WORKING PAPER

ECONOMIA PUBBLICA
PUBLIC ECONOMICS

Department of Economics and Law

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Elton Beqiraj, Giuseppe Ciccarone and Giovanni Di Bartolomeo

Working Paper No. 218
April 2022

Sapienza University of Rome
Via del Castro Laurenziano 9 – 00161 Roma

ISSN 1974-2940

The U.S. Economic Dynamics and Inflation Persistence: A Regime-Switching Perspective[*]

Elton Beqiraj[†] Giuseppe Ciccarone[‡] Giovanni Di Bartolomeo[§]

April 11, 2022

Abstract

This paper revisits the US business cycle accounting for exogenous switches in the inflation intrinsic persistence formalized as changes in the hazard functions. After controlling for Phillips curves shifts, we identify two monetary regimes, leading to a different interpretation from that generally proposed. The Fed operates according to the Brainard Principle by gradually reacting to observed shocks and deviating only episodically to a more active regime. Quantitatively, the main drivers of the business cycle are structural changes in price settings and stochastic volatilities. We also find that structural changes in price and wage adjustments play opposite roles in the Great Inflation. In general, shifts in the Phillips curves are central for correctly understanding the Fed behavior and the business cycle dynamics.

Keywords: *duration-dependent wage adjustments, intrinsic inflation persistence, DSGE models, hybrid Phillips curves, Markow-switching*
JEL Classification: *E24, E31, E32, C11*

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[*] We would like to thank Viktors Ajevskis, Willi Semmler, Carolina Serpieri, and the audience at various conferences and seminars for helpful comments and discussions. All errors are ours. The views expressed herein are those of the authors and do not involve the affiliated institutions.

[†] Department of Economics and Law, Sapienza University of Rome. Email: elton.beqiraj@uniroma1.it.

[‡] Department of Economics and Law, Sapienza University of Rome.
Email: giuseppe.ciccarone@uniroma1.it.

[§] Department of Economics and Law, Sapienza University of Rome and Department of Economics, University of Antwerp. Email: giovanni.dibartolomeo@uniroma1.it.

1 Introduction

During the *Great Inflation* period, lasting from 1965 to 1982, the U.S. economy experienced significant macroeconomic turbulence, characterized by highly volatile inflation and output growth. The transition from stagflation to the calm waters of the 1980s, initiated in October 1979 by Paul Volcker's adoption of a new monetary policy regime focused on price stability, was not without costs. At the end of this transition, the US economy experienced however a long and celebrated period of relative stability, known as the *Great Moderation*, interrupted by the financial crisis and the ensuing *Great Recession* of 2007-08.

A growing body of research has debated on the possible explanations for these historical performances of the U.S. economy. The debate has been traditionally summarized by juxtaposing two contrasting views of the U.S. good/bad performances: an explanation based on good/bad policies (Clarida *et al.*, 2000) and one based, to put it simply, on good/bad luck (Stock and Watson, 2003). According to the former view, the reduction in volatilities observed during the Great Moderation is due to a policy-regime switch (a systemic change) that improved the conduct of monetary policy. The latter view advocates instead that favorable circumstances played a primary role and that policymakers should have prepared themselves for a turn for the worse. A third view has however emphasized the potential role of institutional and structural changes in the way industrialized economies operate. According to this perspective, changes in performance are, at least partially, due to changes in the production structure, work organization, logistics and employment relationships that have affected the price- and wage-adjustment processes, as well as the way the economy responds to disturbances.[1]

The aim of this paper is to integrate the traditional interpretations based on good/bad luck vs. good/bad policies with arguments of structural changes. To this aim, we consider various forms of endogenous regime shifts and empirically quantify different channels, as well as their interplay, affecting the Post–World War II U.S. business cycle. More precisely, we build and estimate a Markov-Switching (MS) model that allows for independent regime changes between two different monetary regimes, two price settings regimes, two wage setting regimes and two shock-volatility regimes. This model accommodates regime changes in the conduct of monetary policy and in the parameters shaping wage and price adjustments, as well as regime switching volatility. Even though we estimate alternative MS specifications, the data favor the full-fledged 16-regime model, providing empirical evidence that price and wage inflation intrinsic persistence matters.

In more details, to capture structural variations in the "technologies" available to price and wage setters along with institutional changes, we introduce in our model endogenous regime switches in the price and wage hybrid Phillips curves. These switches are modeled as changes in the shapes of the non-constant aggregate pricing hazard functions, which

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[1] For instance, Champagne and Kurmann (2013) have stressed the role of the decline in the US labor union power and the increasing flexibility of the labor markets. McConnell and Perez-Quiros (2000) and Kahn et al. (2002) have focused on behavioral changes in corporations' management of inventories. Structural explanations have been put forward, among others, by Ireland (1999), Campbell and Hercowitz (2005), Canova (2009), and Galí and Gambetti (2009).

determine the shapes of those curves. The hazard function, which is a simple way to formalize data distribution in survival analysis, models the firm's (wage-setter's) chance of being able to reset the price (wage) as a function of the length of the current price (wage) spell. As a result, price (wage) resets become time dependent. A negative slope of the hazard function implies that the longer a firm (union) has kept its price (wage) unchanged the higher is the probability of changing it. The key advantage of this approach is that it rationalizes the hump-shaped and intrinsic persistent response of price and wage inflation observed in the data (Sheedy, 2010; Dixon and Le Bihan, 2012; Di Bartolomeo and Di Pietro, 2017).[2]

Our paper is strictly related to the contributions by Bianchi (2013) and Baele *et al*. (2015). Although differing in the macro-shocks switching (in)dependency hypothesis, both studies employ a medium-scale monetary model characterized by switches only in the behavior of the monetary policy authority. In our opinion, this framework is not entirely satisfactory, as it ignores realistic switches in the behavior of the rest of the agents populating the economy who determine the dynamics of the variables on which the behavior of monetary policy depends, i.e., price and wage inflation. As we are convinced that switches in the behavior of both firms and union are key elements in the explanation of the U.S. business cycle dynamics, our theoretical and empirical setup allows for fundamental switches in the price and wage inflation path along with switches in the behavior of monetary policy. Our main findings can be summarized as follows.

The first result is that the best fitting model allows monetary policy to switch between two regimes. Although this evidence is present in several other studies adopting a regime-switching approach, our account for potential regime switches in the slopes of the hybrid Phillips curves allows us to provide an interpretation of the central banker's behavior that differs from that proposed by the literature and that places itself somehow in between in the debate on good/bad policy vs. good/bad luck. According to our estimations, the contrast between *Hawk* and *Dove* central bankers in fact evaporates, as the two monetary regimes we identify are characterized by the same stance of U.S. policymakers towards inflation, yet differing in their degree of gradualism (or caution). This result corroborates the view by Sims and Zha (2006) and Bianchi (2013) challenging the possibility to divide the recent U.S. economic history into pre- and post-Volcker, and envisaging changes in monetary policy regimes as better captured by stochastic and reversible processes.[3]

The second result is that our estimates identify four monetary policy regime switches (turning points) in the US monetary policy. Monetary policy repeatedly fluctuates between conservatism and activism. The presence of active central bankers (who place more importance on current economic conditions and hence rapidly adjust the policy rate to economic developments) appears however to be episodic and short-lived. Active central bankers are followed by conservative central bankers, who react to the shocks observed in the economy with delays, assess with caution the persistence of the observed economic changes

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[2] Fuhrer and Moore (1995) and Fuhrer (2011) discuss the evidence for intrinsic inflation persistence.

[3] It is however worth noting that Sims and Zha (2006) and Bianchi (2013) disagree on the *nature* of these processes.

and implement their monetary policy progressively, as they place more importance on the past dynamics of the fundamental determinants of the policy rate than on those which are currently observed (which formally leads to "monetary policy inertia"). The sudden change in the monetary stance generates however a significant turning point of monetary policy towards a new stance because the conservative central banker continues to a large extent to implement the policies adopted in the past by the active central banker. Somehow paradoxically, this result suggests that the shorter is the life of the active central banker, the more persistent are the effects of the new stance.

The third result is that the main drivers of the shifts in the U.S. business cycle are structural changes in price and wage setting, as well as stochastic volatilities, while switches in the monetary regime display a marginal explanatory power. More precisely, as the Great Inflation is driven by changes in the price and wage hazard, i.e., in the price and wage Phillips curves, price and wage setting institutions matter in the explanation of the U.S. business cycle dynamics. In the 1970s, structural changes in price setting and in wage setting play however different roles: the former changes fuel inflation, whereas the latter changes tend to moderate price dynamics. The Great Moderation is instead characterized by a low-volatility regime, shock shifted after the recession of the early 1980s and the subsequent consolidated recovery, i.e., around 1985. Finally, once we control for the intrinsic persistence of prices, the remarkable decline in macroeconomic volatility experienced by the U.S. economy since the mid-1980s is mainly explained by changes in the shock volatilities (good luck), whereas monetary regimes (good policies) do not account for the observed macroeconomic changes. Monetary activism explains however some observed overreactions to recessions.

The fourth result is that our MS model represents a theoretical attempt to reconcile the time- and the state-dependent price-setting approaches, as the introduction of endogenous regime switches in the hazard functions requires to consider switches in the slopes of the Phillips curve and in the processes governing price and wage intrinsic inflation persistence.

The remainder of the paper is organized as follows. Section 2 introduces the forward-looking MS monetary macro-model. Section 3 describes the linearized representation. Section 4 illustrates the estimation strategy. Section 5 highlights the importance of our approach to avoid misleading implications of the results of the estimates. Section 6 details the estimation results and analyzes the observed switches of policy regimes in the U.S. business cycle. Section 7 provides a new-old interpretation of the conduct of the Fed. Section 8 reconsiders the evolution of the business cycle under the lens of our regime-switching best-fitting model, presenting historical decomposition and counter-factual experiments. Section 9 concludes.

2 The benchmark model

The model economy is populated by a continuum of firms and households, each distributed in the unit interval $[0, 1]$. Households have identical preferences, each of them is endowed with a unit of differentiated labor types. Each firm produces a differentiated good using a composite labor skill as input, which is defined by a continuum of differentiated labor types provided by households. The monetary authority follows a feedback interest rate rule: the nominal interest rate is set to respond to its own lagged value and to deviations of inflation and output from their targets.

2.1 Markov-switching price and wage hazards

Staggered prices and wages are introduced assuming duration-dependent reset probabilities, i.e., the length of a price and/or wage spell influences the reset probability. Formally, adjustments are defined by a hazard and a survival function. The former relates the probability to post a new price with the duration of a price spell. The latter denotes the probability that a price will remain fixed for a given period. Indicating with α_l the probability of resetting a price that has remained fixed for l periods, the hazard function is defined by the sequence of probabilities $\{\alpha_l\}_{l=1}^{\infty}$. Similarly, the survival function is defined by a sequence of probabilities $\{\varsigma_l\}_{l=0}^{\infty}$, where ς_l denotes the probability that a price fixed at time t remains fixed for $t+l$ periods.

The hazard function is specified as follows:[4]

$$\alpha_l = \min\left\{\alpha + \frac{\varphi}{1-\alpha_{l-1}}, 1\right\}, \quad \text{for } l > 1 \tag{1}$$

where α is the initial value of the hazard function (i.e., the initial probability of resetting the price) and φ is a parameter controlling its slope.

The parameter φ has a pivotal role in affecting the hazard shape and the direction of the duration-dependent mechanism. If the slope of the hazard function is positive (negative) older (newer) prices are more (less) likely to be updated than the older (newer) ones. The hazard function generalizes the widely used models of Calvo (1983) and Taylor (1980). The former is obtained when the hazard is flat, i.e., $\varphi = 0$, and α is the probability of resetting the price faced by each price setter in each period independently of the last reset. The latter is instead observed if the hazard function (1) has a spike, which occurs when, at some l, $\alpha_l = 1$. Finally, the case of flexible price is obtained for $\alpha = 1$.

The description of the hazard properties is completed by defining the sequence $\left\{\theta_{l,t}\right\}_{l=0}^{\infty}$, which represents the fractions of price-setters using at time t a price lastly updated l periods before. Under some regularity conditions,[5] the economy always converges to a unique stationary distribution given by:

$$\theta_l = (\alpha + \varphi)\,\varsigma_l \tag{2}$$

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[4] More complex hazard shapes can be obtained by assuming that its slope is controlled by more parameters. For the sake of simplicity, we assume that only one parameter controls the slope of the hazard. The assumption is consistent with evidence based on estimation of single equations (see, e.g., Sheedy, 2010; Di Bartolomeo and Di Pietro, 2017, who also provide further details about the hazard function and its properties).

[5] See Sheedy (2010).

Then, the associated unconditional probability of a price reset is $\alpha+\varphi$ and the unconditional expected duration of a price spell is $(1-\varphi)/(\alpha+\varphi)$.

Finally, the survival function associated to the hazard function can be formalized as:

$$\varsigma_l = \min\left\{\prod_{h=1}^{l}(1-\alpha_h), 1\right\} \quad \text{with } \varsigma_0 = 1 \tag{3}$$

The hazards described above can be used to derive the Phillips curves for prices and wages, which involve lagged inflation and lagged expectations, nesting the Calvo New Keynesian Phillips Curve as a limiting case (where the reset probabilities are constant, and the hazard slopes are flat).

As explained in the introduction, the novelty of this paper is to allow the price and wage setting adjustment processes to evolve over time (along with the behavior of the monetary authorities and stochastic volatilities). These adjustment processes are governed by the shapes of the hazards, that are defined by the two parameters representing the initial values of the slopes, i.e., $\{\alpha_i, \varphi_i\}$ for $i \in \{p, w\}$.

