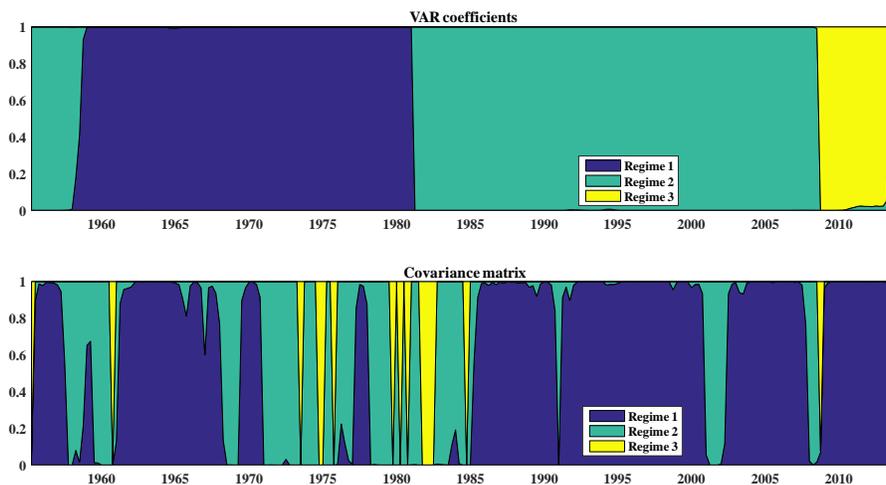


Figure 1: **Smoothed Probabilities of Regimes of MS-VAR.** The top panel reports the probabilities for the three regimes characterizing the VAR coefficients, whereas the lower panel reports the probabilities for the three regimes of the covariance matrix.

the number of observables grows. Furthermore, estimating a Markov-switching VAR model with no restrictions on the properties of regimes by using the debt and deficit series separately is a particularly daunting task because the government debt is a slow-moving process compared to the other observables. When estimating the structural model, we will instead be able to treat the primary deficit and debt as two separate observable variables.

Figure 1 reports the smoothed probabilities at the posterior mode for the three regimes controlling the VAR coefficients (top panel) and the three regimes of the covariance matrix (lower panel). For the covariance matrix, Appendix A shows that the three regimes imply increasing levels of volatility. Regime 2 can be thought as a regime associated with recessions and the turbulent periods of the 1970s until the beginning of the Great Moderation, that 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 according to the VAR estimates. Regime 1 is characterized by a higher primary deficit, higher inflation, and lower real interest rate than Regime 2.

Bianchi and Ilut (2015) also find a similar sequence of regime changes for the pre-crisis period when estimating a dynamic general equilibrium model.<sup>5</sup> They identify a switch from a fiscally led regime, that characterized the 1960s and 1970s, to a monetary-led regime exactly in 1981:Q2, after the appointment of Volcker to Fed Chairman and Reagan's election to President of the United States. As it will become clear when considering the structural model, the stylized facts captured by the conditional steady states

<sup>5</sup>Bianchi and Ilut (2015) do not study the zero lower bound period and they do not estimate a MS-VAR.

described in Table 1 can be rationalized in light of a change in the monetary-fiscal policy mix. Higher deficits lead to higher average inflation. The monetary authority accommodates the increase in inflation by reacting less aggressively to inflation, with the result that real interest rates remain low. Therefore, we can interpret the two regimes in light of a change in the policy mix from fiscally led to monetary led. We refer to Regime 1 as the Fiscally led regime and Regime 2 as the Monetary led regime.

	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.

Regime 3 dominates the last part of the sample starting from 2008Q3. This is the quarter that marks the acceleration of the financial crisis and the worst period of the so-called *Great Recession*. The large contraction in real activity prompted policymakers to take extraordinary actions both on the monetary and on the fiscal side. The 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 its target rate 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 interpreted as the monetary led regime. However, Regime 3 is still the most likely regime at the end of the sample period. Furthermore, this result may be driven by end-of-sample uncertainty. In fact, we know that at the end of 2014 interest rates were still at zero.

Quite importantly, 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 Regime 2 (the monetary led regime) to Regime 3 (the zero-lower-bound regime) in 2008:Q3. Conversely, the role of Gaussian shocks seem to be of secondary importance during that period. To highlight this point, Figure 2 shows the effects of entering the zero-lower-bound regime in 2008:Q3 on the deficit-to-debt ratio, GDP growth, inflation, and the federal funds rate. All Gaussian shocks are shut down in this simulation. The seventy-percent posterior bands (the gray areas) for the effects of this discrete shock capture remarkably well the dynamics of the data (the blue 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 that lowered both output growth and inflation for a few quarters while at the same time triggering 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 there have been noticeable effects of these fiscal imbalances on price dynamics during the zero-lower-bound period. The following exercise serves the purpose of

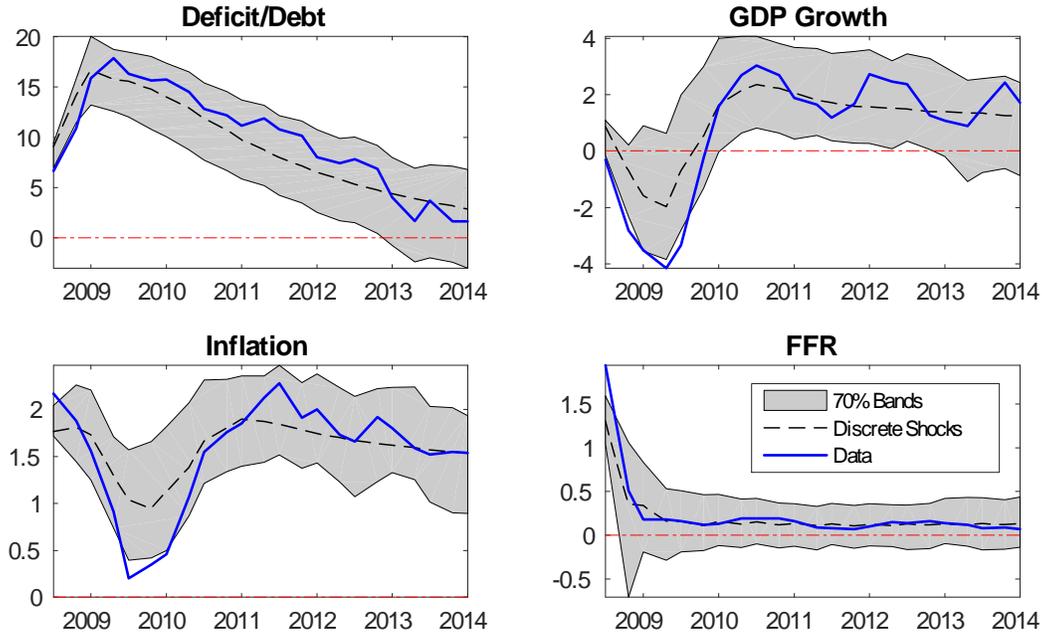


Figure 2: **Entering the zero-lower-bound regime.** The blue solid line reports the actual data. The black dashed line denotes the posterior median of the variables simulated from the MS-VAR by using only the dynamics implied by the constant and the VAR coefficients under Regime 3 starting from 2008:Q3. We initialize the simulations by using the actual value of the observables in 2008Q2. The gray areas capture the seventy-percent posterior set of the simulated variables.

providing direct evidence for the key mechanism studied in this paper, so as to motivate 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.<sup>6</sup> The positive comovement 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 3, 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 inflationary effects of a growing fiscal imbalances due to the Great Recession may have been fairly sizable. The plots report a fiscal shock that raises the deficit-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 2008Q3 and 11.20 percentage points from 2008:Q3 through 2009:Q2 (peak). Consequently, it is conceivable that the deterioration in the government’s fiscal position observed in the data has contributed to raise inflation

<sup>6</sup>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 objectives are to stabilize the business cycles, feature feedbacks to the real economy. Also, 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 standard in the structural VAR literature, this identification scheme is consistent with our DSGE model.

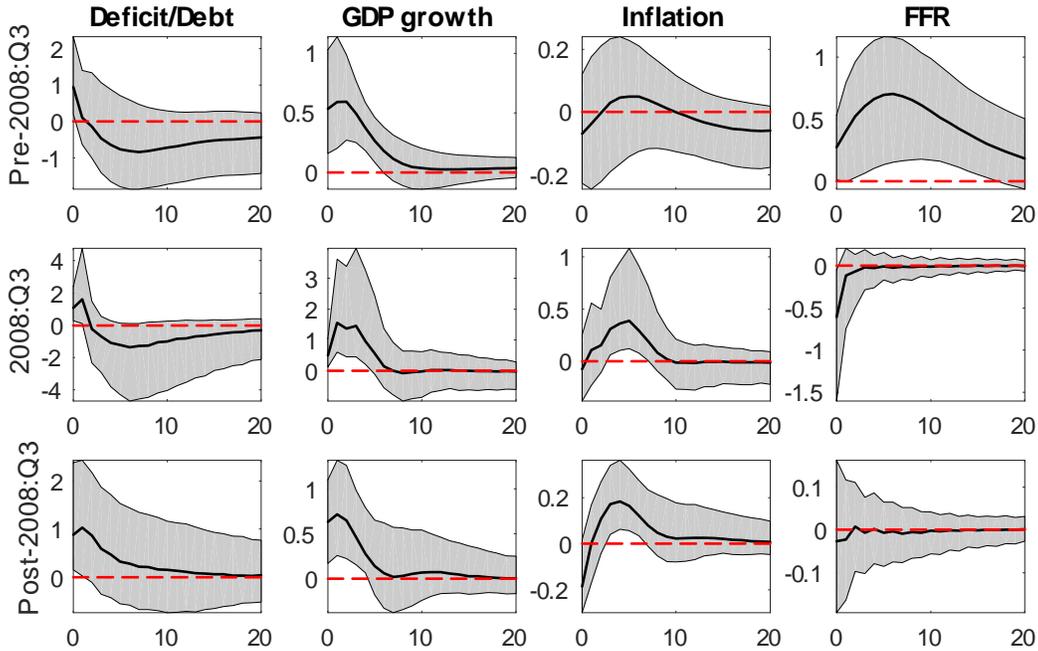


Figure 3: **Fiscal shocks before and at the zero lower bound.** The solid line denotes the posterior median of the response of the observable variables to a one-standard-deviation fiscal shock that raises the deficit-to-debt ratio upon impact and GDP growth within the next five quarters. Gray areas denote seventy-percent posterior set for the responses.

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 3). Before the Great Recession, the Federal Reserve was used to raise the rate relatively aggressively in response to fiscal shocks and in doing so kept a firm control over price dynamics. Furthermore, when the 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.

## 4 The Model

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 based on Bianchi and Ilut (2015) and is obtained by augmenting the prototypical Keynesian model used by Clarida et al. (2000) and Lubik and Schorfheide (2004) with external habits, a maturity structure for debt, and a fiscal block.

### 4.1 A New Keynesian Model

**Households.** The representative household maximizes expected utility:

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

subject to the budget constraint:

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

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  $\Phi$  captures the degree of external habit. In line with Cochrane (2001), we recognize the importance of allowing for a maturity structure of government debt. Longer maturities imply important fluctuations in the return on bonds and consequently in the present value of debt. Hall and Sargent (2011) show that these revaluation effects explain a significant fraction of the fluctuations in the debt-to-GDP ratio. Following Eusepi and Preston (2012) and 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 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 asset can be interpreted as a portfolio of infinitely many bonds, with weights along the maturity structure given by  $\rho^{T-(t+1)}$ . Varying the parameter  $\rho$  varies the average maturity of debt.

The preference shock  $\zeta_d$  is the sum of a continuous and discrete component:  $\zeta_d = d_t + \bar{d}_{\zeta_t^d}$ . The continuous component  $d_t$  has mean zero and time series representation:  $d_t = \rho_d d_{t-1} + \sigma_d \varepsilon_{d,t}$ . The discrete component  $\bar{d}_{\zeta_t^d}$  can assume two values: high or low ( $\bar{d}_h$  or  $\bar{d}_l$ ). The variable  $\xi_t^d$  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  $p_{ji} = P(\xi_{t+1}^d = j | \xi_t^d = i)$ . The values of  $H^d$ ,  $\bar{d}_h$ , and  $\bar{d}_l$  are such that the unconditional mean of the discrete shock  $\bar{d}_{\zeta_t^d}$  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 zero lower bound 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 monopolistically competitive firm  $j$  faces a downward-sloping demand curve:

$$Y_t(j) = (P_t(j)/P_t)^{-1/v_t} Y_t \quad (4)$$

where the parameter  $1/v_t$  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 quadratic adjustment costs represented by an output loss:

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

where  $\Pi_t = P_t/P_{t-1}$  is gross inflation at time  $t$  and  $\Pi$  is the corresponding steady state. Shocks to the elasticity of substitution imply shocks to the markup  $\aleph_t = 1/(1 - v_t)$ . 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  $\kappa \equiv \frac{1-v}{v\varphi\Pi^2}$  is the slope of the Phillips curve. The firm chooses the price  $P_t(j)$  to maximize the present value of future profits:

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

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:  $\ln(A_t/A_{t-1}) = \gamma + a_t$ ,  $a_t = \rho_a a_{t-1} + \sigma_a \epsilon_{a,t}$ ,  $\epsilon_{a,t} \sim N(0, 1)$ .

**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.<sup>7</sup> We rewrite the federal government budget constraint in terms of debt-to-GDP ratio  $b_t^m = (P_t^m B_t^m) / (P_t Y_t)$ :

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

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

<sup>7</sup>Alternative approaches consist of excluding one of the fiscal components or including an observation error. Our results are robust to these alternative specifications.

The linearized federal transfers as a fraction of GDP  $tr_t$  follow the following process:

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

where  $\tilde{tr}_t^*$  represents a long term component that is assumed to be completely exogenous and it is meant to capture the large programs that arise as the result of a political process that is not modeled here. Transfers fluctuate around this trend component as a result of business cycle fluctuations captured by the log-linearized output gap  $(\hat{y}_t - \hat{y}_t^*)$ , where  $\hat{y}_t^*$  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  $\tilde{g}_t = \ln(g_t/g)$  follows an autoregressive process:  $\tilde{g}_t = \rho_g \tilde{g}_{t-1} + \sigma_g \epsilon_{g,t}$ ,  $\epsilon_{g,t} \sim N(0, 1)$ .

