Constrained Discretion and Central Bank Transparency[†]

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Abstract

We develop and estimate a general equilibrium model to quantitatively assess the effects and welfare implications of central bank transparency. Monetary policy can deviate from active inflation stabilization and agents conduct Bayesian learning about the nature of these deviations. Under constrained discretion, only short deviations occur, agents' uncertainty about the macroeconomy remains contained, and welfare is high. However, if a deviation persists, uncertainty accelerates and welfare declines. Announcing the future policy course raises uncertainty in the short run by revealing that active inflation stabilization will be temporarily abandoned. However, this announcement reduces policy uncertainty and anchors inflationary beliefs at the end of the policy. For the U.S. enhancing transparency is found to increase welfare. The same result is found when we relax the assumption of perfectly credible announcements.

Keywords: Policy announcement, Bayesian learning, reputation, forward guidance, macroeconomic risk, uncertainty, inflation expectations, Markov-switching models, likelihood estimation.

JEL classification: E52, D83, C11.

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1 Introduction

The last two decades have witnessed two major breakthroughs in the practice of central banking worldwide. First, most central banks have adopted a monetary policy framework that Bernanke and Mishkin (1997) have termed *constrained discretion*. Bernanke (2003) explains that under constrained discretion, the central bank retains some flexibility in de-emphasizing inflation stabilization so as to pursue alternative short-run objectives such as unemployment stabilization. However, such flexibility is constrained to the extent that the central bank should maintain a strong reputation for keeping inflation and inflation expectations firmly under control. Second, many countries have taken remarkable steps to make their central bank more transparent (Bernanke et al., 1999 and Mishkin 2001).[1]

As a result of these changes, some key questions lie at the heart of modern monetary policy making. First, for how long can a central bank de-emphasize inflation stabilization before the private sector starts fearing a return to a period of high and volatile inflation as in 1970s? Second, does transparency play an essential role for effective monetary policy making? In other words, should a central bank be explicit about the future course of monetary policy? The recent financial crisis has triggered a prolonged period of accommodative monetary policy that some members of the Federal Open Market Committee fear could lead to a disanchoring of inflation expectations.[2] As a result, the research questions outlined above are at the center of the policy debate.

In order to address them, we develop and estimate a model in which the anti-inflationary stance of the central bank can change over time and agents face uncertainty about the nature of deviations from active inflation stabilization. When monetary policy alternates between prolonged periods of active inflation stabilization, *active regime*, and short periods during which the emphasis on inflation stabilization is reduced, *short-lasting passive regime*, the model captures the monetary approach described as constrained discretion. However, the central bank can also engage in a prolonged deviation from the active regime and move to a *long-lasting passive regime*. Agents in the model are fully rational and able to infer if monetary policy is active or not. However, when the passive rule prevails, they are uncertain about the nature of the observed deviation. In other words, agents are not sure if the central bank is engaging in a short or long-lasting deviation from the active regime. The central bank

[1] Since May 1999, the Federal Open Market Committee (FOMC) has included explicit language about the likely future policy stance in its official statements, as documented in Rudebusch and Williams (2008) and Campbell, Evans, Fisher, and Justiniano (2012). Industrialized countries such Canada, Spain, Sweden, and the United Kingdom have publicly announced a target range for inflation and also introduced a wide variety of instruments for communicating with the public. These include regular release of macroeconomic forecasts, discussions of the policy responses to keep inflation on target, and prompt releases of minutes.

[2] As an example see Plosser (2012).

can then follow two possible communication strategies: *Transparency* and *no transparency*. Under no transparency, the nature of the deviation is not revealed. Under transparency, the duration of *short-lasting* deviations is announced.[3]

Under no transparency, when passive monetary policy prevails, agents conduct Bayesian learning in order to infer the likely duration of the deviation from active monetary policy. Given that the behavior of the monetary authority is unchanged across the two passive regimes, the only way for rational agents to learn about the nature of the deviation consists of keeping track of the number of consecutive deviations. As agents observe more and more realizations of the passive rule, they become increasingly convinced that the long-lasting passive regime is occurring. As a result, the more the central bank deviates from active inflation stabilization, the more agents become discouraged about a quick return to the active regime. We then solve the model keeping track of the joint evolution of policy makers' behavior and agents' beliefs using the methods developed in Bianchi and Melosi (2016b). The latter methods are based on the idea of expanding the number of regimes to take into account the learning mechanism. Once a regime is defined in terms of both policy makers' behavior and agents' beliefs, the model can be solved using any of the methods developed for perfect information Markov-switching models. The resulting solution implies that the model dynamics evolve over time in response to the evolution of policy makers' behavior *and* agents' beliefs.

The ability of generating smooth changes in agents' beliefs in response to central bank actions makes the model an ideal laboratory to study the macroeconomic and welfare implications of constrained discretion. In the model, social welfare is shown to be a function of agents uncertainty about future inflation and future output gaps. In standard models, monetary policy affects agents' welfare by influencing the unconditional variances of the endogenous variables. In our nonlinear setting, policy actions exert dynamic effects on uncertainty. Therefore, welfare evolves over time in response to the short-run fluctuations of uncertainty. To our knowledge, this feature is new in the literature and allows us to study changes in the macroeconomic risk due to policy actions and communication strategies and the associated welfare implications.

We measure uncertainty taking into account agents' beliefs about the evolution of monetary policy. As long as the number of deviations from the active regime is low, the increase in uncertainty is very modest and in line with the levels implied by the active regime. This is because agents regard the early deviations as temporary. However, as the number of deviations increases and fairly optimistic agents become fairly pessimistic about a quick return to

[3] Our results still hold if one allows the central bank to announce the duration of the long-lasting deviations as well.

active policies, uncertainty starts increasing and eventually converges to the values implied by the long-lasting passive regime. As a result, for each horizon, our measure of uncertainty is now higher than its long run value. This is because agents take into account that while in the short run a prolonged period of passive monetary policy will prevail, in the long run the economy will surely visit the active regime again. Therefore, an important result arises: Deviations from the active regime that last only a few periods have no disruptive consequences on welfare because they do not have a large impact on agents' uncertainty regarding future monetary policy. Instead, if a central bank deviates for a prolonged period of time, the disanchoring of agents' uncertainty occurs, causing sizeable welfare losses.

The model under the assumption of no transparency is fitted to U.S. data. In line with previous contributions, we identify prolonged deviations from active monetary policy in the 1960s and the 1970s. However, we also find that the Federal Reserve has recurrently engaged in short-lasting passive policies since the early 1980s, supporting the view that constrained discretion has been the predominant approach to U.S. monetary policy in the last three decades. In the analysis, we abstract from the reasons why the Federal Reserve has engaged in such deviations. In fact, we consider such recurrent deviations as a *given* of our analysis. The objective of this paper is to use the estimated model to evaluate how quickly agents' beliefs respond to policy makers' behavior and announcements, what this implies for the evolution of uncertainty and welfare, and what the potential gains are from reducing the uncertainty about the future conduct of monetary policy.

The paper introduces a practical definition of reputation: a central bank has strong reputation if it is less likely to engage in long-lasting deviations from active policies. While our definition of reputation is not exactly as the one used by Kydland and Prescott (1977), Barro and Gordon (1983) and the ensuing literature (Faust and Svensson 2001 and Gali and Gertler 2007), it suits well Bernanke's definition of constrained discretion and has the important advantage of being measurable in the data. Bernanke (2003) explains that for constrained discretion to work effectively, the central bank has to "establish a strong commitment to keeping inflation low and stable." In our paper, the strength of this commitment is called long-run reputation and depends on how often the central bank has engaged in long-lasting deviations from active policy in the data. For instance, the fact that the Federal Reserve conducted a prolonged spell of passive policy in the 1970s has contributed to lowering its reputation in our estimated model. Even though the Federal Reserve's reputation is not immaculate because of the 1970s, it turns out to be strong enough to allow the Federal Reserve to endorse constraint discretion; that is, to deviate from active inflation stabilization for some periods of time with no harm for inflation stability. The reason behind this result is that agents expect the passive policy to be short-lasting at first and do not jump to the conclusion that we are back to the 1970s just because the Federal Reserve has deviated from active policy for a handful of quarters.

What Bernanke (2003) calls Federal Reserve's "commitment to keeping inflation low and stable" is critically affected by the Federal Reserve's time-varying attitude towards inflation stabilization. If the Federal Reserve will engage in prolonged periods of passive policies, its commitment to stabilizing inflation will start deteriorating at a faster and faster pace, inflation will eventually become more volatile, and uncertainty about future inflation will soar. The strength of this commitment is measured in the paper by a precise statistic: the *number of expected consecutive deviations from active monetary policy*. This statistic is dubbed *pessimism* as it captures how pessimistic agents are about observing a switch to the active policy anytime soon. The longer the central bank has been deviating from the active policy, the higher the expected number of consecutive periods of passive policy, and the weaker the central bank's anti-inflation commitment. In Bernanke's parlance, Federal Reserve's discretion is not unlimited and eventually becomes "constrained" if the Federal Reserve disregards inflation stabilization for too long. It is also worthwhile emphasizing that when we evaluate the welfare implications of central bank's transparency, agents are aware that the Federal Reserve's commitment to keeping inflation stable can shrink over time if the Federal Reserve engages in prolonged deviations from active policy.

The Federal Reserve is found to benefit from strong reputation. Based on the estimates, pessimism and hence agents' uncertainty about future inflation change very sluggishly in response to deviations from active monetary policy. In fact, uncertainty is found to stay anchored and move only very gradually as the Federal Reserve deviates from active monetary policy. This finding has the important implication that the Federal Reserve can conduct passive policies for up fairly large number of years before the disanchoring of inflation expectations and an overall increase in macroeconomic uncertainty occur. However, prolonged deviations from the active policy leads agents to become wary about the central bank's willingness to fighting the inflationary/deflationary consequences of future shocks. As a result, agents become more uncertainty about future inflation as the central keeps deviating from the active policy, leading to detrimental effects on welfare.[4] These beliefs dynamics capture the effects of losing central bank's commitment to keeping inflation stable in the sense of Bernanke (2003). In Bernanke's parlance, the central bank's discretion (i.e., the central bank flexibility of deviating from inflation stabilization policy) becomes "constrained."

While this result implies that the Federal Reserve can successfully implement constrained

[4]The long-lasting passive regime is associated with the highest level of uncertainty about future inflation. The short-lasting passive regime is very similar to the active policy regime in this respect as one should expect if these two regimes had to capture "constrained discretion."

discretion even without transparency, our findings suggest that increasing transparency would improve welfare. The estimated model suggests that the welfare gains from transparency range between 0.54% to 3.74% of steady-state consumption. A transparent central bank systematically announces the duration of any short-lasting deviation from the active regime beforehand, whereas in the case of a long-lasting deviation the exact duration is not known. The implications of such a communication strategy vary based on the nature of the deviation. When the central bank engages in a short lasting deviation, announcing its duration immediately removes the *fear of the 1970s*. Under no transparency, instead, agents are not informed about the exact nature of the observed deviation. As a result, whenever a short deviation occurs, *ex-ante* agents cannot rule out the possibility of a long-lasting deviation of the kind that characterized the 1970s. As a result, *ex-post*, agents turn out to have overstated the persistence of the observed deviation. How large this effect is depends on the central bank reputation, captured by the conditional probability of engaging in a long-lasting deviation.

The model allows us to highlight an important trade-off associated with transparency. First, in the short run being transparent reduces welfare because agents are told that passive monetary policy will prevail for a while and thereby future shocks are expected to have more dramatic inflationary/deflationary consequences. It follows that, if the duration of the announced deviation is long enough, over the early periods uncertainty is higher than when no announcement is made. This short-run effect on welfare arises because the central bank publicly commits to a policy that de-emphasizes inflation stabilization for the announced number of future periods. Agents understand that such a commitment to follow the announced policy course limits the central bank's ability of countering the inflationary consequences of future shocks that might occur during the implementation of the announced policy. Therefore, the announcement leads to a higher macroeconomic risk and associated detrimental effects on welfare. Second, as time goes by, agents know that the prolonged period of passive monetary policy is coming to an end. This leads to a reduction in the level of uncertainty at every horizon with an associated improvement in welfare. Notice, that this is exactly the opposite of what occurs when no announcement is made: Agents, in this case, become more and more discouraged about the possibility of moving to the active regime and uncertainty increases. To our knowledge, this is the first paper that studies this critical trade-off associated with central bank's announcement through the lens of an estimated Dynamic Stochastic General Equilibrium (DSGE) model.

We also consider the case in which central bank's announcements are not perfectly credible by assuming that the central bank can lie if the deviations from the active policy is longer than a given number of periods. In this case, there are two potential effects that can make welfare lower or higher compared to the benchmark case of transparency, in which the central bank never lies. The first effect has to do with the fact that agents are better off in the short run when the central bank never announces the hard truth of a prolonged deviation from the active policy. The second effect has to do with the fact that, in the long run, agents eventually realize that the central bank has lied and move to the no-transparency outcome which is associated with a quick deterioration of welfare as the central bank keeps deviating from the active policy. It turns out that the first effect is quantitatively stronger and the central bank can improve welfare even it never reveals deviations that are particularly long.

This paper makes three main contributions to the existing literature. First, we show how to model systematic and recurrent policy makers' announcements in a general equilibrium framework. In light of the recent development of forward guidance, we believe that this contribution should be of independent interest. Second, we show how to characterize and compute social welfare in a Markov switching DSGE model with Bayesian learning and announcements. Interestingly, in our nonlinear framework welfare captures the macroeconomic risk perceived by the agents as a function of the expected or announced policy decisions. Finally, we estimate a microfounded general equilibrium model with changes in policy makers' behavior and Bayesian learning. To the best of our knowledge, this is the first paper that *estimates* a DSGE model with Markov-switching parameters and Bayesian learning. Our learning mechanism implies that agents' beliefs are not invariant to the duration of a certain policy. Therefore, the model captures a very intuitive idea: Agents in the late 1970s were arguably more pessimistic about a return to the active regime with respect to the early 1970s. This feature was not present in previous contributions such as Bianchi (2013) and Davig and Doh (2014).

This paper is part of a broader research agenda that aims to model the evolution of agents' beliefs in general equilibrium models. In Bianchi and Melosi (2014), we study a model in which the current policy makers' behavior influences agents' beliefs about the way debt will be stabilized. In Bianchi and Melosi (2016a), we develop methods to study the evolution of agents' beliefs in general equilibrium models. Unlike those two papers, in this paper we conduct a full estimation of a DSGE model with parameter instability and information frictions. In addition, in this paper we explain how to model recurrent announcements. Finally, we use the results to assess how anchored inflation expectations and uncertainty are in the U.S. economy and to investigate the welfare implications of forward-looking communication by the Federal Reserve.

Our modeling framework goes beyond the assumption of *anticipated utility* that is often used in the learning literature.[5] Such an assumption implies that agents forecast future

[5] For some prominent examples see Marcet and Sargent (1989b,a) Cho, Williams, and Sargent (2002), and

events assuming that their beliefs will never change in the future. Instead, agents in our models *know that they do not know*. Therefore, when forming expectations, they take into account that their beliefs will evolve according to what they will observe in the future. In our context, it is possible to go beyond the anticipated utility assumption because we can keep track of the joint evolution of policymakers' behavior and agents' beliefs. Using anticipated utility would break the link between the observed policy path and the *future policy course*. This link is key for the dynamics of uncertainty. To understand why, consider a prolonged sequence of deviations from the active regime. This would have two effects. First, monetary policy is less active in stabilizing inflation. Second, agents become more pessimistic about a return to the active regime. Both effects are reflected in the model solution with important consequences for the expected impact of future shocks and, consequently, the evolution of uncertainty and welfare.

Eusepi and Preston (2010) study monetary policy communication in a model where agents face uncertainty about the value of model parameters. Unlike Eusepi and Preston (2010), agents in our model are not bounded rational, they only have incomplete information. Cogley, Matthes, and Sbordone (2011) address the problem of a newly-appointed central bank governor who inherits a high average inflation rate from the past and wants to disinflate. In their model, agents conduct Bayesian learning over the coefficients that characterize the conduct of monetary policy, but they are bounded rational to the extent that use anticipated utility to form expectations. Similarly to that paper, in our model the switches in the policy parameters may be rationalized as changes in the central bank's staff's anti-inflationary type, which are modeled in reduced form. However, in our model, regime changes are recurrent, agents learn about the regime in place as opposed to the Taylor rule parameters, and expectations reflect the possibility of changes in beliefs and policy makers' behavior (i.e. we do not assume anticipated utility). Finally, the tractability of our approach allows us to conduct likelihood-based estimation.

Schorfheide (2005) considers an economy in which agents use Bayesian learning to infer changes in a Markov-switching inflation target. In that paper agents solve a filtering problem to disentangle a persistent component from a transitory component. The learning mechanism is treated as external to the model, implying that the model needs to be solved in every period in order to reflect the change in agents' beliefs regarding the persistent and transitory components. Consequently, when agents form expectations they do not take into account how their beliefs will respond to future observations. On the contrary, in this paper agents form expectations by knowing that they do not know. Furthermore, the method developed in Schorfheide (2005) cannot be immediately extended to models in which agents learn about

Evans and Honkapohja (2001, 2003).

changes in the stochastic properties of the model parameters.

