

# Dormant Shocks and Fiscal Virtue\*

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## Abstract

We develop a model in which the current policy makers' behavior influences agents' beliefs about the way debt will be stabilized. The standard policy mix consists of a virtuous fiscal authority that moves taxes in response to debt and a central bank that has full control over inflation. When policy makers deviate from this Virtuous regime, agents conduct Bayesian learning to infer the likely duration of the deviation. As agents observe more and more deviations, they become increasingly pessimistic about a prompt return to the Virtuous regime and inflation begins moving to preserve debt stability. Shocks which were dormant under the Virtuous regime now start manifesting themselves. These changes are initially imperceptible, can unfold over decades, and accelerate as agents' beliefs deteriorate. Therefore, the model is able to account for the observed instability of the link between inflation and fiscal imbalances across time and countries. Dormant shocks explain the run-up of US inflation and uncertainty in the '70s. The currently low long term interest rates and inflation expectations might hide the true risk of inflation faced by the US economy.

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# 1 Introduction

The importance of modeling the interaction between fiscal and monetary policies goes back to the seminal contribution of Sargent and Wallace (1981). However, in many of the models that are routinely used to investigate the sources of macroeconomic fluctuations fiscal policy plays only a marginal role. The vast majority of papers resolve the problem of monetary/fiscal policy coordination assuming that the fiscal authority stands ready to accommodate the behavior of the monetary authority, keeping the process for debt on a stable path. This is a strong assumption as a casual observation of the data shows that countries often experience prolonged periods of severe fiscal imbalance. Quite interestingly, these episodes are frequently followed by significant increases in inflation. In some cases, such increases are short lasting and remarkably violent. In other cases, they unfold over many years, generally starting with small increases and then gaining momentum. Traditional models have a hard time in endogenously generating persistent and accelerating increases in inflation and in explaining the cross-country heterogeneity characterizing the link between inflation and fiscal discipline. In this paper we show that a model in which fully rational agents are uncertain about the future conduct of monetary and fiscal policies can account for these two features.

We model an economy populated by a continuum of agents that are fully rational and understand that debt can be stabilized through movements in taxes or movements in inflation. When the fiscal authority is virtuous and moves primary surpluses in response to fluctuations in the debt-to-GDP ratio, the Central Bank has full control over inflation. Under the assumption of non-distortionary taxation, fiscal shocks do not have any effect on the real economy as they only redistribute the timing of taxation. When policy makers deviate from the Virtuous regime, with the fiscal authority not reacting to debt fluctuations and the Central Bank disregarding the Taylor principle, two situations can arise. If agents expect the return to the Virtuous regime to be close enough in time, inflation stability is preserved. On the other hand, if the deviation is expected to last for a long period of time, high levels of debt require an increase in inflation.

We build over this basic intuition and assume that when facing a deviation from the virtuous rule, agents do not know how long it will take to move back. Instead, they have to conduct Bayesian learning to infer the nature of the deviation. As they observe more and more deviations, they get increasingly convinced that a prompt return to the Virtuous regime is very unlikely. Given that agents are fully rational and understand that debt has to be financed in one way or the other, the drift in agents' beliefs determines a progressive increase in inflation. The initial movement can be almost undetectable, but as initially optimistic agents become relatively pessimistic, inflation accelerates, gaining momentum and getting out of control. At the same time, expected and realized volatilities go up as shocks that are *dormant* under the Virtuous regime slowly start manifesting themselves. Therefore, if an external observer were

monitoring the economy focusing exclusively on output and inflation, he would detect a run-up in inflation and an increase in volatility without any apparent explanation. The observer might then conclude that the volatility of the exogenous shocks and the target for inflation have both increased.

*Dormant* shocks are undetectable when policy makers are virtuous or agents are optimistic that they will be virtuous in the future because agents understand that any imbalance in the debt-to-GDP ratio will be followed by an adjustment in taxation. As agents become discouraged about the future behavior of policy makers, the effects of dormant shocks arise. Therefore, dormant shocks can have effects many years after they occurred, as long as the fiscal imbalance that they generated is not totally reabsorbed by the time the deviation from the Virtuous regime occurs. Furthermore, even after a regime change, their effects can barely be detected if agents find it extremely unlikely that policy makers will engage in a long lasting deviation from the Virtuous regime. In other words, depending on policy makers' *Fiscal Virtue*, inflation can stay low for many periods, as it takes time for agents to become convinced that the economy has entered a long lasting deviation. According to the same logic, if on average policy makers spend a lot of time in the Virtuous regime, agents might become more tolerant when observing a long sequence of deviations. However, no matter how optimistic agents are or how virtuous policy makers have been in the past, if a deviation lasts for an extended period of time, agents will eventually become convinced that a quick return to the Virtuous regime is unlikely. In other words, following a deviation, *Fiscal Virtue* can delay the effects of dormant shocks, but it cannot eliminate them.

The interaction between dormant shocks and *Fiscal Virtue* also provides an appealing explanation for why countries with different levels of debt might have similar levels of inflation for prolonged periods of time, but then experience very different outcomes during *hard times*. When a Virtuous regime prevails or agents are confident that it will prevail in the future, the level of debt is substantially irrelevant. However, if agents become convinced that the economy has entered a long lasting deviation, then interest rate and inflation differentials open up. The larger the difference in *Fiscal Virtue*, the larger the difference in the speed of learning, the faster the opening of the inflation and interest rate differentials.

Therefore, our theoretical framework is capable of accounting for the instability of the link between fiscal discipline and inflation. In our model, agents are fully rational, but uncertain about the way the trade-off between inflation and taxation will be resolved. This creates a continuum of regimes indexed according to agents' beliefs and a smooth transition from the law of motion that prevails under the Virtuous regime to the one that characterizes a long lasting deviation. Therefore, the strict distinction between Ricardian and non-Ricardian regimes typical of the Fiscal Theory of Price Level literature (Leeper (1991), Sims (1994), Woodford (1994, 1995, 2001), Schmitt-Grohe and Uribe (2000), and Cochrane (1998, 2001),

among others) breaks down and is replaced by a series of intermediate regimes that reflect the evolution of agents' expectations about the future conduct of fiscal and monetary policies.<sup>1</sup>

Furthermore, agents *know that they do not know*. Therefore, when forming expectations, they take into account that their beliefs will evolve according to what they observe. In this dimension, our approach is clearly different from the one used in the traditional learning literature that assumes anticipated utility, i.e. that agents form expectations conditional on their beliefs without taking into account that these are likely to change in the future. In our context, it is possible to go beyond the anticipated utility assumption because there is only a finite number of relevant beliefs and they are strictly linked to the behavior of policy makers through the learning mechanism, in a way that we can keep track of their evolution.

In this respect, our paper is related to Eusepi and Preston (2010), who study the problem of macroeconomic stability in a model in which agents use adaptive learning to make forecasts about the future evolution of fiscal and monetary variables. In their model, if agents were fully rational, fiscal policy and the maturity structure of debt would be irrelevant because the Taylor Principle holds and fiscal policy is Ricardian. Instead, when agents do not know the parameters of the true model, non-Ricardian effects might arise. The important difference from our paper is that the model of Eusepi and Preston (2010) does not feature the mechanism of inflation formation proposed by the Fiscal Theory of Price Level which can only arise in models with fully rational agents. In their context, non-Ricardian effects arise because agents might erroneously regard bonds as net-wealth as in Barro (1974). Instead, in this paper non-Ricardian effects arise in the moment fully rational agents become discouraged about debt stability being guaranteed by movements in primary surpluses.

Given that the underlying mechanism relies on uncertainty around the source of financing for the debt-to-GDP ratio, all shocks that move this variable are potentially candidates for dormant shocks. In an environment with no distortionary taxation, shocks to transfers and taxes are particularly interesting, given that they do not have *any* effect on the macroeconomic variables when the Virtuous regime is in place, but they can generate large fluctuations in inflation once policy makers start deviating. Furthermore, given that agents are forward looking, even announced changes in expenditure or taxation would trigger the inflationary mechanism.

We illustrate the key properties of the model using the basic three equations new-Keynesian model used by Clarida et al. (2000) and Lubik and Schorfheide (2004) augmented with a fiscal block. We then conduct a quantitative analysis using a richer model borrowed from Bianchi and Ilut (2012). We first analyze the progressive unfolding of the US Great Inflation: Inflation started increasing in the mid-60s, gained momentum in the early '70s, got out of

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<sup>1</sup>See Cochrane (2011) for an effective discussion of the difference between the early approach of Sargent and Wallace (1981) and the subsequent analysis based on the Fiscal Theory of Price Level. See Atkeson et al. (2009) for an alternative approach to price determination in monetary general equilibrium models.

control towards the end of that same decade, and experienced a sudden drop in the early '80s. We show that this pattern can be explained by the evolution of the monetary/fiscal policy mix, as argued in Bianchi and Ilut (2012). First, the entire run-up of inflation of the '70s can be obtained by considering only two shocks. The first spur of inflation, would be the result of the *announcement* of the Great Society initiatives of president Lyndon Johnson around 1964, while the second acceleration would be caused by Ford's tax cuts. The progressive deterioration of agents' beliefs explains why inflation seemed to gain momentum over time. Second, the sudden drop in inflation of the early '80s can be explained by a sudden switch in the monetary/fiscal policy mix induced by the appointment of Volcker. Finally, if we assume that even under the Virtuous regime agents are concerned about the possibility of a jump to the long lasting inflationary policy mix, we can account for the risk of deflation of the early 2000s as a result of the large primary surpluses of the '90s.

We then use the model to analyze the current situation. Given that dormant shocks might take a long time to unfold, we should not interpret the current low levels of inflation expectations and long term interest rates as reflecting a low risk of high inflation for the US economy. We show that if US policy makers were to follow the current policy mix for a prolonged period of time, inflation might quickly accelerate and get out of control. In other words, the low inflation expectations and long term interest rates reflect the reputation that US policymakers have built in the past twenty/thirty years since the Volcker disinflation. This stock of reputation is not unlimited and it slowly deteriorates as policymakers keep deviating. This also suggests that if inflation is the result of a lack of fiscal discipline, central bankers cannot simply wait to "see inflation" in order to decide to worry about that. At that point, only an immediate change in both fiscal and monetary policies would be able to cut the inflation spiral.

Our paper is related to the extensive literature that explores the evolution of output and inflation over the past sixty years using micro-founded models. Fernández-Villaverde et al. (2010) consider models with time-varying structural parameters and find substantial evidence of parameter instability. Using a large scale DSGE model augmented with stochastic volatilities, Justiniano and Primiceri (2008) find that changes in the volatility of investment shocks play a key role in explaining the evolution of the reduced form properties of the economy. Bianchi (2012b) and Davig and Doh (2008) allow for heteroskedasticity and changes in monetary policy. Finally, Ireland (2007), Liu et al. (2011), and Schorfheide (2005) consider models in which the target for inflation is moving over time. Our model is able to account for changes in the low frequency component of inflation and in the volatility of the endogenous variables.

Our work is also related to Benati (2008), Cogley et al. (2010), Cogley et al. (2011), and Coibion and Gorodichenko (2011). Benati (2008) documents that inflation persistence is not stable across time and across countries. Cogley et al. (2010) study changes in the persistence of the inflation gap measured in terms of short- to medium-term predictability. Cogley et al.

(2011) show that the Gibson’s paradox, i.e. low correlation between inflation and nominal interest rates, vanished during the Great Inflation and reappeared after 1995. Coibion and Gorodichenko (2011) point out that the determinacy region in a model with positive trend inflation could be smaller than what is implied by the Taylor principle. They conclude that the US economy was still at risk of indeterminacy in the ’70s, even if the Taylor principle was likely to be satisfied, because of the high level of trend inflation. Our model is able to generate variability in the persistence and low frequency component of inflation as a result of the evolution of agents’ beliefs about the future behavior of policy makers. Finally, our work is also linked to papers that study the impact of monetary policy decisions on inflation and inflation expectations, such as Mankiw et al. (2004), Nimark (2008), Del Negro and Eusepi (2011), and Melosi (2012, 2013).

The content of this paper can be summarized as follows. Section 2 describes the model, outlining its properties under fixed coefficients. Section 3 introduces regime changes and learning. Section 4 introduces the notion of dormant shocks and explains how they are related to Fiscal Virtue. Section 5 puts the theory to work: First looking at the past, then looking at the future. Section 6 concludes.

## 2 The Model

In order to illustrate the key properties of the model, we consider the basic new-Keynesian model employed by Clarida et al. (2000) and Lubik and Schorfheide (2004) augmented with a fiscal rule. This model has very little built-in persistence, given that it features a purely forward looking Phillips curve. This will allow us to isolate the effects of the learning mechanism.

### 2.1 A new-Keynesian model

The economy consists of a continuum of monopolistic firms, a representative household, and a monetary policy authority. The household derives utility from consumption  $C_t$  and disutility from labor  $h_t$ :

$$E_0 \left[ \sum_{t=0}^{\infty} \beta^t \exp(d_t) [\log(C_t) - h_t] \right] \quad (1)$$

where  $\beta$  is the household’s discount factor and the preference shock  $d_t$  follows an autoregressive process:  $d_t = \rho_d d_{t-1} + \sigma_d \epsilon_{d,t}$ ,  $\epsilon_{d,t} \sim N(0, 1)$ . The household budget constraint is given by:

$$P_t C_t + B_t + P_t T_t = P_t W_t h_t + R_{t-1} B_{t-1} + P_t D_t \quad (2)$$

where  $B_t$  represents nominal bond holdings,  $D_t$  captures dividends paid by firms,  $W_t$  is the real wage,  $T_t$  is a net lump sum tax,  $P_t$  is the price level, and  $R_t$  is the one period gross nominal

interest rate.