Changes in $\{\alpha_i, \varphi_i\}$ are modeled as two independent regime-switching processes (one for the prices and another one for the wages). For each process $i \in \{p, w\}$, we introduce an unobserved state variable s_i, which takes on a finite number of values contained in the set S^i, with the Markov transition probabilities summarized by the matrix $H^i = [h^i(m,n)]$, where $h^i(m,n) = \Pr(s^i_{t+1} = m | s^i_t = n)$ for $m, n \in S^i$. It is worth noting that when the price structure defined by $\{\alpha_p(s^p_t), \varphi_p(s^p_t)\}$ is state dependent, the hazard function, $\alpha_{l,p}(s^p_t)$, and the survival function, $\varsigma_{l,p}(s^p_t)$, are also state dependent. The same occurs for the wage process.

2.2 Households

The economy is populated by a continuum of households, each one supplying all kinds of differentiated labor skills. The representative household chooses consumption (C_t) and the labor to supply ($N_t(j)$) for each labor skill $j \in [0,1]$ to maximize the following separable utility:

$$U(C_t, N_t(j)) = E_0\left\{\sum_{t=0}^{\infty}\beta^t\left[\frac{\exp(z_t)\,(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \int_0^1 \frac{N_t(j)^{1+\gamma}}{1+\gamma}dj\right]\right\} \tag{4}$$

where E_0 is the expectation operator, β is the discount factor, σ denotes the relative risk aversion coefficient, γ is the inverse of Frisch labor supply elasticity, and h denotes an internal habit on consumption. The term, z_t is a preference shock that affects the marginal utility of consumption. A CES aggregator defines the aggregate consumption index: $C_t \equiv [\int_0^1 C_t(i)^{\frac{\varepsilon_p-1}{\varepsilon_p}} di]^{\frac{\varepsilon_p}{\varepsilon_p-1}}$, where ε_p denotes the elasticity of substitution between goods and $C_t(i)$ represents the quantity of i-type good consumed by the representative household.

Assuming complete financial markets, in each period t, the household faces the nominal budget constraint:

$$\int_0^1 P_t(i)C_t(i)\,di + Q_t B_t \leq B_{t-1} + \int_0^1 W_t(j)N_t(j)\,dj + P_t\mathcal{D}_t + T_t \tag{5}$$

In equation (5): $P_t(i)$ denotes the price of the i-type consumption good; B_t denotes the holdings of one-period nominally riskless state-contingent bonds purchased at time t and maturing at $t+1$; each bond pays one unit of money at maturity and its price is Q_t; $W_t(j)$ is the nominal wage for j-type labor, $\mathcal{D}_t$ denotes the profit share, and T_t represents a lump-sum government nominal transfer.

The optimal intertemporal consumption decision is obtained by maximizing (4) subject to (5) and implies:

$$Q_t = \beta E_t\left[\frac{U_{C,t+1}}{U_{C,t}}\frac{P_t}{P_{t+1}}\right] \tag{6}$$

The labor supply decision is delegated to wage setting unions, whose optimal choices are described below. In addition to the intertemporal consumption and labor supply decisions, the household decides also how to allocate its consumption expenditures among the different goods. This requires that the consumption index is maximized for any given level of expenditures. The solution of the optimal consumer problem yields the well-known set of demand equations for each good i:

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon_p} C_t \tag{7}$$

2.3 Firms

The supply side of the economy consists of a continuum of monopolistically competitive firms indexed on the unit interval by $i \in [0,1]$. Each firm behaves as a price-taker in the input market and as a monopolistic competitor in the product market where it sets a price for its product, taking the demand in (7) as given.

The Cobb-Douglas production function of the representative firm writes:

$$Y_t(i) = \exp(a_t)N_t(i)^{1-\phi} \tag{8}$$

where $Y_t(i)$ is the output of good i at time t, $N_t(i)$ is the composite labor input employed by firm i, a_t represents the state of technology and $1-\phi$ measures the elasticity of output with respect to labor. The composite skill $N_t(i)$ is defined by

$$N_t(i) \equiv \left[{}_0^1 N_t(i,j)^{\frac{\varepsilon_w-1}{\varepsilon_w}}\,dj\right]^{\frac{\varepsilon_w}{\varepsilon_w-1}} \tag{9}$$

where $N_t(i,j)$ represents the quantity of the j-type of labor employed by firm i in period t and ε_w denotes the elasticity of substitution between workers.

Cost minimization with respect to the quantity of labor employed in the production activity yields the labor demand schedule:

$$N_t(i,j) = \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} N_t(i) \tag{10}$$

where W_t denotes the aggregate wage index, which is defined as:

$$W_t \equiv \left[\int_0^1 W_t(j)^{1-\varepsilon_w} dj\right]^{\frac{1}{1-\varepsilon_w}} \tag{11}$$

A firm that can renew its price contract chooses P_t^* to maximize its expected discounted profits.[6] The firm knows that the probability that P_t^* remains fixed for the next l periods is $\varsigma_{p,l}(s_t^p)$.[7] Hence, denoting $Y_{t+l|t}$ the output in period l for a firm that has last reset its price at time t, it solves:

$$\max_{P_t^*} \sum_{l=0}^{\infty} \left(\beta^l \varsigma_{p,l}(s_t^p)\right) E_t\left[P_t^* Y_{t+l|t} - C(Y_{t+l|t})\right] \tag{12}$$

where $C(Y_{t+l|t})$ is a (nominal) production cost function. Expected future profits are discounted by making use of the survival function for price adjustment. In maximizing its profit, the firm takes as given the demand schedules derived from (7), i.e., the sequence of demand constraints given by $Y_{t+l|t} = \left(P_t^*/P_{t+l}\right)^{-\varepsilon_p} Y_{t+l}$,[8] where P_t^*/P_{t+l} is the relative price and Y_{t+l} is the aggregate demand.

The first order condition for the profit-maximizing problem yields the state dependent optimal pricing rule:

$$\sum_{l=0}^{\infty} \left(\beta^l \varsigma_{p,l}(s_t^p)\right) E_t\left\{Y_{t+l|t}\left[P_t^*/P_{t+l} - \mu_{p,t} MC_{t+l|t}\right]\right\} = 0 \tag{13}$$

where $MC_{t+l|t}$ is the real marginal cost at time $t+l$ for a firm using a price last updated in period t and $\mu_{p,t} \equiv \exp(\zeta_t)\varepsilon_p/(\varepsilon_p - 1)$ defines the desired price mark-up. In the absence of markup shocks (ζ_t), the optimal pricing rule is given by the markup over the average of the marginal costs for the periods in which the price remains effective.

The aggregate price level implied by equation (13) is a weighted average of past resetted and state dependent prices:

$$P_t = \left(\sum_{l=0}^{\infty} \theta_{p,l}(s_t^p) P_{t-l}^{*\,1-\varepsilon_p}\right)^{\frac{1}{1-\varepsilon_p}} \tag{14}$$

where $\theta_{p,l}(s_t^p) = [\alpha_p(s_t^p) + \varphi_p(s_t^p)]\varsigma_{p,l}(s_t^p)$ is the stationary fraction of firms using a price last posted t periods ago conditional on the state s_t^p. Finally, the analytical expressions of the optimal pricing rule (13) and of the aggregate price index (14) define the firm's state dependent price setting structure.

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[6] As each firm solves the same optimization problem, the index i is omitted.

[7] Note that $\varsigma_{p,l}(s_t^p)$ is conditional to the state s_t^p.

[8] We consider a small-scale closed-economy model ant thus, in equilibrium, $Y_t = C_t$.

2.4 Wage setting

The wage for each type of skill j is set in its labor market by a representative monopoly wage setter (a union) through staggered contracts. From this perspective, the wage setting problem is analogous to the price contracts described above. In each period t, a fraction $(\alpha_w + \varphi_w)$ of wage setters optimally choose a wage, denoted W_t^*,[9] to maximize households' discounted utilities (4) under the budget constraint (5) and the sequence of labor demand schedules (10). Their problem writes:

$$\max_{W_t^*} \sum_{l=0}^{\infty} \left(\beta^l \varsigma_{w,l}(s_t^w)\right) E_t \left[U_{C,t+l} \frac{W_t^*}{P_{t+l}} N_{t+l|t} - \frac{{N_{t+l|t}}^{1+\gamma}}{1+\gamma} \right] \tag{15}$$

where $U_{C,t+l}$ is the marginal utility of consumption and $N_{t+l|t}$ is the level of employment at time $t+l$ for a household earning a wage last reset at period t. The utility is discounted using the survival function for wage adjustments, $\varsigma_{w,l}(s_t^w)$, conditional to the state s_t^w.

The first order condition of wage setters yields the state dependent optimal pricing rule:

$$\sum_{l=0}^{\infty} \left(\beta^l \varsigma_{w,l}(s_t^w)\right) E_t \left\{ N_{t+l|t} U_{C,t+l} \left[\frac{W_t^*}{P_{t+l}} - \mu_w MRS_{t+l|t} \right] \right\} = 0 \tag{16}$$

where $\mu_w \equiv \varepsilon_w / (\varepsilon_w - 1)$ defines the desired wage mark-up and $MRS_{t+l|t} \equiv -U_{N,t+l|t} / U_{C,t+l}$ is the marginal rate of substitution between household consumption and the labor supplied in period $t+l$ by the workers who reset the wage in t.

As in the case of the price setting problem, the aggregate wage level is a weighted average of past updated and state dependent optimal wages:

$$W_t = \left(\sum_{l=0}^{\infty} \theta_{w,l}(s_t^w) {W_{t-l}^*}^{1-\varepsilon_w} \right)^{\frac{1}{1-\varepsilon_w}} \tag{17}$$

where the term $\theta_{w,l}(s_t^w) = [\alpha_w(s_t^w) + \varphi_w(s_t^w)] \varsigma_{w,l}(s_t^w)$ is the stationary fraction of households using a wage last posted t periods ago conditional to the state s_t^w.

The optimal pricing rule (16) and the aggregate wage level (17) characterize the wage adjustment process under non-constant state dependent hazard functions.

2.5 Central bank's behavior

The model is closed by specifying a state dependent monetary policy stance. As. in Bianchi (2013), we assume that the central bank sets the nominal interest rate, R_t, according to the conditional regime specific Taylor rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r(s_t^m)} \left[\left(\frac{\Pi_t}{\Pi} \right)^{\delta_\pi(s_t^m)} \left(\frac{Y_t}{Y} \right)^{\delta_y(s_t^m)} \right]^{1-\rho_r(s_t^m)} \exp(\xi_t) \tag{18}$$

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[9] As each wage-setter solves the same optimization problem, the index j is omitted.

where Π_t is the gross inflation rate, R, Π, and Y denote the steady states of interest rate, inflation and output, ξ_t is a shock in the natural interest rate and $\sigma_z(s^v)$ represents the state dependent standard deviation.

The parameters $\delta_\pi(s_t^m)$ and $\delta_y(s_t^m)$ indicate the conditional responses of the central bank to inflation and output gap, respectively, whereas $\rho_r(s_t^m)$ denotes the interest rate smoothing parameter. As for the case of the shapes of the hazards, changes in these parameters are modeled as an independent regime-switching process. Formally, the process is governed by s_t^m with the Markov transition probabilities summarized by the matrix $H^m = [h^m(i,j)]$, where $h^m(i,j) = \Pr(s_{t+1}^m = i|s_t^m = j)$ for $i, j \in S^m$.

2.6 Markov-switching stochastic volatilities

The volatility of the economy is pinned down by the interaction between changes in the structural parameters - that include the central bank's behavior and the price and wage processes - and the volatility of the structural shocks. We consider four stochastic disturbances affecting households' preference, z_t, state of technology, a_t, price mark-up, ζ_t, and the interest rate, ξ_t.

We assume that the shock $\varrho \in \{z, a, \zeta, \xi\}$ follows the stochastic process

$$\log \varrho_t = \rho_\varrho \log \varrho_{t-1} + \sigma_\varrho\left(v_t^v\right)\varepsilon_t^\varrho \tag{19}$$

where ρ_ϱ is a persistence parameter, $\varepsilon_t^\varrho \overset{i.i.d.}{\sim} N(0,1)$ and $\sigma_\varrho\left(v_t^v\right)$ is the regime-switching standard deviation.

Changes in σ_ϱ are modeled as an independent Markov-switching process governed by an unobserved state variable, s_t^v, following a Markov transition probability summarized by the matrix $H^i = [h^v(i,j)]$, where $h^v(i,j) = \Pr(s_{t+1}^v = i|s_t^v = j)$ for $i, j \in S^v$. It is worth noting that the two regimes for the stochastic volatilities suffice to characterize changes in macroeconomic volatility (Bianchi, 2013).[10]

3 Linearized model dynamics

The steady state of the model is not affected by changes in the regimes, i.e., it is unique and stationary. Shock volatilities, changes in the parameters of the Taylor rule and in the shapes of the hazard functions do not in fact affect the steady state of the model but only the adjustment dynamics when the economy is perturbed.

Given the market-clearing condition $Y_t = C_t$, the linearized Euler equation (6) implies that:

$$y_t = \frac{1}{1+h}E_t y_{t+1} + \frac{h}{1+h}y_{t-1} - \frac{1-h}{\sigma(1+h)}\left(i_t - E_t\pi_{t+1}^p + E_t z_{t+1} - z_t\right) \tag{20}$$

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[10] In this class of models, more regimes for the stochastic volatilities are not favored by the data. For a discussion, see Liu *et al.* (2011).