The paper is then related to a growing literature that models parameter instability to capture changes in the evolution of the macroeconomy. This consists of three branches: Davig and Leeper (2007), Farmer, Waggoner, and Zha (2009), and Foerster, Rubio-Ramirez, Waggoner, and Zha (2013) develop solution methods for Markov-switching rational expectations models, Justiniano and Primiceri (2008), Benati and Surico (2009), Bianchi (2013), Bianchi and Ilut (2013), Davig and Doh (2014), and Fernandez-Villaverde and Rubio-Ramirez (2008) introduce parameter instability in estimated dynamic equilibrium models, while Sims and Zha (2006), Primiceri (2005), Cogley and Sargent (2005), and Boivin and Giannoni (2006) work with structural VARs. Finally, our work is also linked to papers that study the transmission of nominal disturbances in general equilibrium models with information frictions, such as Gorodnichenko (2008), Mackowiak and Wiederholt (2009), Mankiw and Reis (2006), Melosi (2014a and 2014b), and Nimark (2008).

The paper is linked to the literature that studies the macroeconomic effects of forward guidance (Del Negro, Giannoni, and Patterson 2012 and Campbell, Fisher, Justiniano, and Melosi Forthcoming), which is the practice of announcing the future likely path of the interest rate by the central bank. The main difference between our paper and that literature is the object of central bank's communication. In our paper, forward guidance is about the central bank's reaction function whereas in that literature communication is about future deviations from the monetary policy rule.

This paper is organized as follows. Section 2 introduces the baseline model. In Section 3, we show how to solve the model under no transparency and transparency. In Section 4, the model under the assumption of no transparency is fitted to U.S. data. In Section 5 we assess the welfare implications of introducing transparency. In Section 7 we study some extensions and assess the robustness of our results. Section 8 concludes.

2 The Model

The model is built on Coibion, Gorodnichenko, and Wieland (2012), who develop a prototypical New-Keynesian DSGE model with trend inflation and partial price indexation. We make two main departures from this standard framework. First, we assume that households and firms have incomplete information, in a sense to be made clear shortly. Second, we assume parameter instability in the monetary policy rule.

Households: The representative household maximizes the present discounted value of utility stream from consumption and leisure:

$$E\left[\sum_{t=0}^{\infty}\beta^t\left\{\ln C_{t+j}-\frac{\psi}{\psi+1}\int {N_{it+j}}^{1+1/\psi}di\right\}|\mathcal{F}_0\right],$$

where C_t is composite consumption and N_{it} is labor supplied to individual industry i are hours worked in period t. The parameter $\beta\in(0,1)$ is the discount factor, the parameter $\psi\geq 0$ is the Frisch elasticity of labor supply. $E[\cdot|\mathcal{F}_0]$ is the expectation operator conditioned on information of private agents available at time 0. The information set $\mathcal{F}_t$ contains the history of all model variables but not the history of policy regimes ξ_t^p that, as we shall show, determine the parameter value of the central bank's reaction function.

The flow budget constraint of the representative household in period t reads

$$C_t+\frac{B_t}{P_t}\leq\int_0^1\left(\frac{N_{it}W_{it}}{P_t}\right)di+\frac{B_{t-1}R_{t-1}}{P_t}+\frac{Div_t}{P_t}+\frac{T_t}{P_t},$$

where B_t is the stock of one-period government bonds in period t, R_t is the gross nominal interest rate, P_t is the price of the final good, W_{it} os the nominal wage earned from labor in industry i, T_t is real transfers and Div_t are profits from ownership of firms.

Composite consumption in period t is given by the Dixit-Stiglitz aggregator

$$C_t=\left(\int_0^1 C_{it}^{1-1/\varepsilon}di\right)^{\frac{\varepsilon}{\varepsilon-1}},$$

where C_{it} is consumption of a differentiated good i in period t and $\varepsilon>1$ determines the elasticity of substitution between consumption goods. The price level is given by

$$P_t=\left(\int_0^1 P_{it}^{1-\varepsilon}di\right)^{1/(1-\varepsilon)}. \tag{1}$$

In every period t, the representative household chooses a consumption vector, labor supply, and bond holdings subject to the sequence of the flow budget constraints and a no-Ponzi-scheme condition. The representative household takes as given the nominal interest rate, the nominal wages, nominal aggregate profits, nominal lump-sum taxes, and the prices of all consumption goods.

Firms: There is a continuum of monopolistically competitive firms of mass one. Firms are indexed by i. Firm i supplies a differentiated good i. Firms face Calvo-type nominal rigidities and the probability of re-optimizing prices in any given period is given by $1-\theta$ independent across firms. We allow for partial price indexation to steady-state inflation by firms which do not re-optimize their prices, with the parameter $\omega\in(0,1)$ capturing the degree of indexation. Those firms that are allowed to re-optimize their price choose their price P_{it}^* so as to maximize:

$$\sum_{k=0}^{\infty} \theta^k E_t \left[Q_{t,t+k} \left(\bar{\Pi}^{k\omega} P_{it}^* Y_{it+k} - W_{it+k} N_{it+k} \right) | \mathcal{F}_t \right],$$

where $Q_{t,t+k}$ is the stochastic discount factor measuring the time t utility of one unit of consumption good available at time $t+k$, $\bar{\Pi}$ is the gross steady-state inflation rate, N_{it} is amount of labor hired, and Y_{it} is the amount of differentiated good produced by firm i. Firms are endowed with an identical technology of production:

$$Y_{it} = Z_t N_{it}.$$

The variable Z_t captures exogenous shifts of the marginal costs of production and is assumed to follow a stationary first-order autoregressive process in log-difference:

$$\ln z_t = (1 - \rho_z) \ln z + \rho_z \ln z_{t-1} + \sigma_z \eta_{zt}, \ \ \eta_{zt} \sim N(0, 1),$$

where $z_t \equiv Z_t / Z_{t-1}$. We refer to the innovations η_{zt} as technology shocks. Firms face a downward-sloping demand function in every period:

$$Y_{it} = (P_{it}/P_t)^{-\varepsilon} Y_t \tag{2}$$

where P_{it} denotes the price firm i sells its good at time t. Aggregate labor input is defined as

$$N_t = \left(\int_0^1 N_{it}^{1-1/\varepsilon} di \right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

Policy Makers: There is a monetary authority and a fiscal authority. The flow budget constraint of the fiscal authority in period t reads

$$T_t + B_t = R_{t-1} B_{t-1} + G_t,$$

where government consumption is defined as $G_t = (1 - 1/g_t) Y_t$ with the variable g_t following a stationary first-order autoregressive process:

$$\ln g_t = \left(1 - \rho_g\right) \ln g + \rho_g \ln g_{t-1} + \sigma_g \eta_{gt}, \ \ \eta_{gt} \sim N(0, 1). \tag{3}$$

where η_{gt} is an i.i.d. Gaussian shock. We refer to η_{gt} as government shock. The fiscal authority can collect lump-sum taxes or issue new government bonds to finance government consumption. We assume that the fiscal authority always follows a Ricardian fiscal policy.

The monetary authority sets the nominal interest rate R_t according to the Taylor rule

$$R_t = R_{t-1}^{\rho_{r,\xi_t^p}} \left[\left(\frac{\Pi_t}{\bar{\Pi}} \right)^{\phi_{\pi,\xi_t^p}} \left(\frac{Y_t}{zY_{t-1}} \right)^{\phi_{y,\xi_t^p}} \right]^{1-\rho_{r,\xi_t^p}} \exp\left(\sigma_r \eta_{rt}\right), \ \eta_{rt} \sim N(0,1) \tag{4}$$

where $\Pi_t = P_t/P_{t-1}$ denotes the gross inflation rate and Y_t is aggregate output in period t, and $\bar{y}$ is the steady-state value of detrended output Y_t/Z_t. The variable η_{rt} captures non-systematic exogenous deviations of the nominal interest rate R_t from the rule. The variable ξ_t^p is the policy regime that determines the policy coefficients of the rule reflecting the emphasis of the central bank on inflation stabilization relative to output gap stabilization in any period t.

Aggregate Resource Constraint:

Government consumes a share of final goods Y_t. Hence, the aggregate resource constraint reads:

$$Y_t = C_t + G_t.$$

2.1 Policy Regimes

We model changes in the central bank's emphasis on inflation and output stabilization by introducing a Markov-switching process ξ_t^p with three regimes that evolve according to the matrix:

$$\mathcal{P}_p = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ 1-p_{22} & p_{22} & 0 \\ 1-p_{33} & 0 & p_{33} \end{bmatrix} \tag{5}$$

The realized regime determines the monetary policy parameters of the central bank's reaction function. In symbols, for $j \in \{1,2,3\}$:

$$\left(\rho_R\left(\xi_t^p = j\right), \phi_\pi\left(\xi_t^p = j\right), \phi_y\left(\xi_t^p = j\right)\right) = \begin{bmatrix} \left(\rho_R^A, \phi_\pi^A, \phi_y^A\right), \text{ if } j=1 \\ \left(\rho_R^P, \phi_\pi^P, \phi_y^P\right), \text{ if } j=2 \\ \left(\rho_R^P, \phi_\pi^P, \phi_y^P\right), \text{ if } j=3 \end{bmatrix} \tag{6}$$

Under Regime 1, the *active regime*, the central bank's main goal is to stabilize inflation and the Taylor principle is satisfied $\phi_\pi\left(\xi_t^p = 1\right) = \phi_\pi^A \geq 1$. Under Regime 2, the *short-lasting passive regime*, the central bank de-emphasizes inflation stabilization by deviating from the Taylor principle $\phi_\pi^P < 1$, but only for short periods of time (on average). The *same* parameter combination also characterizes Regime 3, the *long-lasting passive regime*. However, under Regime 3 deviations are generally more prolonged. In other words, Regime 2 is less persistent than Regime 3: $p_{22} < p_{33}$. Summarizing, the two passive regimes do not differ in terms of the response to inflation ϕ_π^P and the output gap ϕ_y^P, but only in terms of their relative persistence.

The three policy regimes are meant to capture the recurrent changes in the Federal Reserve's attitude toward inflation and output stabilization in the postwar period. A number of empirical works (Clarida, Gali, and Gertler, 2000, Lubik and Schorfheide, 2004, Bianchi, 2013) have documented that the Federal Reserve de-emphasized inflation stabilization for prolonged periods of time in the 1970s. Furthermore, as argued by Bernanke (2003), while the Federal Reserve has been mostly focused on actively stabilizing inflation starting from the early 1980, it has also occasionally engaged in *short-lasting* policies whose objective was not to stabilize inflation in the short run. This monetary policy approach has been dubbed *constrained discretion*. We introduce this three-regime structure so as to give the model enough flexibility to explain both the long-lasting passive monetary policy of the 1970s as well as the recurrent and short-lasting passive policies of post-1970s. From the vantage point of agents, these three regimes captures two approaches to monetary policy: constrained discretion (Regime 1 and Regime 2) and the 1970s-type passive approach to monetary policy.

The probabilities p_{11}, p_{12}, p_{22} govern the evolution of monetary policy when the central bank follows constrained discretion. The larger p_{12} is vis-a-vis to p_{11}, the more frequent the short-lasting deviations are. The larger p_{22} is, the more persistent the short-lasting deviations are. The probability p_{13} controls how likely it is that constrained discretion is abandoned in favor of a prolonged deviation from the active regime. The ratio $p_{12}/(1-p_{11})$ captures the relative probability of a short-lasting deviation conditional on having deviated to passive regimes and can be interpreted as a measure of central bank's *long-run reputation*. This is because this composite parameter controls how likely it is that the central bank will abandon constrained discretion the moment it starts deviating from the active regime. When $p_{12}/(1-p_{11})$ is close to unity, agents expect that the central bank will refrain from engaging in 1970s-style long-lasting passive policies that - as we shall show - are invariably associated with large inflation instability. Long-run reputation will be measured in the data through the estimation of the model. As it will become clear later on, central bank's long-run reputation has deep implications for the general equilibrium properties of the macroeconomy. Therefore, the parameters of the transition matrix do not only affect the frequency with which the different regimes are observed, but also the law of motion of the economy across the different regimes. This is because agents are fully rational and form expectations taking into account the possibility of regime changes, implying that their beliefs matter for the way shocks propagate through the economy. Therefore, the proposed definition of central bank reputation has the important advantage of being measurable in the data, even over a relatively short period of time.

2.2 Log-Linearized Model and Communication Strategies

In the model, regime changes do not affect the steady state, but only the way the economy propagates around it. Since technology Z_t follows a random walk, we normalize all the non-stationary real variable by the level of technology. We then log-linearize the model around the steady-state equilibrium in which the steady-state inflation does not have to be zero. Let us denote log-deviations of the detrended variable x_t from its own steady-state value x with $\widehat{x}_t \equiv \ln(x_t/x)$. The log-linearized model can be expressed as follows:[6]

$$\hat{y}_t = \mathbb{E}(\hat{y}_{t+1}|\mathcal{F}_t) - \hat{r}_t - \mathbb{E}_t(\hat{\pi}_{t+1}|\mathcal{F}_t) - \rho_z\hat{z}_t + \left(1-\rho_g\right)\hat{g}_t \tag{7}$$

$$\hat{\pi}_t = \frac{\beta-\gamma_1}{\gamma_1}\hat{b}_t \tag{8}$$

$$\hat{b}_t = (1+\varepsilon/\psi)\left(\hat{d}_t - \hat{e}_t\right) + \sigma_m\eta_{m,t} \tag{9}$$

$$\hat{d}_t = (1-\gamma_2)\left(\frac{1}{\eta}\hat{y}_t - \hat{\xi}_t\right) + \gamma_2\left[\varepsilon\left(\frac{\psi+1}{\psi}\right)+1\right]E_t(\hat{\pi}_{t+1}|\mathcal{F}_t) + \gamma_2 E_t\left(\hat{d}_{t+1}|\mathcal{F}_t\right) \tag{10}$$

$$+\gamma_2\left[E_t(\hat{y}_{t+1}|\mathcal{F}_t) - \hat{y}_t + \rho_z\hat{z}_t - \hat{R}_t\right] \tag{11}$$

$$\hat{e}_t = \gamma_1\left[E_t(\hat{y}_{t+1}|\mathcal{F}_t) - \hat{y}_t + \rho_z\hat{z}_t - \hat{R}_t + \theta E_t(\hat{\pi}_{t+1}|\mathcal{F}_t)\right] + \gamma_1 E_t(\hat{e}_{t+1}|\mathcal{F}_t) \tag{12}$$

$$\hat{r}_t = \rho_{R,\xi_t^p}\hat{r}_{t-1} + \left(1-\rho_{R,\xi_t^p}\right)\left[\phi_{\pi,\xi_t^p}\hat{\pi}_t + \phi_{y,\xi_t^p}(\Delta\hat{y}_t + \hat{z}_t)\right] + \sigma_r\eta_{r,t} \tag{13}$$

$$\hat{g}_t = \rho_g\hat{g}_{t-1} + \sigma_g\eta_{gt} \tag{14}$$

$$\hat{z}_t = \rho_z\hat{z}_{t-1} + \sigma_z\eta_{zt} \tag{15}$$

where $\gamma_1 \equiv \theta\beta\bar{\Pi}^{(\omega-1)(1-\varepsilon)}$ and $\gamma_2 \equiv \theta\beta\bar{\Pi}^{(1-\omega)\left[\varepsilon\left(\frac{1}{\psi}+1\right)\right]}$ and $\hat{b}_t$ denotes the optimal reset price of firms. Following Coibion, Gorodnichenko, and Wieland (2012), we add an i.i.d. cost-push shock $\eta_{m,t}$ to the Phillips curve. If one abstracts from imperfect information, this model is very similar to the model studied by Coibion and Gorodnichenko (2011) and Coibion, Gorodnichenko, and Wieland (2012).

Equation (8) suggests that inflation, $\hat{\pi}_t$, is less sensitive to changes in the re-optimizing price, $\hat{b}_t$, as steady-state inflation rises. Coibion, Gorodnichenko, and Wieland (2012) explain that this effect has to do with the fact that, with positive steady-state inflation, firms that reset their price have higher prices than others and receive a smaller share of expenditures, thereby reducing the sensitivity of inflation to these price changes. Indexation of prices tends to offset this effect, with full indexation completely restoring the usual relationship between reset prices and inflation. However, equations (9)-(12) suggest that higher trend inflation $\bar{\Pi}$ makes firms more forward looking in their price-setting decisions by raising the

[6] The detailed derivations of these equations are in an appendix, which is available upon request.

importance of expected future marginal costs and inflation and by inducing them to respond to expected future output growth and interest rate. The increased coefficient on expectations of future inflation, which reflects the expected future depreciation of the reset price and the associated losses, plays a critical role. Coibion, Gorodnichenko, and Wieland (2012) explain that in response to an inflationary shock, a firm which can reset its price will expect higher inflation today and in the future as other firms update their prices in response to the shock. Given this expectation, the more forward looking a firm is, the greater the optimal reset price must be in anticipation of other firms raising their prices in the future. Thus, reset prices become more responsive to current shocks with higher $\bar{\Pi}$. Coibion, Gorodnichenko, and Wieland (2012) argue that this effect dominates the reduced sensitivity of inflation to the reset price in equation (8).