Each of the monopolistically competitive firms faces a downward-sloping demand curve:

$$Y_t(j) = (P_t(j)/P_t)^{-1/\nu} Y_t \quad (3)$$

where  $P_t(j)$  is the price chosen by firm  $j$  and the parameter  $1/\nu$  is the elasticity of substitution between two differentiated goods. The firms take as given the general price level,  $P_t$ , and level of real activity  $Y_t$ . Whenever a firm wants to change its price, it faces quadratic adjustment costs represented by an output loss:

$$AC_t(j) = (\varphi/2) (P_t(j)/P_{t-1}(j) - \Pi)^2 Y_t(j) P_t(j)/P_t \quad (4)$$

The firm's problem consists in choosing the price  $P_t(j)$  to maximize the present value of future profits:

$$E_0 [\sum_{t=0}^{\infty} Q_t (P_t(j)Y_t(j)/P_t - W_t h_t(j) - AC_t(j))]$$

where  $Q_s$  is the household's stochastic discount factor. Labor is the only input in a linear production function,  $Y_t(j) = A_t h_t(j)$ , where total factor productivity  $z_t = \ln(A_t/A)$  follows an autoregressive process:  $z_t = \rho_z z_{t-1} + \epsilon_{z,t}$ ,  $\epsilon_{z,t} \sim N(0, 1)$ .

The government budget constraint is given by:

$$b_t = b_{t-1} (Y_t \Pi_t / Y_{t-1})^{-1} R_{t-1} - s_t$$

where  $b_t = B_t / (P_t Y_t)$  and  $s_t = S_t / (P_t Y_t)$  are the debt-to-GDP ratio and the primary surplus to GDP ratio, respectively. We assume that the government only moves lump sum taxes and provides a subsidy. In other words, we exclude government purchases and we assume that the primary surplus coincides with net lump sum taxes. This will allow us to completely isolate the effects of fiscal shocks deriving from the lack of fiscal discipline. Introducing government purchases ( $G_t$ ) would not modify the mechanism outlined here, but would make the interpretation of the results less immediate. The fiscal authority moves the primary surplus in response to deviations of debt from its own steady state ( $b$ ):

$$(s_t - s) = \rho_s (s_{t-1} - s) + (1 - \rho_s) \delta_{b,\xi_t} (b_{t-1} - b) + \sigma_s \epsilon_{s,t}, \quad \epsilon_{s,t} \sim N(0, 1) \quad (5)$$

while the Central Bank follows the rule:

$$\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_{R,\xi_t}} \left[ \left( \frac{\Pi_t}{\Pi} \right)^{\psi_{\pi,\xi_t}} \left( \frac{Y_t}{Y_t^n} \right)^{\psi_{y,\xi_t}} \right]^{(1-\rho_{R,\xi_t})} e^{\sigma_R \epsilon_{R,t}}, \quad \epsilon_{R,t} \sim N(0, 1) \quad (6)$$

where  $R$  is the steady-state gross nominal interest rate,  $Y_t^n$  is natural output, and  $\Pi$  is the target/steady state level for gross inflation. The unobserved state  $\xi_t$  captures the monetary/fiscal policy combination that is in place at time  $t$ . The unobserved state takes on a finite number of values  $j = 1, \dots, m$  and follows a Markov chain that evolves according to a transition matrix  $H$ .

The model is solved and linearized around the steady state. From now on, all variables should be interpreted as deviations from steady state.<sup>2</sup> The private sector can be described by the following system of equations:

$$\pi_t = \beta E_t(\pi_{t+1}) + \kappa(y_t - z_t) \quad (7)$$

$$y_t = E_t(y_{t+1}) - (R_t - E_t(\pi_{t+1})) + (1 - \rho_d) d_t \quad (8)$$

$$d_t = \rho_d d_{t-1} + \sigma_d \epsilon_{d,t}, \quad \epsilon_{d,t} \sim N(0, 1) \quad (9)$$

$$z_t = \rho_z z_{t-1} + \sigma_z \epsilon_{z,t}, \quad \epsilon_{z,t} \sim N(0, 1) \quad (10)$$

Inflation dynamics are described by the expectational Phillips curve (7) with slope  $\kappa$ . Equation (8) is the linearized intertemporal Euler equation describing the households' optimal choice of consumption and bond holdings.

The linearized government budget constraint is given by:

$$b_t = \beta^{-1} b_{t-1} + b \beta^{-1} (R_{t-1} - \pi_t - \Delta y_t) - s_t \quad (11)$$

where  $b_t$  and  $s_t$  represent now debt and surplus in terms of GDP in linear deviations from the steady state. The fiscal rule is given by:

$$s_t = \rho_s s_{t-1} + (1 - \rho_s) \delta_{b,\xi_t} b_{t-1} + \sigma_s \epsilon_{s,t}, \quad \epsilon_{s,t} \sim N(0, 1) \quad (12)$$

while the linearized monetary policy rule is:

$$R_t = \rho_{R,\xi_t} R_{t-1} + (1 - \rho_{R,\xi_t}) (\psi_{\pi,\xi_t} \pi_t + \psi_{y,\xi_t} [y_t - z_t]) + \sigma_R \epsilon_{R,t}, \quad \epsilon_{R,t} \sim N(0, 1) \quad (13)$$

## 2.2 Fixed coefficients and determinacy regions

Before describing the features of the model with regime changes, it is useful to review the properties of its *fixed coefficient* counterpart. Following Leeper (1991), we can distinguish four regions of the parameter space according to existence and uniqueness of a solution to the model. These regions are summarized in Table 1 and in general they are a function of all parameters of the model. However, in practice, the two policy rules are key in determining

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<sup>2</sup>We linearize with respect to debt and primary surpluses, given that these variables can change sign, while we log-linearize with respect to all the others.



existence and uniqueness of a solution. There are two determinacy regions. The first one, Active Monetary/Passive Fiscal (AM/PF), is the most familiar one: The Taylor principle is satisfied and the fiscal authority moves taxes in order to keep debt on a stable path:  $\psi_\pi > 1$  and  $\delta_b > \beta^{-1} - 1$ . To grasp the intuition behind this result, substitute the tax rule in the law of motion for government debt (assuming for simplicity  $\rho_s = 0$ ) and isolate the resulting coefficient for lagged government debt:

$$b_t = (\beta^{-1} - \delta_b) b_{t-1} + b\beta^{-1} (R_{t-1} - \pi_t - \Delta y_t) - \sigma_s \epsilon_{s,t}$$

Intuitively, in order to guarantee stability of government debt, we need this coefficient to be smaller than one ( $\beta^{-1} - \delta_b < 1$ ), so that debt is mean reverting. This in turn requires the coefficient on debt in the tax rule to satisfy the condition  $\delta_b > \beta^{-1} - 1$ . Therefore, we can think of fiscal policy as passive to the extent that it *passively* accommodates the behavior of the monetary authority ensuring debt stability. Woodford (1995) refers to this regime combination as Ricardian in the sense that the fiscal authority is committed to making the necessary adjustments to fiscal tools in order to neutralize any disturbance affecting the government budget constraint. Under this parameter combination the macroeconomy is *insulated* from fluctuations of the debt-to-GDP ratio as agents understand that any imbalance will eventually be reabsorbed by means of adjustments to primary surpluses.

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:  $\psi_\pi < 1$ . Woodford (1995) refers to this regime combination as non-Ricardian. Under this regime, the macroeconomy is *not insulated* from the fiscal block. In other words, 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. Finally, when both authorities are active (AM/AF) no stable equilibrium exists, whereas when both of them are passive (PM/PF) the economy is subject to multiple equilibria.

As it will be highlighted in the next section, this one-to-one mapping between the regions of the parameter space identified by Leeper (1991) and the terminology introduced by Woodford (1995) applies only in the context of a model with fixed coefficients. When regime changes are introduced the distinction between Ricardian and non-Ricardian regimes becomes more subtle and crucially depends on agents' beliefs about the future evolution of the policy mix.

The profession has extensively studied the behavior of the economy under the AM/PF regime and the problem of indeterminacy, whereas less attention has been devoted to the

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

Table 1: Partition of the parameter space according to existence and uniqueness of a solution (Leeper (1991)).

PM/AF determinacy region. A popular argument is based on the idea that even if the government does not constantly move taxes in order to stabilize debt, this does not imply that it will never do it. In other words, even if agents observe the PM/AF regime for a while, this does not mean that they are going to expect such a situation to prevail forever. We start from this argument to construct a model in which the presence of a period of PM/AF policy mix does not necessarily imply that the economy is subject to inflationary pressure. At the same time, we want to allow for the possibility that if a deviation lasts for a prolonged period of time, agents can rightfully lose confidence about the commitment of the government to stabilize debt. In Section 3.1, we start building the intuition using a model in which agents can exactly infer the likely duration of a deviation from the Virtuous regime. This model will serve as benchmark for the full model with learning that will be introduced in Section 3.2.

### 3 Regime changes and agents' beliefs

Consider the model described by the system of equations (7)-(13) and assume that the evolution of the monetary/fiscal policy mix can be described by a three-regime Markov switching process whose transition matrix  $H$  is:

$$H = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ 1 - p_{22} & p_{22} & \\ 1 - p_{33} & & p_{33} \end{bmatrix}$$

We will make use of the following two guidelines to characterize the matrix  $H$  and the three regimes. First, fiscal and monetary authorities do not have to pursue their goals on a daily basis. Deviations from the Taylor principle are possible and the fiscal authority does not have to constantly move taxes in order to keep debt on target. What is truly necessary is that over a medium-long horizon policy makers act responsibly and that agents understand this. In fact, it is quite reasonable that policy makers want to retain some flexibility in order to respond effectively to extraordinary events. To model this feature, we introduce two regimes. Regime 1 is the Virtuous regime: the Taylor principle is satisfied and fiscal policy accommodates the behavior of the monetary authority (i.e. monetary policy is active and fiscal policy is passive,  $\psi_{\pi,1} = \psi_{\pi}^A > 1$  and  $\delta_{b,1} = \delta_b^P > \beta^{-1} - 1$ ). Under Regime 2, the central bank reacts less than one-for-one to inflation and the fiscal authority does not move surpluses in response to movements

Parameter	Value	Parameter	Value	Parameter	Value
$\psi_\pi^A$	0.80	$\rho_s$	0.90	$100\sigma_R$	0.20
$\psi_\pi^P$	2.00	$\rho_z$	0.90	$100\sigma_s$	0.50
$\psi_y^A$	0.10	$\rho_d$	0.90	$100\sigma_z$	0.70
$\psi_y^P$	0.10	$b$	1.00	$100\sigma_d$	0.40
$\rho_R^A$	0.75	$\kappa$	0.05	$p_{11}$	95%
$\rho_R^P$	0.75	$\beta$	0.99	$p_{12}$	4.95%
$\delta_b^A$	0			$p_{22}$	70%
$\delta_b^P$	0.03			$p_{33}$	99%

Table 2: Parameter choices of the DSGE parameters and of the transition matrix elements.

in government debt (i.e. monetary policy is passive and fiscal policy is active,  $\psi_{\pi,2} = \psi_\pi^P < 1$  and  $\delta_{b,2} = \delta_b^A = 0 < \beta^{-1} - 1$ ). To capture the idea that these deviations are short lasting, we set the persistence of Regime 2 to a relatively low value:  $p_{22} \ll 1$ .

Second, we want to allow for the possibility of long lasting deviations from the standard policy practice. Therefore, we characterize Regime 3 as having the same parameters of Regime 2, but different persistence:  $\psi_{\pi,3} = \psi_{\pi,2} = \psi_\pi^P < 1$ ,  $\delta_{b,3} = \delta_{b,2} = \delta_b^A = 0 < \beta^{-1} - 1$ , and  $p_{33} \gg p_{22}$ . It is important to stress that even if the parameters entering the Taylor and fiscal rules are the same, the two regimes are in fact different. This is because the different persistence has deep implications on what agents expect about the future, as it will be illustrated in Section 3.1. Given that a long lasting deviation represents a substantive shift in the conduct of monetary and fiscal policies, we assume that when in the Virtuous regime policy makers are more likely to engage in a short lasting deviation, i.e. they are more likely to move to Regime 2:  $p_{12} > p_{13}$ .

### 3.1 Perfect information

Before moving to the full model with learning, we will analyze the properties of the companion model in which agents can observe all aspects of the economy, including the regime that is in place at each point in time. We calibrate the model using the values reported in Table 2. When agents are aware of regime changes, standard solution methods do not apply. Instead, we need to use one of the solutions methods developed to handle Markov-switching general equilibrium models. The solution algorithm employed in this paper is based on the work of Farmer et al. (2010). The authors show that it is possible to reduce the task of finding a Minimal State Variable solution to that of computing the roots of a quadratic polynomial in several variables. When a solution exists, it can be characterized as a regime switching vector-autoregression, of the kind studied by Hamilton (1989), Chib (1996), and Sims and Zha (2006):

$$S_t = T(\xi_t, \theta, H) S_{t-1} + R(\xi_t, \theta, H) \varepsilon_t \quad (14)$$

It is worth emphasizing that the law of motion of the DSGE states depends on the model parameters ( $\theta$ ), the regime in place ( $\xi_t$ ), and the probability of moving across regimes ( $H$ ). This means that what happens under regime  $i$  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.

The simplest way to understand the properties of the different regimes is to analyze the impulse responses. Figure 1 contains the results. We shall start focusing on the response to a negative primary surplus shock, reported in the last row. The difference between the long lasting PM/AF regime and the other two regimes is particularly striking. Under the Virtuous regime and the short lasting PM/AF regime, this shock does not have any effect on inflation and output, whereas under the long lasting deviation we observe a large and persistent increase in inflation and an expansion in output. Under the Virtuous regime and the short lasting deviation, the debt-to-GDP ratio starts increasing slowly and steadily in response to the increase in expenditure. The two paths differ only to the extent that under the Virtuous regime the government is adjusting primary surpluses in response to the increase in debt. Under the long lasting deviation the debt-to-GDP ratio experiences a sudden drop, due to the increases in inflation and GDP, followed by a smooth return to the steady state from below because of the increased level of expenditure and the slowdown in growth.