**Policy Rules.** The fiscal authority moves taxes according to the following rule:

$$\tilde{\tau}_t = \rho_{\tau, \xi_t^p} \tilde{\tau}_{t-1} + \left(1 - \rho_{\tau, \xi_t^p}\right) \left[ \delta_{b, \xi_t^p} \tilde{b}_{t-1}^m + \delta_e \left( \tilde{tr}_t^* + g^{-1} \tilde{g}_t \right) + \delta_y (\hat{y}_t - \hat{y}_t^*) \right] + \sigma_{\tau} \epsilon_{\tau,t}, \quad \epsilon_{\tau,t} \sim N(0, 1) \quad (6)$$

where  $\tilde{\tau}_t$  is the level of tax revenues with respect to GDP in deviations from the steady state. Tax revenues respond to the state of the economy, captured by the output gap, to the sum of long run level of transfers and government purchases, and to the level of debt. The strength with which the government tries to stabilize the debt-to-GDP ratio is captured by the coefficient  $\delta_{b, \xi_t^p}$  that is allowed to vary over time.

The central bank follows the rule:

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

where  $\epsilon_{R,t} \sim N(0, 1)$ ,  $R$  is the steady-state gross nominal interest rate,  $Y_t^*$  is the output target,  $\Pi$  is the target/steady-state level for gross inflation, the variable  $\xi_t^p$  captures the monetary/fiscal policy combination that is in place at time  $t$ , and the dummy variable  $Z_{\xi_t^d}$  controls if the economy is in or out of the zero lower bound. When  $\bar{d}_{\xi_t^d} = \bar{d}_h$ , the economy is out of the zero lower bound and monetary and fiscal policies are not constrained ( $Z_{\xi_t^d} = 0$ ). In this case the evolution of the policy mix can be described by the two-regime Markov switching process  $\xi_t^p$ . The properties of the transition matrix and of the regimes will be described below. When  $\bar{d}_{\xi_t^d} = \bar{d}_l$ , the zero lower bound is binding, given that a standard Taylor rule would require a negative nominal interest rate.<sup>8</sup> In this case, policymakers abandon

<sup>8</sup>We assume that whenever the negative preference shock hits, policymakers move to the zero-lower-bound regime described later on and we choose the parameters values in a way that the zero lower bound is binding with high probability when  $\bar{d}_{\xi_t^d} = \bar{d}_l$ . Our approach to model the zero lower bound differs from the conventional one (e.g., see Eggertsson and Woodford 2003; Benhabib, Schmitt-Grohe, and Uribe 2002), 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 that there exist some unlikely states of the world in which the nominal rate  $R_t$  assumes negative values, it has the advantage of making the model tractable and allows us to

the policy mix that they were following and set the net nominal interest rate close to zero ( $Z_{\xi_t^d} = 1$ ).

To match the behavior of the FFR in the data during the zero-lower-bound period, we need to allow for: (1) small disturbances to the FFR, (2) the fact that the FFR is not exactly zero, and (3) the fact that the Federal Reserve lowered the interest rate gradually, even if quickly. The size of the monetary policy shocks to the FFR at the zero lower bound are controlled by  $\sigma_Z$ . This is assumed to be a tenth of the out of the zero lower bound standard deviation of the monetary policy shocks:  $\sigma_Z = \sigma_R/10$ . The persistence of changes in the FFR at the zero lower bound 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 zero lower bound. It can be thought as the fraction of the steady state net interest rate. Notice that if we set  $\sigma_Z = 0$ ,  $\rho_{R,Z} = 0$ , and  $\psi_Z = 1$ , we would obtain  $R_t = 1$  at the zero lower bound. Consequently, the linearized monetary policy rule at the zero lower bound would read  $\tilde{R}_t = -\ln(R)$ . In other words, the net nominal interest rate would be exactly zero.

## 4.2 Policy Changes

To characterize policymakers' behavior out of the zero lower bound, 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 (Table 2) 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 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:  $\psi_\pi > 1$  and  $\delta_b > \beta^{-1} - 1$ . We will refer to this policy combination as *Monetary led regime*.

The second determinacy region, Passive Monetary/Active Fiscal (PM/AF), is less familiar and corresponds to the case in which the fiscal authority is not committed to stabilizing the process for debt:  $\delta_b < \beta^{-1} - 1$ . 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:  $\psi_\pi < 1$ . 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 will label this policy combination as *Fiscally led regime*. Finally, when both authorities are active (AM/AF) no stationary equilibrium exists, whereas when both of them are passive (PM/PF) the economy is subject to multiple equilibria.<sup>9</sup>

In the benchmark model, when the preference shock is high ( $\xi_t^d = h$ ), the economy is out of the zero lower bound ( $Z_{\xi_t^d} = 0$ ) and the evolution of policymakers' behavior is captured by a two-regime Markov

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study the consequences of policy uncertainty.

<sup>9</sup>Benhabib et al. (2001a) show that if money is assumed to enter or not preferences and technology matters for whether a particular monetary/fiscal regime is conducive to determinacy. Our setting is standard in this respect and Leeper's (1991) partition applies.

	Active Fiscal (AF)	Passive Fiscal (PF)
Active Monetary (AM)	No Solution	<b>Determinacy</b>
Passive Monetary (PM)	<b>Determinacy</b>	Indeterminacy

Table 2: Partition of the parameter space according to existence and uniqueness of a solution (Leeper 1991).

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  $p_{ji} = P(\xi_{t+1}^p = j | \xi_t^p = i)$ . 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*, under which the Taylor principle is satisfied and fiscal policy accommodates the behavior of the monetary authority. In terms of policy parameters, this implies that  $\psi_{\pi,M} = \psi_{\pi}^A > 1$  and  $\delta_{b,M} = \delta_b^P > \beta^{-1} - 1$ . Regime F is the *Fiscally led regime*. Under such a regime, the central bank reacts less than one-for-one to inflation and the fiscal authority does not move surpluses in response to movements in government debt:  $\psi_{\pi,F} = \psi_{\pi}^P < 1$  and  $\delta_{b,F} = \delta_b^A < \beta^{-1} - 1$ .

When the low value for the preference shock occurs ( $\xi_t^d = l$ ), the zero lower bound becomes binding ( $Z_{\xi_t^d} = 1$ ), and policymakers' behavior is now constrained. In this third policy combination the nominal interest rate is set to zero and the fiscal authority disregards the level of debt:  $\delta_Z = 0$ . Notice that the zero-lower-bound policy mix can be considered as an extreme version of the Fiscally led policy mix. However, while out of the zero lower bound, switches to the Fiscally led regime capture deliberate choices of policymakers, the adoption of the zero-lower-bound regime is induced 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 ( $\xi_t^d = h$ ), policymakers' behavior is not constrained anymore.

It is worth emphasizing that even if the zero lower bound 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 understand the macroeconomic dynamics at the zero lower bound. To capture this feature, we introduce a parameter controlling the expected exit strategy from the zero lower bound (ZLB). The parameter  $p_{MZ}$  represents the probability that once the discrete preference shock will be reabsorbed, the economy will move to the Monetary led regime.

In summary, the joint evolution of policymakers' behavior and the discrete preference shock is captured by the regime obtained combining the two chains  $\xi_t = [\xi_t^p, \xi_t^d]$ . 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 preference shock, the transition matrix  $H^p$ , which describes policymakers' behavior out of the zero lower bound, and the parameter  $p_{MZ}$  that controls the probability of moving to the Monetary led regime once the negative preference shock

is reabsorbed:

$$H = \begin{bmatrix} p_{hh}H^p & (1 - pu) \begin{bmatrix} p_{MZ} \\ p_{FZ} \end{bmatrix} \\ (1 - p_{hh}) [1, 1] & pu \end{bmatrix}.$$

where  $p_{FZ} = 1 - p_{MZ}$ .

### 4.3 Solving and Estimating 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 zero lower bound and the possibility of changes in policymakers' behavior. Furthermore, they understand that entering the zero lower bound is an event induced by an exogenous shock that can modify policymakers' behavior even 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 zero lower bound. The solution can be characterized as a regime-switching vector autoregression, of the kind studied by Hamilton (1989), Chib (1996), and Sims and Zha (2006):

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

where  $\theta$ ,  $\theta^v$ , 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 ( $\theta$ ), the regime in place ( $\xi_t$ ), and the probability of moving across regimes ( $H$ ). This means that what happens under one regime does not only depend 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.

## 5 Policy Uncertainty and the Zero Lower Bound

The law of motion (7) is combined with a system of observation equations. The likelihood is combined with a prior distribution for the parameters to obtain the posterior. As a first step, a block algorithm is used to find the posterior mode, while a Metropolis algorithm is used to draw from the posterior distribution. Appendix C provides evidence for convergence.

We include seven observables spanning the sample 1954:Q4-2014:Q1: real GDP growth, annualized GDP deflator inflation, FFR, annualized debt-to-GDP ratio on a quarterly basis, federal tax revenues

to GDP ratio, federal expenditure to GDP ratio, and a transformation of government purchases to GDP ratio. Appendix D describes the dataset in detail. All variables are expressed on a quarterly basis: This implies that a value of 200% for the debt-to-GDP ratio corresponds to a 50% debt-to-GDP ratio on annual basis, given that in the latter case quarterly GDP would be multiplied by 4.

For tractability we fix the regime sequence for the out of the zero lower bound regimes based on the VAR evidence presented in Section 3. As explained before, the VAR estimates obtained are also consistent with the results of Bianchi and Ilut (2015) for the pre-2008 period. Bianchi and Ilut (2015) estimate a DSGE model similar to the one described above, but they do not model the zero lower bound and exclude the recent years. They find that the fiscal authority was the leading authority in the '60s and '70s. The fiscally led regime is assumed to be in place from 1957:Q2 to 1981:Q3, while over the remainder of the sample the Monetary led regime is assumed to prevail. The zero lower bound regime starts in 2008:Q4 and remains in place until the end of the sample. As starting date of the zero lower bound 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 2008:Q1 and 2009:Q3 as possible starting dates. The outcome of this exercise is presented in Appendix E.

## 5.1 Parameters Estimates and Regime Probabilities

Table 3 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 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 ( $\rho_{eL} = .99$ ) and the standard deviation of its innovations ( $\sigma_{eL} = .1\%$ ).<sup>10</sup> We fix the discount factor  $\beta$  to .9985, a value broadly consistent with an annualized 2% real interest, and the average maturity to 5 years (this is controlled by the parameter  $\rho$ ). We choose priors for the persistence of the policy regimes roughly in line with the persistence of the two regimes implied by the regime sequence recovered when estimating the MS-VAR. Finally, we chose a loose and symmetric prior for the parameter  $p_{MZ}$ , which captures the probability of the Monetary led policy mix conditional on abandoning the ZLB policy. This parameter captures the uncertainty about the policy that will be carried out after the liftoff of the interest rate from the ZLB. As we shall show, this form of uncertainty is a key element to explain the absence of deflation observed during the Great Recession. Our symmetric and broad prior implies that we maintain an agnostic view with respect to which exit strategy agents should regard as more likely.

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<sup>10</sup>This choice imposes a constraint on the amount of macroeconomic volatility that can be explained by the long term component. Our results are confirmed when removing this constraint.

	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
$p_{MZ}$	0.9225	0.8108	0.9861	D	0.50	0.22
$\psi_Z$	0.9678	0.9596	0.9761	B	0.95	0.02
$\kappa$	0.0073	0.0052	0.0098	G	0.3	0.15
$\rho_{tr}$	0.4599	0.3677	0.5537	B	0.2	0.05
$\delta_y$	0.2766	0.1899	0.3707	N	0.4	0.2
$\delta_e$	0.3661	0.2096	0.5137	N	0.5	0.2
$\phi_y$	-0.2910	-0.3433	-0.2435	N	-0.4	0.2
$\Phi$	0.8628	0.8299	0.8928	B	0.5	0.2
$\rho_g$	0.9796	0.9742	0.9839	B	0.5	0.2
$\rho_a$	0.4053	0.1522	0.6480	B	0.5	0.2
$\rho_d$	0.3944	0.2881	0.4963	B	0.5	0.2
$\rho_{tp}$	0.3267	0.2276	0.4218	B	0.5	0.2
$\rho_\mu$	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
$100\pi$	0.4631	0.3955	0.5369	G	0.5	0.05
$100\gamma$	0.4185	0.3523	0.4849	G	0.4	0.05
$b^m$	1.0689	0.9368	1.1983	N	1	0.1
$g$	1.0865	1.0779	1.0960	N	1.06	0.04
$\tau$	0.1721	0.1670	0.1779	N	0.18	0.01

Table 3: Posterior means, 90% posterior error bands and priors of the model parameters. For the structural parameters, M stands for Monetary led regime, whereas F stands for 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.

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 regime. Under the Fiscally led and ZLB regimes the response of taxes to debt is restricted to zero, while under the Monetary led regime it turns out to be significantly larger than the threshold value described in Subsection 4.2 ( $\beta^{-1} - 1 = .0015$ ).

As mentioned above, we fixed the regime sequence. Therefore the estimates of the transition matrix are determined by the model dynamics across the different regimes and not by the frequency of regime changes. It is therefore useful to review the properties of the estimated transition matrix. Both the Monetary led regime and the Fiscally led regime are 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 zero lower bound. Finally, when at the ZLB agents regard as more likely that once the negative preference shock is reabsorbed policymakers will move to the Monetary led regime ( $p_{MZ} = 92\%$  at the posterior mean). However, it is important to emphasize that this probability is smaller than the estimated persistence of the Monetary led regime ( $p_{MM}$  is around 99%). Therefore, our estimates suggest that when the economy entered the ZLB the probability attached to switching to the Fiscally led regime increased. This result seems quite robust as we started with an agnostic prior centered on 50% and obtained a posterior centered on 92.25% with 90% error bands ranging from 81.08% to 98.61%.

Before proceeding, 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 the 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.<sup>11</sup> Similarly, the properties of the monetary led regime are mostly pinned down by the behavior of the economy during the post-Volcker disinflation period. At the zero lower bound we observe the behavior of the fiscal variables, whereas the FFR is stuck at zero. The parameter  $p_{MZ}$  is then identified by the effects that these fiscal imbalances have on inflation and real activity. As it will become clear in Section 7, for given properties of the monetary led and fiscally led regime, the effects of fiscal imbalances on the macroeconomy vary substantially in response to movements of this parameter. If we were to just estimate the model at the zero lower bound without including the remainder of the sample, we would have many more degrees of freedom because the properties of all three regimes and the exit strategy should be entirely inferred based on the dynamics at the zero lower bound.

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<sup>11</sup>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 a feedback effects from the macroeconomy to the fiscal variables.