The linearized production function (8) is given by:

$$y_t = a_t + \left(1 - \phi\right) n_t \tag{21}$$

From the linearized state dependent price-setting structure (13) and price index (14), the optimal state dependent pricing decision rule is obtained:

$$\begin{aligned} \pi_t^p \;\; = \;\; & \psi_p\left(s_t^p\right)\pi_{t-1}^p + \beta\left[1 + (1-\beta)\,\psi_p\left(s_t^p\right)\right] E_t\pi_{t+1}^p + \\ & -\beta^2\psi_p\left(s_t^p\right) E_t\pi_{t+2}^p + k_p(s_t^p)(mc_t + \zeta_t) \end{aligned} \tag{22}$$

where $\psi_p(s_t^p)$ and $k_p(s_t^p)$ depend on the parameters characterizing the state dependent hazard function for the price:

$$\begin{cases} \psi_p = \frac{\varphi_p(s_t^p)}{[1-\alpha_p(s_t^p)]-\varphi_p(s_t^p)[1-\beta[1-\alpha_p(s_t^p)]]} \\ k_p = \frac{[\alpha_p(s_t^p)+\varphi_p(s_t^p)][1-\beta[1-\alpha_p(s_t^p)]+\beta^2\varphi_p(s_t^p)]}{[1-\alpha_p(s_t^p)]-\varphi_p(s_t^p)[1-\beta[1-\alpha_p(s_t^p)]]}\frac{1-\phi}{1-\phi+\phi\varepsilon_p} \end{cases} \tag{23}$$

Therefore, the degree of intrinsic inflation persistence depends on ψ_p, which in its turn depends on the hazard slope, $\varphi_p\left(s_t^p\right)$. For $\varphi_p\left(s_t^p\right) = 0$, the optimal state dependent pricing decision rule (22) collapses to the standard Calvo/Rotemberg log-linearized Phillips curve.

The linearized marginal cost is given by:

$$mc_t = \omega_t + n_t - y_t \tag{24}$$

The linearized state dependent wage-setters' optimal decision rule implies that:

$$\pi_t^w \;\; = \;\; \psi_w(s_t^w)\pi_{t-1}^w + \beta\left[1 + (1-\beta)\,\psi_w(s_t^w)\right] E_t\pi_{t+1}^w + \tag{25}$$

$$-\beta^2\psi_w(s_t^w)E_t\pi_{t+2}^w - k_w(s_t^w)mrs_t \tag{26}$$

where $\psi_w(s_t^w)$ and $k_w(s_t^w)$ depend on the parameters characterizing the state dependent hazard function for wages:

$$\begin{cases} \psi_w(s_t^w) = \frac{\varphi_w(s_t^w)}{\left(1-\alpha_w(s_t^w)\right)-\varphi_w(s_t^w)\left[1-\beta\left(1-\alpha_w(s_t^w)\right)\right]} \\ k_w(s_t^w) = \frac{\left(\alpha_w(s_t^w)+\varphi_w(s_t^w)\right)\left[1-\beta\left(1-\alpha_w(s_t^w)\right)+\beta^2\varphi_w(s_t^w)\right]}{\left(1-\alpha_w(s_t^w)\right)-\varphi_w(s_t^w)\left[1-\beta\left(1-\alpha_w(s_t^w)\right)\right]}\frac{1}{1+\varepsilon_w\gamma} \end{cases} \tag{27}$$

As in the case of the optimal pricing rule, the degree of intrinsic inflation persistence depends on the state dependent hazard slope, $\varphi_w\left(s_t^w\right)$. For $\varphi_w\left(s_t^w\right) = 0$, the state dependent wage-setters' optimal decision rule (25) collapses to the Calvo-based Phillips wage curve derived by Erceg *et al.* (2000).

The linearized marginal rate of substitution between household consumption and labor supply is:

$$mrs_t = \frac{\sigma}{1-h}\left(y_t - hy_{t-1}\right) + \gamma n_t - z_t \tag{28}$$

Instead, the linearized interest rate rule is given by:

$$r_t = \rho_r(s_t^m) r_{t-1} + \left(1 - \rho_r(s_t^m)\right)\left[\delta_\pi(s_t^m)\pi_t^p + \delta_y(s_t^m) y_t\right] + \sigma_\xi\left(v_t\right)\varepsilon_t^\xi \tag{29}$$

where unanticipated deviations from the systematic component of the monetary policy rule are captured by $\varepsilon_t^\xi \sim N(0,1)$.[11]

For expositional simplicity, it is useful to disentangle the systematic component of the monetary policy rule (29) into two elements. The first element considers the central bank's state dependent response to current deviations in inflation and output gap when adjusting the policy rate. The extend of this response is measured by $\delta_\pi(s_t^m)$, for inflation, and $\delta_y(s_t^m)$ for the output gap. The second element considers the medium-term orientation of the central bank's strategy, that captures the degree of gradualism or inertia in the monetary policy implementation. The strength of this response is measured by $\rho_r(s_t^m)$, that captures the reaction to past observed shocks through past changes in the monetary policy interest rate. In a complementary way, $1 - \rho_r(s_t^m)$ captures the reaction to currently observed shocks through the response to deviations in the fundamental determinants of the interest rate, i.e., inflation and the output gap. For the sake of brevity, we refer to the first element as the Taylor's component (Taylor, 1993) and to the second one as the Brainard's component (Brainard, 1967).

Finally, the stochastic process governing the evolution of the shock $\varrho \in \{z, a, \zeta, \xi\}$ concludes the description of the linearized model:

$$\varrho_t = \rho_\varrho \varrho_{t-1} + \sigma_\varrho\left(v_t^v\right)\varepsilon_t^\varrho. \tag{30}$$

4 Estimation strategy and data

The model described in the previous section is quasi-linear, i.e., it is linear conditioning on monetary policy, price and wage setting, and stochastic volatility regimes. Therefore, the standard methods of solution and estimation by means of linear rational expectations models cannot be employed in the present setup. Assuming a solution exists, we can however transform the quasi-linear monetary model into a regime-switching vector autoregression taken to the data by means of a system of observation equations.[12] Formally, we can rewrite the linearized system of equations in a compact form as follows:

$$A_0(s,\Theta)\,S(t) = A_1(s,\Theta)\,S(t-1) + \Gamma\,Q(s^v,\Lambda)\,\varepsilon(t) + \Pi\,e(t) \tag{31}$$

where $S(t)$ is the state vector containing all the regime-switching variables, $s = [s^p, s^w, s^m]'$ and s^v denote the unobserved state variables that identify the active regimes at time t, Θ and Λ are the vectors of structural parameters and stochastic volatilities, respectively, $Q(s^v,\Lambda)$ is a diagonal matrix collecting the volatilities of the shocks conditional on the regime in place at time t, $\varepsilon(t)$ and $e(t)$ contain the economic shocks and the expectation

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[11] It is worth noting that the interest rate persistence is already captured by $\rho_r(s_t^m)$.

[12] See, among others, Hamilton (1989), Chib (1996), Sims and Zha (2006), and Bianchi (2013).

errors, respectively, and $A_0(s,\Theta)$, $A_1(s,\Theta)$, Γ and Π denote the respective coefficient matrices. As previously anticipated, based on the transition probability across regimes, the linearized model specification (31) can be characterized as the regime-switching vector auto-regression:

$$S(t) = T(s,\Theta,H^p,H^w,H^m)\ S(t-1) + R(s,\Theta,H^p,H^w,H^m)\ Q(s^v,\Lambda)\ \varepsilon(t) \tag{32}$$

The law of motion of the model states thus depends on the structural parameters, the currently observed regime and the regime switching probability: what occurs today also depends on what agents expect is going to occur in the alternative regimes and on how likely it is that a regime change will occur (Davig and Leeper, 2007).

The law of motion (32) can be combined with a system of observation equations:

$$X(t) = D(\Theta) + Z\ S(t) + U\ v(t) \tag{33}$$

where $X(t)$ is the vector of observed variables, D is the coefficient matrix of constants, Z maps the regime-switching law of motion into the observables, $v(t) \overset{i.i.d}{\sim} N(0,I)$ is a the the vector of the error terms and U the relative coefficient matrix. To draw from the posterior, the Metropolis Sampling within Gibbs based on a burn-in and a retain ratio is used.

To estimate the model, we use US quarterly data from the Federal Reserve Bank of St. Louis dataset for the period 1960Q1-2016Q4. As observable variables we use the real gross domestic product as a measure of output, the effective Fed funds rate for the nominal interest rate, the log-difference of the GDP implicit price deflator for price inflation, the real wage obtained by dividing the nominal wage, measured by the compensation per hour in non-farm business sector, by the GDP implicit price deflator. The GDP implicit price deflator and the Fed funds rate are demeaned, while output and real wage are detrended using Baxter and King's bandpass filter.

We use Bayesian techniques to estimate the empirically identifiable parameters. As the rich parameterization of the model precludes the estimation of the entire parameter space, the rest of the parameters are calibrated based on conventional values. For the monetary policy response to inflation and output gap we assume a normal distribution. As in Bianchi (2013), for the model estimation we consider asymmetric priors for the response of interest to inflation in the Taylor rule, while the priors for the response of interest to output gap and the degree of autocorrelation are symmetric across regimes. Asymmetric priors for the interest rate response to inflation should capture the a priori belief that the inflationary stance of the Federal Reserve has changed over time. Conditional on the monetary policy regime, the interest rate response to inflation is centered on a prior mean of 1.4 and 1.6 for *Regime* 1 and *Regime* 2, respectively. The policy reaction to the output gap is centered on a prior mean of 0.125 in both monetary policy regimes, while the monetary policy smoothing parameter is assumed to follow a Beta distribution, with a mean of 0.6 and a standard deviation of 0.2.

The priors for the price hazard function parameters are obtained from Sheedy (2010) based on a single equation GMM estimation of the price hazard function. We assume asymmetric priors for the hazard slopes, φ_p, while we keep the hazard average flexibility, α_p, symmetric across price setting regimes. The hazard slopes follow a Normal distribution, while the hazard average flexibility follows a Beta distribution.[13] The difference in the priors for the slopes is meant to reflect the *a priori* belief that the hazard slope is subject to changes over time. Conditional on the price setting regime, we assume a prior for φ_p equal to 0.122 (a relatively flat slope) in *Regime 1*, and 0.322 (a relatively steep slope) in *Regime 2*. The prior for the hazard average price flexibility α_p is set to 0.132.[14] It follows that the implied duration for the price contracts is 3.5 quarters in *Regime* 1 and 1.5 quarters in *Regime* 2. The associated unconditional probability is, therefore, 0.25 in Regime 1 and 0.45 in Regime 2.

The assumptions on priors for wage setting are symmetric to those on prices. Our *a priori* belief consists in potential switches in the behavior of the wage setters from a relative flexible to a relative rigid wage-bargaining regime. Therefore, we assume asymmetric priors for the hazard slopes, φ_w, and consider the hazard average flexibility, α_w, symmetric across regimes. The priors for wage hazard function parameters are calibrated based on the estimated coefficients from a single equation GMM estimation of the wage hazard function.[15] Conditional on the regime, we assume a prior for φ_w equal to 0.116 (a relatively flat slope) in *Regime 1* and 0.156 (a relatively steep slope), in *Regime 2*. The prior for the hazard average wage flexibility, α_w, is set to 0.318. The considered priors imply a duration for the wage contracts of 2 quarters in *Regime 1* and of 1.8 quarters in and *Regime* 2, respectively. The associated unconditional probability is 0.43 in Regime 1 and 0.47 in Regime 2.

The priors for the stochastic volatilities are symmetric across regimes and quite loose. All the autoregressive coefficients of the shocks follow a Beta distribution, with mean 0.5 and standard deviation equal to 0.2. The priors for the standard deviations of the structural shocks follow an Inverse Gamma, with mean 0.01 and 2 degrees of freedom. The priors for the regime independent parameters are diffuse and broadly consistent with what suggested and adopted in previous studies.[16]

The parameter responsible for the consumption habit is assumed to follow a Beta distribution, with mean 0.6 and standard deviation equal to 0.2. A Gamma distribution, with mean 2 and standard deviation equal to 0.375 is assumed for the inverse Frisch elasticity. The rest of the parameters are calibrated to values that are standard in the literature. We set the discount factor, β, equal to 0.99 and the share of labor in gross output, $1 - \phi$, to 0.64. Finally, we set the elasticity of substitution between goods, ε_p, equal to 6 and the elasticity of substitution between workers' types, ε_w, equal to 8.85, implying a price

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[13] Note that α_p is the probability to reset prices for firms that have adjusted in the previous period.

[14] The state dependent priors for the price hazard slope in the two different regimes are set such that the mean over the price regimes, $\varphi_p = 0.222$, is equal to the GMM estimates provided by Sheedy (2010).

[15] By analogy, the state dependent priors for the wage hazard slope in the two different regimes are set so that the mean over the wage regimes, $\varphi_w = 0.126$, is equal to the GMM estimates provided by Di Bartolomeo and Di Pietro (2017).

[16] See, among others, Del Negro et al. (2007), Smets and Wouters (2007), Justiniano and Primicieri (2008), and Justiniano et al. (2013).

markup and a wage markup of 1.20 and 1.12, respectively. Table 1 summarizes the priors and the calibration for our baseline model.