From these impulse responses, it should be clear that a short lasting deviation from the Virtuous regime has very different implications with respect to a long lasting deviation. The interesting fact here is that the behavior of the two authorities is *identical* across the two regimes. However, the two regimes differ to the extent that they induce different expectations about the future policy makers' behavior. To illustrate this point, for each regime, Figure 2 reports the one-step-ahead probability of observing a deviation from the Virtuous regime and the expected number of consecutive deviations. When the economy is under the Virtuous regime, agents are confident of staying there for a while and the expected number of consecutive deviations is very low. When under the short lasting PM/AF regime, the one-step-ahead probability increases substantially, but the expected number of consecutive deviations is still very low (2.33). Finally and most importantly, when the economy moves to the long lasting PM/AF regime, the number of consecutive deviations expected by the agents increases substantially. Therefore, under the short lasting deviation agents are confident that in the near future the government will run a sequence of primary surpluses to balance the debt-to-GDP ratio. Instead, when a long lasting deviation occurs, agents are discouraged about a prompt return to the Virtuous regime. In this case, the fiscal imbalance generated by the increase in primary deficits calls for an increase in inflation. Given that the Taylor principle does not hold, the monetary authority accommodates such an increase. This determines a drop in real interest rates and output increases. High inflation and the jump in output cause the drop in

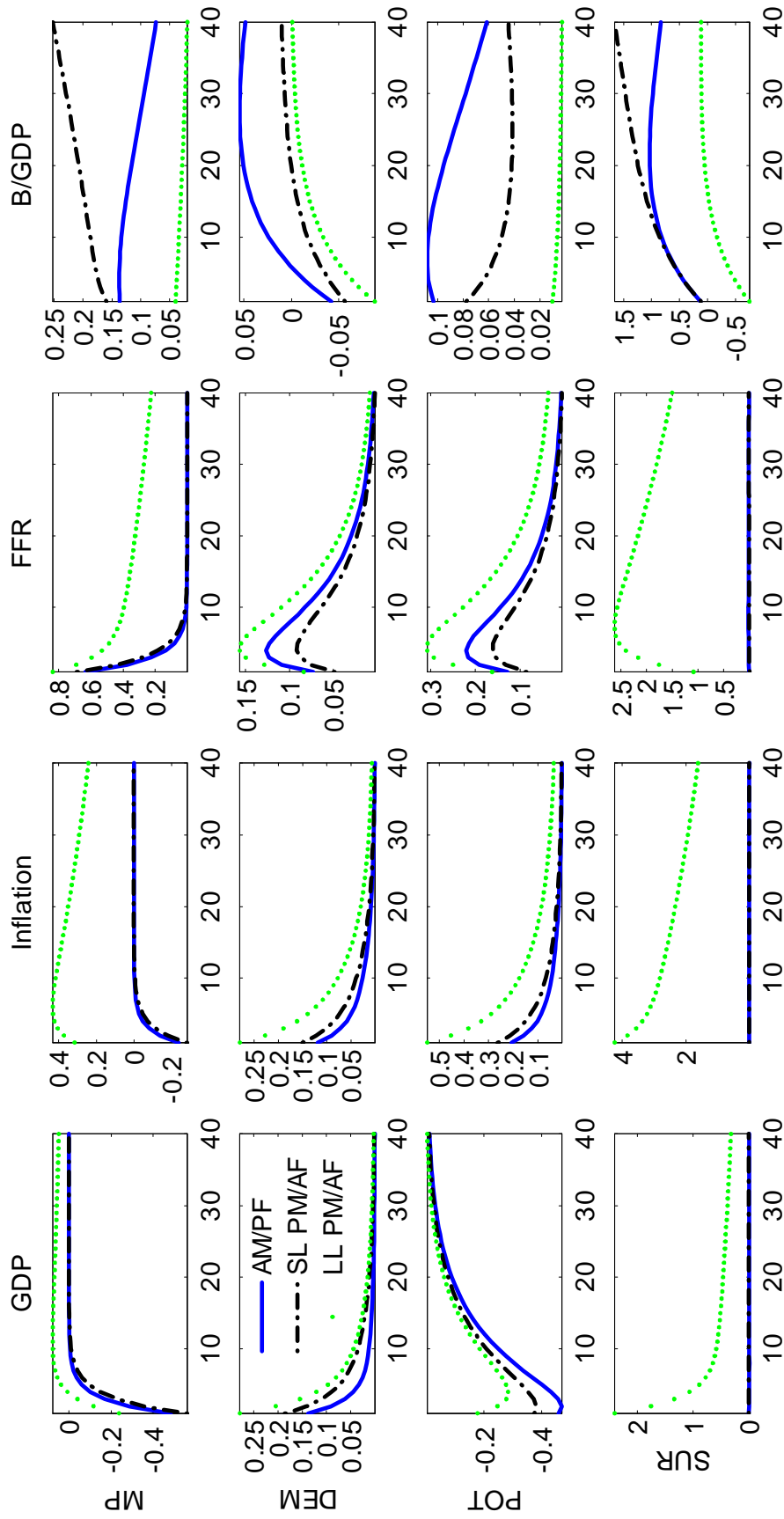


Figure 1: Impulse responses under perfect information.

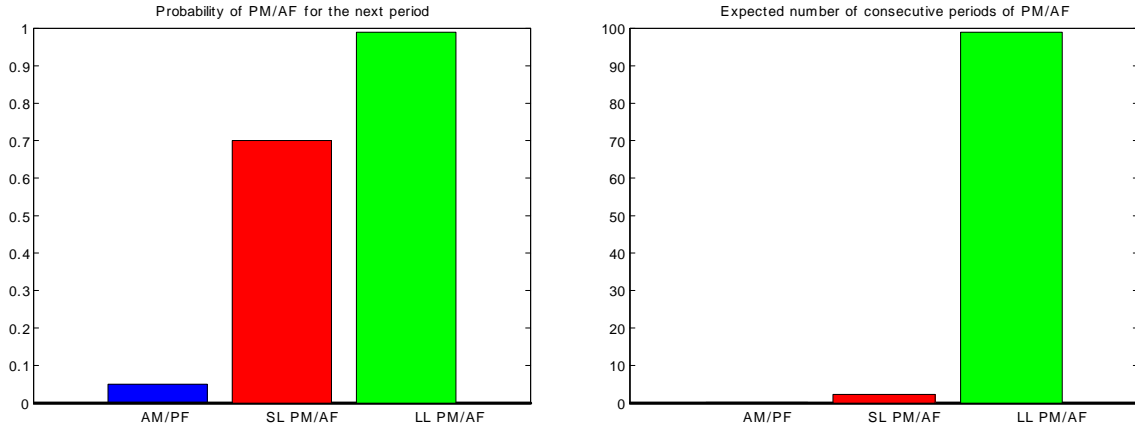


Figure 2: The two columns report respectively the one-step-ahead probability of a deviation from the Virtuous regime and the expected number of consecutive deviations under the different regimes assuming that agents have perfect information.

the debt-to-GDP ratio.

Agents' expectations also affect the response of the economy to the other shocks. The first row reports the responses to a monetary policy shock. Under all regimes, the Federal Reserve retains the ability to generate a recession. However, under the long lasting PM/AF regime, inflation instead of declining, increases. This "stepping on a rake" effect (Sims (2011)) implies that the Central Bank loses its ability of controlling inflation the moment that its actions are not adequately supported by the fiscal authority. Notice that the inflation dynamics under the short lasting deviation are very similar to the ones implied by the Virtuous regime. This occurs despite the fact that the fiscal rule in place at the time of the shock determines an increase in the debt-to-GDP ratio that could appear to be permanent to an external observer. In the short run, given the presence of nominal rigidities, the increase in the FFR determines an increase in the real interest that makes the cost of debt larger. Under the short lasting deviation, agents are confident that a return to the Virtuous regime will soon occur. This is why the increase in debt is not inflationary. Under the long lasting deviation agents anticipate that the government will not increase primary surpluses in the near future and inflation increases in order to stabilize debt. The Central Bank accommodates the increase of inflation and debt slowly declines because of negative real interest rates.<sup>3</sup>

The results shown above allow us to make the first important point: In a model with recurrent regime changes the policy mix is not enough to establish if a regime is Ricardian or not. Instead, the persistence of the regime becomes a key ingredient given that it affects agents' expectations about the conduct of fiscal and monetary policies in the medium and long run.

<sup>3</sup>The stepping on a rake effect is a robust finding and it holds also in the richer model considered by Bianchi and Ilut (2012). However, the short run inflation dynamics can differ depending on the exact features of the model.

When agents are confident about a prompt return to the virtuous policy mix, a fiscal imbalance is not inflationary even if policy makers do not immediately take care of it. Agents understand that with high probability the necessary adjustments will occur in the future. Instead, when the regime change is perceived to be too far into the future, inflation will have to move in order to guarantee debt stability.

### 3.2 Bayesian Learning

We are now ready to analyze the case in which agents cannot observe the regime they are in. Let  $\mathcal{F}_t$  be agents' information set. It is assumed that agents observe the history of the endogenous variables as well as the history of all shocks. However, agents do not observe the history of regimes. Instead, they need to conduct Bayesian learning in order to infer the regime that they are in. Regime changes are modeled as the three-regime Markov switching process described above. In this context, the transition matrix also reflects agents' priors about the evolution of the monetary/fiscal policy mix.

Since agents know the history of endogenous variables and shocks, they can exactly infer the policy mix that is in place at each point in time. However, while the Virtuous regime is fully revealing, when the PM/AF mix prevails agents do not know whether policy makers are engaging in a short-lasting or a long-lasting deviation. Agents have to learn the nature of the deviation in order to form expectations over the endogenous variables of the economy. An important result is then the following: *Agents will grow more and more pessimistic about moving back to the Virtuous regime, the longer the time spent under the alternative policy mix.* To see this, note that after having observed  $\tau \geq 1$  consecutive deviations from the Virtuous regime, agents believe that policy makers will keep deviating in the next period  $t + 1$  with probability:<sup>4</sup>

$$\text{prob} \{s_{t+1} \neq 1 | \mathcal{F}_t\} = \frac{p_{22} (p_{12}/p_{13}) (p_{22}/p_{33})^{\tau-1} + p_{33}}{(p_{12}/p_{13}) (p_{22}/p_{33})^{\tau-1} + 1}. \quad (15)$$

The probability  $\text{prob} \{s_{t+1} \neq 1 | \mathcal{F}_t\}$  has a number of properties that shed light on the key features of the learning mechanism. Since  $p_{22} < p_{33}$ , this probability is monotonically increasing with respect to the number of last consecutive deviations  $\tau$ . As the number of periods  $\tau$  in which the PM/AF policy mix has prevailed increases, agents become more and more pessimistic about the odds of switching to the Virtuous regime in the next period. The reason is that as policymakers keep deviating from the Virtuous regime, agents get increasingly convinced that the two authorities are engaging in a long-lasting deviation (Regime 3) from where switching to the Virtuous regime is more unlikely ( $p_{22} < p_{33}$ ).

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<sup>4</sup>This result can be derived by applying Bayes' theorem and then combining the resulting probabilities with the transition matrix  $H$ . See Bianchi and Melosi (2012b) for a detailed derivation.

Furthermore, agents' pessimism admits an upper and lower bound. If policy makers deviate from the Virtuous regime for a very long time, agents will eventually become convinced of being in the long lasting PM/AF regime and the probability of observing an additional deviation in the next period degenerates to the persistence of such a regime:

$$\lim_{\tau \rightarrow \infty} \text{prob} \{s_{t+1} \neq 1 | \mathcal{F}_t\} = p_{33} \quad (16)$$

Hence,  $p_{33}$  is the upper bound for agents' pessimism. This implies that for each  $\varepsilon > 0$ , there exists an integer  $\tau^*$  such that:

$$p_{33} - \text{prob} \{s_{t+1} \neq 1 | \tau = \tau^*\} < \varepsilon \quad (17)$$

with the important result that for any  $\tau > \tau^*$  agents' beliefs can be effectively approximated using the properties of the long lasting PM/AF regime.

As far as the lower bound is concerned, when agents observe policy makers deviating for the first time (i.e.,  $\tau = 1$ ), then equation (15) shows that the probability of staying in the passive regime is an average of the persistence of the two passive regimes  $p_{22}$  and  $p_{33}$  with weights  $p_{12}/(p_{12} + p_{13})$  and  $p_{13}/(p_{12} + p_{13})$ . This weighted average is the lower bound for agents' pessimism. The smaller the conditional probability  $p_{13}/(p_{12} + p_{13})$ , the closer the lower bound will be to  $p_{22}$ .

The intuition behind such a lower and upper bound for the waves of agents' pessimism goes as follows. For a given number of consecutive deviations  $\tau$ , the probability of observing another deviation next period will be a weighted average of  $p_{22}$  and  $p_{33}$ . When agents observe policy makers deviating from the Virtuous regime for the first time ( $\tau = 1$ ), the weight that they assign to a long lasting deviation depends on the ratio  $p_{12}/p_{13}$  (excluding the degenerate case in which one of these two probabilities is zero). As policy makers keep deviating, agents get increasingly convinced that the economy entered a long-lasting deviation, given that under this regime long deviations are more likely. As the weight assigned to the long lasting deviation increases, the probability of observing an additional deviation increases, given that  $p_{33} > p_{22}$ . When policy makers have deviated from the Virtuous regime for a sufficiently large number  $\tau^*$  of periods, agents are substantially sure to be in the long-lasting PM/AF regime. Consequently, their pessimism will reach its upper bound, which is the probability that next period's policy mix will be again PM/AF conditional on being in the long-lasting passive regime:  $p_{33}$ .