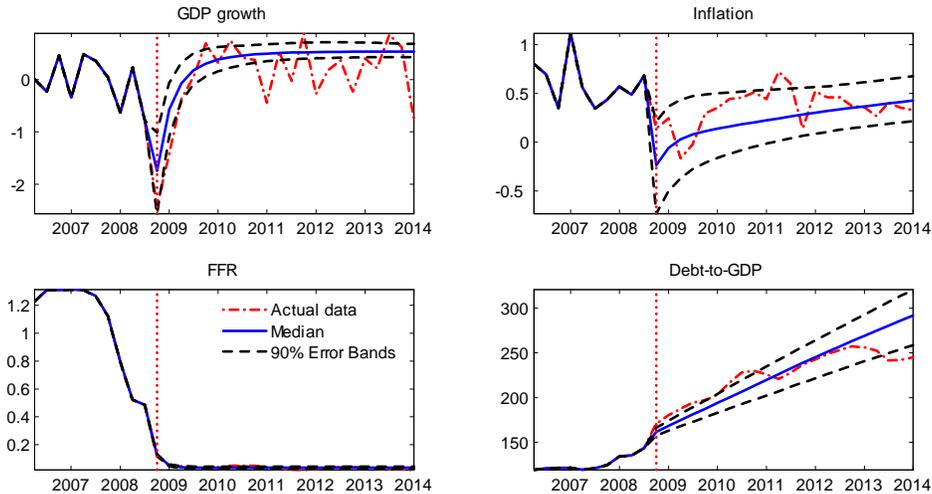


Figure 4: **Macroeconomic dynamics at the zero lower bound.** Response of GDP growth, inflation, FFR, and debt-to-GDP ratio to a discrete negative preference shock. The red dashed line reports actual data.

## 5.2 Dynamics at the Zero-Lower-Bound

Figure 4 reports the estimated impulse response to a discrete negative preference shock  $\bar{d}_t$ . 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. Using actual data as a starting point serves two purposes. First, it allows us to easily assess the relative importance of the discrete preference shock in explaining the macroeconomic dynamics during the current recession. Second, it allows us to account for the fact that the impulse response is not invariant with respect to the state of the economy. This is because the negative preference shock also implies a change in expectations about future policymakers' behavior. We will soon show that the fiscal situation is important to understand how the economy behaves in presence of this increase in policy uncertainty.

The model is able to replicate the key changes that occurred starting with the 2008 crisis as a result of a single disturbance, the discrete negative preference shock. The economy experiences a drop in real activity, a large increase in the debt ratio, monetary policy enters the zero lower bound, but inflation remains relatively stable. It is also interesting to notice that the model is not only able 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.

In order to emphasize that the absence of deflation is tightly linked to uncertainty about future policymakers' behavior, Figure 5 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 zero lower bound (black dashed line). Thus the vertical distance between the two lines captures the effects of uncertainty about the exit strategy on 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

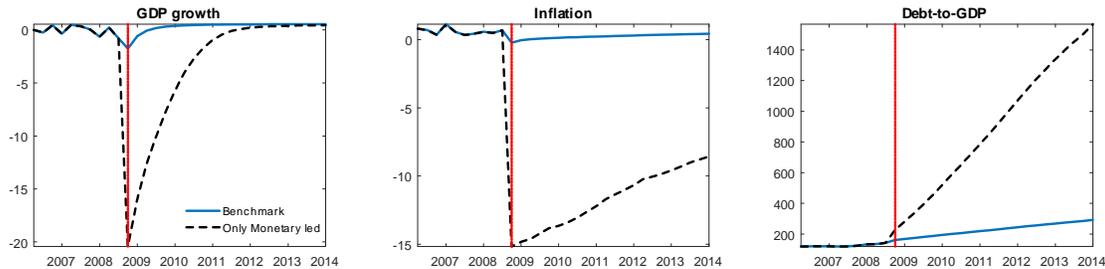


Figure 5: **Actual and counterfactual impulse responses to a discrete negative preference shock.** The solid blue line corresponds to the estimated model, whereas the black dashed line corresponds to a counterfactual economy in which the Monetary led policy mix is the only possible policy mix.

expect that the entire debt-to-GDP ratio will eventually be repaid with an increase in taxation.

Therefore, when the possibility of a switch to the fiscally led regime is ruled out, entering the zero lower bound implies a large contraction in real activity and a large deflation, in line with the textbook version of the New Keynesian model. The fact that the model can in principle reproduce the standard features of the zero lower bound is important: The data could reject the role played by policy uncertainty in explaining inflation dynamics. For example, the estimates could have suggested a very flat Phillips curve, a very small probability of ever moving to the Fiscally led regime, a small preference shock not large enough to determine deflation, or a counteracting mark-up shock that keeps inflation positive. Instead, the estimates suggest that the preference shock was in fact large, in a way to explain the prolonged 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.<sup>12</sup> In Section 7 we will examine more in detail why entering the zero lower bound could lead to an increase in the probability of a change in the monetary/fiscal policy mix.

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 3, the posterior mean of the probability of moving to the Monetary led policy mix once out of the ZLB regime is  $p_{MZ} = 92.25\%$ . This implies that while at the zero lower bound agents are inclined to believe that policymakers will eventually resume the same policy mix observed before the Great Recession. Such a belief is plausible 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 before, the value also implies an increase in the probability of moving away from the Monetary led regime with respect to the pre-crisis period. Also note that in the estimated model the inflationary effects of public uncertainty about the exit strategy are linked to the pre-crisis level of government debt, which is observed to be above its estimated steady-state value (around 170% of quarterly GDP or 42.5% on annual basis).

Figure 6 provides further corroborating evidence for 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 uncer-

<sup>12</sup>In Appendix F 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).

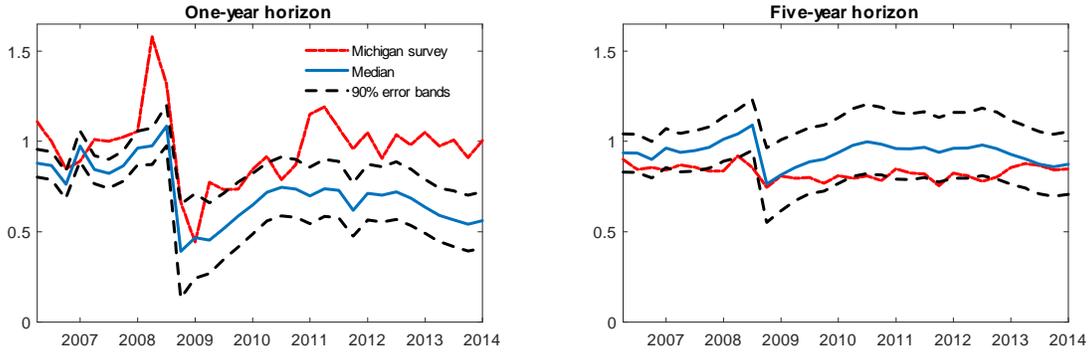


Figure 6: **Inflation expectations.** The figure reports the evolution of the model implied one-year-ahead and five-year-ahead inflation expectations together with the Michigan surveys (red dashed dotted line).

tainty. They are obtained computing the model implied expectations for each draw from the posterior distribution. Even though we do not use inflation expectations for estimation, the model is able to replicate the salient features of the Michigan surveys. First of all, the model captures the upward trend in inflation expectations that is visible right before the recession started and that can be explained in light of an increase in the fiscal burden during those years. In the data, such a trend is somehow more pronounced than in the model toward the early 2008. 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, in line with what predicted by the model, as more time is spent at the zero lower bound inflation expectations show an upward trend as a result of the large debt accumulation.

We find reassuring that the model is able to replicate these key facts even if inflation expectations are not included in the estimates. 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 particularly important to emphasize that inflation expectations moved down, as predicted by our model, when the ZLB was encountered, but they never entered the negative territory. In other words, agents were somehow confident that deflation would not have occurred. Instead, in the baseline New Keynesian model in which the Monetary led policy mix is the only possible regime, agents should expect deflation once the economy enters the zero lower bound. 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.

### 5.3 Inspecting the fiscal mechanism

In order to understand why the possibility of changes in the monetary/fiscal policy is important to rationalize the absence of deflation, Figure 7 reports the impulse responses to an increase in the long term component of transfers under the three different regimes. Impulse responses are computed conditionally on one regime being in place over the entire horizon. Nevertheless, model dynamics reflect the possibility

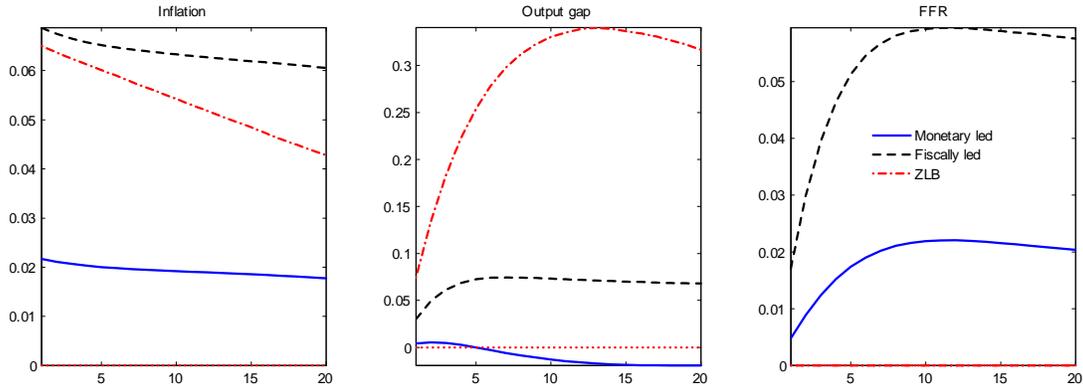


Figure 7: **Impulse responses to a shock to transfers.** The impulse responses are computed assuming a regime in place over the the relevant horizon. However, agents form expectations taking into account the possibility of regime changes.

of regime changes. We choose to report impulse responses to a shock to the long term component of transfers for two reasons. First, under the maintained assumption of non-distortionary taxation shock to the trend component of transfers would not have any impact on the macroeconomy if the Monetary led policy mix were the only possible regime because in that case the government would be fully committed to move taxes in response to fiscal imbalances. Second, this shock has a direct impact on the debt-to-GDP ratio and, consequently, on the amount of spending that would need to be financed with future taxes.

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. Given that the Taylor principle does not hold, the response of the FFR is less than one-to-one. 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 growth in real economic activity. The macroeconomy is therefore not insulated with respect to fiscal imbalances even if taxation is non-distortionary.

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 by taking into account the possibility of moving to the Fiscally led regime. As a result, a high level of debt determines some inflationary pressure even when the Monetary led regime is in place. This feature of the model is in line with the results obtained by Bianchi and Ilut (2015) in an estimated model, Davig and Leeper (2006) in a calibrated model, and Davig et al. (2007) in an analytical example. 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.

Finally, under the zero lower bound regime the effects of the fiscal shock are quite similar to those that characterize the Fiscally led regime. The increase in spending triggers a fairly 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. Therefore, the zero lower bound regime presents many of the characteristics of a Fiscally led regime, even if the probability assigned to a return to the Monetary led regime is quite large. Furthermore, these results suggest that at the zero lower bound, the effects of the shocks are amplified by the fact that the FFR cannot respond to macroeconomic fluctuations.

In summary, two important lessons can be drawn from this exercise. First, under the Fiscally led regime, the macroeconomy is not insulated with respect to fiscal imbalances. Second, as long as agents are aware of regime changes, even under the Monetary led regime and the zero lower bound regime the macroeconomy is not insulated with respect to fiscal disturbances and fiscal imbalances have inflationary pressure. This inflationary pressure would disappear only if the Monetary led policy mix were the only possible one. This explains the large recession and large deflation in the counterfactual economy presented in Figure 5.

## 6 No Fiscal Uncertainty

In the previous section, we have used a counterfactual simulation to highlight the role of fiscal uncertainty in accounting for the absence of deflation. However, it could be that a model without fiscal uncertainty would find another way to rationalize the absence of deflation. Therefore, we go one step further and compare our benchmark model with an estimated nested model obtained by removing the fiscal block (except for government expenditure). Therefore, the model is similar to the traditional New Keynesian model used by 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, FFR, 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. Details about the model and the parameter estimates can be found in Appendix G.

This alternative model is useful to illustrate the importance of allowing for the fiscal block and policy uncertainty in order to capture the dynamics at the zero lower bound. Figure 8 reports the estimated impulse response to a discrete negative preference shock  $\bar{d}_t$  based on this alternative model. The figure is the analogous of Figure 4 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. From the figure, it emerges that, 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 a single shock, 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.

In order to formalize this visual impression, Table 4 reports the average of the squared difference

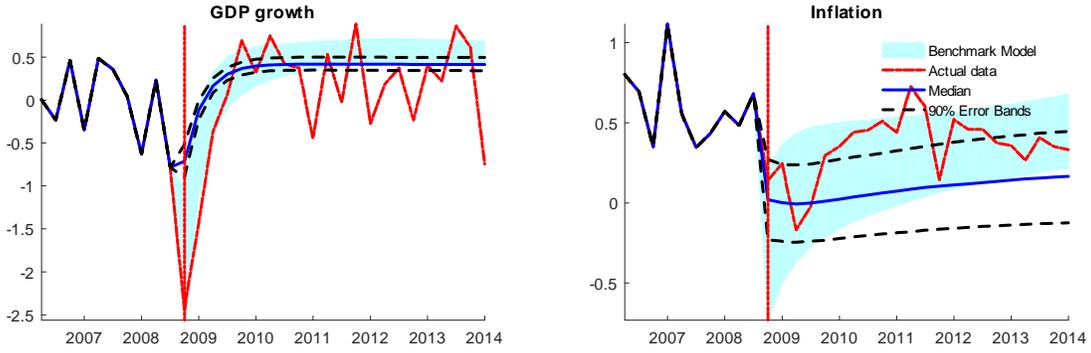


Figure 8: **Macroeconomic dynamics at the zero lower bound for a model without the fiscal block.** Response of GDP growth and inflation to a discrete negative preference shock based on a model that excludes the fiscal block. The red dashed line reports actual data, while the shaded areas report the 90% error bands for the benchmark model.