Table 1 – Prior distributions of the parameters

	Density	Mean	St. Dev.		Density	Mean	St. Dev.
δ_π (s^m= 1)	N	1.400	0.30	β		0.99	
δ_π (s^m= 2)	N	1.600	0.30	ϕ		0.36	
δ_x (s^m= 1)	N	0.125	0.05	ε_p		6	
δ_x (s^m= 2)	N	0.125	0.05	ε_w		8.85	
ρ_r (s^m= 1)	B	0.600	0.20	σ	G	1	0.375
ρ_r (s^m= 2)	B	0.600	0.20	γ	G	2	0.375
α_p (s^p= 1)	B	0.132	0.10	h	B	0.60	0.200
α_p (s^p= 2)	B	0.132	0.10	ρ_a	B	0.50	0.200
φ_p (s^p= 1)	N	0.122	0.20	ρ_z	B	0.50	0.200
φ_p (s^p= 2)	N	0.322	0.20	ρ_ζ	B	0.50	0.200
α_w (s^w= 1)	B	0.318	0.10	σ_a (s^v= 1)	IG	0.01	2.000
α_w (s^w= 2)	B	0.318	0.10	σ_a (s^v= 2)	IG	0.01	2.00
φ_w (s^w= 1)	N	0.116	0.20	σ_z (s^v= 1)	IG	0.01	2.00
φ_w (s^w= 2)	N	0.156	0.20	σ_z (s^v= 2)	IG	0.01	2.00
$h^m(1,2)$	B	0.10	0.05	σ_ξ (s^v= 1)	IG	0.01	2.00
$h^m(2,1)$	B	0.10	0.05	σ_ξ (s^v= 2)	IG	0.01	2.00
$h^p(1,2)$	B	0.10	0.05	σ_ζ (s^v= 1)	IG	0.01	2.00
$h^p(2,1)$	B	0.10	0.05	σ_ζ (s^v= 2)	IG	0.01	2.00
$h^w(1,2)$	B	0.10	0.05	$h^v(1,2)$	B	0.10	0.05
$h^w(2,1)$	B	0.10	0.05	$h^v(2,1)$	B	0.10	0.05

Notes: *N*, *B* and *IG* denote the Normal, the Beta and the Inverse Gamma distributions, respectively. For the Inverse Gamma distribution, the degrees of freedom are indicated. The parameters for which only the mean is reported (and not the distribution and standard deviation) are quarterly calibrated.

4.1 Alternative models and Bayesian comparison

We estimate the following four model specifications, where agents can form rational expectations about the possibility of a regime shift.[17]

1. Model 1: no regime switching.
2. Model 2: two-state Markov-switching in the volatility of the structural shocks (i.e., $s^v \in \{1,2\}$).
3. Model 3: two-state Markov-switching in the volatility of the structural shocks and two-state Markov-switching in the Taylor rule to assess changes in the monetary policy reaction function (i.e., $s^v \in \{1,2\}$ and $s^m \in \{1,2\}$).
4. Model 4 (full MS model): two-state Markov-switching in the volatility of the structural shocks, two-state Markov-switching in the Taylor rule to assess changes in the

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[17] Details on the model estimates are available upon request. Those on our best fit model (Model 4) are described in the following section.

monetary policy reaction function, and two-state Markov-switching in the hazard functions of price and wages (i.e., $s^p \in \{1,2\}$, $s^w \in \{1,2\}$, $s^v \in \{1,2\}$ and $s^m \in \{1,2\}$).

Our results in terms of the log-marginal data densities (L-MDD) of the considered models, summarized in Table 2, confirm the parameter heterogeneity in monetary policy (Bianchi, 2013 and Baele *et al.* 2015). The gain produced by Model 3 in comparison with Model 2 (always in terms of L-MDD) is only marginal and in line, among others, with Leeper and Zha (2003) and Sims and Zha (2006), who identify in the structural disturbances the main explanation of the US business cycle structural changes. However, when comparing Model 3 and Model 4, we find that, in addition to the previous literature, an important role is played by the parameter heterogeneity characterizing the firms' and the workers' behaviors, i.e., the regime-switching price and wage Phillips curves. Considering also that the Bayesian model comparison based on L-MDD penalizes models with a larger number of chains (and hence parameters), we conclude that the full MS model is the one to prefer.

Table 2 – Log-marginal data densities

Model	Description	L-MDD
1	no MS	4199.27
2	$s^v \in \{1,2\}$	4241.05
3	$s^v \in \{1,2\}$ and $s^m \in \{1,2\}$	4242.66
4	$s^p \in \{1,2\}$, $s^w \in \{1,2\}$, $s^v \in \{1,2\}$, and $s^m \in \{1,2\}$	4250.52

Notes: Marginal data densities are reported in log terms for different model specifications.

5 The relevance of Markov-switching multi-comparisons

The importance of a Markov-switching specification in estimating and validating different models through the Bayes' rule based on L-MDD can be illustrated by a simple bi-dimensional example. Imagine that the data identify the alternation of two structural regimes characterized by different dynamic properties. In the first regime, the interest rate strongly responds to an inflation shock, while in the second one it does so weakly. A simple Bayesian estimation will tend to systematically over or underestimate the true dynamics because the parameters estimated without adopting a Markov-switching specification must be consistent with both observed dynamics. If the problem is solved, as often suggested by the literature, by allowing only the monetary policy parameters to switch so as to match the regimes changes, the explanation of the observed alternation of the monetary policy regimes and of the interest rate dynamics will be attributed to the alternation between hawks and doves in the central banker's chair.

The introduction of only one Markov-switching process can however be misleading because the dynamics of the interest rate are endogenous and dependent on several parameters. In our setup, *coeteris paribus*, the dynamics of the interest rate after a shock depend on the Taylor rule parameter δ_π and on the inflation intrinsic persistence φ_p, i.e., the slope of the hazard function. The same observed path for the interest rate following a shock is hence consistent with different combinations of δ_π and φ_p. If we assume that the alternation of regimes is explained by changes in one of the two parameters when it is instead explained by changes in the other one, we will obtain better estimates than in the case in which no Markov-switching parameters are considered, but we will also be induced to espouse an erroneous interpretation.

The issue is illustrated in Panel (a) of Figure 1, where we assume that the true model of the economy is characterized by a Markov-switching process that alternates high ($\bar{\varphi}_p^H$) and low ($\bar{\varphi}_p^L$) inflation persistence, while the response to inflation of the monetary authorities, $\bar{\delta}_\pi$, is not regime dependent. The observed dynamics of the interest rate following a markup shock hence alternate strong and weak responses depending on the value of φ_p. Now assume that we aim at understanding the behavior of this economy by using a theoretical model that matches the interest rate dynamics for different combinations of δ_π and φ_p. Given the markup innovations, the model will generate data consistent with alternating strong and weak interest rate responses to a markup shock, swinging between points A and B in Panel (a) of Figure 1.

These strong and weak responses of the interest rate are represented by the combinations of δ_π and φ_p along the *SS* and *WW loci*, respectively. These *loci* are the parameter combinations that better fit the dynamics of the interest rate, i.e., the value of φ_p that, for each value of δ_π, minimizes the difference between the IRFs generated by the true values of the parameters and those generated by the model. The best estimate is the one corresponding to the true parameters, i.e., $\bar{\varphi}_p^H$ and $\bar{\delta}_\pi$ for the strong response case; $\bar{\varphi}_p^L$ and $\bar{\delta}_\pi$ for the weak response case. [18]

Assume now that we attempt to estimate the model by imposing a Markov-switching process for the monetary response of the central bank to inflation and by considering the shape of the Phillip curve as time invariant. Two monetary regimes where hawk ($\delta_\pi(s_1) = \hat{\delta}_\pi^H$) and dove alternate ($\delta_\pi(s_2) = \hat{\delta}_\pi^L$) will result to match the observed regimes, while the estimated inflation persistence will lie between the true values, $\hat{\varphi}_p \in (\bar{\varphi}_p^L, \bar{\varphi}_p^H)$. This interpretation would be supported by the evidence derived from L-MDD comparisons, as the estimation based on the Markov-switching process in the monetary stance over-performs the simple Bayesian estimation without regime switches because the latter cannot capture the observed systematic changes in the interest rate dynamics. By so doing, the interpreted economic process would however be misunderstood, and the policy implications would be incorrect.

The same conclusion would of course be reached if the strong and the weak interest rate observed reactions to shocks depended on the monetary stance and not on inflation persistence. This case is illustrated in Panel (b) of Figure 1, the true model is in this case characterized by a Markov-switching process that alternates a high ($\bar{\delta}_p^H$) and low ($\bar{\delta}_p^L$) response of the central bank to inflation, while the inflation persistence $\bar{\varphi}_p$ is not regime dependent. The consideration of a Markov-switching process only for the inflation

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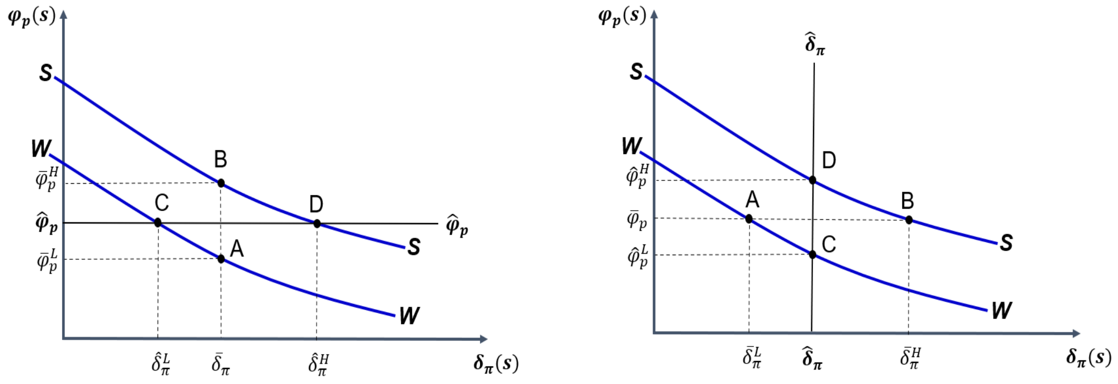
[18] More precisely, the *WW* and *SS* curves are built by selecting the value of φ_p that minimizes the difference between the four-quarter average of the interest rate dynamics generated by the true model and that generated by the alternative model for every given δ_π.

persistence would lead to wrong estimates, i.e., $\hat{\delta}_p \in (\hat{\delta}^L_\pi, \hat{\delta}^H_\pi)$, $\varphi_p(s_1) = \hat{\varphi}^H_\pi$, and $\varphi_p(s_2) = \hat{\varphi}^L_\pi$. Continuing to adopt L-MDD comparisons, the estimations obtained by considering more independent Markov-switching processes would instead indicate that the actual alternation of regimes is between A and B, not between C and D. This would provide the correct rationales associated with the observed dynamics and the correct transmission channels of policies and shocks.

This example, although simplified, is illustrative of a theoretical argument that can be easily extended to any multi-dimensional context. Whereas the adoption of a limited number of Markov-switching processes (one in our example) generally leads to wrong interpretations, the use of multiple Markov-switching processes (two in our example) and of Bayes' rule based on the L-MDD comparisons improves our ability to correctly explain the regime changes and to derive coherent policy implications.

Figure 1 – Monetary policy response and price and monetary regimes



Panel (a) Panel (b)

Notes: Given the true parameter for the Taylor rule (δ_π) and inflation intrinsic persistence (φ_p), the figure shows the combinations of these parameters that better fit the dynamics of the interest rate generated by one markup shock.

6 Empirical results

In the light of the empirical results suggested by the Bayesian model comparison, discussed in the previous section, we present only the estimation outcomes and the economic analysis based on the full MS model (benchmark model), which is characterized by two regime switches in the behavior of monetary authority, two regime switches in the behavior of price setters, two regime switches in the behavior of wage setters and two state stochastic volatilities.

6.1 Parameter estimates

The posterior parameter estimates reported in Table 3 detail the mean, the mode and the 90% error band for the estimated parameters. It also displays the diagonal elements of the transition matrices for the Markov processes. Posterior estimation of the shocks and structural parameters are obtained by use of the Metropolis-Hastings algorithm. The relatively loose priors imply a substantial degree of overlap across regimes.

The estimated hazard functions suggest upward sloping curves for both prices and wages in all the regimes. The positive hazard estimates imply that the duration-dependent mechanism appears to be able to account for inflation intrinsic persistence for both prices and wages observed in the data. The absence of duration- and state-dependent price setting suggested by the empirical results can significantly affect (and potentially bias) the estimation of both monetary and stochastic volatility parameters and regimes, which must otherwise capture the data-observed inflation intrinsic persistence (and its eventual variations) in the related parameters and regime estimates.[19] The parameters estimates relative to the utility function (i.e., habit, relative risk aversion and the inverse of Frisch elasticity) are coherent with standard findings.[20] More importantly, our estimates identify four independent macroeconomic regimes, which drive the price and wage setting processes, the Fed's behavior, and the stochastic volatility. The estimation results are reported in Table 3.