The imperfect information model can be solved under different assumptions on what the central bank communicates to agents about the future monetary policy course. Central bank's communication affects agents' information set $\mathcal{F}_t$. We consider two cases: *no transparency* and *transparency.*

If the central bank is not transparent, it never announces the duration of passive policies. We call this approach *no transparency.* We make a minimal departure from the assumption of perfect information by assuming that agents can observe the history of all the endogenous variables and the history of the structural shocks but not the policy regimes ξ_t^p. It should be noted that agents are always able to infer if monetary policy is currently active or passive. However, when monetary policy is passive, agents cannot immediately figure out whether the short-lasting Regime 2 or the long-lasting Regime 3 is in place. To see why, recall that the two passive regimes are observationally equivalent to agents, given that ϕ_π^p and ϕ_y^p are the same across the two regimes. Therefore, agents conduct Bayesian learning in order to infer which one of the two regimes is in place. In the next section we will discuss how agents' beliefs evolve as agents observe more and more deviations from the active regime.[7]

Under *transparency* all the information held by the central bank is communicated to agents. We assume that the central bank knows for how long it will be deviating from active monetary policy when conducting short-lasting deviations (Regime 2). Long-lasting deviations are intended to capture structural changes in the way monetary policy is conducted (e.g., the type of a newly appointed central banker). Therefore, their duration is unknown to

[7] It might be argued that the central bank could try to signal the kind of deviation perturbing the Taylor rule parameters across the two rules. For example, $\phi_\pi(s_t = 3) = \phi_\pi(s_t = 2) + \xi$ for $\xi \neq 0$ and small. However, the point of the paper is exactly to capture agents' uncertainty about the duration of passive policies. Therefore, the model would be extended to allow for a total of four passive regimes: a long-lasting Regime 4 in which $\phi_\pi = \phi_\pi(s_t = 2)$ and $p_{44} > p_{22}$ and a short-lasting Regime 5 in which $\phi_\pi = \phi_\pi(s_t = 3)$ and $p_{55} < p_{33}$.

the central bank and hence cannot be announced. Notice that under transparency rational agents immediately infer when such a structural change in the conduct of monetary policy has occurred. If a transparent central bank starts deviating from active policy without announcing the duration of such passive policy, this deviation must be a long lasting one (Regime 3).

A transparent central bank announces the duration of short-lasting passive policies, revealing to agents exactly when monetary policy will switch back to the active regime. It is important to emphasize that agents form their beliefs by taking into account that the central bank will systematically announce the duration of *every* short-lasting passive policies. We assume that central bank's announcements are truthful and are believed as such by rational agents. In Section 6, we will consider the case in which the announcements made by the central bank are not always truthful. In Section 7.2, we will study the case in which the central bank has much less information about the duration of its policy course and can only announce the likely duration of the passive policies; that is, the type of passive regime (i.e., $\xi_t^p \in \{2,3\}$) that the central bank will carry out. This case corresponds to a form of transparency in which the central bank communicates only the likely duration rather than the actual duration of the passive policy.

3 Beliefs Dynamics and Model Solution

Different communication strategies imply different dynamics of beliefs and hence different solution methods. Let us first discuss how to solve the model in which the central bank is *not transparent*. Later in this section we will discuss the case in which the central bank is transparent.

No Transparency 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 active regime is fully revealing, when the passive regime is prevailing, agents do not know whether the central bank is engaging in a short-lasting deviation or a long-lasting one. Agents have to learn the nature of the deviation in order to form expectations over the endogenous variables of the economy.

To solve the model under no transparency we use the methods developed in Bianchi and Melosi (2016b). We briefly report the main features of this solution method so as to make this paper self-contained. Denote the number of consecutive deviations from the active regime at time t as $\tau_t \in \{0, 1, ...\}$, where $\tau_t = 0$ means that monetary policy is active at time t. Conditional on having observed $\tau_t \geq 1$ consecutive deviations from the active regime at time t, agents believe that the central bank will keep deviating in the next period $t+1$ with the following probability:[8]

$$prob\{\tau_{t+1} \neq 0 | \tau_t \neq 0\} = \frac{p_{22}(p_{12}/p_{13})(p_{22}/p_{33})^{\tau_t} + p_{33}}{(p_{12}/p_{13})(p_{22}/p_{33})^{\tau_t} + 1}. \quad (16)$$

Equation (16) makes it clear that $prob\{\tau_{t+1} \neq 0 | \tau_t \neq 0\} = prob\{\tau_{t+1} \neq 0 | \mathcal{F}_t\}$ as τ_t is a sufficient statistic for the probability of being in the passive regime next period. This equation captures the dynamics of agents' beliefs about observing yet another period of passive policy in the next period, which is the key state variable we use to solve the model under no transparency.

It should be also observed that equation (16) has a number of properties that are quite insightful to the key mechanism of the model at hand. It is useful to observe that the probability of observing yet another period of passive policy in the next period is a weighted average of the probabilities p_{22} and p_{33} with weights that vary with the number of consecutive periods of passive policy τ_t. When agents observe the central bank deviating from the active regime for the first time ($\tau_t = 1$), the weights for the probabilities p_{22} and p_{33} are $p_{12}/(1-p_{11})$ and $p_{13}/(1-p_{11})$, respectively. These weights can be interpreted as agents' *priors* about which passive regime is in place when the first deviation is observed. As more and more periods of passive policy are observed ($\tau_t \uparrow$), the weight assigned to the short-lasting passive Regime 2 *monotonically* decreases due to the fact that $p_{33} > p_{22}$. Consequently, as the first period of passive policy is observed, agents' beliefs about observing a passive policy in the next period are at their lower bound. Furthermore, as the central bank keeps on deviating, agents get increasingly convinced that the economy has entered a long-lasting deviation, given that under this policy regime long deviations are more likely.

Importantly, how low is the lower bound for the probability of observing yet another period of passive policy will depend on the level of the central bank's long-run reputation. High reputation makes the weight $p_{12}/(1-p_{11})$ close to one, implying that the probability of observing a second consecutive period of passive policy will be very close to p_{22}, the value associated with a short lasting deviation. When reputation is high, it is very unlikely that the central bank engages in a long-lasting passive policy. Therefore, as the first period of passive policy is observed, agents are quite confident to have entered the short-lasting passive regime (Regime 2). If the central bank keeps deviating from the active regime, agents will eventually become convinced of being in the long-lasting passive regime (Regime 3) regardless of the level of the central bank's reputation, $p_{12}/(1-p_{11})$.[9] After a sufficiently long-lasting passive

[8] A proof of equation (16) is worked out in Appendix A.

[9] We abstract from the extreme case in which the central bank's reputation is such that $p_{12}/(1-p_{11}) = 1$.

policy, the probability of observing an additional deviation in the next period degenerates to the persistence of the long-lasting Regime 3. Formally: $\lim_{\tau_t \to \infty} prob\{\tau_{t+1} \neq 0 | \tau_t \neq 0\} = p_{33}$. Hence, p_{33} is the *upper bound* for the probability that agents attach to staying in the passive regime next period. It follows that rational agents cannot get more convinced to observe yet another passive policy in the next period than when they are sure to be in the long-lasting Regime 3. More formally, for each $e > 0$, there exists an integer τ^* such that:

$$p_{33} - prob\{\tau_{t+1} \neq 0 | \tau_t = \tau^*\} < e, \tag{17}$$

with the important result that for any $\tau_t > \tau^*$, agents' beliefs can be effectively approximated using the properties of the long-lasting passive regime (Regime 3).

Endowed with these results, we can solve the model under no transparency by expanding the number of regimes in order to take into account the evolution of agents' beliefs. Now each regime is characterized by central bank's behavior and the *number of observed consecutive deviations from the active policy at any time t* $\tau_t \in \{0, 1, ..., \tau^*\}$. The mapping to the parameter values of the policy rule is as follows:

$$\left(\rho_r(\tau_t = j), \phi_\pi(\tau_t = j), \phi_y(\tau_t = j)\right) = \begin{bmatrix} \left(\rho_r^A, \phi_\pi^A, \phi_y^A\right), \text{ if } j = 0 \\ \left(\rho_r^P, \phi_\pi^P, \phi_y^P\right), \text{ if } 1 \leq j < \tau^* \end{bmatrix} \tag{18}$$

The transition matrix for this new set of regimes $\tau_t \in \{0, 1, ..., \tau^*\}$ can be derived by equation (16) as shown in Appendix A.

Endowed with these results regarding the dynamics of agents' beliefs, one can recast the Markov-switching DSGE model under no transparency and learning as a Markov-switching Rational Expectations model with perfect information. Now regimes are defined in terms of the observed consecutive duration of the passive regimes, τ_t, which, unlike the primitive set of policy regime $\xi_t^p \in \{1, 2, 3\}$, belongs to the agents' information set $\mathcal{F}_t$. This result allows us to solve this model by applying any of the methods developed to solve Markov-switching rational expectations models with perfect information, such as Davig and Leeper (2007), Farmer, Waggoner, and Zha (2009), and Foerster, Rubio-Ramirez, Waggoner, and Zha (2013). We use Farmer, Waggoner, and Zha (2009) to solve the model with learning once the policy regimes are redefined as described above.

It is worth emphasizing that this way of recasting the learning process allows us to tractably model the behavior of agents that *know that they do not know*. In other words,

In this case, agents' beliefs will not evolve at all as the central bank deviates Another limit case is when the central bank's reputation is at its lowest; that is, $p_{12}/(1 - p_{11}) = 0$. In this case, agents know that any passive policy is surely of the long-lasting type and do not update their beliefs during the implementation of the passive policy. We do not consider these two extreme cases in this paper.

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, our approach 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, using discounted least squares 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 central bank' future behavior, and this uncertainty has important consequences for the law of motion of the economy.

Transparency When the central bank is *transparent*, the exact duration of every short-lasting deviation from active policy is truthfully announced. In this model the *number of announced short-lasting deviations from active policy yet to be carried out* τ_t^a is a sufficient statistic that captures the dynamics of beliefs after an announcement. Since the exact duration of long-lasting passive policies is not announced, we also have to keep the long-lasting passive regime as one of the possible regimes. Regimes are ordered from the smallest number of announced deviations (zero, the active policy) to the largest one (τ_*^a). The long-lasting passive regime, whose conditional persistence is p_{33}, is ordered as the last regime. Notationally, regime $\tau_t^a = \tau_*^a + 1$ denotes the long-lasting passive regime. Hence, we redefine the set of policy regimes in terms of this variable with the following mapping to the parameter values of the policy rule:

$$\left(\rho_r\left(\tau_t^a = j\right), \phi_\pi\left(\tau_t^a = j\right), \phi_y\left(\tau_t^a = j\right)\right) = \begin{bmatrix} \left(\rho_r^A, \phi_\pi^A, \phi_y^A\right), \text{ if } j = 0 \\ \left(\rho_r^P, \phi_\pi^P, \phi_y^P\right), \text{ if } 1 \leq j \leq \tau_*^a + 1 \end{bmatrix} \tag{19}$$

where τ_*^a is a large number at which we truncate the redefined set of regimes. The regimes $\tau_t^a \in \{0, 1, ..., \tau_*^a + 1\}$ are governed by the $(\tau_*^a + 2) \times (\tau_*^a + 2)$ transition matrix $\widetilde{\mathcal{P}}^A = [\widetilde{p}_A^{1\prime}, \widetilde{p}_A^{2\prime}, \widetilde{p}_A^{3\prime}]'$, where $\widetilde{p}_A^1$ is a $1 \times (\tau_*^a + 2)$ vector whose $j-th$ element is p_{11} if $j = 1$; $p_{12} p_{22}^{j-2} p_{21}$ if $2 \leq j \leq \tau_*^a + 1$ (the probability that the realized short-lasting passive policy will last exactly $j - 1$ consecutive periods conditional on being in the active regime); and p_{13} if $j = \tau_*^a + 2$. This vector $\widetilde{p}_A^1$ captures the probability of remaining in the active regime, switching to a short-lasting passive regime of duration 1 up to τ_a^*, and to switch to the long-lasting passive regime, conditional on being currently in the active regime. The $\tau_*^a \times (\tau_*^a + 1)$ matrix $\widetilde{p}_A^2$ is defined as $\left[\mathbf{I}_{\tau^a_*}, \mathbf{0}_{\tau^a_* \times 2}\right]$, where $\mathbf{I}_{\tau^a_*}$ is a $\tau^a_* \times \tau^a_*$ identity matrix and $\mathbf{0}_{\tau^a_* \times 2}$ is $\tau^a_* \times 2$ null matrix. This submatrix captures the transition while the announced deviation from the active policy is carried out. $\widetilde{p}^3_A$ is defined as a $1 \times (\tau^a_* + 2)$ vector whose $j-th$ element is $(1 - p_{33})$ if $j = 1$; zero if $2 \leq j \leq \tau^a_* + 1$; and p_{33} if $j = \tau^a_* + 2$. The last row of the matrix $\widetilde{\mathcal{P}}^A$ captures the probability of staying in the long-lasting passive regime or switching to the active regime, conditional on being currently in the long-lasting passive regime. To ensure that the first row sums up to one, we set $\widetilde{p}^1_A(\tau^*_a) = 1 - p_{11} - \sum_{j=1}^{\tau^*_a - 1} \widetilde{p}^1_A(j) - p_{13}$, which, effectively, becomes the probability for the central bank to announce a deviation longer than τ^*_a periods. We choose τ^a_* to be large enough so that $\widetilde{p}^1_A(\tau^*_a) \approx 0$ and the approximation error becomes negligible.[10]

Let us make a simple example to illustrate how to construct the transition matrix governing the evolution of the policy regimes in the case of transparency. To serve the purpose of this simple example, let us truncate the maximum number of announced deviations at $\tau^a_* = 3$ periods. We need to construct a total of $\tau^*_a + 2 = 5$ regimes. The first regime is active $\left(\rho^A_r, \phi^A_\pi, \phi^A_y\right)$ and all of the other regimes (from the second to the fifth) are passive $\left(\rho^P_r, \phi^P_\pi, \phi^P_y\right)$. The 5×5 transition matrix $\widetilde{\mathcal{P}}^A$ can be constructed as follows:

$$\widetilde{\mathcal{P}}^A = \begin{bmatrix} p_{11} & p_{12}p_{21} & p_{12}p_{22}p_{21} & p_{12}p_{22}^2p_{21} & p_{13} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 - p_{33} & 0 & 0 & 0 & p_{33} \end{bmatrix}.$$

Let assume that at time t the central bank announces to conduct a three-period passive policy (i.e., $\tau^a_t = 3$). The system will move to the Regime 4 in period $t + 1$, to Regime 3 in period $t + 2$, to Regime 2 in period $t + 3$, and then back to the Active Regime 1 in period $t + 4$.

Similarly to the case of no transparency, we have recast the Markov-switching DSGE model under transparency as a Markov-switching Rational Expectations model with perfect information, in which the short-lasting passive regime is redefined in terms of the number of *announced deviations* from the active regimes *yet to be carried out*, τ^a_t. This redefined set of regimes belongs to the agents' information set $\mathcal{F}_t$ under transparency. This result allows us to solve the model under transparency by applying any of the methods developed to solve Markov-switching rational expectations models of perfect information.

[10] Since $p_{22} < 1$, it can be easily show that the larger the truncation τ^*_a, the lower the approximation error.

	Posterior			Prior		
Name	Median	5%	95%	Type	Mean	Std.
ϕ_π^A	3.0993	2.5299	3.7031	N	2.5	.5
ϕ_y^A	0.6947	0.5368	0.9126	G	.25	.15
ρ_R^A	0.6864	0.5186	0.7778	B	.5	.2
ϕ_π^P	1.3365	1.0426	1.6032	G	.9	.3
ϕ_y^P	0.4034	0.2541	0.6384	G	.25	.15
ρ_R^P	0.6925	0.5864	0.7774	B	.5	.2
p_{11}	0.9497	0.8955	0.9776	B	.9	.05
p_{22}/p_{33}	0.7070	0.5114	0.8915	B	.8	.1
p_{33}	0.9689	0.9403	0.9868	B	.95	.025
$p_{12}/(1-p_{11})$	0.9536	0.9003	0.9883	B	.95	.025
ψ	0.9998	0.8469	1.1788	G	1	.1
ε	7.7764	4.3259	13.1161	G	8	3
ω	0.6569	0.3562	0.8799	B	.5	.2
θ	0.9189	0.8734	0.9496	B	.5	.2
β	0.9974	0.9955	0.9986	B	.99	.005
ρ_g	0.9496	0.9260	0.9682	B	.5	.2
ρ_z	0.3690	0.1435	0.5959	B	.5	.2
$100 \ln z$	0.4808	0.3144	0.6368	N	.4	.125
$100 \ln (\bar{\Pi})$	0.7433	0.5571	0.9115	N	.5	.125
$100\sigma_g$	2.5499	1.8268	3.8237	IG	2	1
$100\sigma_m$	3.1215	1.7974	5.8893	IG	2	1
$100\sigma_z$	1.4827	1.0278	2.2091	IG	2	1
$100\sigma_r$	0.6009	0.4531	08799	IG	.5	.2

Table 1: Posterior modes, means, and 90% error bands of the model parameters. Type N, G, B, IG stand for Normal, Gamma, Beta, Inversed Gamma density, respectively. Dir stands for the Dirichelet distribution

4 Empirical Analysis

In order to put discipline on the parameter values, the model *under the assumption of no transparency* is fitted to US data. We believe that the model with a non-transparent central bank is better suited to capture the Federal Reserve communication strategy in our sample that ranges from mid-1950s to prior the Great Recession. We then use the results to quantify the Federal Reserve reputation and the potential gains from making the Federal Reserve more transparent.

This section is organized as follows. Section 4.1 briefly deals with the Bayesian estimation of the model. In Section 4.2 we show the evolution of agents' beliefs about future monetary policy, which is key to understand the welfare implications of transparency.