Benchmark Model					
Variable	<i>Median</i>	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	<i>Median</i>	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 4: Average of the squared differences between the actual data and the path implied by the discrete preference shock. The top panel refers to the benchmark model, the lower panel refers to a traditional new-Keynesian model that excludes the fiscal block. The period considered is 2008:Q4-2014:Q1.

between the actual data and the path implied by the discrete shock based on the two models. The benchmark model delivers better results both for inflation and output growth. However, in line with what could already be inferred by the picture, the gains are particularly large for output growth. Not only the median of the squared deviations is significantly smaller, but also the 68% bands do not overlap. As shown in Appendix G, the model without the fiscal block relies on an additional TFP shock in order to reconcile the joint dynamics of inflation and output. 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. The single discrete shock is not able to account for both the lack of deflation and the large recession. The model uses the discrete shock to fit inflation dynamics, leaving the behavior of output to be explained by a contemporaneous TFP shock.

As further evidence in favor of the mechanism proposed in this paper, Figure 9 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, that are outside the 90% error bands most of the time. This is true for both the one-year and the five-year horizons. Furthermore, the alternative model does worse both before and after the economy entered the zero lower bound.

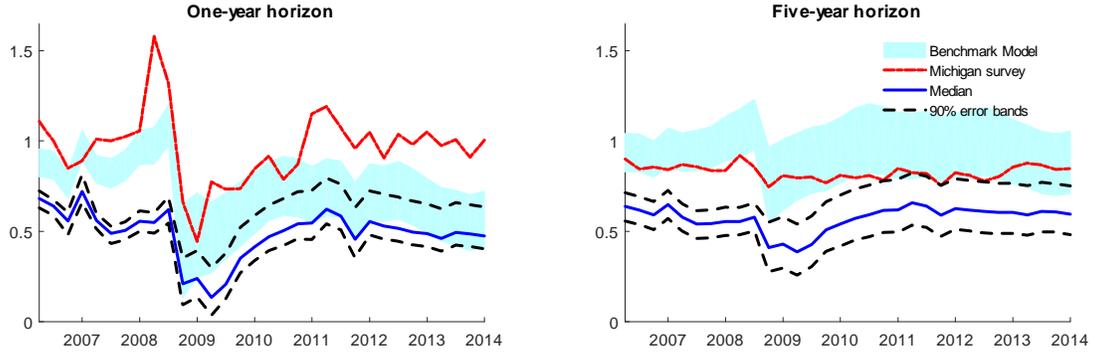


Figure 9: **Inflation expectations for the model without the fiscal block.** The figure reports the evolution of the one-year-ahead and five-year-ahead inflation expectations implied by the alternative model that excludes the fiscal block. The red dashed lines correspond to the Michigan surveys inflation expectations. The shaded areas report the 90% error bands for the benchmark model.

Benchmark Model					
Variable	<i>Median</i>	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	<i>Median</i>	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 5: Mean of squared differences between model implied and actual inflation expectations for the 1-year and the 5-year horizons. The top panel refers to the benchmark model, the lower panel refers to a traditional new-Keynesian 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).

Table 5 formally compares the two models with respect to the ability of replicating the dynamics of inflation expectations. For each model, we compute the squared distance between the model implied inflation expectations and the actual inflation expectations. It is important to check that the improvement in the ability of matching the behavior of inflation expectations does not only occur over the zero lower bound period, because this could be just a lucky coincidence. We therefore take the average of the squared differences over the whole sample for which inflation expectations are available (1978:Q1-2014:Q1) and for two subsamples: before and after entering the zero lower bound. The benchmark model performs better than the alternative model over all subsamples and for both horizons.

Summarizing, three lessons can be drawn by comparing the two models. First, a model that excludes the fiscal block needs to rely on a combination of shocks to match the key macroeconomic dynamics experienced at the zero lower bound. Second, if the data were at odds with the idea that fiscal variables are important to understand the lack of deflation at the zero lower bound, this would emerge from the estimates. This is because the alternative model without the fiscal block is nested in our benchmark model. Therefore, the estimates could shut down the fiscal channel at the zero lower bound and rely on a combination of shocks to explain what happened starting from 2008. Finally, the benchmark model dominates the alternative model also in the ability of matching the behavior of inflation expectations at 1-year and 5-year horizons, two variables that we have not used in our estimation.

## 7 Policy Trade-off

We have shown that policy uncertainty about the way debt will be stabilized can empirically account for the absence of deflation at the zero lower bound. In this section, we are interested in assessing why policy uncertainty is likely to increase once the economy enters the zero lower bound. We will show that while the Monetary led regime leads to a more stable macroeconomic environment during regular times, extraordinary events can make deviating from such a regime desirable. One of such events is a significant drop in aggregate demand, which is induced by the discrete preference shock  $\bar{d}_l$ . Therefore, a policy trade-off arises at the zero lower bound: mitigating a large recession or preserving long-run macroeconomic stability. If agents are uncertain about which one of these goals is more important for policymakers, policy uncertainty naturally arises and deflation is not a necessary implication of entering the zero lower bound.

### 7.1 Mitigating the Recession...

As a first step, we will consider the effects of different policy announcements following the negative preference shock. This will highlight why policymakers might be tempted to move away from the monetary led policy mix once the economy enters the zero lower bound and why this particular kind of policy uncertainty prevents inflation from falling. As before, we consider the US economy as it was in 2008:Q3, when the most recent crisis started, and we analyze the effects of the large negative preference shock  $\bar{d}_l$  occurring in 2008:Q4. Recall that before the shock occurred, policymakers were following the Monetary led regime. We analyze three different scenarios concerning policymakers' behavior. In the

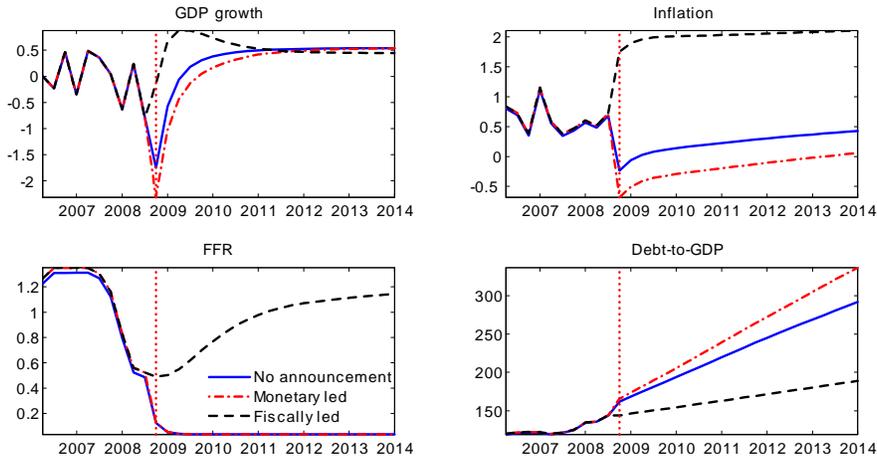


Figure 10: **Macroeconomic Dynamics with Coordinated Announcements:** The figure reports the effects of coordinated announcements following a large negative preference shock that can force the interest rate to the zero lower bound. Three cases are considered for the exit strategy. In the first case ("Monetary led"), policymakers announce a return to the Monetary led regime; in the second case ("Fiscally led"), a switch to the Fiscally led regime is announced; the third case ("No Announcement"), no announcement about the exit strategy is made. This corresponds to the estimated benchmark model and it is represented by the solid blue line.

first scenario, we consider the benchmark model in which no announcement is made. In the second and third scenario policymakers make 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. In the case of announcements, the probability of announcing a return to the Monetary led regime is fixed to  $p_{MZ}$ . Appendix B.3 provides details on how to build the transition matrix for the economy with announcements.

It is worth emphasizing that in these simulations agents are fully aware of the structure of the model. Therefore, they understand that in response to the negative preference shock policymakers can follow one of the two exit strategies outlined above. However, agents do not know *when* the preference shock will return to the high value ( $\xi_t^d = h$ ) and are aware that in the future zero lower bound episodes might occur again. In other words, unlike previous contributions in the literature, we do not impose perfect foresight or an absorbing state for  $\xi_t^d = h$ . Furthermore, policy announcements only remove uncertainty about the regime that we will be in place once the shock is reabsorbed, but not policy uncertainty due to the fact that policy changes might occur further into the future.

Figure 10 reports the results. If policymakers announce that fiscal discipline will be abandoned (black dashed line) agents expect that the preexisting stock of debt and the additional amount of debt accumulated during the recession 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 leaving the zero lower bound.

If instead policymakers explicitly announce that the stance toward fiscal discipline has not changed

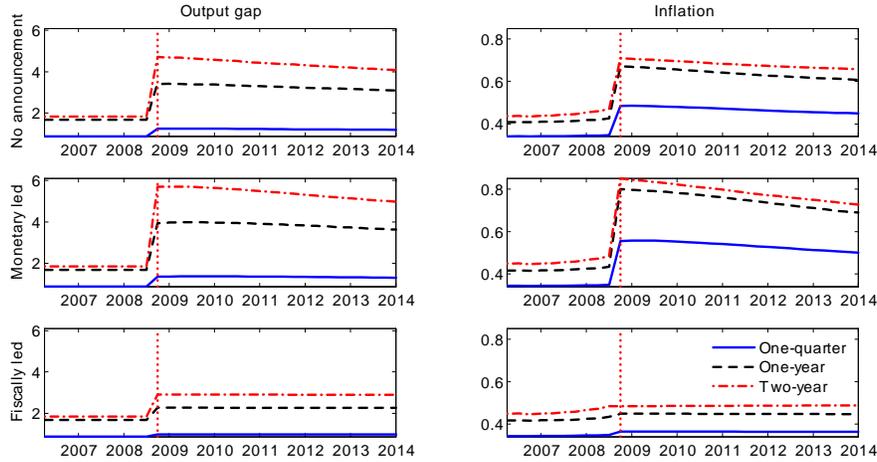


Figure 11: **Evolution of uncertainty under coordinated announcements.** The graphs report the evolution of uncertainty at different horizons following an adverse discrete preference shock and different announcements about future policy makers' behavior.

and that after the economy exits the zero lower bound they will resume the same policies that characterized the pre-crisis period, the economy enters a recession and deflation arises (red dashed-dotted line). The outcomes for this case are qualitatively in line with the traditional view about the zero lower bound. However, the drops in real activity and inflation are substantially mitigated with respect to the counterfactual economy presented in Subsection 5.2 in which the Monetary led policy mix is the only possible regime. This is because the expectations of rapid debt accumulation determine inflationary pressures even if agents expect that the Monetary led regime will follow the end of the zero lower bound. As discussed before, agents are aware of regime changes and hence know that there is a non-zero probability that the Fiscally-led policy mix will follow the announced policy shortly after the economy will be out of the zero lower bound.

The most relevant case from an empirical point of view is obviously represented by the third scenario, whose macroeconomic implications are illustrated by the solid blue line. When policymakers do not make any announcement, agents are uncertain about which exit strategy will in fact prevail. The recession is mitigated and inflation remains very close to its target value. This is because agents attach positive probabilities to the two outcomes described above: In one case, agents expect inflation stability to be preserved, while in the other case they expect a large spur of inflation in order to stabilize debt. Note that as debt keeps increasing, inflation slowly goes up in response to the increasing inflationary pressure.

Figure 11 illustrates the evolution of uncertainty across different horizons for the three scenarios presented above and using the same simulation for the preference shocks. We consider three horizons: 1 quarter (solid blue), 1 year (black dashed line), and 2 years (red dashed-dotted line). Uncertainty is computed by taking into account the possibility of regime changes and future Gaussian shocks by using the methods described in Bianchi (2014). For a variable  $X_t$  and an horizon  $q$ , it corresponds to the conditional standard deviation  $sd_t(X_{t+q})$ . In other words, the figure reports the conditional standard deviations for GDP growth and inflation at different horizons associated with the macroeconomic paths

presented in Figure 10.

Notice that as long as the economy is at the zero lower bound uncertainty is high even if policymakers announce that they will eventually return to the Monetary led regime. This is because the zero lower bound still implies uncertainty about the end of the recession and uncertainty caused by the lack of a systematic monetary policy response to the shocks hitting the macroeconomy. Only if policymakers announce that they will move to the Fiscally led regime, uncertainty drops. This is because the economy is in fact able to leave the zero lower bound thanks to the inflationary pressure coming from the fiscal imbalance. Based on these results, it is then natural to ask why policymakers do not simply announce a switch to the Fiscally led regime. We will analyze the drawbacks of such a policy in the next subsection.

The increase in uncertainty at the zero lower bound is explained by a series of factors. First, the economy is currently in a large recession and even if eventually it will do better, the timing of the recovery is uncertain. Second, as explained above, when the economy is at the zero lower bound, the probability assigned to a switch to the monetary-fiscal policy mix experiences a discrete increase. As it will be shown in Section 7, the Fiscally led regime tends to lead to an increase in macroeconomic uncertainty. Finally, the zero lower bound regime is inherently more volatile because policymakers cannot react to disturbances using the FFR.

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. Over the period from October 5, 2009 to January 23, 2012, the *probability* assigned to deflation over the one year horizon fluctuated between a minimum of 1.88% and a maximum of 44.37%, with a mean of 17.25%, while the *probability* assigned to annualized inflation being larger than 4% over the one year horizon fluctuated between a minimum of 1.75% to a maximum of 33.40%, with a mean of 10.38%. Our results are qualitatively consistent with this large level of uncertainty about inflation and rationalize these large and high-frequency swings in beliefs as changes in agents' expectations about how policymakers will address the issue of stabilizing the growing public debt. 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.

At the same time, it is worth emphasizing that the measures of uncertainty reported here reflect 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 statistical models such as the ones presented by Jurado et al. (2013). 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 zero lower bound, but it stays low while the economy remains at the zero lower bound, given that no further large changes in real activity or inflation occur.<sup>13</sup> Such a measure of uncertainty would be in line with the evidence presented in Jurado et al. (2013). Therefore, our results

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<sup>13</sup>See Justiniano and Primiceri (2008), Bianchi (2013), and Bianchi and Ilut (2015) for example of DSGE models that allow for heteroskedasticity.

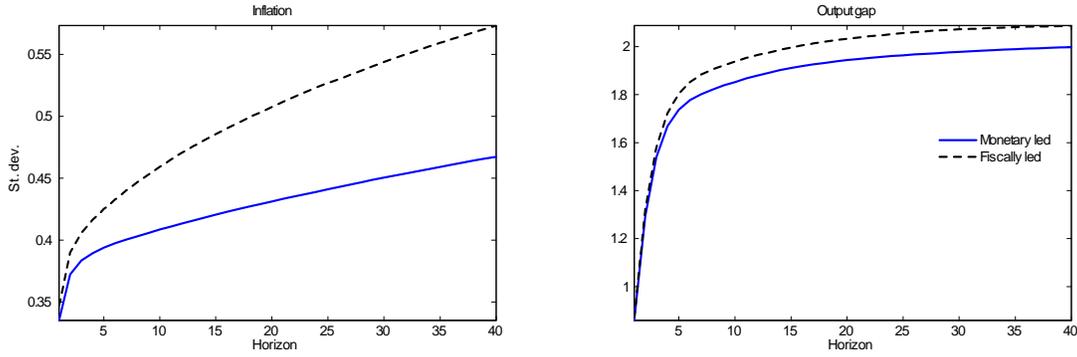


Figure 12: **Evolution of uncertainty when out of the zero lower bound.** The graphs report the evolution of uncertainty at different horizons conditional on being in specific regime at time 0 taking into account the possibility of future regime changes.

should be interpreted as showing that the zero lower bound implies an increase in uncertainty for a given level of volatility of the exogenous shocks.