Table 3 – Modes, Means, 90% error bands of the model parameters

	Mode	Mean	5%	95%		Mode	Mean	5%	95%
δ_π (s^m= 1)	1.603	1.478	1.155	1.703	β		0.99		
δ_π (s^m= 2)	1.603	1.671	1.454	1.950	ϕ		0.36		
δ_x (s^m= 1)	0.199	0.195	0.119	0.272	ε_p		6		
δ_x (s^m= 2)	0.250	0.235	0.152	0.308	ε_w		21		
ρ_r (s^m= 1)	0.483	0.500	0.279	0.775	σ	1.070	1.379	0.748	2.187
ρ_r (s^m= 2)	0.902	0.908	0.887	0.929	γ	2.596	2.610	2.142	3.126
α_p (s^p= 1)	0.049	0.065	0.011	0.137	h	0.928	0.920	0.879	0.955
α_p (s^p= 2)	0.014	0.039	0.005	0.091	ρ_a	0.884	0.903	0.846	0.952
φ_p (s^p= 1)	0.104	0.085	0.006	0.150	ρ_z	0.782	0.783	0.734	0.828
φ_p (s^p= 2)	0.198	0.155	0.095	0.204	ρ_ζ	0.838	0.833	0.767	0.899
α_w (s^w= 1)	0.149	0.173	0.116	0.240	σ_a (s^v= 1)	0.022	0.021	0.014	0.030
α_w (s^w= 2)	0.167	0.190	0.115	0.270	σ_a (s^v= 2)	0.010	0.010	0.007	0.014
φ_w (s^w= 1)	0.172	0.132	0.068	0.187	σ_z (s^v= 1)	0.073	0.086	0.063	0.116
φ_w (s^w= 2)	0.255	0.241	0.198	0.280	σ_z (s^v= 2)	0.042	0.047	0.035	0.062
$h^m(1,2)$	0.106	0.133	0.040	0.227	σ_ξ (s^v= 1)	0.003	0.003	0.003	0.004
$h^m(2,1)$	0.039	0.052	0.021	0.095	σ_ξ (s^v= 2)	0.001	0.001	0.001	0.001
$h^p(1,2)$	0.076	0.100	0.039	0.187	σ_ζ (s^v= 1)	0.016	0.021	0.014	0.033
$h^p(2,1)$	0.056	0.070	0.027	0.133	σ_ζ (s^v= 2)	0.021	0.026	0.017	0.036
$h^w(1,2)$	0.029	0.038	0.016	0.068	$h^v(1,2)$	0.055	0.072	0.032	0.124
$h^w(2,1)$	0.040	0.049	0.020	0.089	$h^v(2,1)$	0.025	0.033	0.014	0.061

Notes: *N*, *B* and *IG* denote the Normal, the Beta and the Inverse Gamma distributions, respectively. For the Inverse Gamma distribution, the degrees of freedom are indicated. Posterior mean estimates are obtained with 500000 Metropolis-Hastings replications on two parallel chains. The parameters for which only the mean is reported (and not the distribution and standard deviation) are quarterly calibrated.

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[19] For example, through the auto-regressive processes of stochastic disorders or through the inertia of monetary policy.

[20] See, e.g., Del Negro *et al.*(2007), Smets and Wouters (2007), Justiniano and Primicieri (2008), and Justiniano *et al.* (2013).

The two monetary regimes that are identified differ in the degree of gradualism (or caution) adopted by the Fed in implementing its monetary policy, i.e., ρ_r, whereas they do not differ in the Fed's systematic responses to inflation and output gap, which are empirically the same in the two monetary regimes. These results suggest that in *Regime* 2 the Fed updates its monetary policy decisions only gradually, implementing monetary policy in a prudential way. Conversely, in *Regime* 1, the Fed abandons its prudence and gives relatively greater weight (importance) to the current economic conditions, becoming active in reacting to the current shocks. We label the two regimes as *Prudential Monetary* policy *Regime* (*PMR*, $s^m = 2$) and *Judgment Monetary* policy *Regime* (*JMR*, $s^m = 1$).

The empirical results also identify two different regimes for stochastic volatilities. In analogy with, e.g., Liu *et al*. (2011) and Bianchi (2013), we refer to *Regime* 1 as the *High Volatility Regime* (*HVR*) and to *Regime* 2 as to the *Low Volatility Regime* (*LVR*). Table 3 shows that *HVR* is associated with high volatility in preferences, technology and interest rate shocks (the estimated variabilities about double when switching from *LVR* to *HVR)*. The preference shocks have a relatively significant incidence in both *LVR* and *HVR;*[21]; technological shocks take on great importance in *HVR* but not in *LVR;* the relevance of interest rate shocks is always relatively low; the volatility of the price markup shocks in the Phillips curve is almost the same in the two regimes and markup shocks are equally important in both regimes associated to the stochastic volatility.

The estimated hazard functions for price and wage setting are always upward sloping, but the two regimes differ in the slope of the hazard and, therefore, in the implied degree of intrinsic persistence (see Sheedy, 2010). We label the regimes characterized by relatively high intrinsic price and wage inflation persistence as *Fuhrer Price setting Regime* (*FPR*, $s^p = 2$) and *Fuhrer Wage setting Regime* (*FWR*, $s^w = 2$), respectively. We, instead, tag the regimes characterized by relatively low intrinsic price and wage inflation persistence as *Calvo Price setting Regime* (*CPR*, $s^p = 1$) and *Calvo Wage setting Regime* (*CWR*, $s^w = 1$), respectively. As previously discussed, the price and wage setting regimes are associated with different unconditional probabilities of a price or a wage reset and expected duration of a price or wage spell. Our estimates imply that the duration of the price contracts lasts about one year and a half in *CFR* and one year in *FPR*. Similarly, nominal wage contracts last about three quarters and a half in *CWP*, while the expected duration of a wage spell is about two quarters in *FWP*. Compared to prices, the (unconditional) expected duration of wages appears to be less sticky, because of their smaller duration.[22]

6.2 Macroeconomic regimes

Figure 2 describes the smoothed probabilities assigned to the different independent regimes that characterize our model economy. Panel A depicts the smoothed probabilities of *PMR* ($s^m = 2$), documenting that monetary-regime switches are clearly episodical. It also identifies three clear short-lived monetary switches: the Fed's stance changes in the attempt

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[21] As these shocks are also translated to wage markups, the result is similar to Liu *et al*. (2011).

[22] The estimated durations are similar to those obtained in, e.g., Rabanal and Rubio-Ramirez (2005) and Galí *et al*. (2011), who also document greater duration in prices than wages.

to respond to the mild 1969 recession, to the early 1980s downturns and to the collapse of the speculative dot-com bubble experienced at the beginning of 2000s. Interestingly, a common factor of the monetary regime switches consists in the fact that the changes in Fed's stance are always triggered by a recession.

Focusing on the changes in volatility regimes, Panel B displays the regime probabilities of *HVR* ($s^v = 1$). The dynamics of the volatility regimes probability show that *HVR* is frequently observed in the period spanning from the early 1970s to the mid-1980s. Conversely, *LVR* prevailed before and after this period, i.e., the Great Moderation. An episodic regime switch is observed in 2009, in the wake of the great financial crisis, when a sharp increase in volatilities is estimated.[23]

Panel C reports the smoothed probabilities of *FPR* ($s^p = 2$). During the period here considered, the regimes that have characterized the dynamics of prices – i.e., *CPR* and *FPR* – alternate. *FPR* characterizes the Great Inflation (1970s-early 1980s) and the period from the great financial crisis to the end of the sample. The Great Inflation is hence characterized by higher persistence in price inflation and the Great Moderation by a lower persistence in price inflation.

Finally, Panel D shows the smoothed probabilities of *FWR* , i.e., $s^w = 2$. Regarding the wage-setting regimes, before 1985, *CWR* was the dominant regime for the dynamics of wage inflation. After that (sub)period, *FWR* covers almost all the Great Moderation and the last years of the sample. The estimated dynamics of the wage-setting regime probabilities are consistent with the structural change of the mid-1980s and potentially support the structural explanation of the Great Moderation related to institutional changes in the labor markets (Champagne and Kurmann, 2013).

Besides the dynamic representation of the smoothed probabilities contained in Figure 2, the relative contribution of the different macroeconomic regimes in explaining the variability of the key macroeconomic variables can also be shown by the synthetic information contained in Table 4 on the share of the variance explained by each regime and on the associated probability. Overall, the regimes that contribute more in terms of variance explained are *JMR, FPR, CWR,* and *HVR.* All these regimes, except the last one, are associated with a higher ergodic probability and hence occur relatively more frequently. As reported in the dynamic version of the smoothed probabilities, the table shows that the probability of observing *JMR* relatively to *PMR* is significantly low and rather episodic and that the contribution of *PMR* to the explanation of the total variance for the key macroeconomic variables is relatively high compared to the *JMR.* This result could however be due to the fact that *JMR* occurs only 12% of the time in the sample, while *PMR* occurs 88% of the time.

The price and wage setting regimes, even if characterized by opposite intrinsic inflation persistence (*FPR* and *CWR,* respectively), are those that contribute most in terms of the variance explained for interest rate, inflation, and output gap. As previously suggested, this result could be related to the fact that both *FPR* and *CWR* are the most frequently

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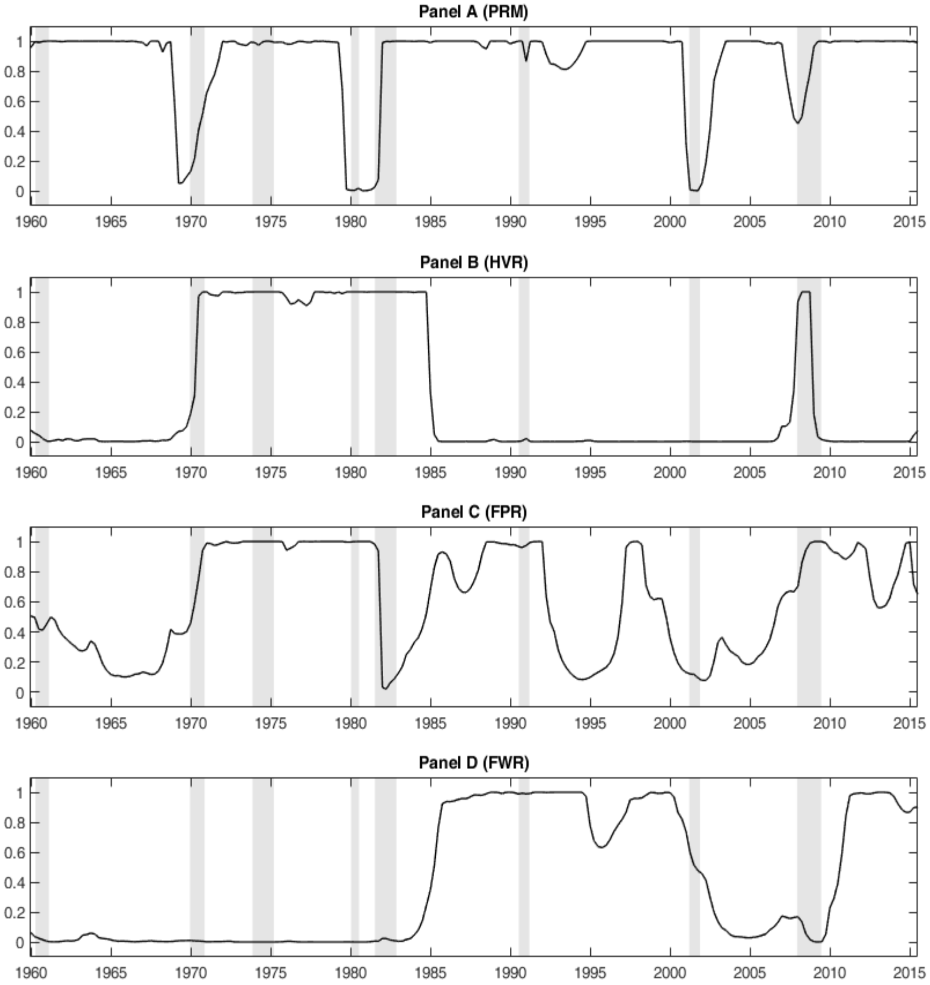
[23] Similar dynamics emerge, among others, in Liu *et al.* (2011) and Bianchi (2013).

Figure 2 – Smoothed regime probabilities



Notes: The figure shows the smoothed probabilities of our Markov-switching sticky price and wage macromodel with four independent regime variables. Panel A shows the smoothed probabilities of the gradualist monetary policy regime and the regime characterized by high volatilities of the structural disturbances. NBER recessions are gray shaded. Panel B shows the smoothed probabilities of the high-slope-price hazard regime and the high-slope-wage hazard regime.

observed regimes, with the former occurring 61% of the time in the sample and the latter occurring 62% of the time.

Finally, as expected, even if *HVR* occurs only 29% of the time in the sample, it explains much of the variability of the key macroeconomic variables, compared to the more frequently observed *LVR*, which occurs 71% of the time. Price regimes associated with more intrinsic persistence are also associated with high volatilities, compared to those associated to flat hazard function. There hence exists a correlation between inflation intrinsic persistence and business cycle volatility.

The next two sections of the paper investigate the four independent regimes and their

Table 4 – Independent macroeconomic regimes: variance explained

Regime	ID	Interest rate	Inflation	Output	Probability
JMR	$s^m = 1$	0.20	0.17	0.13	0.12
PMR	$s^m = 2$	0.80	0.83	0.87	0.88
CPR	$s^p = 1$	0.24	0.20	0.31	0.39
FPR	$s^p = 2$	0.76	0.80	0.69	0.61
CWR	$s^w = 1$	0.80	0.71	0.74	0.62
FWR	$s^w = 2$	0.20	0.29	0.26	0.38
HVR	$s^v = 1$	0.68	0.60	0.55	0.29
LVR	$s^v = 2$	0.32	0.40	0.45	0.71

Notes: The table details the ratio of the variance explained by each independent regime for interest rate, inflation, and output gap and the associated probability. Details on computation are relegated to the Appendix.

impact on the U.S. business cycle.