These ideas are summarized in Figure 3. The first column describes the evolution of agents' beliefs as a function of the number of observed deviations from the Virtuous regime. The Virtuous regime is fully revealing, therefore agents do not face any uncertainty.<sup>5</sup> When agents

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<sup>5</sup>It is not hard to extend the model to allow for a short lasting and a long lasting AM/PF regime. Bianchi and Melosi (2012b) consider this case.



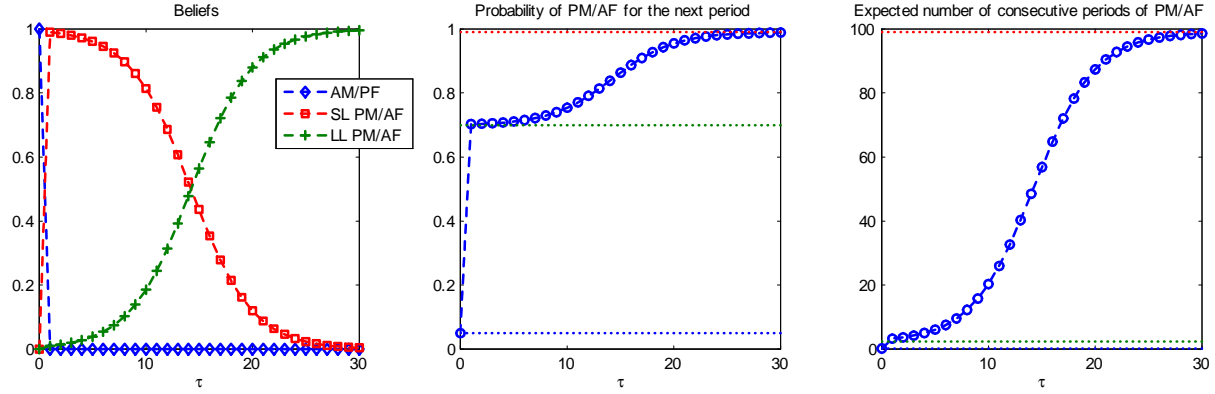


Figure 3: From left to right, the three columns describe, as a function of the number of consecutive deviations  $\tau$ , the evolution of agents' beliefs, the one-step-ahead probability of observing the PM/AF policy mix, and the expected number of consecutive deviations.

observe the first deviation, they are relatively confident that the prevailing regime is the short lasting PM/AF regime, given the assumption  $p_{12} > p_{13}$ . However, as the number of deviations grows, agents become more and more convinced that the economy entered a long lasting deviation. Initially the probability attached to the long lasting PM/AF regime increases slowly, but it eventually accelerates as agents from relatively optimistic become relatively pessimistic. This has important implications on agents' expectations regarding the future behavior of policy makers. The second and third columns of Figure 3 report the one-step-ahead probability of observing the PM/AF policy mix and the expected number of consecutive deviations implied by the drift in beliefs. As agents observe more and more deviations, they become more and more pessimistic and the expected number of consecutive deviations increases. The moment agents from relatively optimistic become relatively pessimistic, the expected number of consecutive deviations accelerates. Finally, as agents become convinced of being in a long lasting deviation the expected number of consecutive deviations converges to the one prevailing under the long lasting PM/AF regime. This drift in beliefs about the future behavior of policy makers has deep implications for the way shocks propagate through the economy. However, before we will briefly describe the solution method for the model with learning.

### 3.2.1 Solving the model with learning

It is very important to emphasize that the evolution of agents' beliefs about the future conduct of fiscal and monetary policies plays a critical role in the Markov-switching model with learning. In fact, unlike the perfect information model described in Section 3.1, the dynamics of the endogenous variables in the model with learning cannot be fully captured by the three policy regimes. Instead, agents expect different dynamics for next period's endogenous variables depending on their beliefs about a return to the Virtuous regime.

Therefore, learning requires expanding the number of regimes and re-defining them as a combination between policy makers' behavior and agents' beliefs. Such new regimes reflect different degrees of pessimism while agents are learning about the persistence of the deviation from the Virtuous regime. Bianchi and Melosi (2012b) show that the Markov-switching model with learning described above can be recasted in terms of an expanded set of  $(\tau^* + 1) > 3$  new regimes, where  $\tau^* > 0$  is defined by the condition (17). The increased number of regimes captures the degree of pessimism associated with observing deviations from the Virtuous regime for  $\tau = 1 \dots \tau^*$  periods. The  $\tau^* + 1$  regimes are given by:

$$[(\xi_t = 1, \tau_t = 0), (\xi_t \neq 1, \tau_t = 1), (\xi_t \neq 1, \tau_t = 2), \dots, (\xi_t \neq 1, \tau_t = \tau^*)]$$

and the transition matrix  $\tilde{H}$  is defined as:

$$\tilde{H} = \begin{bmatrix} p_{11} & p_{12} + p_{13} & 0 & \dots & 0 & 0 \\ 1 - \frac{p_{12}p_{22} + p_{13}p_{33}}{p_{12} + p_{13}} & 0 & \frac{p_{12}p_{22} + p_{13}p_{33}}{p_{12} + p_{13}} & \dots & 0 & 0 \\ 1 - \frac{p_{12}p_{22}^2 + p_{13}p_{33}^2}{p_{12}p_{22} + p_{13}p_{33}} & 0 & 0 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 1 - \frac{p_{12}p_{22}^{(\tau^*-1)} + p_{13}p_{33}^{(\tau^*-1)}}{p_{12}p_{22}^{(\tau^*-2)} + p_{13}p_{33}^{(\tau^*-2)}} & 0 & 0 & 0 & \frac{p_{12}p_{22}^{(\tau^*-1)} + p_{13}p_{33}^{(\tau^*-1)}}{p_{12}p_{22}^{(\tau^*-2)} + p_{13}p_{33}^{(\tau^*-2)}} \\ 1 - \frac{p_{12}p_{22}^{\tau^*} + p_{13}p_{33}^{\tau^*}}{p_{12}p_{22}^{(\tau^*-1)} + p_{13}p_{33}^{(\tau^*-1)}} & 0 & 0 & 0 & \frac{p_{12}p_{22}^{\tau^*} + p_{13}p_{33}^{\tau^*}}{p_{12}p_{22}^{(\tau^*-1)} + p_{13}p_{33}^{(\tau^*-1)}} \end{bmatrix}.$$

Hence, one can recast the Markov-switching DSGE model with learning as a Markov-switching Rational Expectations system, in which the regimes are re-defined in terms of realized duration of the passive regimes,  $\tau_t$ . This result allows us to solve the model with regime switches and learning by applying any of the methods developed to solve Markov-switching rational expectations models.

It is worth emphasizing that this way of recasting the learning process allows us to easily model the behavior of agents that *know that they do not know*. In other words, agents are aware of the fact that their beliefs will change in the future according to what they observe in the economy. This represents a substantial difference with the anticipated utility approach in which agents form expectations without taking into account that their beliefs about the economy will change over time. Furthermore, the approach described above differs from the one traditionally used in the learning literature in which agents form expectations according to a reduced form law of motion that is updated recursively (for example OLS regressions). The advantage of adaptive learning is the extreme flexibility given that, at least in principle, no restrictions need to be imposed on the type of parameter instability characterizing the model. However, such flexibility does not come without a cost, given that agents are not really aware of the model they live in, but only of the implied law of motion. Instead, in this paper agents fully

understand the model and they are aware of the trade-offs that characterize it. However, they are uncertain about the future behavior of policy makers and this uncertainty has important consequences for the law of motion of the economy.

### 3.2.2 Impulse responses

In order to understand the properties of the model, we will start illustrating how learning affects the propagation of the shocks. Figure 4 contains impulse responses conditional on different starting values of  $\tau$  and assuming that the PM/AF regime is in place over the entire horizon. The dark/reddish colors correspond to large *starting* values for  $\tau$ , while as the colors become lighter and lighter turning into light blue, the starting number of deviations falls to 1 (i.e. at the time of the shock agents observe the first deviation to the PM/AF regime). We do not report here the response under the Virtuous regime because this would look very similar to the one prevailing under perfect information, as the regime is fully revealing.<sup>6</sup>

Before proceeding, it is worth stressing an important point. The assumption that the PM/AF regime prevails over the entire horizon implies that the number of observed deviations  $\tau$  grows over time. This in turn determines a progressive change in the law of motion as agents become more and more convinced of being in the long lasting PM/AF regime. The law of motion then stabilizes in the moment that agents become certain that they entered a long lasting deviation ( $\tau = \tau^*$ ). The law of motion would change again if agents were to observe a return to the Virtuous regime. This case will be analyzed in the Section 5.1.

**Fiscal shocks.** We shall start considering the responses to a negative primary surplus shock when agents have observed a large number of consecutive deviations. In this case, agents are already convinced of being in the long lasting PM/AF regime. As a result, the impulse responses resemble very closely the ones implied by the same regime under perfect information.<sup>7</sup> Following the shock, inflation increases immediately and then it slowly declines. At the same time, the debt-to-GDP ratio experiences a large drop as a result of higher growth and larger inflation, despite the increase in the primary deficit. As it was the case for the perfect information case, these dynamics reflect the expectation that the government will not increase future surpluses in order to cover the current deficits.

When the starting number of deviations is low, these effects are initially mitigated because agents are confident about a prompt return to the Virtuous regime. During the first few periods, inflation and GDP barely move, even if the current behavior of policy makers is still characterized by the PM/AF policy mix. Consequently, we do not observe the drop in the debt-

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<sup>6</sup>Nevertheless the impulse responses would not be *identical* because the uncertainty that prevails under the PM/AF regime also affects the law of motion under the virtuous regime.

<sup>7</sup>However, even when agents think that they are in the long-lasting PM/AF regime with probability one, the law of motion still slightly differs from the one implied by the model with perfect information because agents' expectations about the future reflect the additional uncertainty deriving from the learning mechanism.

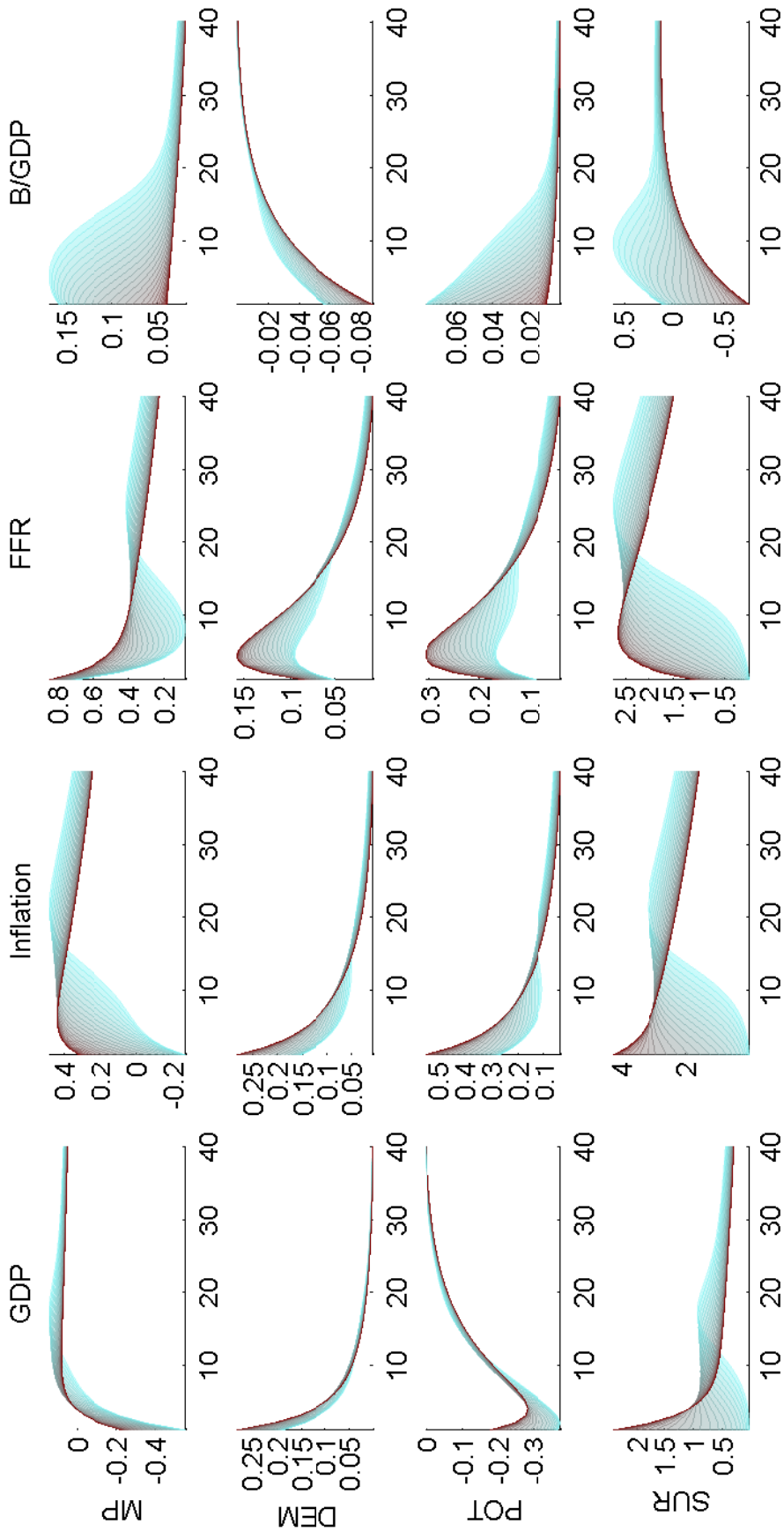


Figure 4: Impulse responses under learning assuming that the PM/AF regime prevails over the relevant horizon. Moving from the light-blue to the dark-red, the initial number of observed deviations increases. The impulse responses under the Virtuous regime are very similar, although not identical, to the ones that prevail under perfect information.

to-GDP ratio, that instead starts increasing because of the primary deficits. However, as agents observe more and more deviations, their expectations start drifting, the law of motion evolves, and the non-Ricardian dynamics start arising. Inflation starts increasing smoothly, then it accelerates in the moment that agents become relatively pessimistic, and it finally reaches its peak after approximately seven years. Symmetrically, real interest rates decline because the Taylor principle does not hold, output starts growing, and the debt-to-GDP ratio falls.