4.1 Data and Estimation

For observables, we use three series of U.S. quarterly data: the annualized GDP growth rate, the annualized quarterly inflation (GDP deflator), and the Federal Funds Rate (FFR). The sample spans from 1954:Q4 to 2009:Q3. Table 1 reports the prior and the posterior distribution of model parameters. The model is estimated by using a Gibbs sampling algorithm in which both the regime sequence and the model parameters are sampled. The algorithm is similar to the one used in Bianchi (2013). Convergence is checked by using the Brooks-Gelman-Rubin potential reduction scale factor using within and between variances based on the five multiple chains. The five chains consist of $270,000$ draws each, 1 every $1,000$ draws is saved.

The parameter values are quite standard with the central bank responding fairly aggressively to inflation when monetary policy is active. The central bank is also responding more aggressively to the output gap under the active policy. The degree of price indexation is fairly high compared to other studies (Coibion, Gorodnichenko, and Wieland 2012). This may be due to the stylized nature of the model we have estimated. However, the 90-percent posterior interval encompasses values for this parameter that are in line with what used in the literature. We check that our results are robust to lower degrees of price indexation in Appendix D. In fact, we find that lower values of price indexation end up raising the welfare gains from transparency.

The posterior median of the elasticity of substitution ε implies a net markup equal to approximately 13%. The Calvo parameter θ implies a fairly large degree of nominal rigidities as is common when small-scale models are estimated. The Frisch elasticity of labor supply is close to one. The probability of being in the short-lasting passive regime conditional on having switched to passive policies, $p_{12}/(1-p_{11})$, plays a critical role in the model. As noticed in Section 2, this parameter value relates to the strength of the Federal Reserve's *long-run reputation* to refraining from long-lasting deviations. This parameter is found to be fairly close to one, confirming that the Federal Reserve has strong reputation. This number means that as agents observe a deviation from the active regime, they expect that the Federal Reserve is conducting a short-lasting passive policy with probability 95.36%.

Recall that the regime structure of the model we have estimated (i.e., the model under no transparency) is defined in terms of how many consecutive periods of passive policy are observed, τ_t. After the model is estimated, we can compute the sequence of posterior probabilities over the periods of consecutive passive policies τ_t at any date of the sample. Note that we will have as many of these probabilities as many numbers of regimes; that is, (τ^*+1) in our notation. Such a large dimensionality makes it challenging to effectively report the dynamics of the regime probabilities in a graph. A most effective approach is to

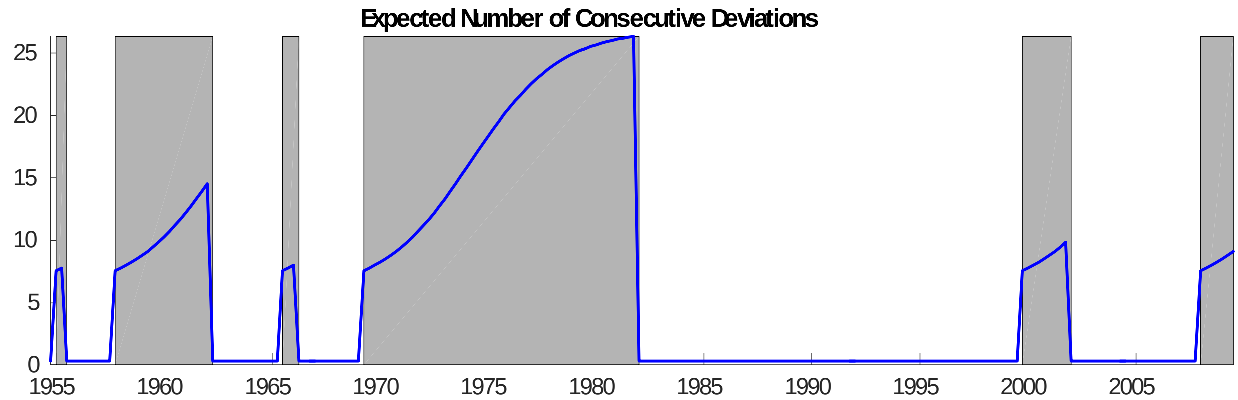

Figure 1: The gray shaded areas mark periods of passive monetary policy based on the regime sequence associated with the posterior mode based on the Gibbs sampling algorithm. The blue solid line reports the corresponding expected number of consecutive deviations from the active regime.

report the estimated *expected* number of consecutive deviations from the active policy over the sample. As it will become clearer later, the higher the number of expected consecutive deviations, the larger is the posterior probability mass associated with passive policy of longer durations (Regime $\xi_t^p = 3$). Furthermore, this statistic is critical to understand the effects of communication on social welfare, as we will show later.

The shaded areas in Figure 1 show the periods of passive monetary policy based on the regime sequence associated with the posterior mode based on the Gibbs sampling algorithm. The blue solid line reports the corresponding expected number of consecutive deviations from the active regime. This can be considered a measure of agents' pessimism because, as we will show later in the paper, a larger number of expected consecutive deviations determines an increase in uncertainty and, as a result, a decline in agents' welfare. The figure highlights as the short-lasting deviations from active policy only imply a modest increase in this statistic. Instead, at the end of the 1970s and early 1980s the number of expected consecutive deviations approaches its highest value, $(1 - p_{33})^{-1}$, reflecting the fact that most of the posterior probability is shifted toward regimes associated with passive policies of fairly long duration. The number of expected duration of passive policy grows gradually throughout the 1970s and reaches relatively high levels at the end of this decade. This suggests that agents slowly changed their expectations about future policy as they observed more and more periods of passive policy in the 1970s. After the 1970s, large posterior probability is attributed to either active regime or to passive policies of very short realized duration. This is captured by the number of expected deviations from active policy being either close to zero, when the active regime prevails, or else slightly positive, but below 10 quarters, i.e. 2 years and half, when short lasting deviations occur during the 2001 recession and in correspondence of the most recent recession. This is the essence of

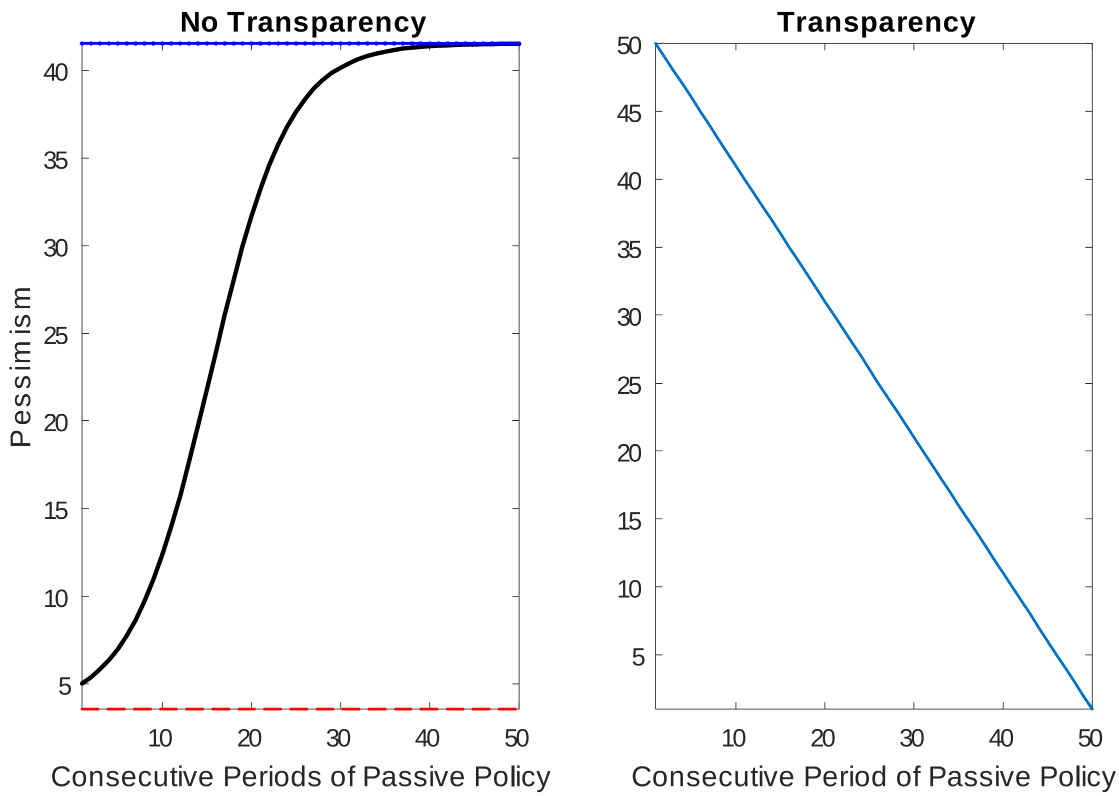

Figure 2: Pessimism on the vertical axis is measured as the number of expected consecutive deviations ahead. On the left plot the two horizontal lines denote the smallest lower bound $(1-p_{22})^{-1}$ and upper bound of pessimism $(1-p_{33})^{-1}$. These statistics are computed at the posterior mode.

constrained discretion we want to study in this paper.

Finally, we want to evaluate whether there is empirical support for our benchmark model with no transparency. To this end, we estimate an alternative model in which parameters are not allowed to change and then compare the two models by using Bayesian model comparison. We find that the data strongly favor the Markov-switching specification, despite the larger number of parameters. In fact, the model with fixed parameters can attain a higher posterior probability only if one attaches extremely low prior probabilities ($< 1.39E-11$) that the Markov-switching model fits the data better than the alternative.

4.2 Communication and Beliefs Dynamics

Monetary policy decisions on stabilizing inflation and communication strategies critically affect social welfare and the macroeconomic equilibrium by influencing agents' pessimism about future monetary policy. In this paper, we will use the word *pessimism* to precisely mean agents' expectations about the duration of an observed passive policy. A high level of pessimism means that agents expect an observed passive policy to last for relatively long; that is, close to the expected duration of the long-lasting passive Regime $(1-p_{33})^{-1}$. While expecting a longer lasting deviation from the active regime is not necessarily welfare decreasing, we will show that expecting a prolonged period of passive policy impairs social welfare in the estimated model.

We measure pessimism by computing the number of *expected* consecutive periods of passive monetary policy conditional on the *observed* duration of passive policy $\tau \geq 1$. To construct such a measure, let us denote the probability of being in the short-lasting passive regime (Regime $\xi_t^p = 2$) after τ consecutive periods of passive policy has been observed as $\mathfrak{P}(\tau) \equiv \frac{p_{12}p_{22}^{\tau-1}}{p_{12}p_{22}^{\tau-1}+p_{13}p_{33}^{\tau-1}}$. The number of expected consecutive deviations from the active policy conditional on having observed τ consecutive periods of passive policy can be computed as follows: $\mathfrak{P}(\tau)(1-p_{22})^{-1}+[1-\mathfrak{P}(\tau)](1-p_{33})^{-1}$, $\tau \geq 1$.[11] If monetary policy is active ($\tau = 0$), the number of expected consecutive deviations is based on the probability of observing a deviation to one of the two passive regime in the next period as well as the expected number of deviations conditional on the two passive regimes. The number of expected deviations admits an upper bound at $(1-p_{33})^{-1}$, which is attained as $\tau \to \infty$ or, in the case of the estimated model, as $\tau \to \tau^*$. Furthermore, note that $\mathfrak{P}(1)$ corresponds to what we have called central bank's long-run reputation. The stronger the central bank's reputation, the closer $\mathfrak{P}(1)$ is to unity, and the closer the lower bound for this statistic is to $(1-p_{22})^{-1}$, which its *lowest* possible value for pessimism. This conditional statistic is monotonically increasing with the number of observed deviations from the active policy τ.

Let us consider the case in which the central bank decides to engage in passive policies lasting fifty consecutive periods. While a policy of such a long duration is clearly quite implausible for the U.S., this example is illustrative of how transparency affects pessimism relative to no transparency. Figure 2 reports the evolution of pessimism under no transparency (left graph) and under transparency (right graph) at the posterior mode. The two horizontal lines mark the smallest lower bound and upper bound for pessimism. The former is given by the expected duration of the short-lasting passive Regime $(1-p_{22})^{-1}$. The smallest lower bound is attained at the first period of passive policy only if the conditional probability of a short-lasting deviation is one: $p_{12}/(1-p_{11}) = 1$. The left graph shows that the intercept of the solid line is quite close to the bottom dashed line, implying that agents's mostly expect that the Federal Reserve is engaging in a short-lasting deviation as the first period of passive policy is observed. This result is due to the fact that the Federal Reserve's reputation is estimated to be fairly high ($p_{12}/(1-p_{11}) = 0.9536$).

[11] Note that the expected number of deviations conditional on being in the short-lasting passive regime (Regime $\xi_t^p = 2$) and in the long-lasting passive regime (Regime $\xi_t^p = 3$) can be computed as $(1-p_{22})^{-1}$ and $(1-p_{33})^{-1}$, respectively.

The upper bound for pessimism is given by the expected duration of the long-lasting passive policy $(1 - p_{33})^{-1}$ and is attained only after a very large number of consecutive deviations from the active regime. Such a gradual increase in pessimism suggests that the Federal Reserve can enjoy a great deal of leeway in deviating from active monetary policy in order to stabilize alternative short-lasting objectives. This result is again due to the strong reputation of the Federal Reserve. If the reputation coefficient $p_{12}/(1 - p_{11})$ were close to zero, then the expected number of consecutive deviations would experience a larger jump and, hence, the convergence to the upper bound would be much faster than what shown in Figure 2.

As shown in the right graph, pessimism follows an inverse path under transparency. Unlike the case of no transparency, agents' pessimism is very high at the initial stage of the deviation from the passive policy but it decreases as the time goes by. This result comes from assuming that agents are fully rational and the announcement is truthful. As the one hundred periods of passive monetary policy are announced ($t = 0$), an immediate rise in pessimism occurs. As the number of periods of passive policy yet to be carried out decreases, agents' pessimism declines accordingly. At the end of the policy ($t = 50$), pessimism reaches its lowest level, with agents expecting to return to the active regime with probability one in the following period. It should be noted that at the end of the announced deviation transparency allows the central bank to lower agents' pessimism below the smallest lower bound attainable under no transparency: This result emerges because the central bank is able to inform agents about the exact period in which the passive policy will be terminated. This assumption will be relaxed in Section 7.2.

To sum up, Figure 2 allows us to isolate two important effects of transparency on agents' pessimism about future monetary policy: (i) *transparency raises pessimism at the beginning of the policy*; (ii) *transparency anchors down pessimism at the end of the policy.* As we shall show, these two effects play a critical role for the welfare implications of transparency.

5 Welfare Implications of Transparency

In this section, we use the model to assess the welfare implications of introducing transparency. Before proceeding, it is worth emphasizing that the regime changes considered in this paper do not affect the steady state, but only the way the economy fluctuates around the steady state. The period welfare function can then be obtained by taking a log-quadratic approximation of the representative household's utility function around the deterministic steady state:

$$\mathbb{W}_i\left(s_t\left(i\right)\right) = -\sum_{h=1}^{\infty} \beta^h \left[\Theta_0 + \Theta_1 var_i\left(\hat{y}_{t+h}|s_t\left(i\right)\right) + \Theta_2 var_i\left(\hat{\pi}_{t+h}|s_t\left(i\right)\right)\right], \tag{20}$$

where $i \in \{N, T\}$, $var_i(\cdot)$ stands for the stochastic variance associated with agents' forecasts of inflation, and the output gap at horizon h. The coefficients Θ_i, $i \in \{0, 1, 2\}$ are functions of the model's parameters and are defined in the Appendix B. The subscript i refers to the communication strategy: $i = N$ stands for the case of no transparency, while $i = T$ denotes transparency. Finally, $s_t(i)$ denotes the policy regime: $s_t(i = N) \in \{0, 1, ..., \tau^*\} = \tau_t$ and $s_t(i = T) \in \{0, 1, ..., \tau_*^a + 1\} = \tau_t^a$, where, recall $s_t(i = T) = \tau_*^a + 1$ denotes the long-lasting passive regime, whose exact realized duration is not announced.

The term Θ_0 captures the steady-state effects from positive trend inflation. These effects stem from the the rise in cross-sectional steady-state dispersion in prices, which leads to inefficient allocations of resources across industries, due to positive trend inflation (Coibion, Gorodnichenko, and Wieland, 2012). These steady-state effects are eliminated if price indexation is perfect ($\omega = 1$). The term Θ_1 is directly related to the increasing disutility of labor supply. Since households' costs of supplying labor are convex, the expected disutility from labor rises with the volatility of output around its steady state. As discussed in Coibion, Gorodnichenko, and Wieland (2012), the magnitude of this coefficient is invariant to the level of trend inflation $\bar{\Pi}$. The term Θ_2 captures the effects of price dispersion on social welfare. Positive trend inflation generates some price dispersion. The increased price dispersion following an inflationary shock becomes now more costly because of the higher initial price dispersion due to positive trend inflation. Higher nominal rigidities (θ) lead to stronger effects of price dispersion on welfare (Θ_2). It should be noted that zero trend inflation ($\bar{\Pi} = 1$) or positive trend inflation with perfect indexation ($\omega = 1$) would imply that the steady-state costs associated with positive trend inflation goes to zero ($\Theta_0 = 0$). A detailed derivation of the welfare function can be found in Coibion, Gorodnichenko, and Wieland (2012). These welfare coefficients Θ_0, Θ_1, and Θ_2 depends on the government-purchase-to-output ratio in steady state, which we assume to be equal to 22%.

It can be shown that conditional on a price markup shock the active policy is associated with a lower volatility of inflation but a higher volatility of the output gap compared to deviating to passive policies. This result captures the monetary policy trade-off due to these inefficient shocks, which is a well-known feature in the context of linear DSGE models. However, conditional on the other three shocks (i.e., the discount factor shock $\eta_{g,t}$, the technology shock η_{zt}, and the monetary shock η_{rt}), the active policy always leads to a lower level of both volatilities and hence to an unambiguously higher welfare.