## 7.2 ...at the Cost of Higher Macroeconomic Uncertainty

In the previous subsection, we showed that policymakers could escape the Great Recession and partially mitigate the associated increase in uncertainty if they were willing to move to the Fiscally led regime. In this subsection, we will present the drawback of such a regime change: While the regime shift would largely mitigate the recession in the short run, it would also imply an increase in macroeconomic uncertainty in the long run. In other words, we will show that the Monetary led regime generally implies a more stable macroeconomic environment when out of the zero lower bound.

Figure 12 reports the evolution of uncertainty at different horizons, from 1 quarter to 10 years, for the Monetary led and the Fiscally led regime. This measure of uncertainty is computed by taking into account the possibility of regime changes and the occurrence of Gaussian shocks. 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, the central bank behaves according to the Taylor principle, leading to a further reduction in volatility. If instead policymakers follow the Fiscally led regime, uncertainty increases at all horizons. This is because of two reasons. First, the central bank reacts less aggressively to economic fluctuations given that the Taylor principle is not satisfied. Second, agents anticipate that all fiscal imbalances that are largely neutralized when policymakers follow the Monetary led regime will now strongly affect inflation and real economic activity. Inflation, not taxation, will mainly adjust to stabilize the path for debt. In other words, the macroeconomy is heavily affected by fiscal imbalances when policymakers adopt a Fiscally led policy mix. As a result, under this policy mix, uncertainty is higher at every horizon because agents expect all future fiscal imbalances to be largely inflated away.

The level of uncertainty under the Monetary led regime is higher than what would be if the Monetary led regime were the only possible one. This is for two reasons. First, as shown in Subsection 5.3, the macroeconomy is not fully insulated with respect to fiscal imbalances because agents always discount

the possibility of a switch to the Fiscally led policy mix. This effect is present at all horizons. Second, uncertainty is computed by taking into account that in the future the economy might in fact switch to the Fiscally led policy mix. This effect is increasing with the time horizon. In fact, as the horizon approaches infinity, the regime probabilities converge to their ergodic values and so does uncertainty.

In summary, our estimates imply that when out of the zero-lower-bound, the Monetary led regime is generally preferable because it leads to a stable macroeconomic environment. To the extent that macroeconomic stability is desirable, countries with a strong reputation for fiscal discipline will benefit from a more favorable outcome *during regular times*. This result is key to understand the ensuing slow recovery and why many countries, including the US, have not explicitly announced a departure from their long-run policy strategy during the Great Recession. When a departure from the Monetary led policy mix is announced, the persistence of the Fiscally led policy mix is critical to explain the increase in inflation expectations. The announcement is effective in mitigating 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 agents expect that debt will be inflated away. If the Fiscally led regime had low persistence, the announcement would lead to effects on the output gap, inflation, and the macroeconomic volatility that are very similar to those associated with announcing a return to the Monetary led policy mix. Agents would simply expect a change in the timing of the fiscal adjustments. Therefore, the increase in uncertainty and the reduction in the magnitude of the recession are two sides of the same coin.

## 8 Escaping the Great Recession

We showed that at the zero lower bound policymakers could generate an increase in inflation expectations to stimulate the economy by embracing the Fiscally led regime. However, in order for such a regime change to have an effect, agents have to perceive it as long lasting. In fact, announcing that a Fiscally led policy mix will be implemented for too short a time after the economy has exited the zero lower bound would lead to virtually the same macroeconomic effects as announcing fiscal discipline. In other words, once out of the recession, policymakers have to follow the Fiscally led policy mix for a *prolonged* period of time. Since such a prolonged deviation from fiscal discipline leads to a persistent increase in uncertainty at all horizons, policymakers can be rightfully reluctant to abandon the Monetary led regime because this regime guarantees a stable macroeconomic environment during regular times.

In this section, we propose a possible resolution of this policy trade-off. Policymakers can achieve the goal of increasing inflation expectations and at the same preserving long-run macroeconomic stability by committing to inflating away only the amount of debt resulting from the large preference shock itself. At same time, policymakers would commit to fully repay the pre-existing amount of debt and to follow the Monetary led rule in response to all other business cycle shocks. This commitment determines a sort of *automatic stabilizer*. The large preference shock can potentially cause a deep recession and a corresponding large increase in debt. The expectation that this extra amount of debt is going to be inflated away determines an increase in inflation expectations and a corresponding drop in the real

interest rate. This stimulates real economic activity, reducing the size of the output contraction. This mechanism can be strong enough to prevent the economy from hitting the zero lower bound. At the same time, agents understand that the increase in inflation is the result of a well-defined, exceptional contractionary event, which policymakers are not responsible for, while policy strategies to cope with business cycle disturbances are unchanged. Therefore, the level of uncertainty once out of the recession immediately returns to the pre-crisis levels.

To illustrate these points, we modify the model and assume that policymakers behave according to the Monetary led policy mix all the time, except when responding to the discrete preference shock  $\bar{d}_{\xi^d}$ . Specifically, we assume that the response of the nominal interest rate to inflation and of primary surpluses to debt are both zero if movements in these variables result from the discrete preference shock. In response to all the other fluctuations, policymakers instead follow the Monetary led policy mix. In order to implement this policy we construct a *shadow economy* to keep track of the amount of debt deriving from the discrete preference shock. Policymakers do not react to debt and inflation caused by the discrete preference shock, while they follow the Monetary led policy mix in response to all other shocks. If we denote debt and inflation of the shadow economy in which discrete preference shocks are shut down as  $b_t^{nd}$  and  $\pi_t^{nd}$ , we can write the linearized policy rules as:

$$\begin{aligned}\tilde{\tau}_t &= \dots \delta_{b,M} \tilde{b}_{t-1}^{nd} + \delta_{b,E} \left( \tilde{b}_{t-1} - \tilde{b}_{t-1}^{nd} \right) + \dots, \\ \tilde{R}_t &= (1 - \rho_{R,M}) \left( \psi_{\pi,M} \tilde{\pi}_t^{nd} + \psi_{\pi,E} \left( \tilde{\pi}_t - \tilde{\pi}_t^{nd} \right) \right) + \dots,\end{aligned}$$

where we assume  $\delta_{b,E} = \psi_{\pi,E} = 0$  and the letter "E" stands for "Escaping."<sup>14</sup> This implies that future fiscal adjustments are not enough to stabilize the entire stock of debt  $\tilde{b}_{t-1}$ , but only  $\tilde{b}_{t-1}^{nd}$ : The amount  $\tilde{b}_{t-1} - \tilde{b}_{t-1}^{nd}$  is going to be inflated away. At the same time, the central bank accommodates the resulting increase in inflation  $\tilde{\pi}_t - \tilde{\pi}_t^{nd}$ . This is the increase of inflation necessary in order to inflate away the additional amount of debt resulting from the recession induced by the negative preference shock.

In Figure 13, we consider two scenarios. In the first one (solid blue line), the shock specific rule is implemented. In the second one, we report the behavior of the economy under the estimated benchmark model (black dashed line). Under the shock specific rule, the drop in real activity is substantially smaller than under the estimated benchmark model, and we do not observe deflation. This is due to the mechanism outlined earlier: The increase in expected inflation prevents a large drop in inflation today and determines a decline in the path of the real interest rate. Notice that instead inflation keeps increasing as more time is spent with the negative preference shock in place. However, the increase in inflation is quite modest. This is because the recession is largely mitigated, implying that the amount of debt that needs to be inflated away turns out to be small. Furthermore, it is important to point out that the behavior of the macroeconomy does not depend on the level of debt prevailing when the economy entered the zero lower bound because the preexisting amount of debt is always backed by future fiscal adjustments.

It is also worth pointing out that the macroeconomy also behaves differently when out of the zero

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<sup>14</sup>Appendix H explains more thoroughly how we model the shock-specific policy rule.

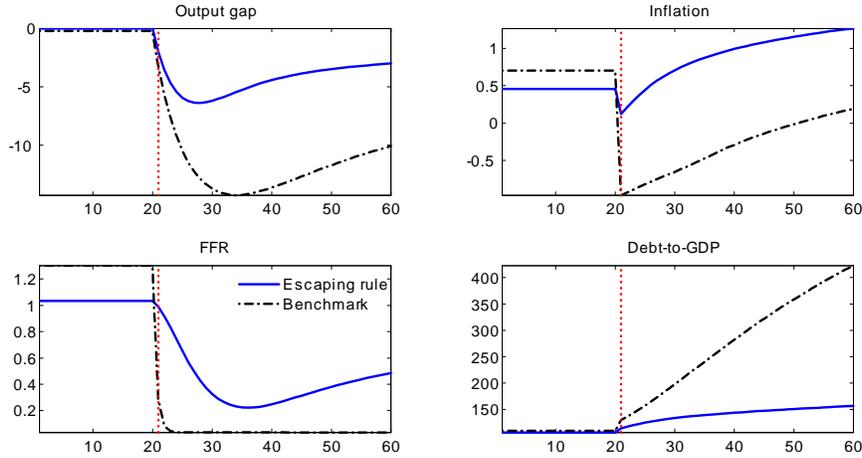


Figure 13: **Escaping the Great Recession.** The graph reports the evolution of the macroeconomy in response to a discrete negative preference shock for the estimated model (black-dashed line) and for the counterfactual economy in which all debt accumulated during the recession is inflated away.

lower bound because agents form expectations by taking into account all alternative scenarios. As a result, inflation is generally closer to its deterministic steady state when out of the zero lower bound. This result stems from the fact that agents are not concerned about the possibility of large spurs of inflation deriving from a shift in the monetary/fiscal policy mix.

The fact that policymakers inflate away only an amount of debt that can be imputed to the large negative preference shock has important consequences for the level of uncertainty and macroeconomic volatility faced by agents in the model. Figure 14 shows that the shock specific rule leads to a substantial reduction in uncertainty. When out of the zero lower bound uncertainty is lower because business cycle shocks are always stabilized according to the Monetary led policy mix. In correspondence of the negative preference shock, the reduction in uncertainty is even more visible. The low level of uncertainty arises because policymakers are in fact able to avoid the zero lower bound and can keep reacting to the shocks hitting the macroeconomy. The result is that the overall level of uncertainty is lower than in the benchmark case both in and out of the zero lower bound. Policymakers do not have to trade off short-run gains with long-run losses anymore.

Furthermore, given that policymakers always follow the Monetary led policy mix with respect to all business cycle disturbances, we observe a further reduction in inflation volatility with respect to the case in which switches to the Fiscally led policy mix are possible. Under the proposed policy, agents know that policymakers would generate a spur of inflation only in response to a large negative preference shock. Notice that this *reduces* uncertainty because it prevents the possibility of large deflationary states. In this respect, it is interesting to notice that the resulting equilibrium path for inflation is in line with the well-established prescriptions of Eggertsson and Woodford (2003) for coping with zero-lower-bound episodes: policymakers should foster a smooth increase of inflation during and after the zero-lower-bound period. However, the mechanism outlined in this paper is quite different.

Our results are related to the idea that liquidity traps can be ruled out by making them fiscally unsustainable, as first proposed by Woodford (2003) and explored in a perfect foresight setting by

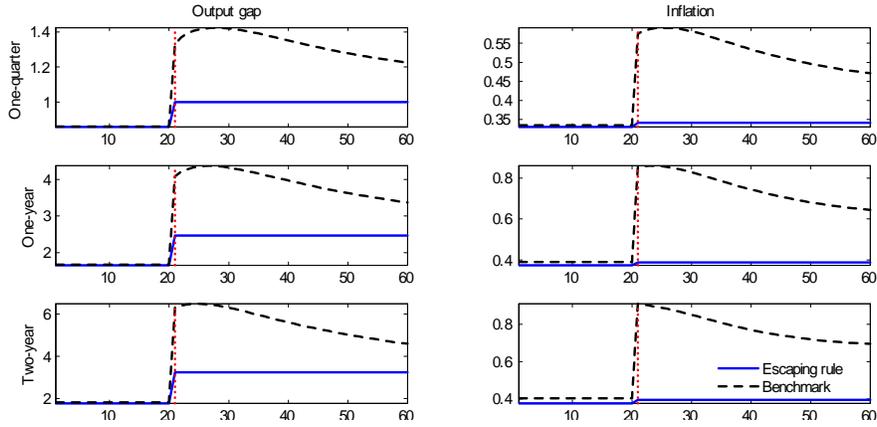


Figure 14: **Evolution of uncertainty.** The graph reports the evolution of uncertainty at different horizons for the estimated model (black-dashed line) and for the counterfactual economy in which all debt accumulated during the recession is inflated away.

Benhabib et al. (2002). An important difference is that we empirically study the relation between policy uncertainty, inflation dynamics, and macroeconomic uncertainty at the zero lower bound in a stochastic environment. A central result of our paper consists of highlighting the trade-off between avoiding deflation and preserving long run macroeconomic stability that seems to characterize the current policy debate. A fiscally led policy mix would allow policymakers to escape the Great Recession, but it would give rise to high macroeconomic uncertainty once the economy is out of the zero lower bound. Finally, our shock specific rule is able to resolve this policy trade-off without abandoning the appeal of simple rules.

In summary, the shock specific rule succeeds in mitigating the recession, and at the same time in preserving macroeconomic stability. The proposed policy succeeds in mitigating deep recessions because it modifies agents' beliefs about policymakers' long-run behavior in response to a specific shock. In fact, policymakers are committing to never increase taxes in response to the amount of debt accumulated during these deep recessions and at the same time not to fight the resulting increase in inflation. This policy triggers an increase in short-run inflation expectations and an immediate increase in inflation as large preference shocks hit the economy. At the same time, the proposed policy preserves long-run macroeconomic stability because policymakers are still committed to fully repay any preexisting stock of debt and to fully neutralize all other present and future disturbances affecting the debt-to-GDP ratio.