**The ability to control inflation.** When the initial number of deviations is small, in response to a monetary policy shock inflation declines on impact and stays below the steady state for several periods. However, as agents become aware of the possibility that the economy entered a long lasting deviation, inflation starts increasing and the stepping on a rake effect appears. If agents have already observed a large number of deviations, the entire sequence of events occurs more quickly and inflation immediately increases. These dynamics have two important implications. First, when the initial number of deviations is small, a central bank might be initially induced to believe that it is still able to control inflation, given that the stepping on a rake effect does not immediately manifest itself. Second, as policy makers keep deviating and the ability of the central bank to control inflation deteriorates, a central bank might erroneously be induced to think that structural changes are occurring in the economy that are making the sacrifice ratio less favorable.

## 4 Dormant shocks and Fiscal Virtue

As shown in Section 3.2.2, when learning is introduced in the model with regime changes, the economy responds gradually to the shocks as agents update their beliefs about the future behavior of policy-makers. The response to a fiscal shock is particularly interesting, given that the learning mechanism can substantially prolong its effects and move the peak of the responses further into the future. In this section, we will analyze these features more in detail introducing the notion of *dormant shocks* and characterizing their effects as a function of *fiscal virtue*.

### 4.1 Dormant shocks

Figure 5 considers a large negative shock to primary surpluses occurring at time 0 under the Virtuous regime. After five years policy makers start deviating from the Virtuous regime and they keep deviating for twenty years. The left panel reports the impulse responses while the right panel contains the evolution of expected volatility at different horizons, from 1 year (light blue) to 5 years (dark red). This measure of uncertainty is computed taking into account the possibility of regime changes and the evolution of agents' beliefs using the methods described in Bianchi (2012a). For a variable  $X_t$  and an horizon  $T$ , it corresponds to the square root of

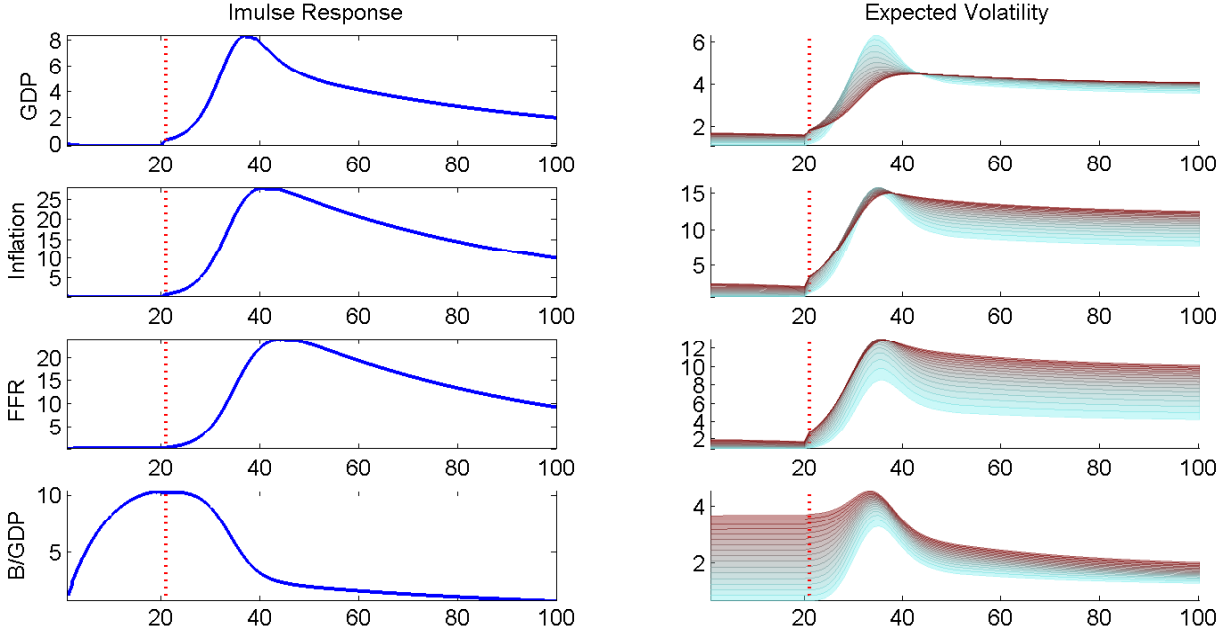


Figure 5: The two columns report the evolution of the endogenous variables and the correspondent expected volatilities assuming a large primary surplus shock occurring at time 0 and a regime change from the AM/PF to the PM/AF regime after five years. In the right column, moving from the light blue to the dark red the time horizon increases from one to five years. Expected volatilities are computed taking into account the possibility of regime changes.

$$V(X_{t+T}|\mathcal{F}_t).$$

Notice that as long as the Virtuous regime prevails the effects on inflation, output, and FFR are basically undetectable as agents expect taxes to be raised in order to repay the growing debt. However, as soon the policy mix changes, the learning process begins. At this point an external observer that were focusing exclusively on the three standard macroeconomic variables would be observing a slow moving increase in inflation, an acceleration in output growth (and a positive output gap), combined with a weak response of the FFR. All of these changes would be without any apparent explanation, as no new shocks have occurred. Fiscal shocks have therefore an interesting property in this environment: They can manifest themselves many years after they occurred. In the meantime, they are just *dormant shocks*, given that they do not have any apparent effect on the three standard macroeconomic variables. Notice that this aspect makes them very hard to identify. If an econometrician were trying to understand the causes of the slow-moving increase in inflation, he might be tempted to conclude that a change in the target for inflation occurred. On the other hand, he might want to include fiscal variables in order to estimate the model under the assumption that a non-Ricardian regime is in place. However, if he happens to exclude the early years of the sample, he might have a very hard time trying to recover any movement in the fiscal variables that could in fact explain the slow moving increase

in inflation.

The increase in inflation is not the only effect of the changed economic environment. As outlined in the right column, agents also face an increase in uncertainty. The expected volatilities of the macroeconomic variables start increasing smoothly and reach a peak in the moment that agents from relatively optimistic become relatively pessimistic. These beliefs coincide with the peak of uncertainty because agents attach similar probabilities to two very different scenarios: A large spur of inflation to cover the large debt or a return to the Virtuous regime with a subsequent drop in inflation. This also explains why uncertainty is *larger* at short horizons than at long horizons: In the long run debt is expected to be closer to the steady state, independently of the path taken by policy makers, while in the short run the large stock of debt can have pervasive effects on the macroeconomy. Dormant shocks have therefore another interesting effect: After many years they can cause an increase in the volatility of the endogenous variables and consequently in agents' uncertainty. Once again, these effects are dormant as long as the economy is under the Virtuous regime.

As agents become convinced that debt will be inflated away, the volatilities approach the values associated with the long lasting PM/AF regime. Under this regime macroeconomic uncertainty is larger than under the Virtuous regime for three reasons. First, given that the Fed reacts less strongly to deviations of inflation from the target, any shock has a larger *direct* impact on the dynamics of inflation. Second, any shock that moves the debt-to-GDP ratio is also going to have an *indirect* impact on all the macroeconomic variables. Third, the fiscal shocks that are dormant under the Virtuous regime, affect the macroeconomic variables under the long lasting PM/AF.

Summarizing, an observer that were monitoring the evolution of our hypothetical economy would be detecting a progressive increase in volatility and uncertainty, measured by *expected* volatility. At the same time, she would observe an increase in inflation that seems to gain momentum over time. Our external observer would probably conclude that the target for inflation has changed and that the volatility of the exogenous shocks has increased.

## 4.2 Fiscal Virtue

The previous section has emphasized that dormant shocks can have effects many years after they occurred. In this section we will elaborate more on this point, trying to understand what determines the lag between the time of the regime change and the peak of the inflation increase that such a regime change triggers. We will show that two margins are important to understand how quickly the events described above unfold. The first margin is represented by the relative probability of entering a short lasting versus a long lasting deviation and controls agents' *a-priori beliefs* following a first deviation from the Virtuous regime. The second margin is given

$100p_{13}/(p_{12} + p_{13})$	$p_{22}$	$\tau^*$	$100p_{13}/(p_{12} + p_{13})$	$p_{22}$	$\tau^*$
.04	0.70	40	1.00	.90	97
.20	0.70	36	1.00	.80	48
<b>1.00</b>	<b>0.70</b>	<b>31</b>	<b>1.00</b>	<b>.70</b>	<b>31</b>
5.00	0.70	26	1.00	.60	23

Table 3: Parameter values used in the study of dormant shocks. The persistences of the long lasting PM/AF regime and of the AM/PF regime are fixed at .99 and .95, respectively.

by the relative persistence of the short and long lasting deviations and controls agents' *tolerance* for a long sequence of deviations.

Figure 6 considers the same exercise of the previous subsection for different values of the ratio  $p_{13}/(p_{12} + p_{13})$ . Recall that this ratio controls agents' a-priori beliefs of entering a long lasting versus a short lasting deviation. In other words, it determines the probability attached to the long lasting regime once agents observe the first realization of the PM/AF policy mix. As this ratio declines, agents are a-priori more and more optimistic about the possibility of facing only a temporary deviation. Consequently, it takes longer for agents to become convinced that they entered a long lasting deviation. To capture this idea, the different curves are labelled according to the implied  $\tau^*$ , i.e. the number of deviations required for agents' beliefs to approximately coincide with the ones implied by the long lasting PM/AF regime. As explained in Subsection 3.2 this value represents an upper bound on agents' pessimism. The dotted green line represents the benchmark case in which  $p_{13}/(p_{12} + p_{13}) = 1\%$  and  $\tau^* = 31$ . Table 3 summarizes the mapping for the other three curves.

As the ratio  $p_{13}/(p_{12} + p_{13})$  declines and  $\tau^*$  increases, the peak of the inflation spur moves to the right. When agents attach a conditional probability of .04% to the long lasting regime, the peak in inflation occurs thirteen years after the shock took place and eight years after the regime change occurred. When instead agents are relatively pessimistic and  $p_{13}/(p_{12} + p_{13}) = 5\%$ , the learning process is faster and the peak of inflation occurs only six years after the regime change. Given that the ratio  $p_{13}/(p_{12} + p_{13})$  controls a-priori agents' beliefs, it is capturing the credibility of policy-makers in agents' eyes. Agents' beliefs are likely to reflect some historical evidence, in which case the matrix  $H$  would be pinned down by the relative frequency of short lasting and long lasting deviations. Alternatively, we could imagine that agents form subjective conjectures about how likely it is that the government will engage in a persistent deviation from the Virtuous regime. In other words, agents could retain the occurrence of a long lasting deviation more or less likely according to policy makers' reputation. However, no matter what agents' a-priori beliefs are, *as long as agents update them according to what they observe, the government cannot indefinitely avoid increasing taxes*. In other words, no matter how optimistic agents are, if the government deviates for a long period of time, eventually it will



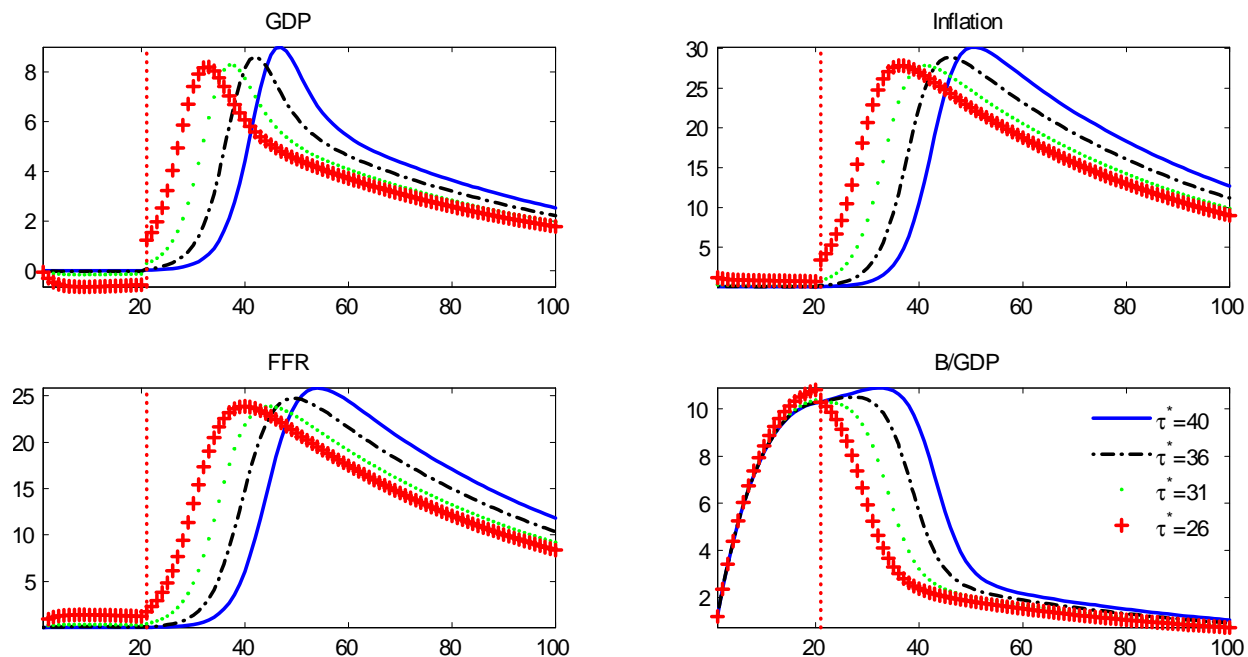


Figure 6: The figure considers the effects of large a "dormant shock" to primary surplus for transition matrices that differ according to the a-priori relative probability of a short lasting deviation. The shock occurs at time 0, while the regime change occurs after 20 periods (red vertical bar). The different a-priori beliefs are captured by the different periods necessary to convince agents that they entered a long lasting deviation ( $\tau^*$ ).