Equation (20) makes it explicit that social welfare depends on agents' uncertainty about future inflation and the future output gap. It should be noted that agents' uncertainty in any given period captures the macroeconomic risk associated with the observed policy regime and communication strategy, $s_t(i)$. Unlike standard New Keynesian models with fixed parameters where welfare is merely a function of the unconditional variance of inflation and the output gap, our model allows to study the dynamic effects of policy actions and forward-looking communication on welfare. To the best of our knowledge, this is the first paper that studies this feature using a structural model. Furthermore, the learning mechanism plays an important role in our welfare analysis by linking the concept of central bank's long-run reputation, which can be directly measured in the data, to the central bank's ability of controlling the dynamics of the macroeconomic risk associated with policy actions. This last point will be the focus of the next session.

To assess the desirability of transparency, we compute the model predicted welfare gains/losses from transparency as follows:

$$\Delta\mathbb{W}^e = \sum_{\tau_a=0}^{\tau_a^*+1} p_T^*(\tau^a)\cdot\mathbb{W}_T(\tau^a) - \sum_{\tau=0}^{\tau^*} p_N^*(\tau)\cdot\mathbb{W}_N(\tau) \tag{21}$$

where $p_T^*(\tau^a)$ stands for the vector of the ergodic joint probabilities of a passive policy of *announced* duration τ^a. $p_N^*(\tau)$ stands for the vector of ergodic joint probabilities of a passive policy of *observed* duration τ. It is important to emphasize that welfare gains from transparency are not conditioned on a particular shock or policy path. Instead, the welfare gain is measured by the unconditional long-run change in welfare that arises if the central bank systematically announces the duration of any deviation from active monetary policy.

Uncertainty about the future output gap will turn out to play only a minor role for social welfare since the estimated value of the slope of the Phillips curve is very small and the elasticity of substitution among goods ε is quite large. Such a flat Phillips curve is a standard finding when DSGE models are estimated using U.S. data and the estimated value of the elasticity of substitution are in line with previous studies and micro data on U.S. firms' average profitability. These two features cause the estimated coefficient for the inflation risk in the welfare function (Θ_2) to be bigger than the other two coefficients (Θ_0 and Θ_1) by several orders of magnitude. Therefore, welfare turns out to be tightly related to agents' uncertainty about future inflation, which, as we shall show, depends on the time-varying level of pessimism about observing a future switch to active monetary policy.

Section 5.1 outlines how uncertainty about future inflation evolves as the central bank conducts passive policies of different durations and under different communication strategies.

In Section 5.2, we use the model to assess the welfare implications of increasing central bank transparency.

5.1 Evolution of Uncertainty

We have shown that agents' uncertainty about future inflation crucially affects social welfare in the estimated model. In this section, we will show how uncertainty is tightly linked to agents' pessimism about observing active monetary policy in the future. As shown in Section 4.2, transparency has two effects on pessimism: (i) pessimism rises at the beginning of the policy (henceforth, the *short-run effect of transparency on pessimism*); (ii) pessimism is anchored down at the end of the policy (henceforth, the *anchoring effect of transparency on pessimism*). As we shall show, these two effects play a critical role for the welfare implications of enhancing central bank's transparency.

To illustrate how uncertainty responds to pessimism, we consider the case in which the Federal Reserve conducts a forty-quarter-long deviation from active monetary policy.[12] While such a long-lasting deviation is very implausible to be observed in the estimated model, this example allows us to highlight the key implications of the two communication strategies (no transparency and transparency) on social welfare. The upper panel of Figure 3 shows the evolution of uncertainty about inflation at different horizons h under no transparency, left panel, and under transparency, right panel. At each point in time, the evolution of agents' uncertainty is measured by the h-period ahead standard deviation of inflation given the communication strategy:

$$sd_i\left(\pi_{t+h}|\tau_t\right) = 100\left[\sqrt{var_i\left(\pi_{t+h}|s_t\left(i\right)\right)} - \sqrt{var_i\left(\pi_{t+h}|s_t\left(i\right)=0\right)}\right]$$

where $i \in \{N, T\}$ captures the communication strategy.[13] We analytically compute the conditional standard deviations taking into account regime uncertainty by using the methods described in Bianchi (2016).

As shown in the upper left graph, when the central bank does not announce its policy course beforehand, uncertainty about future inflation is relatively low at the beginning of the policy because agents interpret the first deviations from active policy as short lasting. This result is driven by the high reputation of the Federal Reserve, implying that agents attach 95% probability of being in the short-lasting passive regime as the first period deviation from

[12] The analysis is conducted for an economy at the steady-state and hence without conditioning on a particular shock. The exercise is only conditioned on the policy path and intends to facilitate the exposition of the welfare implications of transparency in the next section.

[13] The graphs plot the results for h from 1 to 60: At horizon $h = 0$, uncertainty is zero as agents observe current inflation.

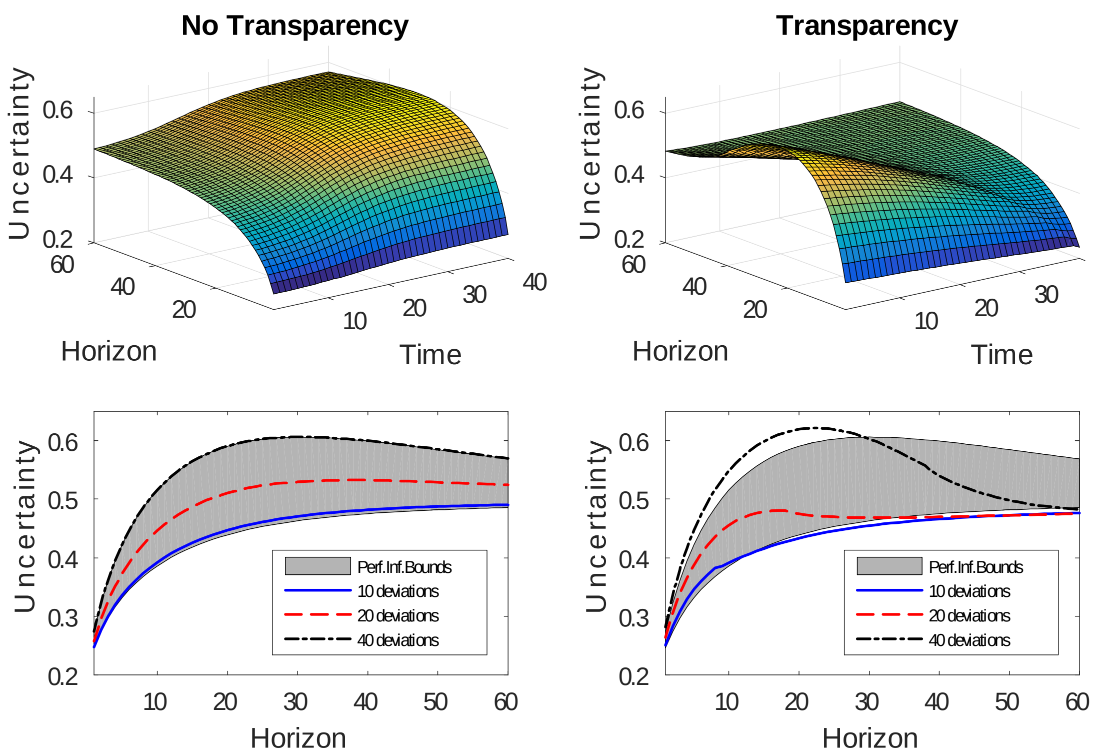

Figure 3: Upper graphs: Evolution of uncertainty about inflation at different horizons (h) over forty periods of passive policy (time) under no transparency (left graph) and under transparency (right graph). The vertical axis reports the standard deviations in percentage points at the posterior mode. Lower graphs: Dynamics of uncertainty across horizons after having observed (left plot) or announced (right plot) 10, 20, and 40 consecutive quarters of passive policy. The gray areas denote the bound for the dynamics of uncertainty about inflation across horizons when agents know the nature of the observed passive policy. The upper (lower) bound is when the passive policy is of short-lasting (long-lasting) type. Parameter values are set at the posterior mode.

active policy is observed. As more and more periods of passive policy are observed, agents become progressively more convinced that the observed deviation may have a long-lasting nature and uncertainty about future inflation *gradually* takes off. Uncertainty rises because expecting a longer spell of passive policies raises concerns about the central bank's ability of controlling the inflationary consequences of future unanticipated shocks. Note that the increase in uncertainty occurs at every horizon because agents expect passive monetary policy to prevail for many periods ahead and thereby anticipate that the inflationary/deflationary consequences of future shocks will be more severe. It is worth emphasizing that the pattern of agents' uncertainty over time mimics the evolution of pessimism depicted in Figure 2. Summarizing, under no transparency, following a prolonged deviation from the active regime uncertainty starts low and then gradually accelerates. Since higher uncertainty maps into higher welfare loss, the progressive *disanchoring* of uncertainty about future inflation is a reason of concern for a non-transparent central bank.

The lower left panel shows the dynamics of uncertainty across different horizons when 10, 20, and 40 quarters of deviations are observed in the no-transparency case. The gray area captures the dynamics of uncertainty across horizons in the case of perfect information; that is, the case in which agents know whether the passive regime in place is short or long lasting. Thus, the lower- (upper-) bound of the gray area captures the uncertainty when agents know for certain that the short- (long-) lasting passive regime is in place. Observing 40 quarters of consecutive deviations from the active policy, uncertainty evolves as if agents knew with certainty that the central bank is conducting a long-lasting policy (the black dashed-dotted line). After observing so many deviations, agents are certain that this is a long-lasting passive policy. Agents cannot get more uncertain about future inflation developments than that. Therefore, the dynamics of uncertainty when agents knows perfectly that the nature of the passive policy is long-lasting represents an upper bound for agents' uncertainty under no-transparency. The dynamics of uncertainty conditional on a short-lasting passive policy under perfect information constitutes a lower bound for uncertainty under no-transparency. It can be shown that the higher the central bank's long-run reputation $p_{12}/(1-p_{11})$, the closer the dynamics of uncertainty to this lower bound as the central bank starts deviating. The lower left graph shows that the dynamics of uncertainty is rather close to the lower bound even when ten consecutive periods of passive policy are observed. This finding suggests that in our estimated model uncertainty dynamics remain anchored even after a ten-quarter-long deviation from active policy. This result is interpreted as reflecting the high reputation of the Federal Reserve and suggests that the Federal Reserve has a considerable leeway in deviating from active policies before significantly lowering social welfare.

The right upper graph of Figure 2 shows the dynamics of uncertainty about future inflation in the case of transparency. Comparing the upper graphs (the scale of the z-axes are identical) illustrates that uncertainty is higher under transparency at the beginning of a forty-period long passive policy. This is captured by the pronounced hump-shaped dynamics of short- and medium-horizon uncertainty. This result is driven by the *short-run effect of transparency on pessimism.* The announcement commits the central bank to follow a passive policy for the next forty periods, causing agents to expect more dramatic inflationary/deflationary consequences from future shocks that will materialize during the implementation of the announced policy path. The lower right graph compares the dynamics of uncertainty after *announcing* passive policy of increasing durations (10, 20, and 40 quarters) with the upper and lower bound for the case of no transparency (the gray area). This graph of Figure 2 shows that after announcing 40 quarters of passive policy uncertainty is above the gray area at short and medium horizons, implying that uncertainty becomes higher than the upper bound for the case of no transparency. This overreaction of short-run uncertainty is driven by the *short-run effect of transparency on pessimism* and contributes to lowering the welfare gains from transparency.

Compared to the case of no transparency, short- and medium-horizon uncertainty is larger at the beginning of the policy. However, forty-quarter-ahead inflation uncertainty appears to be smaller in the case of transparency. This result is due to the *anchoring effect of transparency on pessimism*. While agents know monetary policy will be passive for forty quarters, they also know there will be a switch to the active regime in forty quarters. Announcing the timing of the return to active monetary policy determines a fall in uncertainty in correspondence of the horizons that coincide with announced date (40 quarters in this numerical example). In the upper right graph of Figure 3, such a decline in uncertainty shows up as a *valley* in the surface representing the level of uncertainty. As we shall show, this feature of transparency has the effect of raising social welfare by systematically anchoring agents' uncertainty at the end of the announced deviations from the active regime. Furthermore, at long horizons uncertainty is always lower under transparency. The lower right graph shows that under transparency long-run uncertainty is lower than the lower bound for the case of no-transparency case even when very persistent passive policies are announced. This result is due to *anchoring effect of transparency on pessimism* and contributes to raising the welfare gains from transparency.

To sum up, under no transparency uncertainty *increases* across all horizons as the policy is implemented, under transparency uncertainty *decreases* because agents are aware that the end of the prolonged period of passive monetary policy is approaching. These opposite patterns for uncertainty under the two communication strategies are due to the *anchoring effect of transparency on pessimism*.

It should be noted that the evolution of uncertainty conditional on being in the active regime is not the same across the two alternative communication strategies. This is because transparency determines an overall reduction in uncertainty that manifests itself also under the active regime, even if under the active regime no announcement is made. A transparent central bank enjoys lower uncertainty even when monetary policy is active because agents understand that should a short-lasting passive policy of any durations be implemented in the future, the central bank will announce its duration beforehand. As it will soon become clear, such a communication strategy is effective in reducing uncertainty by removing the fear of a long-lasting deviation for the frequent short-lasting deviations and creating an anchoring effect for the sporadic long-lasting deviations. Since the active regime occurs often, its weight for the welfare calculation in equation (21) is relatively large, implying that welfare gains conditional on being in the active regime will critically affect the welfare-based ranking of

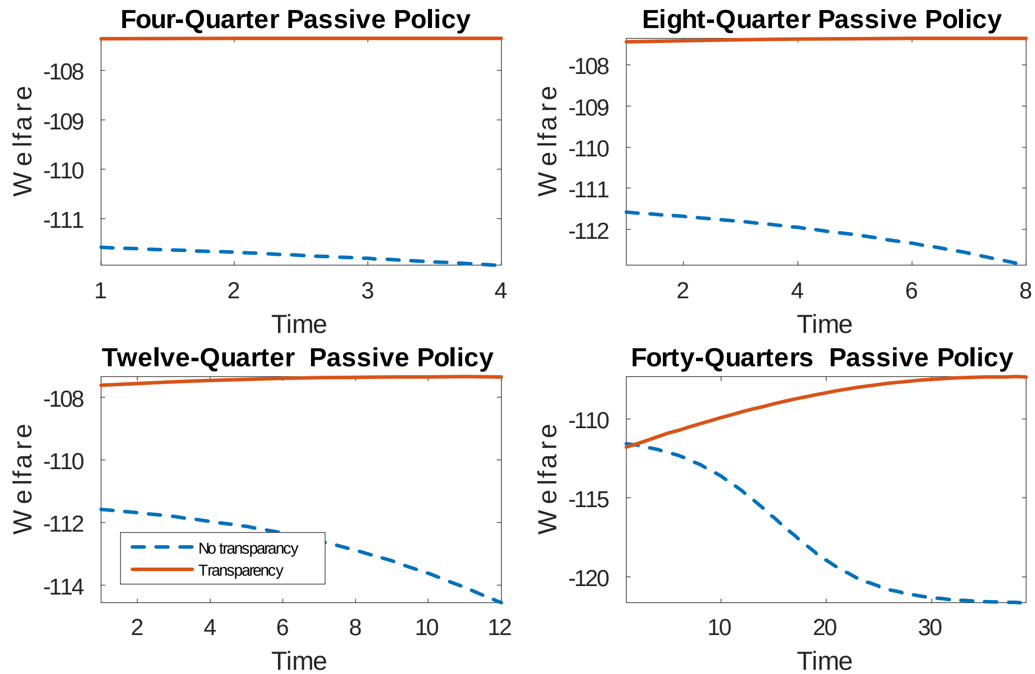

Figure 4: Evolution of welfare $W_i\left(s_t\left(i\right)\right)$ defined in equation (20) as a passive policy of duration 4 (upper-left graph), 8 (upper right graph), 12 (lower left graph), and 40 quarters (lower right graph) is implemented under no transparency ($i = N$), the blue dashed line, and under transparency ($i = T$), the red solid line. Parameter values are set at the posterior mode.

the two alternative communication strategies.

For the sake of brevity, we do not discuss the evolution of uncertainty about the output gap. Uncertainty about future output plays a negligible role in our welfare analysis for reasons we have discussed in Section 5.

5.2 Welfare Gains from Transparency

This section derives the welfare gains from enhancing central bank transparency in our model estimated to the U.S. economy. In Section 5.2.1, we conduct a numerical exercise to illustrate the dynamics of the welfare gains/losses from transparency during the implementation of a passive policy. In Section 5.2.2, we compute and discuss the model predicted welfare gains from transparency.

5.2.1 A Numerical Example

For the sake of illustrating the dynamics of welfare, let us consider passive policies of duration 4, 8, 12, and 40 quarters.[14] Figure 4 shows the dynamics of welfare $\mathbb{W}_i(s_t(i))$, defined in equation (20), over time as these policies are implemented under the two communication schemes: no transparency $i = N$ and transparency $i = T$. It should be observed that welfare under transparency (red solid line) is always higher than welfare under no transparency (blue dashed line) at every time during the implementation of passive policies of four-, eight-, and twelve-quarter duration. Nonetheless, welfare under transparency is lower than welfare under no transparency at the very early stage of a forty-quarter-long passive policy. Larger gains from transparency, measured by the vertical distance between the two lines, are reaped at the end of this prolonged passive policy. As discussed earlier, when the announcement is made, agents become suddenly more pessimistic and hence being transparent may lower welfare compared to no transparency at the beginning of the policy.