**Policy Implementation: An Example.** An important question is how the policy presented here could be implemented in practice. As is common in the literature, we assume in this paper that agents have perfect information and can observe the shocks hitting the economy. In reality, policymakers and agents might not have the possibility of exactly disentangling the contribution of the different shocks to the evolution of the macroeconomy. In that case, a simpler policy would consist of announcing a target for the debt-to-GDP ratio based on the pre-crisis level of debt. Policymakers would commit to raise enough taxes in order to repay the pre-existing level of debt or a projection of this value, but they would not respond to any movement in the debt-to-GDP ratio that occurs during the crisis. The part

of debt above the announced target would then be inflated away. Policymakers would then return to the Monetary led regime once the crisis is over. This approach implies that any business cycle shock that occurs during the crisis would also change the level of debt that is going to be inflated away, while in the policy presented in this paper only the amount of debt deriving from the discrete preference shock would be inflated away. As a result this more realistic approach is associated with a slightly higher uncertainty during the crisis than the shock-specific strategy we outlined, but it would have the important advantage of being easy to implement and to communicate.

Finally, in our model, the shock-specific policy occurs in response to a large negative preference shock. In reality there might be many disturbances that could require a similar change in policy. Furthermore, there might be disagreement among policymakers about whether a realized shock is large enough to trigger the policy change. A simple criterion would consist of following this alternative policy in response to all disturbances that would imply a negative policy interest rate under the Monetary led policy mix.

## 9 Conclusions

It might be argued that many countries, including the US, are now in a situation with large uncertainty about the way policymakers will deal with the large stock of debt that has been accumulated during the recent crisis. Part of the debt is expected to be absorbed by higher growth once the economy is out of the crisis. However, it is quite likely that this factor alone will not be enough to correct the dynamics of the US sovereign debt in absence of substantial fiscal adjustments or increases in inflation. 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.

In this situation, changes in beliefs about the exit strategy can generate large swings in inflation expectations and in the state of the economy. Policymakers can avoid a large collapse in output announcing a prolonged deviation from the Monetary led regime. Such an announcement is effective as long as the deviation is perceived to last for *sufficiently long*. Nonetheless, policymakers might be rightfully reluctant to follow this strategy because it leads to an unstable macroeconomic environment once the economy is out of the zero lower bound.

However, this policy trade-off can be resolved by announcing that only the portion of debt deriving from the exceptionally large shock will be inflated away. This creates a sort of automatic stabilizer: When the negative preference shock hits, agents foresee an increase in spending that in turn translates into an increase in inflation. Inflation starts increasing immediately through the expectation channel. The decline in real interest rates largely mitigates the recession and, consequently, the increase in debt itself. The final outcome is an equilibrium in which a moderate increase in inflation is spread over several quarters. Importantly, macroeconomic volatility returns to the pre-crisis levels as soon as the shock is absorbed because policymakers never changed their behavior with respect to the other disturbances affecting the macroeconomy. Therefore, policymakers succeed in mitigating the recession and preserving a stable macroeconomic environment.

## References

- Aruoba, S. and F. Schorfheide (2013). Macroeconomic dynamics Near the Zero Lower Bound: A Tale of Two Equilibria. working paper.
- Baker, S., N. Bloom, and S. Davis (2013). Measuring Economic Policy Uncertainty. Stanford working paper.
- Ball, L. and S. Mazumder (2011). Inflation Dynamics and the Great Recession. Johns Hopkins University, mimeo.
- Barsky, R., A. Justiniano, and L. Melosi (2014, May). The Natural Rate of Interest and Its Usefulness for Monetary Policy. *American Economic Review* 104(5), 37–43.
- Bassetto, M. (2002, November). A game-theoretic view of the fiscal theory of the price level. *Econometrica* 70(6), 2167–2195.
- Basu, S. and B. Bundick (2012, September). Uncertainty shocks in a model of effective demand. NBER Working Papers 18420, National Bureau of Economic Research, Inc.
- Benhabib, J., S. Schmitt-Grohe, and M. Uribe (2001a, March). Monetary Policy and Multiple Equilibria. *American Economic Review* 91(1), 167–186.
- Benhabib, J., S. Schmitt-Grohe, and M. Uribe (2001b, January). The Perils of Taylor Rules. *Journal of Economic Theory* 96(1-2), 40–69.
- Benhabib, J., S. Schmitt-Grohe, and M. Uribe (2002, June). Avoiding Liquidity Traps. *Journal of Political Economy* 110(3), 535–563.
- Bernanke, B. S. (2011). The U.S. Economic Outlook.
- Bianchi, F. (2013). Regime Switches, Agents’ Beliefs, and Post-World War II U.S. Macroeconomic Dynamics. *Review of Economic Studies* 80(2), 463–490.
- Bianchi, F. (2014). Methods for Measuring Expectations and Uncertainty in Markov-switching Models. CEPR discussion paper 9705.
- Bianchi, F. and C. Ilut (2015). Monetary/Fiscal Policy Mix and Agents’ Beliefs. CEPR discussion paper 9645, NBER working paper 20194.
- Bianchi, F., C. Ilut, and M. Schneider (2012). Uncertainty Shocks, Asset Supply and Pricing over the Business Cycle. NBER Working Paper No. 20081.
- Bianchi, F. and L. Melosi (2013, May). Dormant Shocks and Fiscal Virtue. In *NBER Macroeconomics Annual 2013, Volume 28*, NBER Chapters, pp. 1–46. National Bureau of Economic Research, Inc.
- Blanchard, O. J. and R. Perotti (2002). An empirical characterization of the dynamic effects of changes in government spending and taxes on output. *Quarterly Journal of Economics* 117(4), 1329–1368.
- Bloom, N. (2009). The Impact of Uncertainty Shocks. *Econometrica* 77, 623–685.
- Chib, S. (1996). Calculating Posterior Distributions and Model Estimates in Markov Mixture Models. *Journal of Econometrics* 75, 79–97.
- Christiano, L., M. Eichenbaum, and S. Rebelo (2011). When is the Government Spending Multiplier Large? *Journal of Political Economy* 119(1), 78–121.
- Christiano, L. J., M. S. Eichenbaum, and M. Trabandt (2015, January). Understanding the Great Recession. *American Economic Journal: Macroeconomics* 7(1), 110–67.

- Clarida, R., J. Gali, and M. Gertler (2000). Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory. *Quarterly Journal of Economics* 115, 147–180.
- Cochrane, J. H. (1998). A Frictionless Model of U.S. Inflation. In B. S. Bernanke and J. J. Rotemberg (Eds.), *NBER Macroeconomics Annual 1998*, pp. 323–384. Cambridge, MA: MIT Press.
- Cochrane, J. H. (2001). Long Term Debt and Optimal Policy in the Fiscal Theory of Price Level. *Econometrica* 69, 69–116.
- Coibion, O. and Y. Gorodnichenko (2015, January). Is the Phillips Curve Alive and Well after All? Inflation Expectations and the Missing Disinflation. *American Economic Journal: Macroeconomics* 7(1), 197–232.
- Coibion, O., Y. Gorodnichenko, and J. Wieland (2012). The optimal inflation rate in new keynesian models: Should central banks raise their inflation targets in light of the zero lower bound? *Review of Economic Studies* 79(4), 1371–1406.
- Correia, I., E. Farhi, J. P. Nicolini, and P. Teles (2012). Unconventional Fiscal Policy at the Zero Bound. *American Economic Review*, forthcoming.
- Davig, T., H. Chung, and E. M. Leeper (2007). Monetary and Fiscal Policy Switching. *Journal of Money, Credit, and Banking* 39(4), 607–635.
- Davig, T. and T. Doh (2014, December). Monetary Policy Regime Shifts and Inflation Persistence. *The Review of Economics and Statistics* 96(5), 862–875.
- Davig, T. and E. M. Leeper (2006). Fluctuating Macro Policies and the Fiscal Theory. *NBER Macroeconomics Annual 2006*, 247–298.
- Davig, T. and E. M. Leeper (2007). Generalizing the Taylor Principle. *American Economic Review* 97(3), 607–635.
- Del Negro, M., M. P. Giannoni, and F. Schorfheide (2015, January). Inflation in the Great Recession and New Keynesian Models. *American Economic Journal: Macroeconomics* 7(1), 168–96.
- Drautzburg, T. and H. Uhlig (2011, June). Fiscal stimulus and distortionary taxation. NBER Working Papers 17111, National Bureau of Economic Research, Inc.
- Eggertsson, G. B. (2006). The Deflation Bias and Committing to Being Irresponsible. *Journal of Money, Credit, and Banking* 38(2), 283–321.
- Eggertsson, G. B. (2008, September). Great Expectations and the End of the Depression. *American Economic Review* 98(4), 1476–1516.
- Eggertsson, G. B. and M. Woodford (2003). The Zero Interest-rate Bound and Optimal Monetary Policy. Brookings Panel on Economic Activity.
- Eusepi, S. and B. Preston (2012). Fiscal Foundations of Inflation: Imperfect Knowledge. Working Paper.
- Farmer, R. E., D. F. Waggoner, and T. Zha (2009). Understanding Markov-Switching Rational Expectations Models. *Journal of Economic Theory* 144, 1849–1867.
- Fernandez-Villaverde, J., P. Guerron-Quintana, and J. F. Rubio-Ramirez (2010, April). Fortune or Virtue: Time-Variant Volatilities Versus Parameter Drifting in U.S. Data. NBER Working Papers 15928, National Bureau of Economic Research, Inc.

- Fernandez-Villaverde, J., P. Guerron-Quintana, and J. F. Rubio-Ramirez (2011). Supply-side policies and the zero lower bound. Working Papers 11-47, Federal Reserve Bank of Philadelphia.
- Fernandez-Villaverde, J., K. Kuester, P. Guerron-Quintana, and J. F. Rubio-Ramirez (2013). Fiscal Volatility Shocks and Economic Activity. University of Pennsylvania working paper.
- Fernandez-Villaverde, J., J. F. Rubio-Ramirez, P. Guerron-Quintana, and M. Uribe (2011). Risk Matters. The Real Effects of Volatility Shocks. *American Economic Review* 101(3), 2530–2561.
- Fuhrer, J. and B. Madigan (1994). Monetary policy when interest rates are bounded at zero. Working Papers in Applied Economic Theory 94-06, Federal Reserve Bank of San Francisco.
- Galí, J. (2008). *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework*. Princeton University Press.
- Galí, J. (2014, September). The Effects of a Money-financed Fiscal Stimulus. Economics Working Papers 1441, Department of Economics and Business, Universitat Pompeu Fabra.
- Gilchrist, S., J. Sim, and E. Zakrajsek (2012). Uncertainty, Financial Frictions, and Investment Dynamics. Technical Report 1285, Boston University mimeo.
- Gust, C., D. Lopez-Salido, and M. Smith (2013). The Empirical Implications of the Interest-Rate Lower Bound. working paper.
- Hall, G. J. and T. J. Sargent (2011). Interest Rate Risk and Other Determinants of Post-WWII U.S. Government Debt/GDP Dynamics. *American Economic Journal: Macroeconomics* 3(3), 192–214.
- Hall, R. E. (2011, April). The long slump. *American Economic Review* 101(2), 431–69.
- Hamilton, J. D. (1989). A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle. *Econometrica* 57, 357–384.
- Johannsen, B. K. (2013). When are the Effects of Fiscal Policy Uncertainty Large? Board of Governors of the FRS, mimeo.
- Jurado, K., S. C. Ludvigson, and S. Ng (2013, July). Measuring Uncertainty. NBER Working Papers 19456, National Bureau of Economic Research, Inc.
- Justiniano, A. and G. Primiceri (2008). The Time Varying Volatility of Macroeconomic Fluctuations. *American Economic Review* 98(3), 604–41.
- Kim, C.-J. and C. R. Nelson (1999). *State-Space Models with Regime Switching*. Cambridge, Massachusetts: MIT Press.
- King, R. G. and M. Watson (2012). Inflation and Unit Labor Cost. *Journal of Money, Credit and Banking* 44, 111–149.
- Kitsul, Y. and J. Wright (2013). The Economics of Options-implied Inflation Probability Density Functions. *Journal of Financial Economics*, forthcoming.
- Kliem, M., A. Kriwoluzky, and S. Sarferaz (2013). On the low-frequency relationship between public deficits and inflation. working paper.
- Krugman, P. R. (1998). It's baaack: Japan's slump and the return of the liquidity trap. *Brookings Papers on Economic Activity* 29(2), 137–206.
- Krugman, P. R. (2013). Japan Steps Out. *The New York Times*, January 13.
- Leeper, E. M. (1991). Equilibria Under Active and Passive Monetary and Fiscal Policies. *Journal of*

- Monetary Economics* 27, 129–147.
- Leeper, E. M., M. Plante, and N. Traum (2010, June). Dynamics of fiscal financing in the united states. *Journal of Econometrics* 156(2), 304–321.
- Leeper, E. M., T. B. Walker, and S.-C. S. Yang (2013). Fiscal Foresight and Information Flows. *Econometrica* 81(3), 1115–1145.
- Liu, Z., D. Waggoner, and T. Zha (2011). Sources of the Great Moderation: A Regime-Switching DSGE Approach. *Quantitative Economics* 2(2), 251–301.
- Longstaff, F., H. Lustig, and M. Fleckenstein (2013, July). Deflation Risk. NBER Working Papers 19238, National Bureau of Economic Research, Inc.
- Lubik, T. and F. Schorfheide (2004). Testing for Indeterminacy: An Application to U.S. Monetary Policy. *American Economic Review* 94(1), 190–217.
- Mertens, K. and M. O. Ravn (2011). Understanding the aggregate effects of anticipated and unanticipated tax policy shocks. *Review of Economic Dynamics* 14(1), 27 – 54.
- Mertens, K. and M. O. Ravn (2013, June). The dynamic effects of personal and corporate income tax changes in the united states. *American Economic Review* 103(4), 1212–47.
- Mertens, K. and M. O. Ravn (2014). Fiscal Policy in an Expectations Driven Liquidity Trap. *Review of Economic Studies*, forthcoming.
- Misra, K. and P. Surico (2013). Consumption, Income Changes and Heterogeneity: Evidence from Two Fiscal Stimulus Programmes. Mimeo, London Business School.
- Mountford, A. and H. Uhlig (2009). What are the effects of fiscal policy shocks? *Journal of Applied Econometrics* 24(6), 960–992.
- Orphanides, A. and V. Wieland (1998). Price stability and monetary policy effectiveness when nominal interest rates are bounded at zero. Finance and Economics Discussion Series 1998-35, Board of Governors of the Federal Reserve System (U.S.).
- Orphanides, A. and V. Wieland (2000, December). Efficient monetary policy design near price stability. *Journal of the Japanese and International Economies* 14(4), 327–365.
- Rogoff, K. (2008). Embracing Inflation. *The Guardian*, Decemeber 2.
- Romer, C. D. and D. Romer (2010). The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks. *American Economic Review* 100(3), 763–801.
- Sargent, T. and N. Wallace (1981). Some Unpleasant Monetarist Arithmetic. *Federal Reserve Bank of Minneapolis Quarterly Review* Fall, 1–17.
- Schmitt-Grohe, S. and M. Uribe (2000, February). Price level determinacy and monetary policy under a balanced-budget requirement. *Journal of Monetary Economics* 45(1), 211–246.
- Schmitt-Grohe, S. and M. Uribe (2012). The Making Of A Great Contraction With A Liquidity Trap And A Jobless Recovery. Columbia University working paper.
- Schorfheide, F. (2005). Learning and Monetary Policy Shifts. *Review of Economic Dynamics* 8(2), 392–419.
- Sims, C. A. (1994). A Simple Model for Study of the Determination of the Price Level and the Interaction of Monetary and Fiscal Policy. *Economic Theory* 4, 381–399.