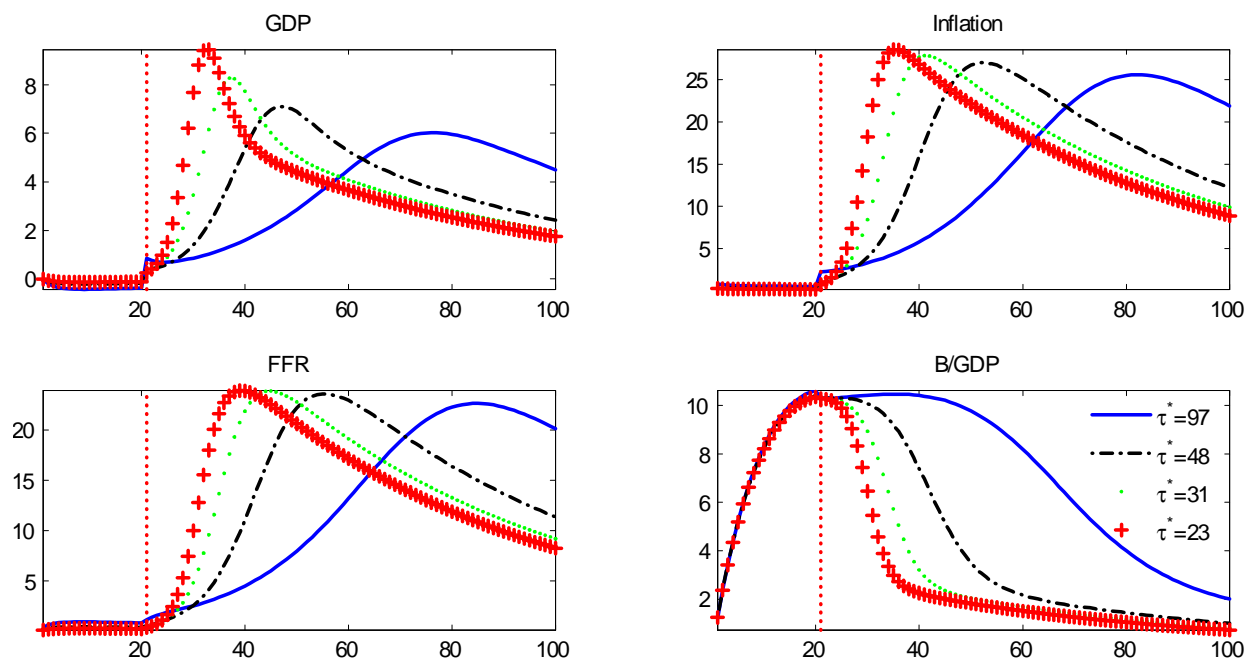


Figure 7: The figure considers the effects of a large "dormant shock" to primary surplus for transition matrices that differ according to the relative persistence of the two PM/AF regimes. The shock occurs at time 0, while the regime change occurs after 20 periods (red vertical bar). The different a-priori beliefs are captured by the different periods necessary to convince agents that they entered a long lasting deviation ( $\tau^*$ ).

induce a change in expectations leading to an increase in inflation and uncertainty. At the same time, if the government has been virtuous in the past, it has probably built some reputation for avoiding long lasting deviations. This translates into a low value for  $p_{13}/(p_{12} + p_{13})$  and implies that policy makers can deviate for a longer period of time without losing control of inflation expectations.

However, the a-priori relative probability of the two deviations is not the only margin that affects the timing of the peak of inflation. The relative persistence of the short and long lasting deviations,  $p_{22}/p_{33}$ , is also important. When  $p_{22}/p_{33}$  is low, the learning process is faster as agents need only a few consecutive observations to conclude that they entered a long lasting deviation. In the limiting case in which the ratio is zero, agents just need two consecutive deviations to conclude that they entered a long lasting regime and that with very high probability they will face a long series of PM/AF realizations. On the other hand, when  $p_{22}/p_{33}$  is large the learning process unfolds very slowly and consequently the peak of inflation moves further to the right. Figure 7 illustrates this point. The benchmark case is once again represented by the dotted line and the parameter choices are summarized in Table 3. Notice that when  $p_{22}/p_{33} = .9/.99 = 0.4762$  the peak of inflation occurs more than 20 years after the shock occurred and more than 15 years after the regime took place. Even in this case, the ratio can be interpreted as characterizing policy makers' credibility, but across a different dimension. Specifically, agents might have different views about what it means for a deviation to be short lasting. When, for a given persistence of the long lasting regime, this ratio increases, it means that agents can tolerate a longer series of deviations before deciding that they entered a long lasting PM/AF regime. Even in this case, the relative persistence of the two regimes can be the result of some past evidence or determined by an arbitrary conjecture about what it means for a regime to be short lasting. What matters is that the persistences of the two regimes differ largely enough to make the distinction meaningful. Furthermore, it is important to keep in mind that the characterization of one regime affects the laws of motion of all the others. This implies that for a given set of parameters there is a limit to how large the ratio  $p_{22}/p_{33}$  can be made without causing the short lasting regime, and possibly the Virtuous regime, to be inflationary.

Fiscal Virtue can make the unfolding of the effects of dormant shocks smooth, a property that seems appropriate to characterize inflation dynamics in economies, such as the US, with a strong reputation. Countries for which the commitment to fiscal responsibility is less clear are more likely to be subject to sudden shifts in agents' expectations as agents need only a few deviations in order to decide that the economy entered a long lasting deviation. This suggests an interesting interpretation of the different impulse responses considered in this subsection: Following a shock of the same magnitude, countries with different levels of fiscal virtue might experience similar levels of inflation as long a Virtuous regime is in place. However, once the two

economies experience a deviation from the Virtuous regime, substantial inflation differentials would arise as the speed of learning greatly differs across the two countries.

## 5 Extended Model

In this second part of the paper we conduct a quantitative analysis based on a richer model augmented with external habits, government purchases, inflation indexation to past inflation, a maturity structure for government debt, and a richer fiscal block in which government expenditure and taxation are modeled separately. The model and the parameter estimates are taken from Bianchi and Ilut (2012). Bianchi and Ilut (2012) estimate a DSGE model subject to a structural break from a PM/AF to an AM/PF regime in order to explain the rise and fall of US inflation. Here we expand the number of regimes to allow for a short lasting and a long lasting PM/AF regime and introduce the learning mechanism.

To facilitate the interpretation of the results, we combine the law of motion of the model variables with a system of observation equations including variables that often enter the economic debate. We reconstruct the following observables: real GDP growth rate, annualized quarterly inflation, annualized quarterly FFR, and debt to GDP ratio on a quarterly basis. Appendix A contains an accurate description of the model, the parameter values, and impulse responses under perfect information and learning.

### 5.1 A Look at the Past...

In the previous section, we have introduced the concept of dormant shocks and shown how they can propagate slowly over time and have the largest impact many years after they took place. We will now put the theory to work showing how a few shocks, combined with the learning mechanism, can go a long way in explaining the historical dynamics of inflation. A fully specified estimation exercise is beyond the scope of this paper and, although feasible, poses some significant computational challenges. We take these challenges up in Bianchi and Melosi (2012a) and Bianchi et al. (2012). Instead, here we conduct a simulation based on the estimates obtained by Bianchi and Ilut (2012).

First, we will show how the learning mechanism can account for the slow moving increase in inflation even when only a few shocks are considered. Specifically, we will show that two events could be central to understand the two spurs of inflation of the '70s. The first one coincides with the first reference to the "Great Society" made by President Johnson in May 1964. Following Bianchi and Ilut (2012), we model this as a large and persistent increase in government transfers that affects the long term component of government expenditure. The second shock is President Ford's tax cut in the mid-'70s .

We choose a transition matrix in order to satisfy two criteria. First, we make the learning process substantially slower making the short lasting and long lasting PM/AF persistences more similar. Second, we increase the relative a-priori probability of moving to the long lasting PM/AF higher and decrease the persistence of the Virtuous regime. This second change does not play any role in explaining the high inflation of the '70s but it helps in explaining the risk of deflation faced by the US economy in the late '90s and early 2000's as the result of the large primary surpluses during those years. The underlying intuition goes as follows. Making the long lasting PM/AF more likely determines a "contamination effect" on the Virtuous regime, with the result that even under such a regime fiscal shocks have some effect on the level of inflation. These effects are mild, given that the relative probability is still small, but not negligible. We then consider the following parameterization for the transition matrix:

$$H = \begin{bmatrix} .9200 & .0720 & .0080 \\ .0600 & .9400 & \\ .0050 & & .9950 \end{bmatrix}$$

These values imply that it takes quite a long time for agents to become convinced that they entered a non-Ricardian world. Specifically,  $\tau^*$  is in this case equal to 110 quarters, implying that it takes more than 27 years for agents to be sure that they live in a long lasting PM/AF regime. On the other hand, agents are a-priori relatively worried about the possibility of entering this regime: Following the first deviation, agents attach a  $p_{13}/(p_{12} + p_{13}) = 10\%$  probability to having entered the long lasting PM/AF regime. Therefore, even when the Virtuous regime is in place, agents are so concerned about the possibility of entering the long lasting PM/AF regime that high debt implies inflationary pressure.

We start the economy using the smoothed estimates for the DSGE states obtained by Bianchi and Ilut (2012). We then assume a path for tax revenues and total government expenditure that approximates the actual ones. These are reported in the second and third panels of Figure 8. Given these paths and a sequence for policy makers behavior to be described below, we reconstruct a path for inflation. This is reported in the first panel of Figure 8. The two solid black vertical lines mark the key events that are used to explain the increase in trend inflation of the '70s: The first reference made to the Great Society plans and the Ford's tax cut. We also assume that policy makers started deviating from the Virtuous regime once the first reference to the Great Society was made. Finally, we use the estimates of Bianchi and Ilut (2012) to pin down the return to the Virtuous regime, occurring in mid-1980, a few quarters after the appointment of Volcker (August 1979). This is marked with a dashed red line.

Several aspects of this simulation are worth being mentioned. First, following the *Great Society shock*, inflation starts to rise, but very smoothly. In the short run, such low frequency movements are probably hard to detect. Second, by the time the Ford's tax cut hits, inflation has

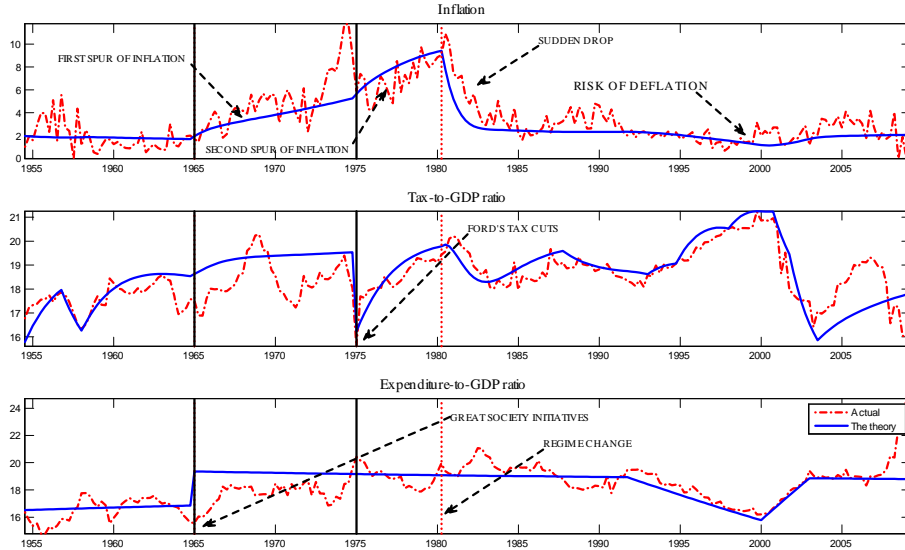


Figure 8: The figure shows the results for a simulation meant to illustrate the properties of the model with learning. Four events are key. First, a large shock to the long term component of expenditure and a switch from the AM/PF to the PM/AF regime assumed to coincide with the first reference to the Great Society made by President Johnson (first solid vertical line). Second, the Ford's tax cut (second solid vertical line). Third, the switch from the PM/AF to the AM/PF regime a few quarters after the appointment of Volcker (dashed vertical line). Fourth, the large primary surpluses of the '90s, captured by a series of favorable shocks to tax revenues and expenditure.

already gained some momentum due to the acceleration in agents' pessimism. Agents are now more pessimistic about the possibility of a quick return to the Virtuous regime. Consequently, inflation rises faster following this second fiscal shock. Third, the switch to the Virtuous regime determines a sudden drop in inflation as agents' beliefs about the future behavior of policy makers are subject to a drastic swing. Fiscal shocks are now largely neutralized as agents revise their expectations about the way the debt will be financed. However, as explained above, because agents are still worried about the possibility of a regime change and expenditure is still high, inflation does not go back to the steady level. Instead, it stabilizes on a larger value that reflects the deviation of government debt from its own steady state. Finally, the large primary surpluses of the '90s determine a smooth and persistent decline in inflation that gets close to zero. This feature is again linked to the fact that even when the economy is under the Virtuous regime, agents are concerned about the size of debt. As the debt gets largely reduced, inflation expectations accordingly decline.