However, transparency lowers pessimism as the passive policy is implemented because agents expect less and less periods of passive policy ahead. Therefore, welfare generally increases as the passive policy is implemented. In contrast welfare is downward sloping under no transparency because the central bank does not communicate the duration of passive policies, agents' pessimism gradually unfold, progressively lowering welfare.

5.2.2 Model Predicted Welfare Gains from Transparency

To assess the welfare gains from transparency we use equation (21), which combines the welfare associated with the policy regimes (τ_t for the case of no transparency and τ_t^a for the case of transparency) and their ergodic probabilities. To facilitate the comparison, we redefine the regimes under transparency τ_t^a in terms of observed periods of passive policy τ_t and recompute welfare under transparency associated with these new set of regimes as shown in Appendix C.

The upper panel of Figure 5 shows the welfare gains from being transparent associated with having observed passive policies for τ_t periods at the posterior mode reported in Table 1. The lower panel reports the ergodic probabilities of regimes τ_t. Quite clearly, only short deviations from the active policy are plausible for the US. The upper panel shows that for passive policies of plausible durations transparency raises welfare. This result implies that the model predicted welfare gains from transparency $\Delta\mathbb{W}^e$ in equation (21) are positive. Interestingly, the welfare gains from transparency for observed deviations τ_t gradually decline

[14] This is a numerical example and is made for the sake of illustrating the evolution of welfare. We pick fairly prolonged deviations from the active regime so as to make these dynamics more visible in the graphs. Such long-lasting passive policies have low probability of occuring based on our estimates.

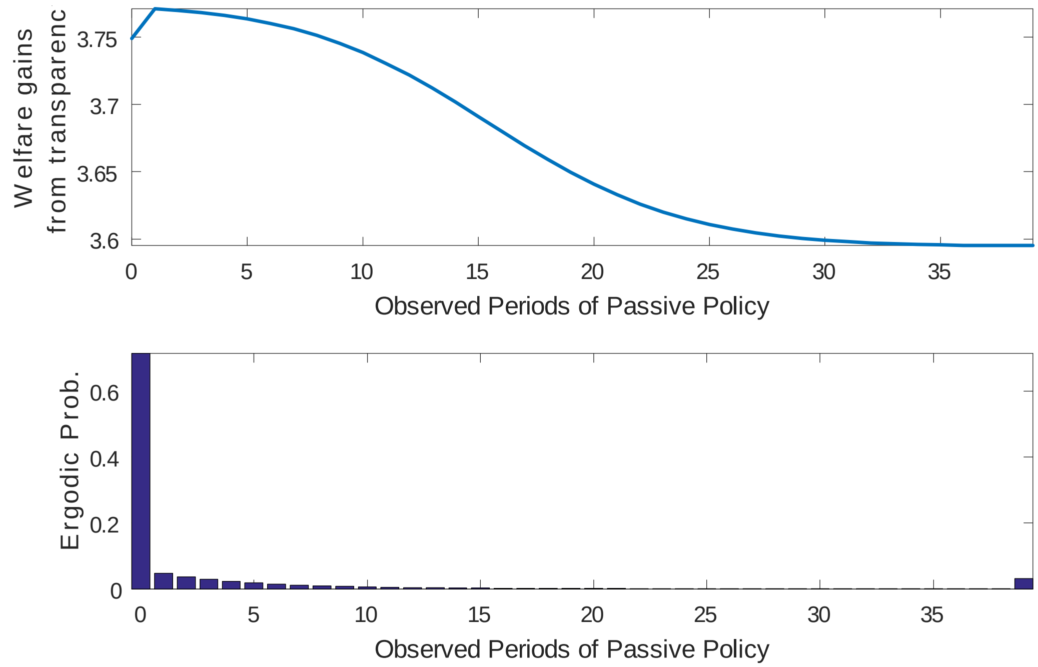

Figure 5: The upper graph reports the dynamics of the welfare gains from transparency as a function of the observed periods of passive policy (τ_t). The lower graph reports the ergodic probability of observing the periods of passive policy on the x-axis (τ_t). Parameter values are set at the posterior mode.

as the number of observed deviations τ_t increases. This negative second-order derivative is explained by the fact that announcing deviations of longer and longer durations progressively strengthens the *short-run effect of transparency on pessimism* which raises the risk of macroeconomic instability, as shown in Figure 3.

We find that gains from transparency are roughly 3.74% of steady-state consumption for the U.S. economy. This result implies that the anchoring effects due to transparency dominate its short-run effects. In other words, transparency is welfare improving because it allows the central bank to effectively sweep away the fear of a return to the 1970s-type of passive policies. The 70-percent posterior credible interval for the welfare gains from transparency is $1.74\% - 5.30\%$ (in terms of steady-state consumption). Importantly, the upper plot captures the welfare gains from *systematically* announcing the duration of short-lasting passive policies. This explains why when the central bank conducts an active policy $(\tau_t = 0)$, the welfare gains from transparency are *not* zero. They are, in fact, positive capturing the welfare gains from expecting that the central bank will systematically and truthfully announce the duration of any future short-lasting passive policy.

It is useful to clarify the difference between Figure 4 and Figure 5. The former figure shows the dynamics of welfare under transparency and no transparency as passive policies of select durations (four, eight, twelve, and forty quarters) are implemented. The x-axes of

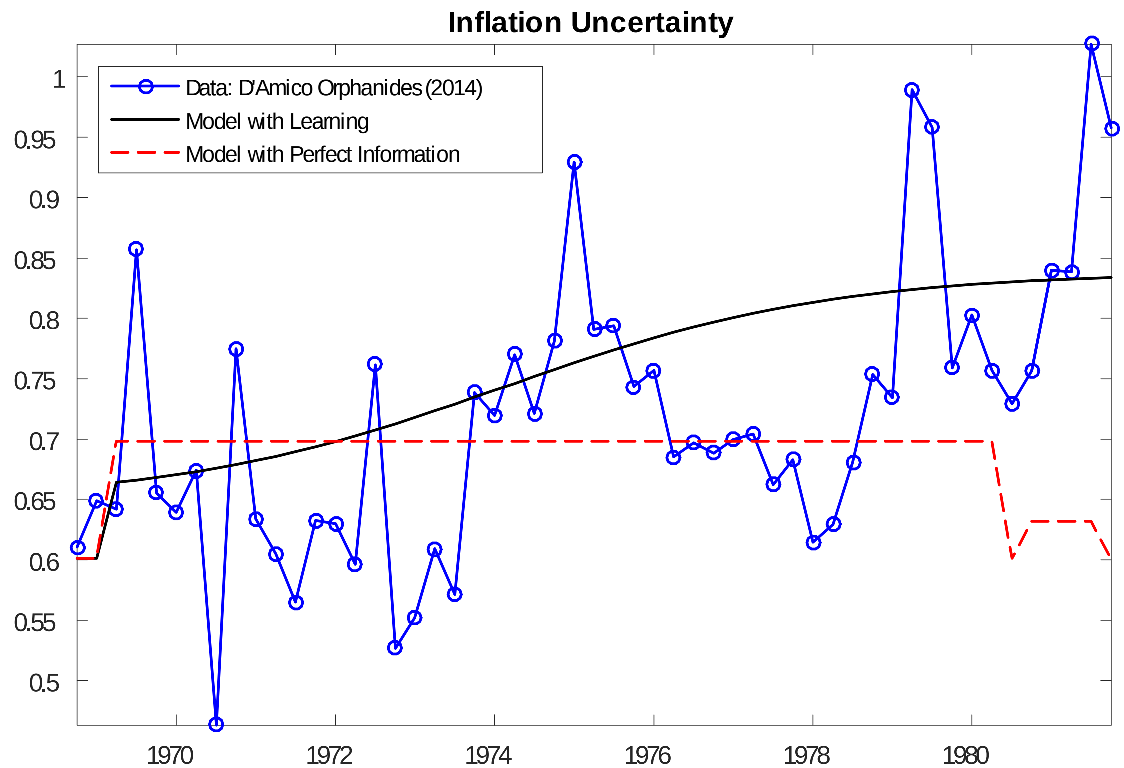

Figure 6: Long-Run Trend of Uncertainty about Future Inflation Predicted by the Model with Learning and the Perfect Information Model. The dynamics of inflation uncertainty resulting only from policy actions. The dynamics of uncertainty predicted by the two models is rescaled so that in 1968Q4 inflation uncertainty is equal to the least square constant estimated using uncertainty in the data.

those plots show how far the central bank has gone in implementing these passive policies of select durations. In contrast, Figure 5 shows the welfare *gains* from transparency conditional on having observed τ consecutive periods of passive policy. Note that the magnitude of these gains when the number of consecutive deviation is equal to 40 ($\tau = 40$) is not same as the cumulative vertical distance between the two lines in the lower right plot of Figure 4. The reason is that welfare gains associated with observing 40 periods of passive policy in Figure 5 include gains associated with passive policies of realized duration of 40 quarters *and longer*.

5.3 Inflation Uncertainty in the Data

One property of the estimated model is that beliefs change gradually as more and more periods of passive policy are observed. If we had assumed that agents perfectly knew the realization of policy regimes (perfect information), beliefs would have responded abruptly as the central bank changes its attitude toward inflation stabilization. In this section, we want to test the diverging predictions of these two models on the dynamics of inflation uncertainty in the 1970s, which both models identify as a period in which a long-lasting passive policy has been implemented.[15] This test is intended to validate the learning mechanism put forward in the paper.[16] We focus on uncertainty about inflation because this variable is the key driver of social welfare in the estimated model, as we will explain shortly.

Figure 6 compares the dynamics of one-year-ahead inflation uncertainty measured by D'Amico and Orphanides (2014) from the Survey of Professional Forecasters with the trend in the one-year-ahead inflation uncertainty predicted by the estimated Markov-switching model with learning (no transparency) and by the estimated Markov-switching model with perfect information. In the latter model, agents perfectly know which type of policy regime is in place; that is, the primitive regimes belong to agents' information set. In symbols, $\xi_t^p \in \mathcal{F}_t$. Since uncertainty is not an observable in our estimation, the comparison in Figure 6 constitutes an external validation exercise. It is important to bear in mind that Figure 6 reports changes in model-predicted uncertainty only due to policy changes (not those driven by Gaussian shocks). In this light, the solid and the dashed lines have to be interpreted as the long-run trend of inflation uncertainty predicted by the two competing models. The model with perfect information predicts a sharp rise in inflation uncertainty as monetary policy switches to the long-lasting passive policy. After the switch to passive policy, the perfect information model predicts that long-run uncertainty stays put at this higher level throughout the 1970s. In contrast, the model with learning predicts a smaller rise in uncertainty as monetary policy becomes passive in the late 1960s and a gradual run-up in inflation uncertainty thereafter. This gradual increase in uncertainty is due to the prolonged period of passive policy that caused agents to become progressively more convinced that this policy has long-lasting nature. The data (the dotted line) suggest that inflation uncertainty grew slowly in the 1970s, favoring the dynamics predicted by the model with learning.

[15] The dynamics of beliefs during periods of active policy or short-lasting passive policy are very similar in these two models, making it hard to discriminate their relative fit over sample periods that do not include the 1970s.

[16] Comparing the marginal likelihood of the estimated model with that of the same model with perfect information leads to inconclusive results. It is likely that estimating the models with a data set that includes inflation expectations may help select one of the two models. However, reliable survey-based expectations data are available only from the early 1970s. Yet, using the entire sample is key to estimate the properties of the active regime and of the transition matrix. Using uncertainty as an observable variable is computationally very challanging as uncertainty follows a non-linear law of motion, requiring MC filtering to evaluate the likelihood of the models.

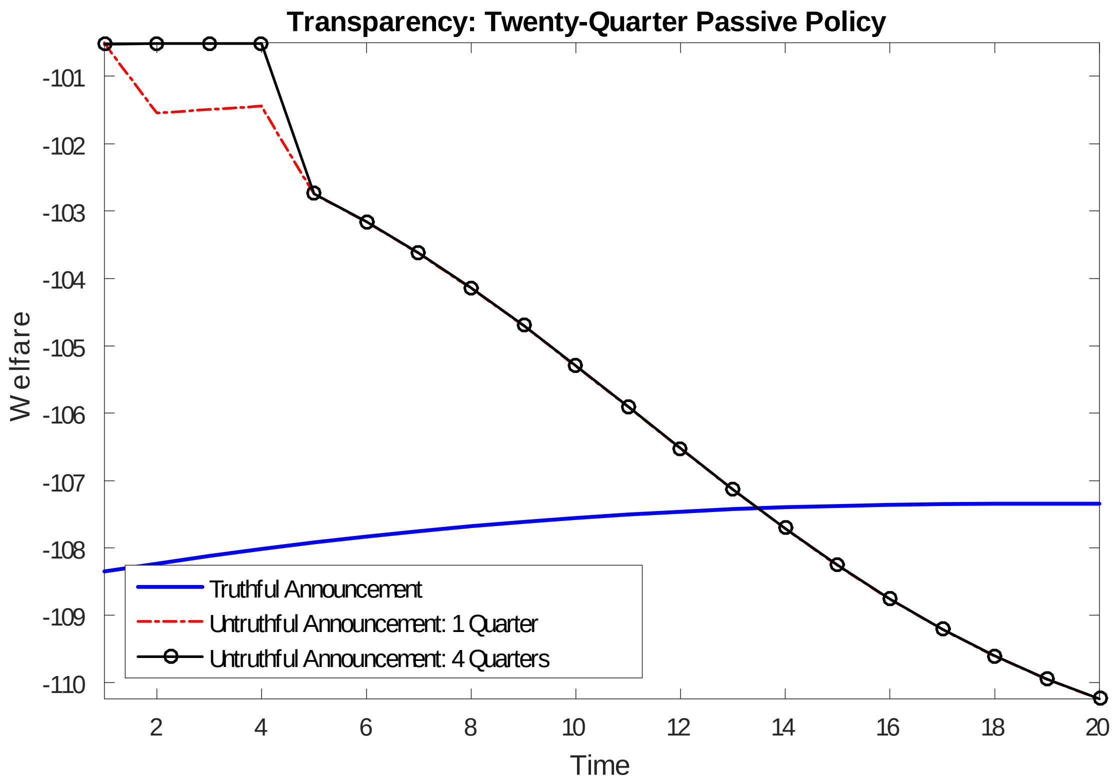

Figure 7: Welfare evolution as a twenty-quarter deviation from the active policy is implemented under imperfectly credible announcements.

6 Imperfectly Credible Announcements

In this section we study the consequences of imperfectly credible announcements. Let us consider the case in which the central bank systematically announces the duration of short-lasting deviations but it lies if the duration is longer than $\overline{\tau}$. Furthermore, we conjecture that the probability of lying is higher as the length of the announced deviation is longer. This last assumption causes the probability of returning to an active policy to decline as the horizon of the announced policy increases. To model this idea, we assume that the duration of passive policies τ is drawn accordingly with the Markov-switching process implied by the primitive matrix $\mathcal{P}$, defined in Section 3. If the drawn duration of the passive policy τ is smaller than or equal to $\overline{\tau} > 0$, the central bank announces $\tau_a = \tau$. If the drawn duration of the passive policy τ is larger than $\overline{\tau}$, the central bank lies and announces a number of consecutive deviations between 1 and $\bar{\tau}$. It is assumed that when the central bank lies, it is more likely that a prolonged period of passive policy is announced. This property implies that the longer the announced deviation, the more likely the central bank has lied and keep deviating from the active policy at the end of the announced passive policy. Thus, the probability of returning to an active policy declines as the horizon of the announced policy

τ_a	$f(\tau_a)$
1	0.1
2	0.2
3	0.3
4	0.4

Table 2: Probability that the central bank announces τ_a periods of passive policy conditional on having lied.

increases. Consistently with how we have defined transparency, the central bank does not announce long-lasting deviations.

A detailed description of how to specify the transition matrix for the regimes in the case of imperfectly credible announcements is provided in Appendix E. In what follows, we assume that $\bar{\tau} = 4$ and the mapping $f(\tau_a)$, which sets the probability that the central bank announces τ_a periods of passive policy conditional on having lied ($\tau > \bar{\tau}$), is defined in Table 2. This mapping implies that if the central bank lies, it is four time more likely that a four-quarter deviation from the active policy is announced relative to a one-quarter deviation. This last assumption causes the probability of returning to an active policy to decline as the horizon of the announced policy increases.

It turns out that this specification does not substantially change the main results of the paper. Even if the central bank can lie, transparency is still welfare improving. In fact, limiting the number of periods of passive policy the central bank can announce leads to slightly higher welfare gains from transparency than the benchmark case in which the central bank truthfully reveals the duration of the short-lasting passive policy all the times. For the sake of illustrating the key mechanism in the case of imperfectly credible announcements, Figure 7 shows the dynamics of welfare as a twenty-period passive policy is implemented. We report the dynamics of welfare under transparency in the benchmark case (solid blue line) and in the cases in which the central bank announces that the passive policy will last one period (dot-dashed line) and four periods (solid line with circles). This plot shows that a transparent central bank gains from lying about the duration of passive policy in the short run. These gains from telling a lie stem from preventing the sudden rise in pessimism that occurs at the beginning of an announced passive policy. However, in the longer-run lying backfires in that welfare follows a pattern that is similar to that under no transparency. It should be noted that when the deviation is in fact short-lasting (i.e., $1 \leq \tau \leq \bar{\tau}$), the central bank's inability to make perfectly credible announcements contributes to lowering the welfare gains from transparency compared to the benchmark case in which the transparent central bank never lies. This is because rational agents always attach some probability that the central bank is lying even when the central bank is, in fact, telling the truth.