7 The conduct of the Fed: a *new-old* interpretation

Although the existence of the two monetary policy regimes identified by our estimates is often found in the MS monetary model literature (e.g., Bianchi, 2013 and Baele *et al.*, 2015), our empirical results suggest a novel interpretation of the central banker's behavior. Whereas in that literature, the observed monetary regimes are usually associated with different reactions to inflation (and output) and the degree of interest rate smoothing is similar across regimes, once we account for potential switches in intrinsic price and wage inflation persistence, the traditional contrast between *Hawk* and *Dove* central bankers vanishes and the two regimes differ only in the degree of gradualism (or caution) adopted by the Fed in the implementation of monetary policy. As intuitively suggested by Figure 2, our rationale for this result runs as follows. If endogenous changes in the slopes of the price adjustment curves are neglected, the effects of these switches are inappropriately captured in the potentially biased estimates of the endogenous coefficients of monetary policy, exacerbating the monetary regime differences in the estimated monetary responses to inflation.[24] In this respect, while Sims and Zha (2006) and Cogley and Sargent (2006) emphasize the importance of accounting for regime shifts in the stochastic volatility of exogenous shocks to identify shifts in monetary policy, we stress that it is also essential to account for the structural regime shifts in the price and wage adjustment processes.[25]

The results obtained with U.S. data suggest that *PMR is* the regime predominantly observed. The unconditional probability of observing *PMR* is relatively high (0.88), while observing *JMR* is rather episodical (0.12). It follows that "as a general rule, the Federal Reserve tends to adjust interest rates incrementally, in a series of small or moderate steps in the same direction" (Bernanke, 2004) and only rarely deviates from this behavior. However,

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[24] Changes in the shapes of the hazard functions capture changes in the price and wage inflation intrinsic persistence, whereas changes in the Brainard component of the monetary policy rule captures changes in the policy inertia.

[25] The model that assumes endogenous regime switches in the price and wage adjustments outperforms the one in which only endogenous regimes for monetary policy and disturbance volatility are admitted (see Table 2).

the fact that regime changes to *JMR* are short-lived does not mean that their effects are not persistent. Paradoxically, the opposite is true, as it can be clarified with a simple example.

Assume that in period *t* the Fed adopts its usual inertial policy (*PMR*), which cautiously incorporates the current economic shocks into the persistent policy reaction, and that an unexpected short-lived inflation shock occurs. Under *PMR*, the Fed would react to this shock with delay, gradually changing its anti-inflationary policy. Now assume that before the shock a sudden regime change to *JMR* occurs: the Fed deviates from PMR as it reckons as very relevant the shocks being currently observed. If the monetary policy regime change was permanent, the sharp anti-inflationary policy would lose its strength over time, as the shock progressively vanishes. But if the regime change to *JMR* is short-lived, the quick return to the prudential regime *PMR* will continue to attach, in the design of policies, more weight to the effects of the recently observed inflationary shock and less to the (current) situation unfolding, thus increasing the persistence of the effects of the *JMR*.

Our interpretation of the Fed's conduct can hence be summarized in the evidence that it has operated according to a principle of prudence, gradually incorporating the observed economic changes into its policy reaction. This conduct has been only rarely revised in the face of particularly relevant episodes that have become focal for the re-definition of monetary policy, but the regime changes due to judgment monetary policy have produced persistent effects.

To individuate the macroeconomic effects of the Fed's deviations from the rule of caution, we now compare the actual dynamics of the macro-variables with a counterfactual analysis where *PMR* is imposed over the entire sample by assuming that agents know this is the only possible regime. The results are illustrated in Figure 3, which focuses on the three switches in the FED's stance identified in the data and due to: *i)* the attempt to respond to the mild recession occurring at the end of 1969; *ii)* the early 1980s downturns; *iii)* the collapse of the speculative dot-com bubble at the beginning of 2000s. It is noteworthy that the switch is always triggered by a recession. The Z_t^p shows the observed dynamics of the interest rate, inflation, and output (solid blue lines) and the counterfactual simulations (dashed red lines).

In all these episodes, where observed deviations from the rule of caution imply a shift in the Fed's emphasis, away from the stabilization of inflation and towards the stabilization of output, had the Fed continued to operate according to a principle of prudence, lower inflation and higher unemployment (a larger output gap) would have been observed. In 1969, for instance, differently from the 1953-54 and 1957-58 recessions, the Fed did not permit money growth to fall in the early stages of the contraction, in this way differing from previous behaviors. Poole (1975: 100) emphasized that this reaction of the Fed to the new conditions is the cause of the containment of the subsequent recession, when unemployment peaked at 6.1%, well below the levels observed during the 1957-58 and 1960-61 recessions. Figure 3 (Episode 1) illustrates the change of stance and confirms the effects described by Poole (1975: 100).

As for the second episode we consider, the early 1980s recessions were triggered by the tight monetary policy following the appointment of Paul Volcker as the Fed's Chairman in August 1979, in the effort to fight mounting inflation. During the 1981-82 recession, unemployment makes its worst economic downturn in the US post-World War II era (but during the COVID-19 crisis). Despite the requests of the Congress, Volcker kept the point about anti-inflationary policies, in the belief that the Fed would have otherwise suffered from a credibility problem when it came to keep inflation in check. As inflation fell, the Fed allowed the federal funds rate to decline and the unemployment rate quickly fell from the nearly 11% peak at the end to 1982 to 8% one year later (Goodfriend and King, 2005). The qualitatively discussed and quantitatively identified change in monetary policy is evident in Figure 3 (Episode 2).[26]

Regarding the last episode, in the period 2000-07, a change in the Fed's policy stance appears to have occurred. The Fed began to reduce the fund rates, from 6.5% in January 2001 to 1% in June), which are shown in Figure 3 (Episode 2) to be persistently below the values prescribed by caution, as a result of its reduced emphasis on the stabilization of inflation. It is worth stressing that this conclusion is in line with the findings of Belongia and Ireland (2016) for the same historical period.

Even though the observed contingent judgments and the consequent deviations from the rule of caution tend to avoid sudden falls in production, this is not a general rule, as the Fed's monetary stance did not change when other severe recessions occurred (e.g., after the 1973 oil crisis or the 1973-74 stock market crash). Our intuition in this regard is that at the time the Fed was strongly committed to a policy of long-term disinflation and so did not allow contingent changes to affect its policy stance.[27]

Summing up, by controlling for the potential time-varying nature of price and wage inflation, our interpretation of the conduct of the FED's monetary policy reconciles the traditional results of the MS literature, which connect the stance of monetary policy to different regimes (Hawk vs. Dove central bankers), with the view usually put forward by the practitioners of central banking, which is mostly based on prudence and contingent judgments.

8 Revisiting the US business cycle

According to our findings, the main drivers of the business cycle are structural changes in price and wage setting processes and the volatility of stochastic disturbances, whereas monetary regime changes are episodic and have limited impact on macroeconomic variabilities. In the light of these results, in this section we analyze two crucial episodes of the American business cycle, the Great Inflation of the 1970s and the Great Moderation of the 1980s.

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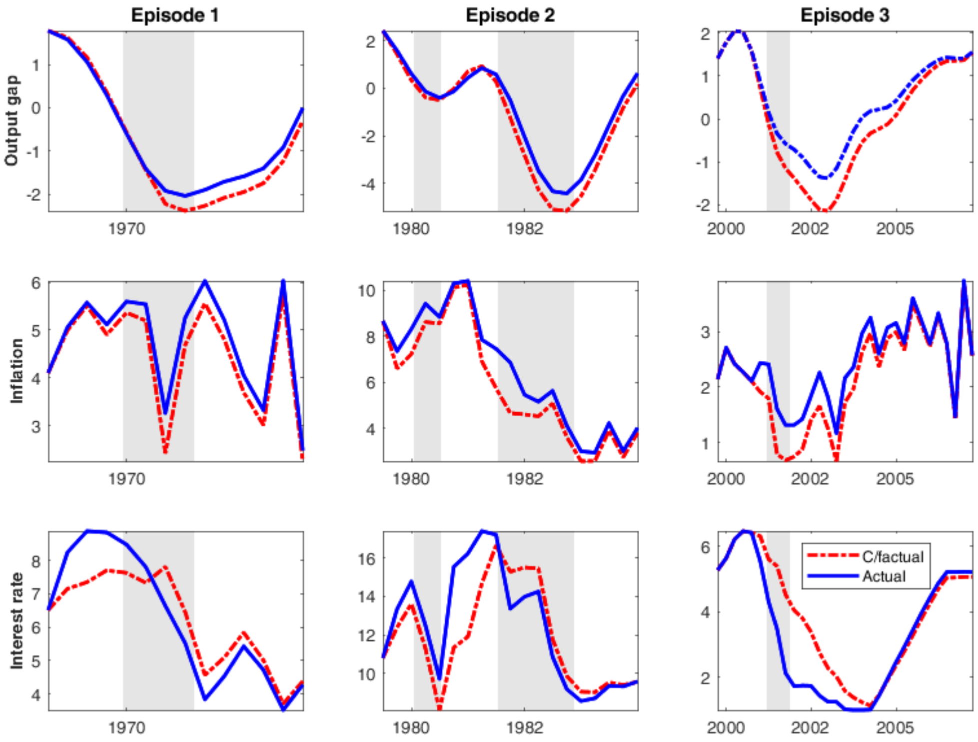
[26] Our estimates are also in line with the evidence regarding the Fed's behavior in the early 1980s. The figure shows how the Fed's attempt to ease up was unsuccessful. The return to a stop-and-go policy resulted in higher inflation without reducing the output gap (and unemployment).

[27] An additional counterfactual exercise in provided in the Appendix.

Figure 3 – Monetary policy episodes



Notes: The figure plots the observed and counterfactual PMR for the interest rate, the inflation, and the output gap series. Blue continuous lines indicate the observed paths. Red dashed lines indicate the counterfactual, that is, assuming that the prudent monetary policy regime (PMR) holds for all the sample. The figure focuses on three monetary episodes, the full sample figure is reported in the Appendix.

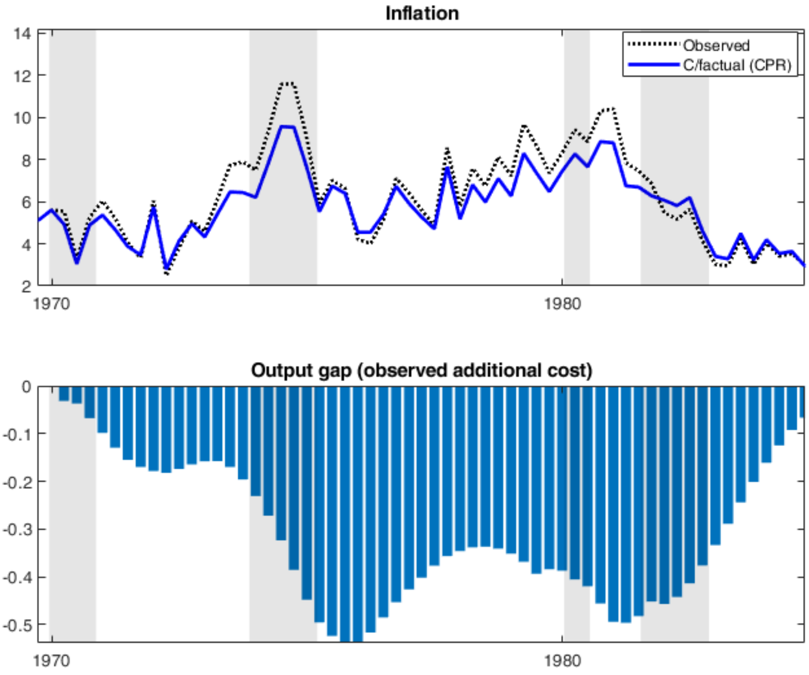
8.1 The Great Inflation, price- and wage-setting

Structural changes in price and wage setting are governed by switches in the hazard functions and are reflected in changes in both the slopes of the price and wage Phillips curves and the intrinsic persistence of price and wage inflation. Before investigating the contribution of the price and wage setting regimes on inflation in the 1970s, recall that this sub-sample is characterized by high intrinsic persistence in price dynamics (*FPR*) and low intrinsic persistence in wage dynamics (*CWR*).

The impact of different price-setting regimes in the era of Great Inflation is shown in Figure 4, which depicts observed inflation (black lines) and that associated with the counterfactual scenario (blue line), obtained by assuming that *CPR* holds for all the sub-sample, as well as the difference between the observed output gap and the counterfactual. It is straightforward to verify that the shift of the price Phillips Curve contributed to the Great Inflation. Furthermore, the output gap under the observed high intrinsic persistence regime in price inflation (*FPR*) is systematically below that of the low intrinsic persistence counterfactual (*CPR*) and the "cost" in terms of (quarterly) output gap is not negligible.

The Z_t^P hence suggests that the prevalence of *FPR* in the 1970s, implying both a positive inflation bias and a negative output bias, can be considered as one of the components that led to the *Great Stagnation*, even though other complementary factors must of course be considered.[28]

Figure 4 – Great Stagflation



Notes: The figure plots the observed (FPR) and counter-factual scenario (CPR) in the 1970s. The black line is the observed path for (annualized) inflation, while the blue line is the counter-factual scenario (i.e., the CPR is assumed to prevail for the entire duration of the sub-sample). The blue bars indicate the difference in percentage points between the output gap observed (FPR in place) and the output gap associated with the counterfactual (CPR in place). For the output gap the observed additional cost is reported.