Summarizing, in this Section we have taken an historical perspective to show how dormant shocks can be used to explain low frequency movements in the process for inflation. An important lesson is that it might take a long time to see significant effects of these shocks on inflation and a false sense of security might pervade policy makers. We have also shown how,

with appropriate assumptions on the transition matrix  $H$ , it is possible to generate a contamination effect from the inflationary regime to the Virtuous regime. This allowed us to link the low inflation of the late '90s early 2000s to the large primary surpluses run by the Clinton administration.

## 5.2 ...to find out the Future

After having shown that the model can account for the events of the past, we now move to analyzing the current situation. Is the US economy heading toward a prolonged period of high inflation? Should policy makers feel reinsured that long term interest rates and inflation expectations seem to be under control? In order to answer these questions we will compute forecasts conditional on different scenarios on the policy makers' behavior. For each simulation, we compute the path for 5-year ahead inflation expectations and the 5-year interest rate. Both of them are computed taking into account the possibility of regime changes using the methods developed in Bianchi (2012a).

Policy makers announce that the economy will be at the zero-lower-bound for one year. We approximate such an announcement using a third regime that has the same characteristics of the PM/AF regime, but for which the response to the output gap is set to zero. We believe this is a convenient and potentially appropriate way to model the zero-lower-bound, given that the Central Bank would probably react if inflation started rising substantially.

In the first scenario, the zero-lower-bound period is followed by the PM/AF policy, while in the second case the virtuous policy mix prevails. Furthermore, we assume that policy makers do not make any announcement regarding the exit strategy, so agents do not know how the economy will evolve after the zero-lower-bound period. Therefore, it is very important to specify what agents expect is going to happen once the deviation is over. We assume that in the last period of the announced deviation, the probability that agents attach to going back to the Virtuous regime is equal to the one that would prevail if they had observed one year of PM/AF policy. Notice that agents anticipate that this is the way they will think one year from the time of the announcement.

We assume a transition matrix that implies a high level of reputation for the monetary/fiscal policy mix:

$$H = \begin{bmatrix} .9750 & .0249 & .0001 \\ .0800 & .9200 & \\ .0100 & & .9900 \end{bmatrix}$$

The a-priori beliefs that agents assign to a long lasting deviation is very low, .4%, and agents tolerate relatively long deviations as the ratio  $p_{22}/p_{33}$  is relatively high. Therefore it takes more than ten years for agents to become convinced that they entered a long lasting period of

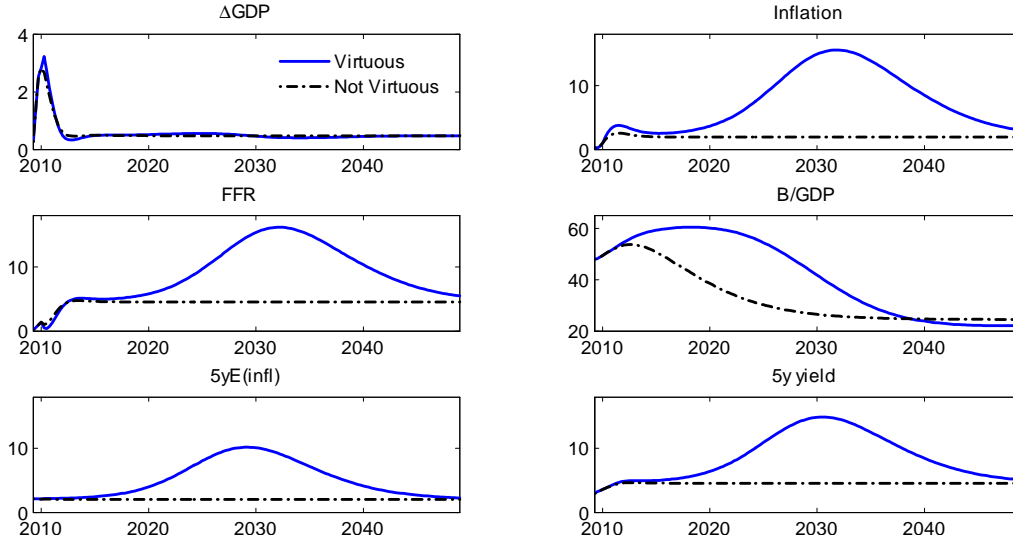


Figure 9: Conditional forecasts based on a transition matrix that implies high reputation of policy-makers in preventing large fluctuations in inflation. The zero-lower-bound is announced for one year. After that, two scenarios are considered: Always PM/AF or always AM/PF. In both cases, no announcement is made about the exit strategy from the zero-lower-bound. Five year ahead inflation expectations and the 5-year yield are computed taking into account the possibility of regime changes.

PM/AF policy ( $\tau^* = 129$ ).

Figure 9 reports the results. The first aspect that is worth noting is that long term inflation expectations are initially very well anchored independently of the behavior of policy makers. In a similar fashion, the five year yield is very low, in line with what is observed in the data. This is because even if the PM/AF policy mix prevails, agents are initially optimistic about the probability of moving back to the virtuous combination. However, as time goes by, the behavior of policy makers starts making a difference. If they insist in following the PM/AF regime combination, agents get increasingly convinced that the economy entered a long lasting period of PM/AF policy mix. Accordingly, inflation and inflation expectations start drifting. Eventually inflation gets to levels that are comparable to the ones observed in the '70s. If instead the virtuous policy mix is in place, this pattern is absent, as agents observe taxes being raised in order to stabilize debt. In both cases, GDP growth experiences an acceleration in the short run that reflects the fact that the economy is going back to the steady state. However, while under the virtuous policy combination output does not move any further, if the PM/AF policy mix prevails, we observe very low frequency movements in growth that reflect the slow revision in agents beliefs. Interestingly, the first spur of inflation that is associated with the recovery dies out very quickly, with the result that an external observer could be induced to think that the central bank has still full control of inflation dynamics. But this is just an illusion, as the run-up of inflation that follows makes clear.

These conditional forecasts highlight the risks associated with trying to infer the risk of high

inflation looking at current inflation expectations or long term interest rates. If it takes time for agents to learn about the nature of the deviation that they are currently experiencing, than their expectations are likely to be initially very well anchored. This is likely to be especially true for an economy like the US that, as suggested by Woodford (2011), has experienced a prolonged period of monetary dominated policy mix. In such an economy, the a-priori beliefs about the possibility of entering a long lasting deviation are arguably very low. Furthermore, it is worth pointing out that short lasting interventions that do not resolve the long run problems of debt sustainability cannot be interpreted as changes in policy mix. These are only shocks that do not move agents' beliefs about the resolution of the long term sustainability of government debt.

## 6 Conclusions

When agents are uncertain about the way debt will be repaid the strict distinction between Ricardian and non-Ricardian regimes typical of the Fiscal Theory of Price Level literature breaks down. In its stead, a continuum of regimes reflecting agents' beliefs about the future behavior of policy makers arises. As agents observe more and more deviations from a Virtuous regime in which the Fed has full control of inflation, they become increasingly convinced that inflation will have to increase in order to stabilize the debt-to-GDP ratio. This implies that the law of motion characterizing the economy evolves over time in response to what agents observe. Therefore, the model is able to generate a run-up in inflation as relatively optimistic agents become more and more pessimistic.

We introduced the notion of dormant shocks. These are shocks that move the debt-to-GDP ratio and that have no effects on the macroeconomic variables when policy makers behave according to a Virtuous regime. However, as policy makers start deviating from such a regime and agents become more and more discouraged about the possibility of moving back to the Virtuous regime, the effects of the dormant shocks arise, with a progressive movement in inflation and an increase in uncertainty.

We used the model to point out that currently low inflation expectations and low long term interest rates are likely to reflect the reputation US policy makers have built over the years. This means that the true risk of inflation might be higher than what it appears and crucially related to the way policy makers will behave in the future.



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## A Extended model

In this appendix we describe the model used in the quantitative analysis of Section 5. The model is a simplified version of the one used in Bianchi and Ilut (2012).

### A.1 Model description

**Households.** The representative household maximizes the following utility function:

$$E_0 \left[ \sum_{s=0}^{\infty} \beta^s e^{d_s} \left[ \log (C_s - \Phi C_{s-1}^A) - h_s \right] \right] \quad (18)$$

subject to the budget constraint:

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

where  $D_t$  stands for real dividends paid by the firms,  $C_t$  is consumption,  $P_t$  is the aggregate price level,  $h_t$  is hours,  $W_t$  is the real wage,  $N T_t$  stands for net taxes, and  $C_t^A$  represents the average level of consumption in the economy. The parameter  $\Phi$  captures the degree of external habit. The preference shock  $d_s$  has mean zero and time series representation:  $d_t = \rho_d d_{t-1} + \sigma_d \varepsilon_{d,t}$ . 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 of bonds and consequently in the present value of debt. News about future surpluses can then translate into smooth changes in inflation, as opposed to a discrete jump in the current price level, even

in absence of any additional friction. Hall and Sargent (2011) show that revaluation effects explain a significant fraction of the fluctuations of the debt-to-GDP ratio. Following Eusepi and Preston (2010) 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.

**Firms.** Each of the monopolistically competitive firms faces a downward-sloping demand curve:

$$Y_t(j) = (P_t(j)/P_t)^{-1/\nu} Y_t \quad (19)$$

where the parameter  $1/\nu$  is the elasticity of substitution between two differentiated goods. The 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:

$$AC_t(j) = .5\varphi (P_t(j)/P_{t-1}(j) - \Pi_{t-1})^2 Y_t(j) P_t(j)/P_t \quad (20)$$

where  $\Pi_t = P_t/P_{t-1}$  is gross inflation at time  $t$ .

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

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

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

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. The term  $T P_t$  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 to avoid stochastic singularity when estimating the

model given that we treat debt, taxes, and expenditures as observables.<sup>8</sup> We rewrite the federal government budget constraint in terms of debt-to-GDP ratio  $b_t^m = (P_t^m B_t^m) / (P_t Y_t)$ :

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

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

The (linearized) federal government expenditure as a fraction of GDP,  $\tilde{e}_t$ , is the sum of a short term component  $\tilde{e}_t^S$  and a long term component  $\tilde{e}_t^L$  ( $\tilde{e}_t = \tilde{e}_t^L + \tilde{e}_t^S$ ).<sup>9</sup>

$$\begin{aligned} \tilde{e}_t^L &= \rho_{eL} \tilde{e}_{t-1}^L + \sigma_{eL} \epsilon_{eL,t}, \quad \epsilon_{eL,t} \sim N(0, 1) \\ \tilde{e}_t^S &= \rho_{eS} \tilde{e}_{t-1}^S + (1 - \rho_{eS}) \phi_y (\hat{y}_t - \hat{y}_t^n) + \sigma_{eS} \epsilon_{eS,t}, \quad \epsilon_{eS,t} \sim N(0, 1). \end{aligned}$$

The long term component 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. Consistently with this interpretation, we assume that this component of government expenditure is known one year ahead. Instead, the short term component is meant to capture the response of government expenditure to the business cycle and responds to the (log-linearized) output gap ( $\hat{y}_t - \hat{y}_t^n$ ), where  $\hat{y}_t^n$  is the natural output, the level of output that would prevail under flexible prices. Notice that government expenditure is the sum of *federal* transfers and good purchases.

The *federal* and *local/state* governments buy a fraction  $\zeta_t$  of total output, equally divided among the  $J$  different goods. We define  $g_t = 1/(1 - \zeta_t)$  and we assume that  $\tilde{g}_t = \ln(g_t/g^*)$  follows the process:

$$\tilde{g}_t = \rho_g \tilde{g}_{t-1} + (1 - \rho_g) \phi_{eS} \tilde{e}_{t-1}^S + \sigma_g \epsilon_{g,t}, \quad \epsilon_{g,t} \sim N(0, 1). \quad (21)$$

Before proceeding it is important to point out that we assume that local and state governments participate in purchasing goods and that they are supposed to run a balanced budget. Therefore, changes in net taxes at the state level are neutral as agents understand that they will be offset by future changes in the opposite direction. We believe this is a reasonable assumption as it is quite unlikely that in the United States local governments can exercise influence on the conduct of monetary policy.

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<sup>8</sup>An alternative approach consists of excluding one of the fiscal components, for example the series for debt. Our results are robust to this alternative specification. We also considered an alternative specification in which an observation error for the series of debt is included and the term premium shock eliminated. The results are virtually identical.

<sup>9</sup>In what follows, for a given variable  $X_t$ ,  $\hat{x}_t \equiv \log((X_t/A_t)/(X/A))$  represents the percentage deviation of a detrended variable from its own steady state. For all the variables normalized with respect to GDP (debt, expenditure, and taxes)  $\tilde{x}_t$  denotes a linear deviation ( $x_t = X_t - X$ ), while for all the other variables  $\tilde{x}_t$  denotes a percentage deviation ( $\tilde{x}_t = \log(X_t/X)$ ). This distinction avoids having the percentage change of a percentage.