We set $\bar{\tau} = 4$ and the threshold τ^* as when we solve the model with no transparency (i.e., large enough so that the approximation error becomes negligible.) When we allow the central bank to lie, there are two potential effects that can make welfare lower or higher compared to the benchmark case of transparency in which the central bank never lies. The first effect has to do with the fact that agents are better off in the short run when the central bank never announces the hard truth of a prolonged deviation from the active policy. The second effect has to do with the fact that in the long run agents realize that the central bank has lied and move to the no-transparency outcome which is associated with a quick deterioration of welfare as the central bank keeps deviating from the active policy. It turns out that the first effect is quantitatively stronger and the central bank can improve welfare when it refrains from announcing exceptionally long deviations.

7 Robustness and Extensions

In this section we conduct a series of robustness exercises and consider an extension of the benchmark communication strategy. In Section 7.1 we investigate whether transparency is welfare increasing for passive policies of every plausible duration. In Section 7.2, we relax the assumption that the central bank knows exactly the realized duration of the ongoing passive policy and investigate whether transparency would still deliver welfare improvements. Specifically, we study the effects of a central bank that announces the *type* of deviations (short lasting or long lasting) from the active regime. This announcement reveals which type of passive regime is in place rather than revealing the exact duration of short-lasting passive policies.

7.1 Short-Run Benefits from Transparency

In the previous sections, we have showed that enhancing central bank's transparency would raise the social welfare. The computation of expected welfare gains from transparency is obtained using the ergodic distribution of the policy regimes and hence captures the *long-run* gains. It should be also noted that these long-run welfare gains have been computed under the assumption that agents understand that the central bank will systematically announce the duration of every short-lasting passive policy, whereas in the case of a long-run deviation the exact duration would be unknown. The fact that welfare gains from transparency are positive in the active regime (when no announcement is actually made) suggests that this systematic feature of the central bank's communication policy contributes to raise the welfare gains from transparency. A transparent central bank enjoys higher welfare when monetary policy

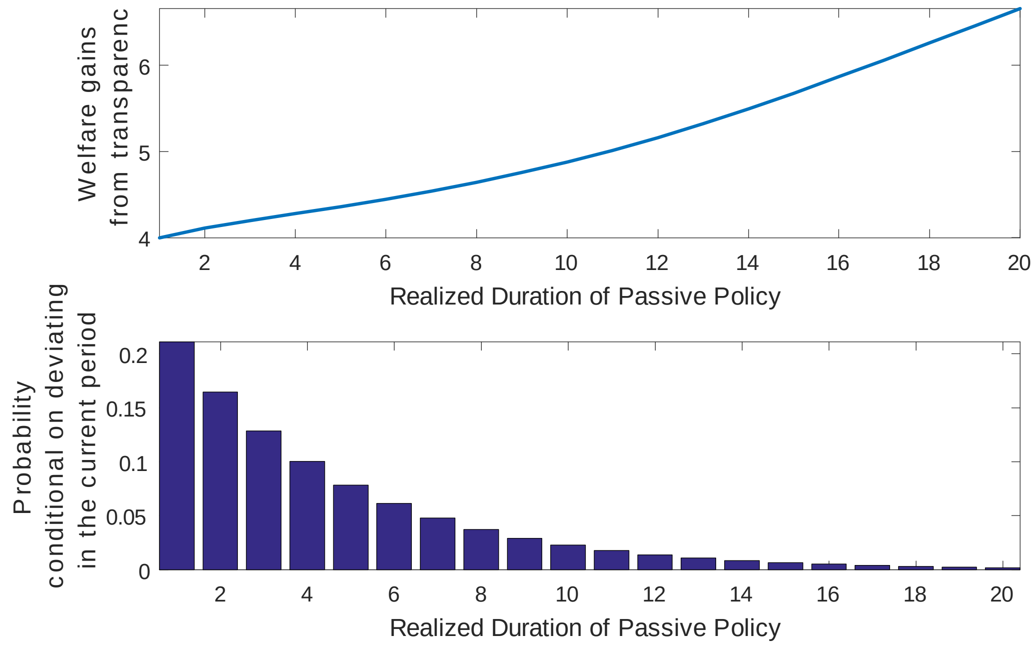

Figure 8: Upper graph: Average per-period welfare gains from transparency associated with passive policies of given realized durations. Lower graph: the ergodic distribution of the duration of passive policies. Parameter values are set at their posterior mode.

is active because agents understand that should a short-lasting passive policy be implemented in the future, the central bank will announce its duration beforehand. However, it remains to be seen if the central bank is better off following transparency for any possible duration of the short-lasting deviations. In other words, are there short-lasting deviations for which the central bank would rather be not transparent?

We find that the positive gains from transparency occur for every plausible duration of the passive policy. To see this, the upper plot of Figure 8 shows the dynamics of the average per-period welfare gains from transparency associated with short-lasting passive policy of various durations, while the lower plots in Figure 8 report the corresponding ergodic probabilities of such policies. The important result is that welfare gains are positive for all plausible durations of short-lasting passive policies. This finding suggests that the central bank is better off by announcing passive policies of *every* plausible duration. Quite interestingly, the upper graph suggests that the central bank is better off even if it has to announce passive policies of fairly long durations. This is an important result that implies that the overall reduction of uncertainty that occurs owing to introducing transparency overcomes any short-run loss associated with announcing a prolonged deviation from the active policy.

It should be noted the difference between the welfare gains from transparency in Figure 5 and those of Figure 8. Figure 5 reports the welfare gains from having announced the duration of the ongoing passive policy when τ_t deviations out of the announced $\tau_t^a \geq \tau_t$ have been

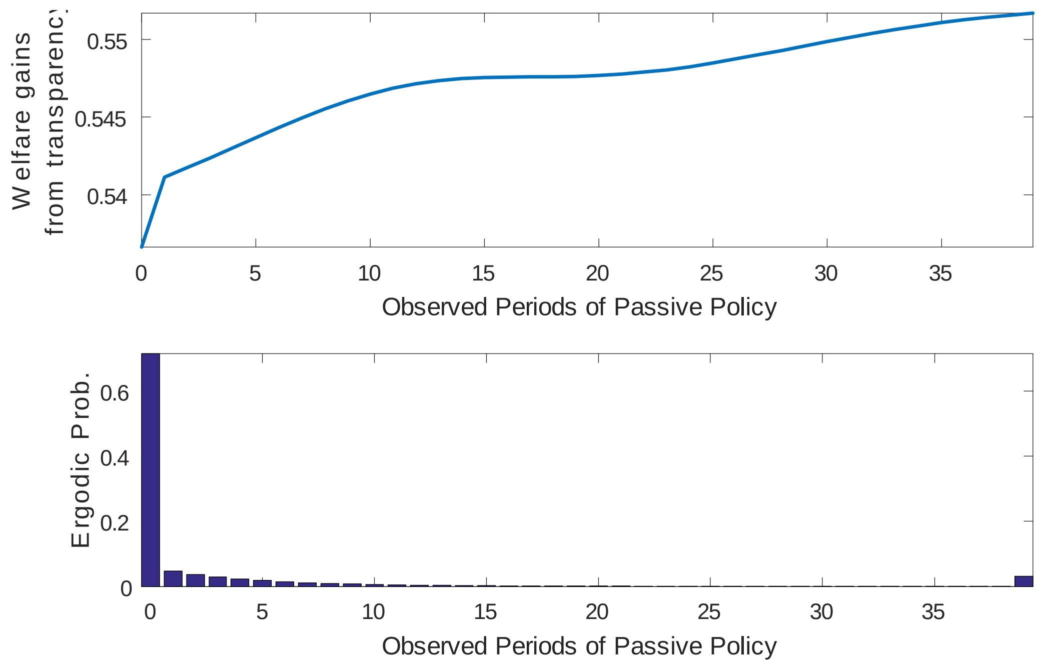

Figure 9: The upper graphs report the dynamics of the welfare gains from transparency as a function of the observed periods of passive policy (τ_t) when the central bank is assumed to have limited information. The lower graph reports the ergodic probability of observing the periods of passive policy on the x-axis. Parameter values are set at their posterior mode.

observed. Figure 8 shows the average per-period welfare gains, should the Federal Reserve decide to announce *a passive policy of a certain duration*. The latter measure evaluates the average of welfare gains from transparency across periods of policy implementation whereas the former measure, coupled with the ergodic probability distribution of the observed durations of policies (τ_t), captures the expected benefit from being transparent over the *long run*.

7.2 Limited Information

We have modeled transparency as a communication strategy in which the central bank shares all the information about the policy regime to households and firms. Since we assume that the central bank knows the exact duration of its short-lasting passive policies, transparency implies that such information is shared with the public. In this section, we relax the assumption that the central bank knows the exact duration of passive policies. Rather, we assume that the central bank knows only the *expected duration* of the deviations from the active regime; that is, the bank perfectly knows only if the passive policy is short-lasting, Regime 2, or long-lasting, Regime 3. Now, under transparency the central bank truthfully announces the *expected duration* of passive regimes to households and firms. Since the central bank truthfully tells the type of passive regime to agents, the model boils down to a Markov-switching model with perfect information given that now the history of policy regimes $\xi_t^p \in \{1, 2, 3\}$ belongs to the agents' information set.

The upper graph of Figure 9 shows the welfare gains from transparency associated with observing different durations of passive policies. The lower graph reports the ergodic probability of observing passive policies of different durations where zero duration means the active policy.[17] The important result that emerges from this graph is that welfare gains from transparency are always positive for policies of any plausible duration.

Compared to the case in which the central bank announces the exact duration of the short-lasting passive policies, the magnitude of the welfare gains from transparency is smaller as the central bank knows less about the duration of the policy it is implementing. In fact, the model predicted welfare gains from transparency amounts to 0.54% of steady-state consumption. Thus, our analysis suggests that the welfare gains from transparency are positive and are quantified to range from 0.54% to 3.74% depending on the degree of information of the central bank.

8 Concluding Remarks

We have developed a general equilibrium model in which the central bank can deviate from active inflation stabilization. The central bank alternates active policies aimed to stabilize inflation and passive policies that de-emphasize inflation stabilization. Agents observe when monetary policy becomes passive but they face uncertainty regarding its nature. Importantly, when passive policies are observed, they cannot rule out the possibility that a persistent sequence of deviations is in fact a return to the kind of monetary policy that characterized the 1970s. Instead, they have to keep track of the number of deviations to learn if monetary policy entered a short-lasting or a long-lasting period of passive monetary policy. The longer the deviation from the active policy is, the more pessimistic about the evolution of future monetary policy agents become. This implies that as the central bank keeps deviating, uncertainty increases and welfare deteriorates.

When the model is fitted to U.S. data, we find that the Federal Reserve benefits from strong reputation. As a result, the Federal Reserve can deviate for a fairly prolonged period of time from active monetary policy before losing control over agents' uncertainty about future inflation. Nevertheless, increasing transparency about future central bank's behaviors would

[17] Computing the upper graph requires to transform the primitive regimes, $\xi_t^p \in \{1, 2, 3\}$, into the set of regimes used for the case of no transparency, which are defined in terms of the observed durations of passive policies τ_t. The details of this transformation are provided in Appendix C.

improve welfare by anchoring agents' pessimism when facing exceptionally prolonged periods of passive monetary policy and removing the fear of the 1970s for the frequent short-lasting deviations.

In the model, agents learn only the persistence of passive policies, while the active regime is fully revealing. This implies that agents' expectations are completely revised as soon as the central bank returns to the active regime. In Bianchi and Melosi (2016b) we develop a more general methodology that could be used to study a model in which agents have to learn about the likely duration of both passive and active policies. This extension implies that central bank reputation varies over time. While we regard this feature as very interesting, it would also make the task of solving and estimating the model computationally challenging, preventing us from estimating the model. We regard estimation as an important ingredient of the paper because the proposed framework is new in the literature, with the result that the parameters controlling central bank reputation cannot be borrowed from previous contributions. Furthermore, we believe that this extension is unlikely to affect the main conclusions of the paper. This is because announcing the return to a long lasting period of active monetary policy would still have the effect of anchoring agents' pessimism and uncertainty.

A nice feature of the paper is to introduce a convenient way to model gradual changes in beliefs about future policy decisions and macroeconomic outcomes. In the parsimonious setting studied in this paper, we have shown that waves of agents' pessimism or optimism about future policy actions play a central role in shaping the response of macroeconomic variables and households' welfare to macroeconomic shocks in forward-looking rational expectations models. Expanding the analysis to state-of-the-art monetary DSGE models such as Christiano, Eichenbaum, and Evans, 2005 and Smets and Wouters, 2007 would be an intriguing extension, but it would also imply a significant increase in computational time. Furthermore, our sequence of policy regimes is very much in line with the one in Bianchi (2013) and is unlikely that expanding the size of the model would change this.

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A Solving the Model with No Transparency

It is very important to emphasize that the evolution of agents' beliefs about the future conduct of monetary policies plays a critical role in the Markov-switching model with learning. In fact, three policy regimes ξ_t^p are not a sufficient statistic for the dynamics of the endogenous variables in the model with learning. Instead, agents expect different dynamics for next period's endogenous variables depending on their beliefs about a return to the active regime.

To account for agents learning we expand the number of regimes and redefine them as a combination between central bank' behaviors and agents' beliefs. Bianchi and Melosi (2016b) show that the Markov-switching model with learning described previously can be recast in terms of an expanded set of $(\tau_t^* + 1) > 3$ new regimes, where $\tau_t^* > 0$ is defined by the condition (17). These new set of regimes constitute a sufficient statistics for the endogenous variables in the model as they capture the evolution of agents' beliefs about observing a switch to the active regime in the next period. The $\tau^* + 1$ regimes are given by

$$\left[\left(\xi_t^p = 1, \tau_t = 0\right), \left(\xi_t^p \neq 1, \tau_t = 1\right), \left(\xi_t^p \neq 1, \tau_t = 2\right), ..., \left(\xi_t^p \neq 1, \tau_t = \tau^*\right)\right],$$

and the transition matrix $\widetilde{P}_p$ is defined using equation (16); that is,

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

Equation (16) measures the probability that monetary policy remains passive in period $t+1$ conditional on having observed τ_t consecutive periods of passive policy at time t. Realize that $\tau_{t+1} \neq 0$ can be true only if either $\xi_{t+1}^p = 2$ or $\xi_{t+1}^p = 3$. Hence, the probability, $prob\left\{\tau_{t+1} \neq 0 | \tau_t \neq 0\right\}$, in the main text, can be obtained by using the law of total probability as follows:

$$\begin{aligned} prob\left\{\tau_{t+1} \neq 0 | \tau_t \neq 0\right\} &= prob\left\{\xi_t^p = 2 | \tau_t \neq 0\right\} prob\left\{\xi_{t+1}^p = 2 | \xi_t^p = 2, \tau_t \neq 0\right\} \quad (23) \\ &\quad + prob\left\{\xi_t^p = 3 | \tau_t \neq 0\right\} prob\left\{\xi_{t+1}^p = 3 | \xi_t^p = 3, \tau_t \neq 0\right\}, \end{aligned}$$

where we have used the fact that $p_{23} = p_{32} = 0$ to simplify the expression. Note that the Markovian property of the process implies that

$$prob\left\{\xi_{t+1}^{p} = 2|\xi_{t}^{p} = 2, \tau_t \neq 0\right\} = p_{22}, \quad (24)$$

$$prob\left\{\xi_{t+1}^{p} = 2|\xi_{t}^{p} = 2, \tau_t \neq 0\right\} = p_{33}. \quad (25)$$

The Bayes' theorem allows us to write:

$$prob\left\{\xi_{t}^{p} = 2|\tau_t \neq 0\right\} = \frac{p_{12}p_{22}^{\tau_t}}{p_{12}p_{22}^{\tau_t} + p_{13}p_{33}^{\tau_t}}, \quad (26)$$

$$prob\left\{\xi_{t}^{p} = 3|\tau_t \neq 0\right\} = \frac{p_{13}p_{33}^{\tau_t}}{p_{12}p_{22}^{\tau_t} + p_{13}p_{33}^{\tau_t}}, \quad (27)$$

where p_{12} (p_{13}) is the probability that switching to the passive block was originally due to a switch to the short-lasting (long-lasting) passive regime $\xi_t^p = 2$ ($\xi_t^p = 2$) and $p_{22}^{\tau_t}$ ($p_{33}^{\tau_t}$) is the probability that the short-lasting (long-lasting) passive regime lasts for τ_t consecutive periods conditional on the original switch to the short-lasting (long-lasting) passive regime. Replacing this results into equation (23) leads to

$$prob\left\{\tau_{t+1} \neq 0|\tau_t \neq 0\right\} = \frac{p_{12}p_{22}^{\tau_t+1} + p_{13}p_{33}^{\tau_t+1}}{p_{12}p_{22}^{\tau_t} + p_{13}p_{33}^{\tau_t}}. \quad (28)$$

Dividing both sides by $p_{13}p_{33}^{\tau_t}$ delivers equation (16) in the main text.