As the Great Inflation was also characterized by low intrinsic persistence in wage dynamics (*CWR*), we now carry out a counter-factual exercise similar to that just presented for price inflation. The black line in Figure 5 is observed inflation and the red line is the inflation that would have been observed had a high wage-inflation intrinsic persistence (*FWR)* been in place. The figure also shows the difference between the actual output gap and the counter-factual output gap. A high intrinsic persistence of wages would have implied far greater inflation than that actually observed, accompanied by an evident worsening of the real economy: differently from Figure 4, the cost in terms of quarterly output under the counterfactual *FWR* is greater than that under the observed *CWR*. The wage regime in force

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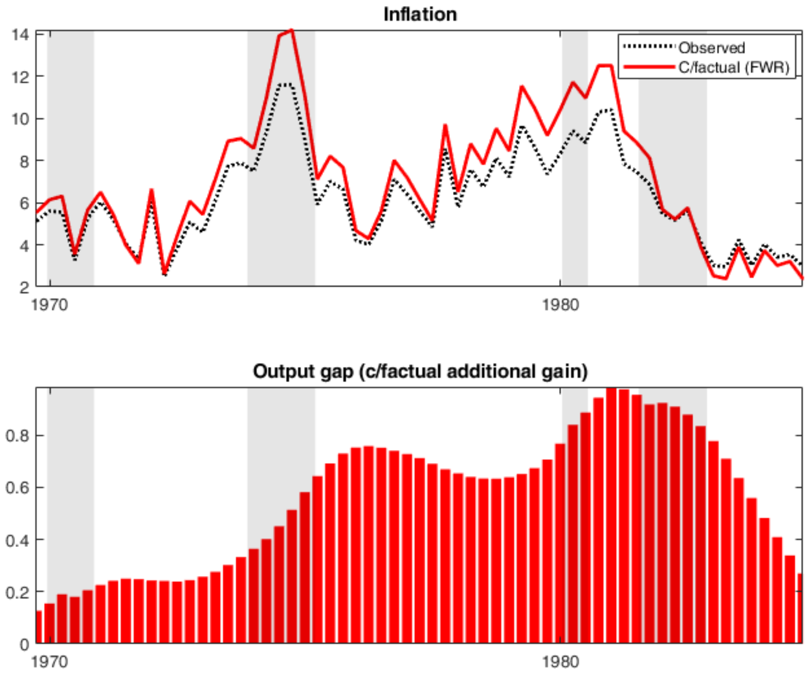
[28] See, among others, Blinder and Rudd (2013).

in the 1970s thus effectively reduced inflationary pressures and produced non negligible gains in terms of output gap.[29]

Figure 5 – Wage moderation during the Great Inflation



Notes: The figure plots the observed (CWR) and counter-factual scenario (FWR) in the 1970s. The black line is the observed path for (annualized) inflation, while the red line is the counter-factual scenario (i.e., the FWR is assumed to prevail for the entire duration of the sub-sample). The red bars indicate the difference in percentage points between the output gap associated with the counterfactual (FWR in place) and the output gap observed (CWR in place). For the output gap, the counterfactual additional gain is reported.

To summarize the analysis of Figures 4 and 5, and provide further insights on the importance of different macroeconomic regimes in shaping US business cycle dynamics during the Great Inflation, we show in Table 5 the observed and the counterfactual standard deviations for inflation, output gap and interest rate. It is in this way clear that a lower persistence of price inflation (counterfactual *CPR*), as compared to the actual *FPR*, would have implied a significant reduction in the observed volatility of the interest rate (−8.5%), of the output gap (−3%) and, more importantly, of inflation (−22%). Furthermore, a regime of wage moderation associated with high persistence in wage inflation (counterfactual *FWR*), as compared to the actual *FWR*, would have implied a significant increase in the observed

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[29] Champagne and Kurmann (2013) highlight how the volatility of wages was significantly lower during the 1970s compared with the following years. More precisely, they document that the business cycle volatility of the aggregate wage relative to the volatility of aggregate output was between 2.5 to 3.5 times smaller in 1953-1984 than in 1984-2006. This finding is driven by the observed difference in the business cycle volatility of hourly wages.

volatility of the interest rate (16.2%), of the output gap (8.7%) and, more importantly, of inflation (29.7%).[30]

Table 5 – Observed vs. c/factual volatilities during the Great Inflation

	Interest rate	Inflation	Output
Great Inflation	3.63	2.39	1.86
Counterfactuals			
Low intrinsic persistence in price inflation (*CPR*)	3.32	1.87	1.80
High intrinsic persistence in price inflation (*FPR*)	3.69	2.38	1.89
Low intrinsic persistence in wage inflation (*CWR*)	3.63	2.39	1.86
High intrinsic persistence in wage inflation (*FWR*)	4.22	3.10	2.02

Notes: The table details the observed, Great Inflation, and counterfactual standard deviations for the key macroeconomic variables, i.e., interest rate, inflation, and output gap in different price, s^p, and wage, s^w, setting regimes. Standard deviations are expressed in terms of quarterly percentage points.

8.2 The Great Moderation, price- and wage-setting

According to our results, monetary regime changes have little relevance in explaining the Great Moderation of the 1980s, whereas switches in the volatility of the structural shocks matter. To further explore the issue, we plot in Figure 6 the observed low volatility regime LVR (solid blue line) and the counter-factual high volatility regime (dashed red line), obtained by imposing that the economy is always in the *HVR*. The panels describe the dynamics of the interest rate, inflation, and output gap. During the Great Moderation, the variances of both the output gap and the interest rate are considerably larger (3.2 and 5.9, respectively) than those that would have obtained under *HVR*. Furthermore, in line with the output gap and the interest rate dynamics, the variance of the price and of the wage inflation are also considerably larger (8.0 and 7.0, respectively) than under the counterfactual *HVR*.[31]

Table 6 summarizes the potential role of different wage and price setting regimes, characterized by different degrees of persistence of price and wage inflation. The first row shows the observed standard deviations of inflation, output gap and interest rates during the Great Moderation. The subsequent rows show the standard deviations of the same variables under the counterfactuals analyses, where different degrees of persistence of both price and wage inflation are assumed for the whole subsample. Unsurprisingly, the table shows that both the price- and the wage-adjustment regimes have a relatively smaller impact on the volatility of interest rate and output gap. Instead, a significant importance in determining inflation dynamics is played by price inflation regimes: a lower (higher) intrinsic persistence in price inflation would have implied a reduction (increase) of 14.8% (14.8%) in the standard deviation of inflation.

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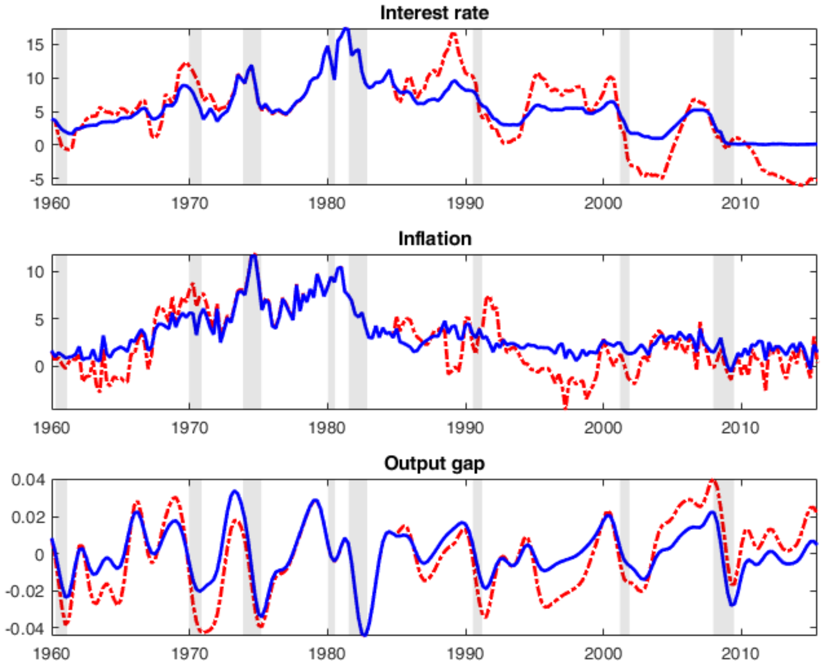
[30] This result confirms the evidence by Champagne and Kurmann (2013) discussed in the previous footnote.

[31] Our findings are consistent with the interpretation of the U.S. business cycle fluctuations provided by Stock and Watson (2003), who document that the U.S. economy experienced a general reduction in macroeconomic volatilities between 1985 and 2007.

Figure 6 – Volatility regimes and the Great Moderation



Notes: The figure plots the observed and counterfactual HVR for the interest rate, the inflation, and the output gap series. Blue continuous lines indicate the observed paths. Red dashed lines indicate the counterfactual scenario, i.e., assuming that the high volatility regime (HVR) holds for all the sample.

Table 6 – Observed vs. c/factual volatilities during the Great Moderation

	Interest rate	Inflation	Output
Great Moderation	2.37	0.88	0.94
Counterfactuals			
Low intrinsic persistence in price inflation (*CPR*)	2.39	0.75	0.92
High intrinsic persistence in price inflation (*FPR*)	2.50	1.01	0.90
Low intrinsic persistence in wage inflation (*CWR*)	2.39	0.84	0.94
High intrinsic persistence in wage inflation (*FWR*)	2.45	0.92	0.92

Notes: The table details the observed, Great Moderation, and counterfactual standard deviations for the key macroeconomic variables, i.e., interest rate, inflation, and output gap in different price, s^p, and wage, s^w, setting regimes. Standard deviations are expressed in terms of quarterly percentage points.

9 Conclusions

This paper has proposed a novel interpretation of the U.S. business cycle based on the introduction in a New-Keynesian macro-model of endogenous regime switches in the price and wage intrinsic inflation persistence, as well as regime-switching behavior in monetary policy and macro shocks. Persistence has been introduced by modeling price and wage hazard according to a vintage-dependent-price-setting approach. Changes in the shape of the hazards imply shifts in the price and wage Phillip curves.

The main results we reach can be summarized as follows. (i) The main drivers of the U.S. business cycle are structural changes in price and wage settings, and stochastic volatilities; the former changes affect the business cycle means and the macro shocks affect its volatilities. (ii) The analysis of monetary policy regimes is more complex than that often proposed in the literature in terms of a simple dichotomy between Hawk and Dove central bankers.

These results allow us to explain the Great Inflation as driven by changes in the price and wage hazard. More precisely, whereas structural changes in price adjustments fueled inflation, changes in the wage-setting process tended to moderate price dynamics. This suggests that price and wage setting institutions matter in the explanation of this historical event. Furthermore, the remarkable decline in macroeconomic volatility experienced by the U.S. economy during the Great Moderation, when a low-volatility regime was in place, is mainly explained by changes in the shock volatilities (good luck), whereas monetary regimes (good policies) do not account for the observed macroeconomic changes.

Finally, in line with the view usually supported by central banking practitioners, we have documented that monetary policy is generally guided by a principle of caution, i.e., the reaction to the observed disturbances is metabolized by the central bankers gradually and prudently. In some circumstances, the central banker leaves however the safe waters of caution and changes the monetary policy stance by focusing on the current macroeconomic conditions. Regime changes are hence more articulated than suggested by the common interpretation based on switches in the policymakers' attitude towards inflation.

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Appendix

A. Convergence

Table A1 details the Gelman–Rubin diagnostic, i.e., the Potential Scale Reduction Factor, based on two chains of $500,000$ Gibbs sampler draws, each with a burn-in and retain ratios of 10% per chain. As it can be easily appreciated, the Potential Scale Reduction Factor for each estimated parameter approaches unity from above, converging to one, or to values very close to one, and far below the threshold value of 1.1.

Table A1 – Gelman–Rubin diagnostic: Potential Scale Reduction Factor (PSRF)

	PSRF		PSRF		PSRF		PSRF		PSRF
σ	1.00	α_p $(s = 1)$	1.00	ρ_r $(s= 1)$	1.05	σ_a $(s^*= 1)$	1.01	$v^p(1,2)$	1.00
γ	1.03	α_p $(s= 2)$	1.00	ρ_r $(s= 2)$	1.06	σ_a $(s^*= 2)$	1.00	$v^p(2,1)$	1.00
h	1.00	φ_p $(s= 1)$	1.00	δ_π $(s= 1)$	1.05	σ_z $(s^*= 1)$	1.01	$v^w(1,2)$	1.00
ρ_a	1.01	φ_p $(s= 2)$	1.00	δ_π $(s= 2)$	1.01	σ_z $(s^*= 2)$	1.03	$v^w(2,1)$	1.00
ρ_z	1.00	α_w $(s= 1)$	1.00	δ_x $(s= 1)$	1.00	σ_υ $(s^*= 1)$	1.01	$v^m(1,2)$	1.00
ρ_ζ	1.00	α_w $(s= 2)$	1.00	δ_x $(s= 2)$	1.01	σ_υ $(s^*= 2)$	1.00	$v^m(2,1)$	1.03
		φ_w $(s= 1)$	1.00			σ_ζ $(s^*= 1)$	1.01	$v^*(1,2)$	1.00
		φ_w $(s= 2)$	1.00			σ_ζ $(s^*= 2)$	1.00	$v^*(2,1)$	1.00

Notes: The Gelman–Rubin diagnostic is based on two chains of 500,000 of Gibbs sampler draws each with a burn-in and retain ratio of 10

B. Variance decomposition and ergodic distribution for all regimes

The regime variable $S = [s^m, s^p, s^w, s^v]$ contains 16 different regimes, as each of the four independent regimes has two states. The unconditional variance of any X_t variable is then given by:

$$var(X_t) =_{i \in S} var(X_t | S_t = i) P_i$$

where P_i is the unconditional, ergodic regime probability and $var(X_t|S_t = i)$ is the regime-dependent variance. The contribution of a particular regime $i \in S$ to the total variance is then:

$$r_X(S_t = i) = \frac{var(X_t|S_t = i)}{var(X_t)}$$

Similarly, the contribution of a particular independent regime $s_t^i = j$ (with $i \in \{m, p, w, v\}$ and $j \in \{1, 2\}$) to the total variance is

$$g_X(s_t^i = j) =_{z \in S|s_t^i = j} var(X_t|S_t = z)/var(X_t)$$

In the above expression, $S|s_t^i = j$ identifies the subset of all regimes in S where the independent regime $s_t^i = j$ is in place.