**Monetary and Fiscal Rules.** The Central Bank moves the FFR according to the rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R(\xi_t)} \left[ \left(\frac{\Pi_t}{\Pi}\right)^{\psi_\pi(\xi_t)} \left(\frac{Y_t}{Y_t^n}\right)^{\psi_y(\xi_t)} \right]^{(1-\rho_R(\xi_t))} \sigma_R e^{\epsilon_{R,t}}, \quad \epsilon_{R,t} \sim N(0, 1) \quad (22)$$

where  $R$  is the steady-state (gross) nominal interest rate,  $Y_t^n$  is natural output, and  $\Pi$  is gross steady state inflation. The federal fiscal authority moves taxes according to the rule:

$$\tilde{\tau}_t = \rho_\tau(\xi_t) \tilde{\tau}_{t-1} + (1 - \rho_\tau(\xi_t)) \left[ \delta_b(\xi_t) \tilde{b}_{t-1}^m + \delta_e \tilde{e}_t \right] + \delta_y (\hat{y}_{t-1} - \hat{y}_{t-1}^n) + \sigma_\tau \epsilon_{\tau,t}, \quad \epsilon_{\tau,t} \sim N(0, 1) \quad (23)$$

where  $\tilde{\tau}_t$  denotes (linearized) tax revenues with respect to GDP.

In equations (6) and (5),  $\xi_t$  is an unobserved state variable capturing the monetary/fiscal policy combination that is in place at time  $t$ . The unobserved state takes on a finite number of values  $j = 1, \dots, m$  and follows a Markov chain that evolves according to a transition matrix  $H$ . The targets for inflation and debt are assumed to be constant over time.<sup>10</sup> What changes is the strength with which the Government tries to pursue its goals, not the goals themselves. This is in line with the idea that policy makers might find high inflation or high debt acceptable under some circumstances, perhaps in order to preserve output stability, but not desirable in itself.

## A.2 The linearized model

Once the model is solved, the variables can be rescaled in order to induce stationarity. The model is then linearized with respect to taxes, government expenditure, and debt, whereas it is loglinearized with respect to all the other variables. We obtain a system of equations:

1. IS curve:

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

2. Phillips curve:

$$(1 + \beta) \tilde{\pi}_t = \kappa (1 - \Phi\gamma^{-1})^{-1} [\hat{y}_t - \tilde{g}_t - \Phi\gamma^{-1} [\hat{y}_{t-1} - \tilde{g}_{t-1} - a_t]] + \kappa \mu_t + \tilde{\pi}_{t-1} + \beta E_t [\tilde{\pi}_{t+1}]$$

where  $\kappa \equiv \frac{1-v}{v\varphi\Pi^2}$ .

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<sup>10</sup>See Ireland (2007), Liu et al. (2011), and Schorfheide (2005) for models that allow for a time-varying target.

3. Monetary policy rule:

$$\tilde{R}_t = \rho_R \tilde{R}_{t-1} + (1 - \rho_R) [\psi_\pi \tilde{\pi}_t + \psi_y (\hat{y}_t - \hat{y}_t^n)] + \sigma_R \epsilon_{R,t}$$

4. Total Government purchases:

$$\tilde{g}_t = \rho_g \tilde{g}_{t-1} + (1 - \rho_g) \phi_{e^S} \tilde{e}_{t-1}^S + \sigma_g \epsilon_{g,t}$$

5. Fiscal rule:

$$\tilde{\tau}_t = \rho_\tau (\xi_t) \tilde{\tau}_{t-1} + (1 - \rho_\tau (\xi_t)) [\delta_b (\xi_t) \tilde{b}_{t-1}^m + \delta_e \tilde{e}_t] + \delta_y (\hat{y}_{t-1} - \hat{y}_{t-1}^n) + \sigma_\tau \epsilon_{\tau,t}$$

6. Debt:

$$\tilde{b}_t^m = \beta^{-1} \tilde{b}_{t-1}^m + b^m \beta^{-1} \left( \tilde{R}_{t-1,t}^m - \hat{y}_t + \hat{y}_{t-1} - a_t - \tilde{\pi}_t \right) - \tilde{\tau}_t + \tilde{e}_t^S + \tilde{e}_t^L + tp_t$$

7. Return long term bond:

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

8. No arbitrage:

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

9. Expenditure, short term component:

$$\tilde{e}_t^S = \rho_{e^S} \tilde{e}_{t-1}^S + (1 - \rho_{e^S}) \phi_y (\hat{y}_t - \hat{y}_t^n) + \sigma_{e^S} \epsilon_{e^S,t}$$

10. Long term component (assumed to be known four periods in advance):

$$\tilde{e}_t^L = \rho_{e^L} \tilde{e}_{t-1}^L + \sigma_{e^L} \epsilon_{e^L,t}$$

11. Term premium/maturity shock:

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

12. Technology:

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

13. Demand shock:

$$d_t = \rho_d d_{t-1} + \sigma_d \epsilon_{d,t}$$

Parameter	Value	Parameter	Value	Parameter	Value
$\psi_\pi(\xi_t = 1)$	0.6244	$\delta_e$	0.7045	$100\sigma_R$	0.1972
$\psi_\pi(\xi_t = 2)$	2.3522	$\delta_y$	0.0869	$100\sigma_\tau$	0.4564
$\psi_y(\xi_t = 1)$	0.3716	$\rho_e$	0.9950	$100\sigma_a$	0.6518
$\psi_y(\xi_t = 2)$	0.1527	$\Phi$	0.7779	$100\sigma_e$	0.3653
$\rho_R(\xi_t = 1)$	0.8480	$\rho_a$	0.4540	$100\sigma_d$	6.9498
$\rho_R(\xi_t = 2)$	0.8132	$\rho_d$	0.6125		
$\delta_{\tau,b}(\xi_t = 1)$	0	$\kappa$	0.0128	$p_{11}$	0.9000
$\delta_{\tau,b}(\xi_t = 2)$	0.0327	$100 \ln(\gamma)$	0.4896	$p_{12}$	0.0990
$\rho_\tau(\xi_t = 1)$	0.7306	$b^*$	0.9644	$p_{22}$	0.7000
$\rho_\tau(\xi_t = 2)$	0.8921	$\tau^*$	0.1846	$p_{33}$	0.9900

Table 4: Parameter choices of the DSGE parameters and of the transition matrix diagonal elements based on Bianchi and Ilut (2011).

### A.3 Impulse responses

Here we report the impulse responses for the extended model under perfect information and learning.



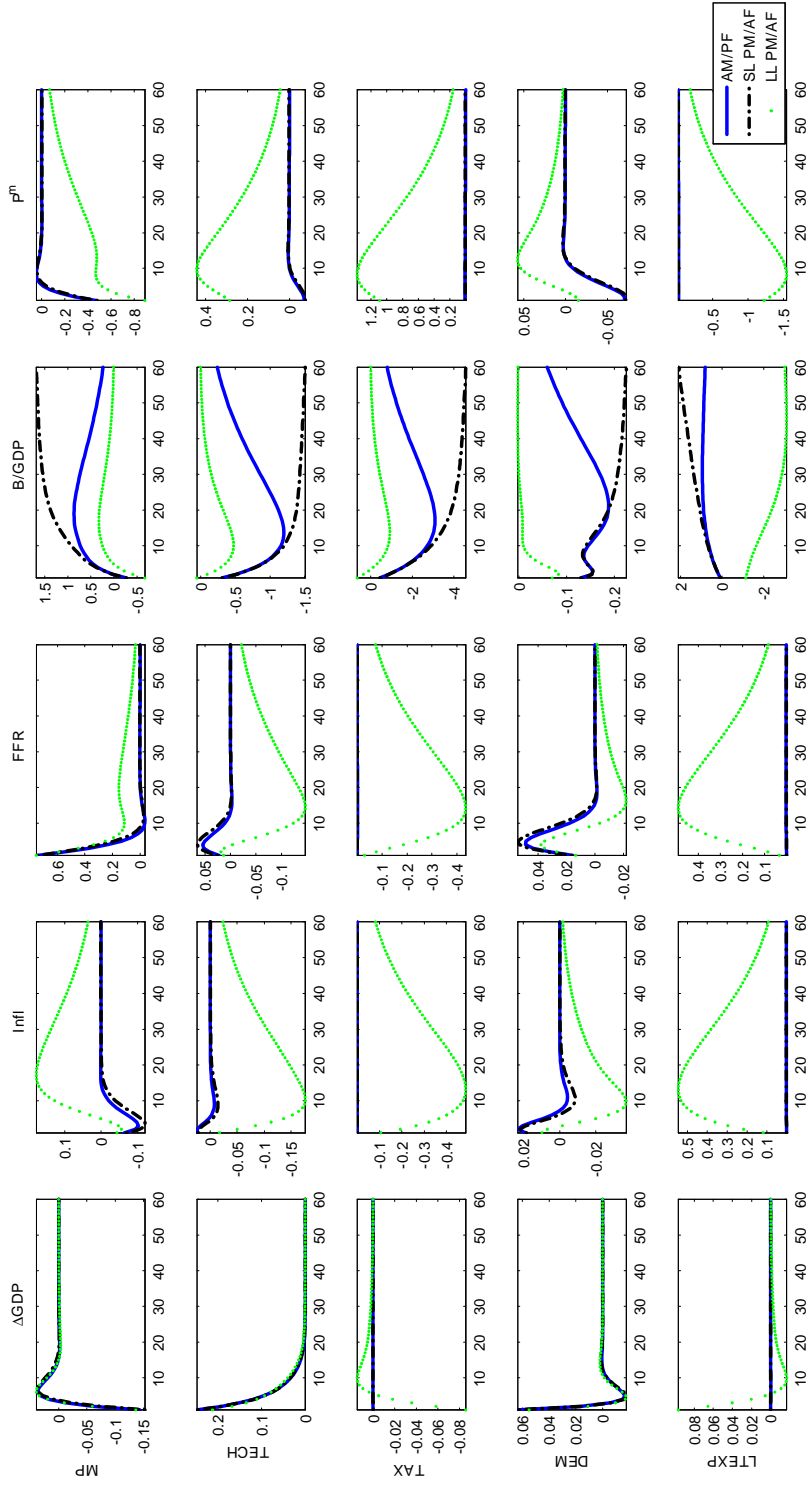


Figure 10: Impulse responses under perfect information.

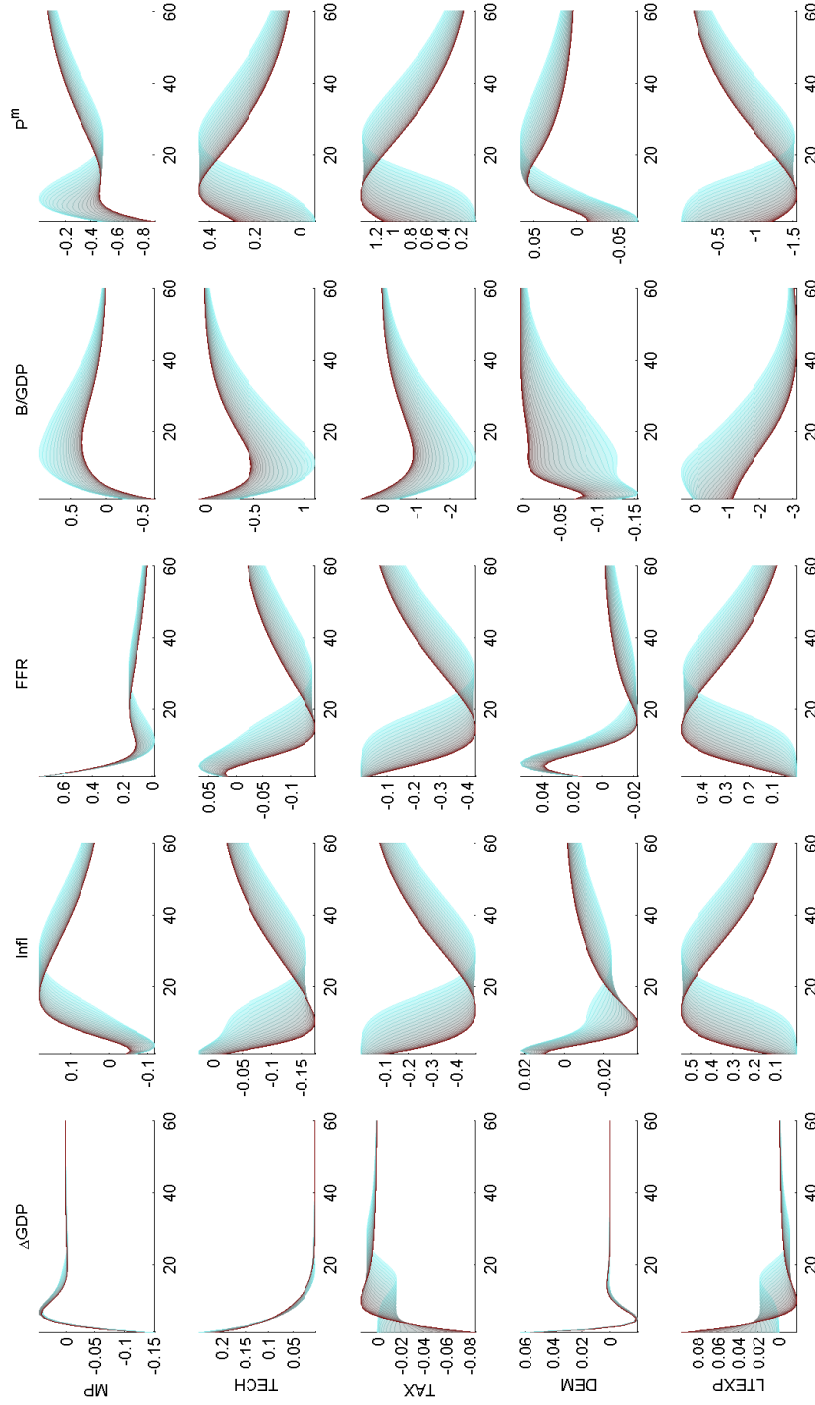


Figure 11: Impulse responses under learning assuming that the PM/AF regime prevails over the relevant horizon. Moving from the light-blue to the dark-red, the initial number of observed deviations increases. The impulse responses under the AM/PF are very similar, although not identical, to the ones that prevail under perfect information.