B Welfare Function

The period welfare function can then be obtained by taking a log-quadratic approximation of the representative household's utility function around the deterministic steady state:

$$\mathbb{W}_i\left(s_t\left(i\right)\right) = -\sum_{h=1}^{\infty} \beta^h \left[\Theta_0 + \Theta_1 var_i\left(\hat{y}_{t+h}|s_t\left(i\right)\right) + \Theta_2 var_i\left(\hat{\pi}_{t+h}|s_t\left(i\right)\right)\right], \quad (29)$$

where $i \in \{N, T\}$, $var_i(\cdot)$ stands for the stochastic variance associated with agents' forecasts of inflation, and the output gap at horizon h. The subscript i refers to the communication strategy: $i = N$ stands for the case of no transparency, while $i = T$ denotes transparency. Finally, $s_t(i)$ denotes the policy regime: $s_t(i = N) \in \{0, 1, ..., \tau^*\} = \tau_t$ and $s_t(i = T) \in \{0, 1, ..., \tau_*^a + 1\} = \tau_t^a$, where, recall $s_t(i = T) = \tau_*^a + 1$ denotes the long-lasting passive regime, whose exact realized duration is not announced.

The coefficients Θ_0, Θ_1, and Θ_2 are defined as follows:

$$\begin{aligned}
\Theta_0 &\equiv \left[1-\frac{1-\Phi}{1-\bar{g}}\left(1-\left(1+\psi^{-1}\right)Q_y^0\right)\right]\ln x_* - \frac{(1-\Phi)\left(1+\psi^{-1}\right)}{2\left(1-\bar{g}_y\right)}\ln\left(x_*\right)^2 \\
&\quad -\frac{1-\Phi}{1-\bar{g}}\left\{\left(1+\psi^{-1}\right)\left[Q_y^0\right]^2 - Q_y^0 + \frac{\varepsilon^2\left(1+\eta^{-1}\right)}{2}\bar{\Delta}\right\} \\
\Theta_1 &= -\frac{\frac{1}{2}\left(1+\psi^{-1}\right)}{1-\bar{g}_y} \\
\Theta_2 &= \frac{\frac{1}{2}\varepsilon^2}{\left(1-\bar{g}_y\right)}\Gamma_3\left\{\left[Q_y^1\left(\varepsilon^{-1}-1\right)+\left(1+\psi^{-1}\right)\left(1+\frac{\varepsilon-1}{\varepsilon}Q_y^0Q_y^1\right)\right]-\left(1+\psi^{-1}\right)\frac{\varepsilon-1}{\varepsilon}Q_y^1\ln x_*\right\}
\end{aligned}$$

where $\Phi \equiv -\log\left[(\varepsilon-1)/\varepsilon\right]$, the steady-state government purchase share $\bar{g}_y$ is set equal to 0.22, and

$$\begin{aligned}
x_* &\equiv \left[\left[\frac{1-\theta\bar{\Pi}^{(\omega-1)(1-\varepsilon)}}{1-\theta}\right]^{\frac{\eta+\varepsilon}{\eta(1-\varepsilon)}}\frac{1-\theta\beta\bar{\Pi}^{(1-\omega)\varepsilon\left(\frac{1}{\psi}+1\right)}}{1-\theta\beta\bar{\Pi}^{(1-\omega)(\varepsilon-1)}}\right]^{\psi} \\
Q_y^0 &\equiv \frac{0.5\frac{\varepsilon-1}{\varepsilon}\bar{\Upsilon}}{\left[1+0.5\left(\frac{\varepsilon-1}{\varepsilon}\right)^2\bar{\Upsilon}\right]^2} \\
Q_y^1 &\equiv \frac{1-0.5\left(\frac{\varepsilon-1}{\varepsilon}\right)^2\bar{\Upsilon}^2}{\left[1+0.5\left(\frac{\varepsilon-1}{\varepsilon}\right)^2\bar{\Upsilon}\right]^3} \\
\Gamma_0 &\equiv \left\{1+(\varepsilon-1)Q_p^1\left[(1-\theta)\left(\bar{b}+Q_p^0\right)-\theta(1-\omega)\bar{\Pi}\right]\right\}^{-1} \\
\Gamma_1 &\equiv \left\{1-(\varepsilon-1)(1-\omega)\bar{\Pi}Q_p^1\right\}\Gamma_0 \\
\Gamma_3 &\equiv \frac{\Gamma_0}{1-\theta\Gamma_1}\left\{(1-\theta)M^2+\theta\right\} \\
Q_p^0 &\equiv \frac{0.5(1-\varepsilon)\bar{\Delta}}{\left[1+0.5(1-\varepsilon)^2\bar{\Delta}\right]^2} \\
Q_p^1 &\equiv \frac{1-0.5(1-\varepsilon)^2\bar{\Delta}^2}{\left[1+0.5(1-\varepsilon)^2\bar{\Delta}\right]^3}
\end{aligned}$$

where the cross-sectional price dispersion in the non-stochastic steady state is given by $\bar{\Delta} = \bar{\Pi}^2\frac{\theta(1-\omega)^2}{(1-\theta)^2}$ and the cross-sectional dispersion of output in the non-stochastic steady state is $\bar{\Upsilon} = \varepsilon^2\bar{\Delta}$. The log of the optimal reset price in the non-stochastic steady state is given by $\bar{b} = \log\left[\left(\frac{1-\lambda\bar{\Pi}^{(\omega-1)(1-\theta)}}{1-\lambda}\right)^{\frac{1}{1-\theta}}\right]$ and $\bar{M} \equiv \frac{b_t-\bar{b}}{\pi_t-\log\left(\bar{\Pi}\right)} = \frac{\theta\bar{\Pi}^{(\varepsilon-1)(1-\omega)}}{1-\theta\bar{\Pi}^{(\varepsilon-1)(1-\omega)}}$.

C Transformation of Regimes under Transparency

In Figure 5 we express welfare under transparency in terms of number of observed deviations from the active regime. This corresponds to the definition of policy regime under no transparency. This is done in order to facilitate the analysis of how the welfare gains from transparency varies with passive policies of duration τ.

First of all, the probability that τ periods of deviation from the active regime are due to the implementation of a short-lasting passive policy (primitive Regime 2) is defined as follows:

$$\mathfrak{P}(\tau) = \frac{p_{12}p_{22}^{i-1}}{p_{12}p_{22}^{i-1} + p_{13}p_{33}^{i-1}}$$

Furthermore, we compute the probability that i consecutive periods of passive policy has been announced conditional on having observed $\tau \leq i$ period of short-lasting passive policy as follows:

$$\alpha(i) = \frac{p_{12}p_{22}^{i-1}p_{21}}{\sum_{j=\tau}^{\tau_*^a+\tau-1} p_{12}p_{22}^{j-1}p_{21}} \text{ for any } \tau \leq i \leq \tau + \tau_*^a$$

Note that the numerator captures the probability that a deviation of duration i is realized and hence announced (recall all announcements are truthful). The denominator is the probability of (announcing) a short-lasting passive policy lasting τ periods or longer (up to the truncation τ^*).

The welfare associated with a policy that has been deviating for $\tau \geq 1$ consecutive periods under transparency is given by[18]

$$\widetilde{\mathbb{W}}_T(\tau) = \mathfrak{P}(\tau)\sum_{j=0}^{\tau_a^*}\alpha(j+\tau)\,\mathbb{W}_T(\tau_a = j) + [1 - p(\tau)]\,\mathbb{W}_T(\tau_a = \tau_a^* + 1) \tag{30}$$

Note the difference from $\mathbb{W}_T(\tau_a)$ in equation (20), which is the welfare function defined in terms of policy regimes for the case of transparency (i.e., τ_a the number of announced deviations yet to be carried out). $\mathbb{W}_T(\tau_a)$ is the welfare under transparency associated with a announcing τ_a periods of passive policy. $\widetilde{\mathbb{W}}_T(\tau;\theta)$ is the welfare under transparency associated with having observed τ consecutive periods of passive policy. We can show that this recasting of policy regimes leads to a negligible approximation error as

$$\sum_{\tau=0}^{\tau^*} p_N^*(\tau)\cdot\widetilde{\mathbb{W}}_T(\tau) \approx \sum_{\tau_a=0}^{\tau_a^*+1} p_T^*(\tau_a)\cdot\mathbb{W}_T(\tau_a)$$

[18] The Regime $\tau_a^* + 1$ denotes the long-lasting passive regime ($\xi_p = 3$).

The welfare gains from transparency can be alternatively computed as follows

$$\Delta\widetilde{\mathbb{W}}^{e} \equiv \sum_{\tau=0}^{\tau^*} p_N^*(\tau) \cdot \left[\widetilde{\mathbb{W}}_T(\tau) - \mathbb{W}_N(\tau)\right]$$

This formula can be used to compute the welfare gains from transparency that are identical to those obtained by using the formula (21) in the main text (up to some very tiny computational error). Figure 5 is computed is plotting the conditional welfare gains from transparency $\left[\widetilde{\mathbb{W}}_T(\tau) - \mathbb{W}_N(\tau)\right]$ for 1$\leq \tau \leq \tau^*$ in the upper panel and the ergodic probability $p_N^*(\tau)$ in the lower panel.

We analyze the welfare gains from transparency under limited information (i.e., the welfare in the perfect information case) by the central bank in Section 7.1. To do so, we first compute the long-run welfare under perfect information as follows

$$\widetilde{\mathbb{W}}_P(\tau) = \alpha(\tau)\,\mathbb{W}_P(\xi^p = 2) + [1 - \alpha(\tau)]\,\mathbb{W}_P(\xi^p = 3)\,, \text{ for } 1 \leq \tau \leq \tau^*$$

where $\mathbb{W}_p$ denotes the welfare under perfect information and $\xi_t^p \in \{1, 2, 3\}$ the primitive set of policy regimes and the weight α is defined as follows:

$$\alpha(\tau) = \frac{p_{12}p_{22}^{\tau-1}}{p_{12}p_{22}^{\tau-1} + p_{13}p_{33}^{\tau-1}},$$

which capture the probability that the observed τ consecutive deviations from the active policy stems from a short-lasting passive policy ($\xi_p = 2$). For $\tau = 0$ (i.e., conditional on being in the active regime, $\xi_t^p = 1$ or $\tau = 0$) the welfare $\widetilde{\mathbb{W}}_P(0) = \mathbb{W}_P\left(\xi_p = 1\right)$.

This computation gives almost identical welfare gains from transparency to the alternative computation on the right-hand-side of the following expression:

$$\sum_{\tau=0}^{\tau^*} p_N^*(\tau) \cdot \widetilde{\mathbb{W}}_P(\tau) \approx \sum_{\xi_t^p \in \{1,2,3\}} p\left(\xi_t^p\right) \mathbb{W}_P\left(\xi_t^p\right)$$

The upper panel of Figure 9 reports the welfare gains from transparency $\left(\widetilde{\mathbb{W}}_P(\tau) - \mathbb{W}_N(\tau)\right)$ conditional on the observed duration of passive policies under limited information by the central bank (i.e., the central bank does not know the actual duration of policies; it only knows the type of policies active, short-lasting passive, and long-lasting passive). The lower panel reports the ergodic probability of observing policy of given duration τ; that is, $p_N^*(\tau)$.

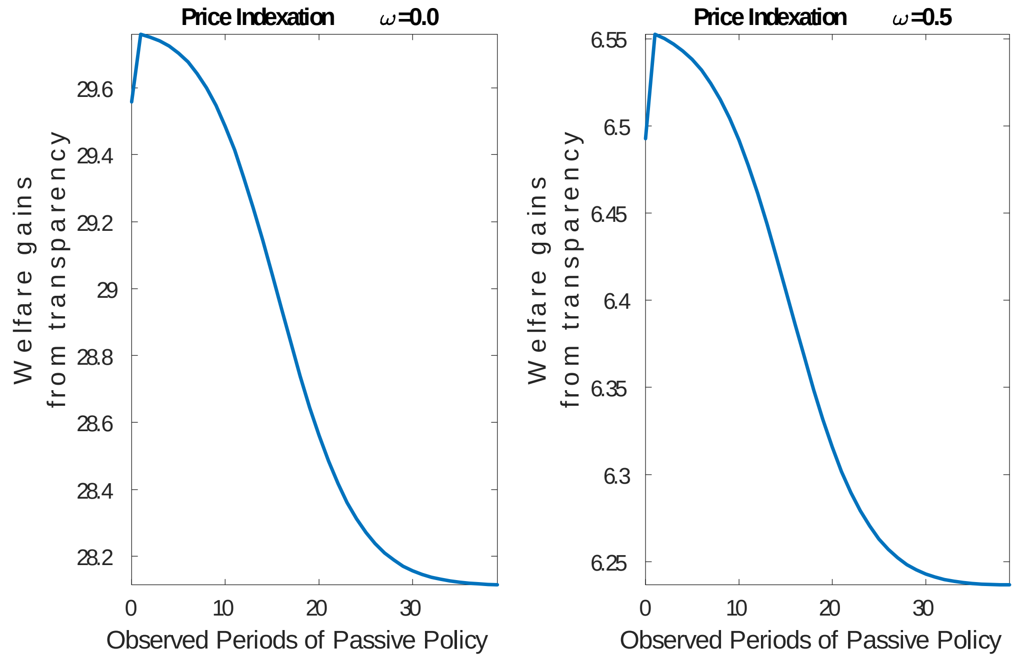

Figure 10: The graphs report the dynamics of the welfare gains from transparency as a function of the observed periods of passive policy (τ_t) under no price indexation (left graph) and under partial price indexation, $\omega = 0.5$, (right graph). The other parameter values are set at the posterior mode.

D Lower Price Indexation

Figure 10 shows the welfare gains from transparency conditional on observing a given number of periods of (short-lasting) passive policy. A quick comparison of these plots with the upper graphs in Figure 5 shows that welfare gains from transparency are higher when price indexation is lower. Interestingly, the pattern of these gains with respect to the observed duration of passive policy is qualitatively very similar to that in the estimated model (Figure 5).

E Imperfectly Credible Announcements

To solve the model in which central bank's announcement are only partially credible we redefine the structure of the three regimes (i.e., active, short-lasting passive, and long-lasting passive) into a new set of regimes λ_t determining the Taylor rule parameters as follows: $\left(\phi_\pi(\lambda_t = i), \phi_y(\lambda_t = i)\right) = \begin{bmatrix} \left(\phi_\pi^A, \phi_y^A\right) & \text{, if } i = 1 \\ \left(\phi_\pi^P, \phi_y^P\right) & \text{, if } i > 1 \end{bmatrix}$. The evolution of the re-defined set of regimes λ_t is governed by the transition matrix $\widetilde{\mathcal{P}}^A$. To simplify the description of this matrix, let us consider the case in which $\overline{\tau} = 4$ and $\tau^* = 7$ (i.e., the truncation for the model with no transparency). The transition matrix $\widetilde{\mathcal{P}}^A$ reads:

$$\begin{bmatrix}
p_{11} & 0 & 0 & 0 & p_1^a & 0 & p_2^a & 0 & 0 & p_3^a & 0 & 0 & 0 & p_4^a & 0 & 0 & 0 & p_{13} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1-\eta(1) & 0 & 0 & \eta(1) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1-\eta(2) & 0 & \eta(2) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1-\eta(3) & \eta(3) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1-\eta(4) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \eta(4) & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1-\widetilde{p}_{56} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \widetilde{p}_{56} & 0 & 0 \\
1-\widetilde{p}_{67} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \widetilde{p}_{67} & 0 \\
1-\widetilde{p}_{78} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \widetilde{p}_{78} \\
1-\widetilde{p}_{88} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \widetilde{p}_{88}
\end{bmatrix}$$

where we denote the probability (conditional on being in the active regime) of announcing $\tau_a = i$ consecutive periods of passive monetary policy with p_i^a. Note that this probability is defined as $p_{\tau_a}^a = \pi_{\tau_a} + \gamma f(\tau_a)$, where π_i denotes the probability that the duration of the passive policy (conditional on being in the active regime) is shorter than i periods; that is, $\pi_{\tau_a} \equiv p_{12} p_{22}^{\tau_a - 1} p_{21}$, and γ denotes the probability (conditional on being in the active regime) that the central bank lies when making an announcement. This probability is defined as follows:

$$\gamma \equiv prob(\tau > \overline{\tau}) = p_{12} - \sum_{i=\tau_a}^{\overline{\tau}} \pi_i$$

where p_{12} is the probability of switching to the short-lasting passive regime conditional on being in the active regime. $f(\tau_a)$ is a monotonically increasing (deterministic) function that determines the probability that the central bank announces τ_a consecutive periods of passive policy conditional on having lied ($\tau > \overline{\tau}$). A monotonically increasing function f captures the property that when the central bank lies, it is more likely that a a relatively longer deviation from the active policy is announced. Furthermore, the probability that the announcement made turns out to be untrue after having observed the announced number of deviations τ_a is denoted by $\eta(\tau_a) = \gamma / (1 - p_{12}) f(\tau_a)$. Recall that probabilities $\tilde{p}_{ij}$ are the probabilities in the transition matrix in the case of no transparency.

Note that after $\tau_a + 1$ periods the central bank's lie is discovered and agents know that the policy will stay passive until $\overline{\tau} \geq \tau_a$. Moreover, for any period of the short-lasting passive policy after $\overline{\tau}$ agents have to learn the persistence of the regime in place as they do in the no-transparency world. This is why the lower-right submatrix of the matrix $\widetilde{\mathcal{P}}^A$ is a the submatrix of the transition matrix $\mathcal{P}$; which is the matrix that capture the evolution of policy regimes under no transparency. Note that in the case of an untruthful announcement agents start learning after having already observed $\bar{\tau} + 1$ periods of passive monetary policy. So the learning based on counting the number of consecutive periods of passive policy starts from $\bar{\tau} + 1$; that is, 5 periods in this example.