- Sims, C. A. (2002). Solving Linear Rational Expectations Models. *Computational Economics* 20(1), 1–20.
- Sims, C. A. (2010a). Commentary on Policy at the Zero Lower Bound. Princeton University, working paper.
- Sims, C. A. (2010b). Modeling the Influence of Fiscal Policy on Inflation. Princeton University, working paper.
- Sims, C. A. and T. Zha (2006). Were There Regime Switches in US Monetary Policy? *American Economic Review* 91(1), 54–81.
- Uhlig, H. (2010, May). Some fiscal calculus. *American Economic Review* 100(2), 30–34.
- Wei, C. and F. Joutz (2012). Monetary Policy under Financial Uncertainty . University of Wisconsin - Madison, working paper.
- Werning, I. (2012). Managing a Liquidity Trap: Monetary and Fiscal Policy. MIT working paper.
- Wolman, A. L. (1998). Staggered price setting and the zero bound on nominal interest rates. *Economic Quarterly* (Fall), 1–24.
- Woodford, M. (1994). Monetary Policy and Price Level Determinacy in a Cash-in-Advance Economy. *Economic Theory* 4, 345–389.
- Woodford, M. (1995). Price Level Determinacy without Control of a Monetary Aggregate. *Carnegie-Rochester Series of Public Policy* 43, 1–46.
- Woodford, M. (2001). Fiscal Requirements of Price Stability. *Journal of Money, Credit, and Banking* 33, 669–728.
- Woodford, M. (2003). *Interest and prices: Foundations of a theory of monetary policy*. Princeton, New Jersey: Princeton University Press.

# A Markov-switching VAR

In this appendix, we describe the MS-VAR used in Section 3.

## A.1 Model setup

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

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

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

where  $Z_t$  is a  $(n \times 1)$  vector of data. The unobserved states  $\xi_t^\Sigma$  and  $\xi_t^\Phi$  can take on a finite number of values,  $j^\Phi = 1, \dots, m^\Phi$  and  $j^\Sigma = 1, \dots, m^\Sigma$ , and follow two independent Markov chains.<sup>15</sup> 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  $\xi_t \equiv (\xi_t^\Phi, \xi_t^\Sigma)$ , the associated transition matrix  $H \equiv H^\Phi \otimes H^\Sigma$ , and vector  $\theta_{\xi_t} \equiv (\Phi_{\xi_t^\Phi}, \Sigma_{\xi_t^\Sigma})$  with the corresponding set of parameters. For each draw of the parameters  $\theta_{\xi_t}$  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  $t = 1, \dots, T$ , and are part of the output obtained computing the likelihood function associated with the parameter draw  $H, \theta_{\xi_t}$ . The filtered probabilities can be obtained using the following recursive algorithm:

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

$$\pi_{t+1|t} = H \pi_{t|t} \quad (11)$$

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

where  $\eta_t$  is a vector whose  $j$ th 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  $\xi_0$ . We assume that

<sup>15</sup>Note that the regime switch is modeled for a VAR in its reduced form. Sims and Zha (2006) work with the structural form of the VAR. However, given that our goal is to establish some stylized facts by taking an agnostic approach, we decided not to impose ex-ante identifying restrictions on the covariance matrix.

the nine regimes have equal probabilities  $p(\xi_0 = i) = 1/9$  for  $i = 1 \dots m$ . The likelihood for the entire data sequence  $Z^T$  is obtained multiplying the one-step-ahead conditional likelihoods  $p(Z_t|Z^{t-1})$ :

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

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:

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

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  $\pi_{t|t}^{\Phi} = p(\xi_t^{\Phi}|Y^t; H, \theta_{\xi_t})$  we have:

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

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  $\xi_t^{\Phi, T}$ , we can compute the residuals of the MS-VAR at each point in time. Then, given  $\xi_t^{\Sigma}$ , 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  $\xi_t^{\Sigma} = 1 \dots m^{\Sigma}$ .
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  $i = 1 \dots m^{\Phi}$ :

- (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:  $(\xi_t^\Phi = i, \xi_t^\Sigma = 1), \dots, (\xi_t^\Phi = i, \xi_t^\Sigma = m^\Sigma)$ . Denote these subsamples with  $(y_{i,\xi_t^\Sigma}, x_{i,\xi_t^\Sigma})$ , where the  $y_{i,\xi_t^\Sigma}$  and  $x_{i,\xi_t^\Sigma}$  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  $j = 1 \dots m^\Sigma$  the following formulas need to be applied recursively:

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

where the algorithm is initialized using the priors for the VAR coefficients  $B_L = B_0$  and  $P_L^{-1} = P_0^{-1} = (S_0 \otimes N_0^{-1})^{-1}$ . 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  $\text{vec}(\Phi_{\xi_t^\Phi}) \sim N(P_T B_T, P_T)$  with  $\xi_t^\Phi = i$ .

3. Sampling  $H^\Phi$  and  $H^\Sigma$ : 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  $H^\Phi$  and  $H^\Sigma$ , the posterior distribution is given by:

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

where  $\eta_{ij}^\Phi$  and  $\eta_{ij}^\Sigma$  denote respectively the numbers of transitions from state  $i^\Phi$  to state  $j^\Phi$  and from state  $i^\Sigma$  to state  $j^\Sigma$ .

## 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 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 D. As a measure of the fiscal stance, we consider the variable deficits over debt. The government debt series is the market value of the U.S. government debt available on the Dallas Fed website. The sample period ranges from 1954:Q4-2014:Q1.

## A.5 Volatility regimes

Table 6 reports the estimates of the covariance matrix across different volatility regimes.

$\xi_t^\Sigma = 1$	$u_{ER}$	$u_{TY}$	$u_{PE}$	$u_{VS}$
$u_{ER}$	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 6: 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.

## 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:

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

where  $M_a = \exp(\gamma)$  and  $\bar{d}_{\xi_t^d}$  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:

$$\tilde{\pi}_t = \kappa \left( \left[ \frac{1}{1 - \Phi M_A^{-1}} + \frac{\alpha}{1 - \alpha} \right] \hat{y}_t - \frac{1}{1 - \Phi M_A^{-1}} \tilde{g}_t - \frac{\Phi M_A^{-1}}{1 - \Phi M_A^{-1}} (\hat{y}_{t-1} - \tilde{g}_{t-1} - a_t) \right) + \beta E_t [\tilde{\pi}_{t+1}] + \tilde{\mu}_t$$

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

3. No arbitrage condition

$$\tilde{R}_t = E_t \left[ \tilde{R}_{t,t+1}^m \right]$$

4. Return long term bond

$$\tilde{R}_{t-1,t}^m = R^{-1} \rho \tilde{P}_t^m - \tilde{P}_{t-1}^m$$

5. Government budget constraint:

$$\begin{aligned} \tilde{b}_t^m &= \beta^{-1} \tilde{b}_{t-1}^m + b^m \beta^{-1} \left( \tilde{R}_{t-1,t}^m - \hat{y}_t + \hat{y}_{t-1} - a_t - \tilde{\pi}_t \right) \\ &\quad - \tilde{\tau}_t + \tilde{t}r_t + g^{-1} \tilde{g}_t + \tilde{t}p_t \end{aligned}$$

6. Monetary policy rule

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

7. Fiscal rule

$$\tilde{\tau}_t = \rho_{\tau,\xi_t^p} \tilde{\tau}_{t-1} + \left( 1 - \rho_{\tau,\xi_t^p} \right) \left[ \delta_{b,\xi_t^p} \tilde{b}_{t-1}^m + \delta_e \left( \tilde{t}r_t^* + g^{-1} \tilde{g}_t \right) + \delta_y \left( \hat{y}_t - \hat{y}_t^* \right) \right] + \sigma_{\tau} \epsilon_{\tau,t}$$

8. Transfers

$$\left( \tilde{t}r_t - \tilde{t}r_t^* \right) = \rho_{tr} \left( \tilde{t}r_{t-1} - \tilde{t}r_{t-1}^* \right) + (1 - \rho_{tr}) \phi_y \left( \hat{y}_t - \hat{y}_t^* \right) + \sigma_{tr} \epsilon_{tr,t}, \quad \epsilon_{tr,t} \sim N(0, 1)$$

9. Long term component of transfers

$$\tilde{t}r_t^* = \rho_{tr^*} \tilde{t}r_{t-1}^* + \sigma_{tr^*} \epsilon_{tr^*,t}, \quad \epsilon_{tr^*,t} \sim N(0, 1)$$

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

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

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  $\aleph_t = 1/(1 - v_t)$ , follows an autoregressive process,

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

14. Output target

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

## B.2 Model solution

As explained in the main text, the Markov-switching process for the discrete preference shock  $\bar{d}_{\xi_t^d}$  is defined in a way that its steady state is equal to zero. In order to solve the model with regime changes in the policy rules and a discrete shock, we combine the methods developed by Farmer et al. (2009) with the approach used by Schorfheide (2005), Liu et al. (2011), and Bianchi et al. (2012) to handle discrete shocks. Specifically, 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:

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

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

#### B.3.2 Coordinated announcements

In the counterfactual economy with coordinated 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  $p_{MZ}$ . 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:

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

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

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

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

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

The matrix  $\bar{\Sigma}$  corresponds to the inverse of the Hessian computed at the posterior mode  $\bar{\theta}$ . The parameter  $c$  is set to obtain an acceptance rate of around 35%. The posterior is obtained combining the priors with the likelihood computed using the modified Kalman filter described in Kim and Nelson (1999).

Table 7 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 (1 every 3000 draws is saved). The numbers are well below the 1.2 benchmark value used as an upper bound for convergence.

## D Dataset

Real GDP, the GDP deflator, and the series for fiscal variables are obtained from the Bureau of Economic Analysis. We follow Leeper et al. (2010) in constructing the fiscal variables. 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 FFR is obtained averaging monthly figures downloaded from the St. Louis Fed web-site. Finally, we depart from other papers in the literature that reconstruct the series for government debt using the interest payments

Parameter	PSRF	Parameter	PSRF	Parameter	PSRF	Parameter	PSRF
$\psi_{\pi,M}$	1.01	$\psi_Z$	1	$\rho_d$	1	$100\sigma_R$	1
$\psi_{y,M}$	1.05	$\kappa$	1.15	$\rho_{tp}$	1	$100\sigma_g$	1
$\rho_{R,M}$	1.01	$\delta_{b,M}$	1	$\rho_\mu$	1.01	$100\sigma_a$	1
$\rho_{\tau,M}$	1	$\rho_{tr}$	1.01	$100\pi$	1	$100\sigma_\tau$	1
$\psi_{\pi,F}$	1.06	$\delta_y$	1.03	$100\gamma$	1	$100\sigma_d$	1.04
$\psi_{y,F}$	1.05	$\Phi$	1.04	$b^m$	1.01	$100\sigma_{tr}$	1
$\rho_{R,F}$	1	$\delta_e$	1.07	$g$	1	$100\sigma_{tp}$	1
$\rho_{\tau,F}$	1.02	$\rho_g$	1	$\tau$	1.02	$100\sigma_\mu$	1
$d_l$	1.01	$\rho_a$	1.01	$\phi_y$	1.01	$p_{FF}$	1.02
$p_{hh}$	1.09	$p_{ll}$	1.02	$p_{MM}$	1.01	$p_{MZ}$	1.01

Table 7: 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.

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
<b>2008:Q4</b>	<b>6,522.4</b>	<b>6,521.1</b>
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 8: 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.

reported in the NIPA tables and instead we use the debt series at market values from the Dallas Fed web-site. Hall and Sargent (2011) argue that the interest payments reported by the Government are not consistent with any well defined law of motion for debt. Specifically, the Government reports data that do not fully take into account revaluation effects. Revaluation effects are important in the context of our model that allows for a maturity structure of government debt. However, as explained by Leeper et al. (2010), the two series are highly correlated implying that the choice of the series for debt is going to play only a minor role in the context of a structural estimation.

## E 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 8, 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).

# F A Prototypical New Keynesian Model with a Fiscal Block

The objective of this appendix is to show that the results of Section 5.2 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 paper. Let us consider a prototypical New Keynesian DSGE model of the type studied in Woodford (2003) and Galí (2008) 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.<sup>16</sup> 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:

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

where  $x_t$  denotes the gap between the actual output and its flexible-price level (henceforth, the output gap),  $\pi_t$  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

$$\pi_t = \kappa x_t + \beta E_t \pi_{t+1} \quad (14)$$

The monetary policy reaction function is:

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

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  $\xi_t^d$ . 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  $\psi_{\pi, \xi_t^p}$ , which controls how strongly the central bank adjusts the nominal interest rate to inflation, are affected by the exogenous discrete Markov-switching process  $\xi_t^p$ .

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

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

where  $\Delta y_t^n$  stands for the growth rate of natural output, whose value at any time is assumed to depend

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<sup>16</sup>The model can be derived from first principle. We direct the interested readers to Woodford (2003) and Galí (2008) and to Bianchi and Ilut (2015) for the derivation of the fiscal block.

on the realization of a discrete Markov-switching process  $\xi_t^d$ .