Table A2 details the contribution of all regimes to the total variance for the interest rate, inflation, and output, as well as their long-run ergodic distribution. The first column identifies the 16 regimes by a 4 digits index. The first digit individuates the monetary regime (1: *Taylor's JMR*, 2: *Brainard's PMR*); the second the price regime (1: *Calvo's PR*, 2: *Fuhrer's PR*); the third the wage regime (1: *Sticky WR*, 2: *Flexible WR*); and the fourth one the volatility regime (1: *High VR*, 2: *Low VR*). The second, the third, and the fourth columns of the table report the ratio of the variance for the interest rate, inflation, and output conditional on the regime combination to its total variance, respectively. Finally, the last column details the regime's probability in the ergodic distribution, which measures its unconditional probability.

Table A2 – Variance decomposition and ergodic distribution for all regimes

Regime $S = [s^m, s^p, s^w, s^v]$	Interest rate	Inflation	Output	Regime probability
$[1, 1, 1, 1]$	0.6	0.5	0.5	0.3
$[1, 1, 1, 2]$	1.2	0.9	1.5	2.8
$[1, 1, 2, 1]$	0.0	0.0	0.0	0.0
$[1, 1, 2, 2]$	1.0	0.8	0.9	1.7
$[1, 2, 1, 1]$	15.1	12.8	9.4	5.8
$[1, 2, 1, 2]$	0.8	0.7	0.7	1.3
$[1, 2, 2, 1]$	0.3	0.3	0.1	0.1
$[1, 2, 2, 2]$	0.6	0.5	0.4	0.6
$[2, 1, 1, 1]$	9.9	6.5	9.0	4.6
$[2, 1, 1, 2]$	6.6	5.7	11.3	18.9
$[2, 1, 2, 1]$	0.4	0.4	0.4	0.2
$[2, 1, 2, 2]$	4.5	5.3	6.8	11.1
$[2, 2, 1, 1]$	40.8	38.4	35.1	17.4
$[2, 2, 1, 2]$	4.5	5.6	6.6	10.7
$[2, 2, 2, 1]$	0.9	1.4	0.8	0.4
$[2, 2, 2, 2]$	12.7	20.3	16.4	24.3

Notes: The values detailed in the table are reported in percent. Therefore, each column sums to 100.

C. Monetary policy regime: Counterfactual analysis

Figure A1 shows changes in monetary policy regimes over the sample. *PMR* is the most common regime, while switches to *JMR* are only episodically observed. The figure illustrates the marginal contribution of monetary regime switches to the sample volatility.

D. Impulse response functions

Figures A2 and A3 depict the impulse response functions of the selected macro-variables for different shocks and economic regimes. The rows individuate the shocks (monetary, mark-up, TFP, and preferences), while the columns refer to the macroeconomic variables (output, interest rate, and inflation). Therefore, each cell, depicts the variable response to the considered shock in different selected and independent regime combinations.[32]

Figures A2 and A3 differ in the benchmark comparison. Specifically, Figure A2 allows for comparison between "low" regimes, i.e., *1-1-1* vs. *1-2-1*, *2-1-1-* and *1-1-2*, where digits identify the different regimes. For instance, by comparing *1-2-1* to *1-1-1*, we can investigate

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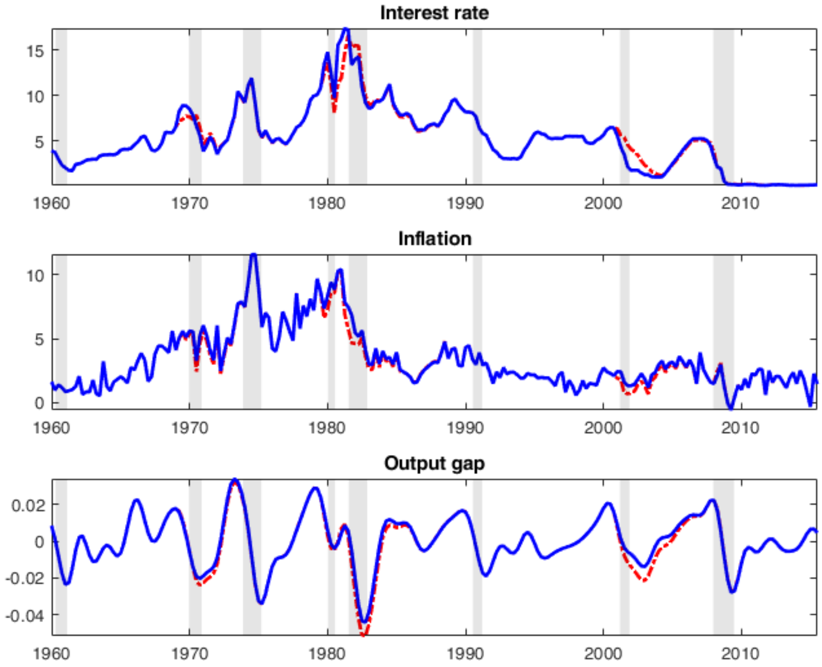
[32] It is worth noting that as we are looking at the impulse repose function, we do not consider the high/low volatility regimes.

Figure A1 – Monetary policy regimes



Notes: The figure plots the observed and counterfactual *PMR* for the interest rate, the inflation, and the output gap series. Blue continuous lines indicate the observed paths. Red dashed lines indicate the counterfactual, i.e., assuming that the prudent monetary policy regime (*PMR*) holds for all the sample.

the qualitative and quantitative effects of a change in the price regime from the benchmark, i.e., *JMR*, *CPR*, *CWR* to a high price regime, i.e., *JMR*, *FPR*, *CWR*. Instead, by comparing *2-1-1* to *1-1-1*, we investigate the effects of *PMR* vs. the benchmark, i.e., *PMR*, *CPR*, *CWR* vs. *JMR*, *CPR*, *CWR*. Figure A3 shares the same aim with Figure A2 but considers the case of "high" regimes, i.e., *2-2-2* vs. *1-2-2*, *2-1-2*, *2-2-1*. The benchmark in the latter case is identified by *PMR*, *FPR*, *FWR*.

The figures show no qualitative differences in the reaction functions, which have the expected paths. However, they differ from a quantitative point of view.

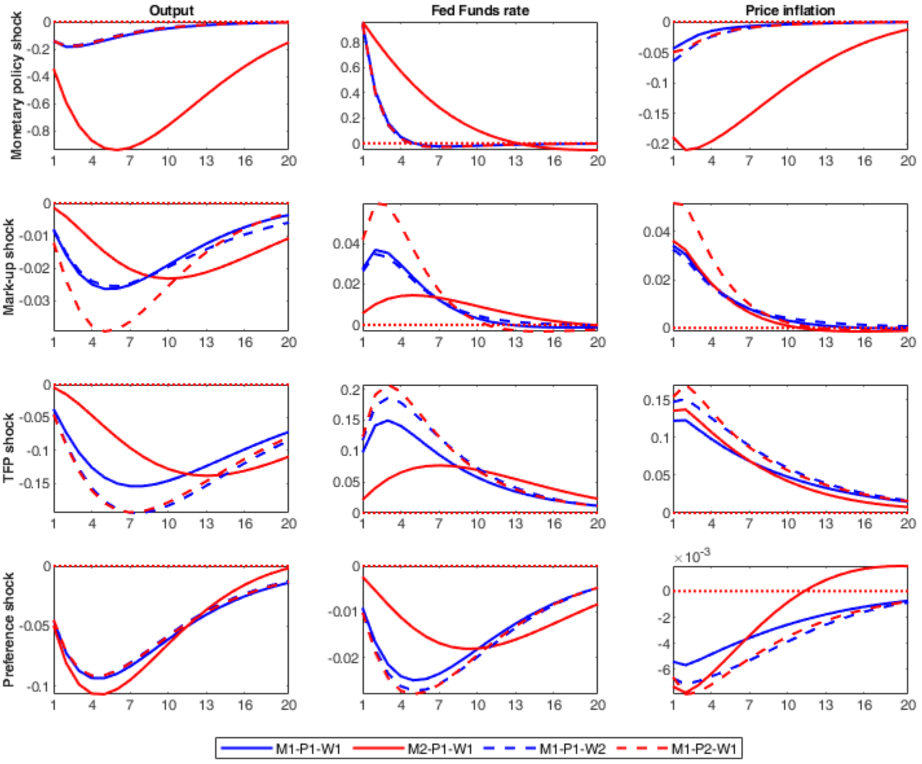
In the case of a monetary shock, the difference in the monetary regime matters. In the "low" case, depicted in Figure A2, the impulse responses to a contractionary monetary shock are significantly different according to whether the monetary authority is in a *Taylor's JMR* or *Brainard's PMR*. When the monetary authority is in *PMR*, a more drastic recession materializes after the shock, accompanied with a sharp reduction in price inflation. The rationale for this result is the weak response of monetary policy to the shock. A similar result holds for the case of the "high" regime depicted in Figure A3. By contrast, changes in the other regimes have minor effects for the dynamics of the considered variables. The effects are slightly larger in the "high" case where regimes changes lead to higher output contraction and lower inflation compared to the benchmark.

Compared to a monetary shock, Figure A2 and A3 (row 2) graphically suggest that the mark-up shock is associated to more heterogeneity in the impulse responses. The dynamics of the different regimes associated to price and monetary policy are different from the benchmark, while the dynamics associated to the wage regimes are quite the same compared to the benchmark. Not surprising, the *PMR* in both figures leads to more inertia in the monetary response, switching the peak of the recession 5-6 quarter forward. Instead, the intrinsic persistence in prices, *FPR*, amplifies the effects of mark-up shocks on both output and inflation.

The effects of TFP shocks are, *ceteris paribus*, quantitatively the most heterogenous. *PMR* are associated to larger fluctuation in both cases described in Figure A2 and A3. The effects of regimes changes in price and wages are similar. Shifts to high persistence, *FPR* and *FWR*, always imply deeper recession and higher inflation at least on impact.

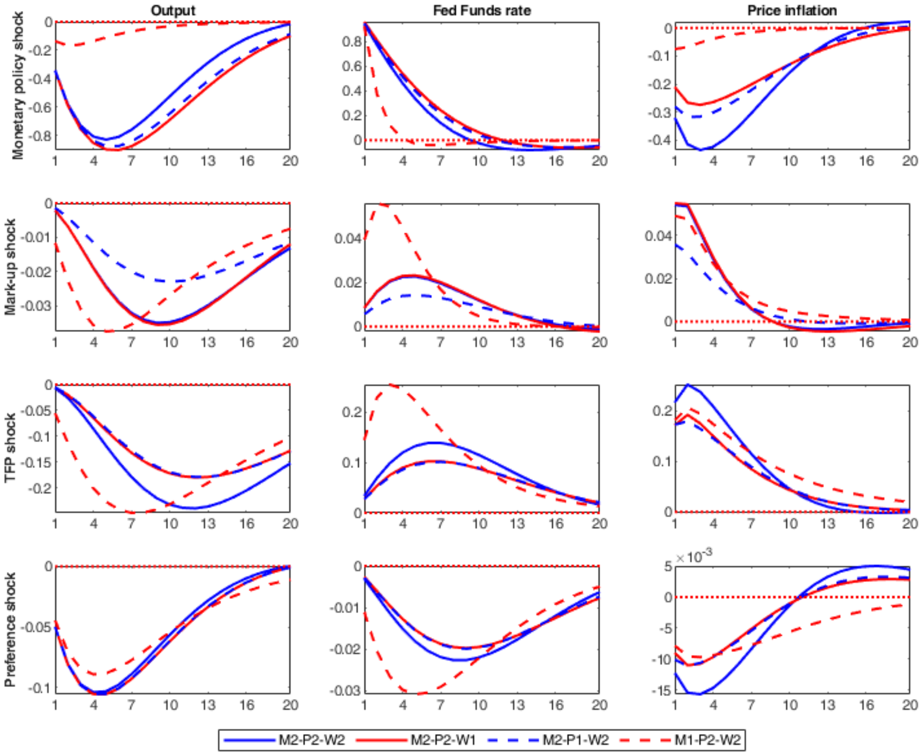
Finally, in the "low" case, preference shocks have different effects on output depending on the monetary regime in place (see Figure A2: last row). All switches to regimes alternative to the benchmark, i.e., more persistence in prices or wages or prudent monetary regimes, imply, *ceteris paribus,* a deeper deflation compared to the benchmark. Similar results are confirmed for inflation also in the "high" case (see Figure A3: last row). However, the less persistence in the wage dynamics implies a different path compared to the benchmark which translates in a less severe recession.

Figure A2 – Low monetary, price and wage inflation regimes



Notes: The figure shows the regime dependent impulse responses of output gap, Fed funds rate and price inflation to monetary policy, markup, TFP and preference shocks, respectively. Moreover, each panel reports the responses of the considered variables in mainly low monetary, price and wage inflation regimes. M1 (M2) represents the estimated judgment monetary policy regime (prudential monetary policy), whereas P1 (P2) and W1 (W2) represent the Calvo (Fuhrer) price and wage setting regime, respectively.

Figure A3 – High monetary, price and wage inflation regimes



Notes: The figure shows the regime dependent impulse responses of output gap, Fed funds rate and price inflation to monetary policy, markup, TFP and preference shocks, respectively. Moreover, each panel reports the responses of the considered variables in mainly high monetary, price and wage inflation regimes. M2 (M1) represents the estimated prudential monetary policy (judgment monetary policy) regime, whereas P2 (P1) and W2 (W1) represent the Fuhrer (Calvo) price and wage setting regime, respectively.