The fiscal rule that determines the primary surplus  $\tau_t$

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

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  $\delta_{b,\xi_t^p}$  whose value depends on the realization of the Markov-switching process  $\xi_t^p$  that also determines the central bank's response to inflation in the Taylor rule. Hence, the process  $\xi_t^p$  captures the monetary-fiscal policy mix *out of the zero lower bound*

The government's budget constraint is driven by

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

There are two exogenous Markov-switching processes:  $\xi_t^p$  and  $\xi_t^d$ . 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  $\delta_{b,\xi_t^p} > (\beta^{-1} - 1)$ .<sup>17</sup> 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  $\delta_{b,\xi_t^p} \leq (\beta^{-1} - 1)$ . The transition matrix driving the policy regime out of the zero lower bound  $\xi_t^p$  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  $\xi_t^d$  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  $\xi_t = [\xi_t^p, \xi_t^d]$ . The combined chain can assume three values:  $\xi_t = \{[M, h], [F, h], [Z, l]\}$ . The corresponding transition matrix  $H$  is obtained by

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<sup>17</sup>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	$p_{MZ}$	0.50
$\kappa$	0.03	$100\pi$	0.5
$\sigma$	1.00	$b$	0.30
$\psi_x$	0.10	$\beta$	0.995
$\rho_i$	0.85	$\Delta y_t^n (\xi_t^d = h)$	5.30
$\delta_x$	0.5	$\Delta y_t^n (\xi_t^d = l)$	-21.33

Table 9: Parameters used for the prototypical new-Keynesian model.

combining the transition matrix  $H^d$ , which describes the evolution of the preference shock; the transition matrix  $H^p$ , which describes policymakers' behavior out of the zero lower bound, and the parameter  $p_{MZ}$  that controls the probability of moving to the Monetary led regime once the negative preference shock is reabsorbed:

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

Table 9 reports the parameter values we will use to study the property of this stylized model. The parameters  $\pi$ , 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. This number is consistent with what Barsky et al. (2014) find during the Great Recession and the ensuing slow recovery in the US when the Federal Funds rate hit its lower bound. In the benchmark calibration, we set the probability of moving to the Monetary led policy mix after the ZLB episode equal to  $p_{MZ} = 50\%$  so as to capture a situation of sizable uncertainty about the policymakers' behaviors when the economy will exit the ZLB.

Figure 15 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 9 and a counterfactual case in which agents are much more certain that the policy mix out of the ZLB will be Monetary led ( $p_{MZ} = 85\%$ ). Both economies are hit by a negative shock to the natural rate at time 6.<sup>18</sup>

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 future policymakers' behavior largely mitigates the output gap. These results are qualitatively in line with the ones obtained from our estimated model in Section 5.2. The exercise made in this section makes it clear

<sup>18</sup>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.

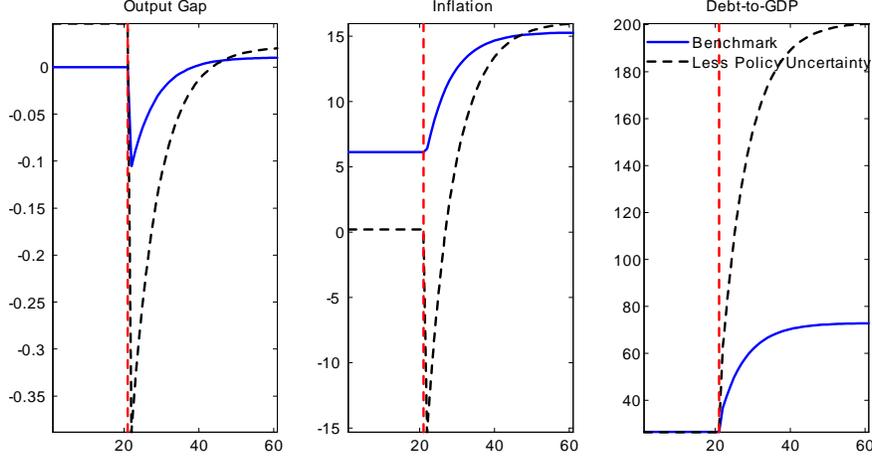


Figure 15: **Prototypical new-Keynesian model.** The figure reports the impulse responses to a discrete shock to the natural interest rate. In the Benchmark model there is high policy uncertainty, while in the counterfactual economy agents think that they are more likely to move to the Monetary led regime.

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.

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

### G.1 System of equations

1. Linearized Euler equation:

$$(1 + \Phi M_a^{-1}) \hat{y}_t = - (1 - \Phi M_a^{-1}) \left[ \hat{R}_t - E_t \tilde{\pi}_{t+1} - (1 - \rho_d) d_t - \bar{d}_{\xi_t^d} + E_{\xi_t^d} \bar{d}_{\xi_{t+1}^d} \right] - (\Phi M_a^{-1} - \rho_a) a_t + E_t \hat{y}_{t+1} + (1 - \rho_g + M_a^{-1} \Phi) \tilde{g}_t + M_a^{-1} \Phi (\hat{y}_{t-1} - \tilde{g}_{t-1})$$

where  $M_a = \exp(\gamma)$  and  $\bar{d}_{\xi_t^d}$  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:

$$\tilde{\pi}_t = \kappa \left( \left[ \frac{1}{1 - \Phi M_A^{-1}} + \frac{\alpha}{1 - \alpha} \right] \hat{y}_t - \frac{1}{1 - \Phi M_A^{-1}} \tilde{g}_t - \frac{\Phi M_A^{-1}}{1 - \Phi M_A^{-1}} (\hat{y}_{t-1} - \tilde{g}_{t-1} - a_t) \right) + \beta E_t [\tilde{\pi}_{t+1}] + \tilde{\mu}_t$$

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

3. No arbitrage condition

$$\tilde{R}_t = E_t \left[ \tilde{R}_{t,t+1}^m \right]$$

4. Return long term bond

$$\tilde{R}_{t-1,t}^m = R^{-1} \rho \tilde{P}_t^m - \tilde{P}_{t-1}^m$$

5. Monetary policy rule

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

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

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

7. TFP growth

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

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

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

9. Output target

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

## G.2 Parameter estimates

Table 10 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, FFR, 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.

## G.3 Dynamics at the zero lower bound

Figure 16 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 6, we also report the 90% error bands for the impulse response to the discrete preference shock only. While 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
$p_{MZ}$	0.5009	0.1478	0.8451	D	0.50	0.22
$\psi_Z$	0.9698	0.9608	0.9781	B	0.95	0.02
$\kappa$	0.0707	0.0467	0.1025	G	0.3	0.15
$\Phi$	0.8601	0.8147	0.8996	B	0.5	0.2
$\rho_g$	0.9919	0.9847	0.9971	B	0.5	0.2
$\rho_a$	0.1608	0.0583	0.2786	B	0.5	0.2
$\rho_d$	0.9358	0.9083	0.9599	B	0.5	0.2
$\rho_\mu$	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
$100\pi$	0.5678	0.4800	0.6607	G	0.5	0.05
$100\gamma$	0.4100	0.3352	0.4912	G	0.4	0.05
$g$	1.0758	1.0604	1.0942	N	1.06	0.04

Table 10: Posterior means, 90% posterior error bands and priors of the parameters for the model that excludes 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.

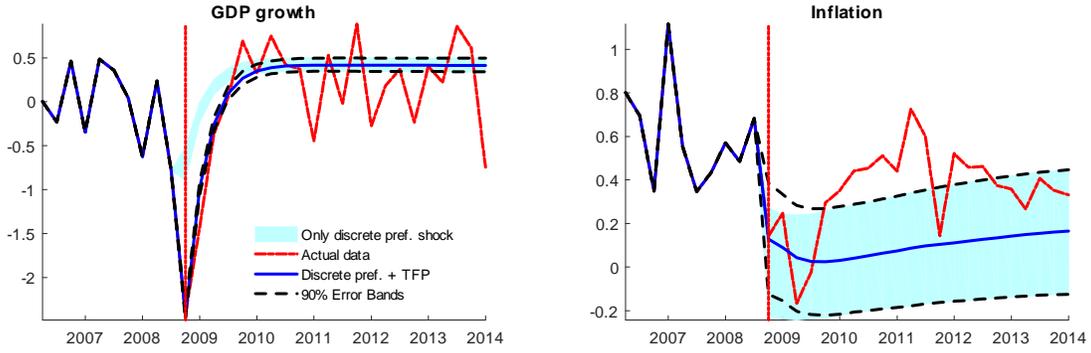


Figure 16: **Macroeconomic dynamics at the zero lower bound without fiscal block: The role of TFP shocks.** Response of GDP growth and inflation to a discrete negative preference shock and a contemporaneous negative TFP shock based on a model that excludes the fiscal block. The red dashed line reports actual data, while the shaded areas report the 90% error bands when only the discrete preference shock occurs.

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 is removed, a combination of shocks is necessary to explain the joint dynamics of output and inflation.

Figure 17 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 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 at the cost of generating deflation. Dividing the estimated 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.

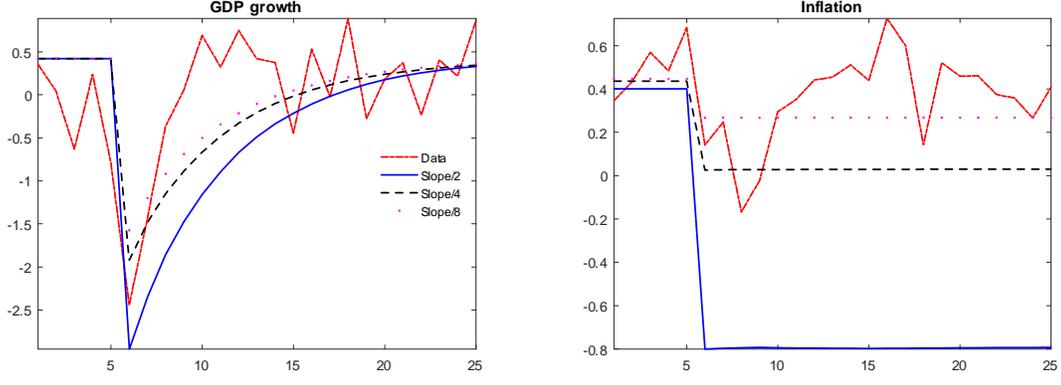


Figure 17: **Macroeconomic dynamics at the zero lower bound without fiscal block: The role of nominal rigidities.** Response of GDP growth and inflation to a large discrete negative preference shock for different values of the slope of the Phillips curve,  $\kappa$ .

## H Shock-Specific Policy Rules

In this appendix, we detail the DSGE model used to perform the analysis of Section 8, in which policymakers do not respond to movements in debt deriving from the discrete preference shocks  $\xi_t^d$ . For the sake of exposition, we consider a simplified version of the DSGE model used in the estimates. This DSGE model can be expressed as follows:

THE ACTUAL ECONOMY:

$$\tilde{\pi}_t = \beta E_t(\tilde{\pi}_{t+1}) + \kappa(\tilde{y}_t - a_t), \quad (19)$$

$$\tilde{y}_t = E_t(\tilde{y}_{t+1}) - \left( \tilde{R}_t - E_t(\tilde{y}_{t+1}) \right) + d_t - E_t(d_{t+1}), \quad (20)$$

$$\tilde{b}_t = \beta^{-1} \tilde{b}_{t-1} + b\beta^{-1} \left( \tilde{R}_{t-1} - \tilde{\pi}_t - \Delta \tilde{y}_t \right) - \tilde{\tau}_t, \quad (21)$$

$$\tilde{\tau}_t = \delta_{b,M} b_{t-1}^{nd} + \delta_{b,E} (b_{t-1} - b_{t-1}^{nd}) + \delta_{y,M} (\tilde{y}_t^{nd} - \tilde{y}_t^{*,nd}) + \delta_{y,E} (\tilde{y}_t - \tilde{y}_t^{nd}), \quad (22)$$

$$\tilde{R}_t = \rho_R \tilde{R}_{t-1} + (1 - \rho_R) \left( \begin{array}{c} \psi_{\pi,M} \pi_t^{nd} + \psi_{\pi,E} (\pi_t - \pi_t^{nd}) \\ + \psi_{y,M} [\tilde{y}_t^{nd} - \tilde{y}_t^{*,nd}] + \psi_{y,E} [\tilde{y}_t - \tilde{y}_t^{nd}] \end{array} \right) + \sigma_{R,E} \epsilon_{R,t}. \quad (23)$$

where we have used the fact that  $\tilde{y}_t^* = \tilde{y}_t^{*,nd}$ .

THE SHADOW ECONOMY

$$\tilde{\pi}_t^{nd} = \beta E_t(\tilde{\pi}_{t+1}^{nd}) + \kappa(\tilde{y}_t^{nd} - a_t), \quad (24)$$

$$\tilde{y}_t^{nd} = E_t(\tilde{y}_{t+1}^{nd}) - \left( \tilde{R}_t^{nd} - E_t(\tilde{y}_{t+1}^{nd}) \right), \quad (25)$$

$$\tilde{b}_t^{nd} = \beta^{-1} \tilde{b}_{t-1}^{nd} + b\beta^{-1} \left( \tilde{R}_{t-1}^{nd} - \tilde{\pi}_t^{nd} - \Delta \tilde{y}_t^{nd} \right) - \tilde{s}_t^{nd}, \quad (26)$$

$$\tilde{s}_t^{nd} = \delta_b^{nd} \tilde{b}_{t-1}^{nd} + \delta_y (\tilde{y}_t^{nd} - a_t) + x_t, \quad (27)$$

$$\tilde{R}_t^{nd} = \rho_R \tilde{R}_{t-1}^{nd} + (1 - \rho_R) \left( \psi_{\pi, M} \tilde{\pi}_t^{nd} + \psi_{y, M} [\tilde{y}_t^{nd} - a_t] \right) + \sigma_R \epsilon_{R, t}. \quad (28)$$

EXOGENOUS PROCESSES

$$d_t = \bar{d}_{\xi_t^d}, \quad (29)$$

$$a_t = \rho_a a_{t-1} + \sigma_a \epsilon_{a, t}, \quad (30)$$

It should be noted that the equations governing the behavior of the shadow economy (24)-(28) differ from those of the actual economy (19)-(23) in only one dimension: While the actual economy is buffeted by all types of shocks (i.e.,  $\xi_t^d$  and  $\epsilon_{a, t}$ ), the shadow economy is not hit by the discrete preference shock  $\xi_t^d$ . The equations of the shadow economy work as a device to keep track of the changes in the policy targets (i.e., the stock of debt  $b_{t-1}^{nd}$  and the rate of inflation  $\pi_t^{nd}$ ) in equations (22) and (23). Finally, it is important to point out that equations (19)-(30) constitute a system of linear rational expectations equations with fixed coefficients that can be easily solved using one of the many solvers available (e.g., *Gensys* by Sims, 2002).