Calvo vs. Rotemberg in a Trend Inflation World: An Empirical Investigation*

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Abstract

This paper estimates and compares New-Keynesian DSGE monetary models of the business cycle derived under two different pricing schemes - Calvo (1983) and Rotemberg (1982) - under a positive trend inflation rate. Our empirical findings (i) support trend inflation as an empirically relevant feature of the U.S. great moderation; (ii) provide evidence in favor of the statistical superiority of the Calvo setting; (iii) support the absence of price indexation under the Calvo mechanism only. The superiority of the Calvo model (against Rotemberg) is due to the restrictions imposed by such a pricing scheme on the aggregate demand equation. The determinacy regions implied by the two estimated models indicate relevant differences in the implementable simple policy rules.

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1 Introduction

The Calvo (1983) and Rotemberg (1982) models are the two most popular pricing schemes in the New-Keynesian business cycle literature.[1] Under the typically employed linear approximation around "zero inflation in steady state", these two pricing mechanisms lead to the very same reduced-form macroeconomic dynamics (Rotemberg, 1987, Roberts, 1995) and to equivalent welfare indications (Nisticò, 2007).[2] Given such a model equivalence, the choice of the Calvo vs. Rotemberg pricing scheme has typically been no more than a matter of macroeconomists' taste.

In a recent contribution, Ascari and Rossi (2009) show that, contrary to conventional wisdom, the Calvo and Rotemberg models may imply substantially different macroeconomic dynamics if log-linearized around a positive steady state inflation rate, that is assuming trend inflation.[3] The two models, then, have very different policy implications regarding the inflation-output relationships, the determinacy conditions, and the disinflation dynamics.[4] Given that (i) the Calvo and the Rotemberg models are the two most popular way of modelling nominal price rigidities, (ii) they result in different log-linearized dynamic macroeconomic models under positive trend inflation, and that (iii) positive mean inflation is an undeniable empirical fact in OECD countries in the post-WWII sample, it seems natural to proceed to a comparative quantitative investigation of these two pricing schemes.

This paper fits the Calvo and Rotemberg frameworks derived under positive trend

[1] For in-depth analyses of the new-Keynesian model of the business cycle, see King (2000) and Woodford (2003).

[2] Lombardo and Vestin (2008) discuss the conditions under which welfare costs might be different under these two pricing schemes.

[3] As in the literature, trend inflation indicates a positive steady state level of inflation.

[4] The zero steady state assumption, which is empirically problematic, has already been questioned from a theoretical standpoint. Ascari (2004) and Yun (2005) show that first-order effects arise on the Calvo price setting setup under trend inflation. Elaborating further with the Calvo set-up, Ascari and Ropele (2007, 2009) study the implications of different trend inflation levels for the optimal monetary policy and for the Taylor principle.

inflation to 1984:I-2008:II U.S. macroeconomic data. Several findings arise. First, models acknowledging a positive trend inflation rate display a better (or, at least, no worse) fit than a baseline "zero inflation in steady state" framework. Given the different policy implications stemming from a trend inflation-equipped framework (as opposed to the baseline model) in terms of optimal policy and determinacy of simple monetary policy rules (Ascari and Ropele, 2007, 2009), our results push towards the employment and development of macroeconomic frameworks consistently accounting for a positive steady-state inflation rate. Second, the U.S. data support Calvo (as opposed to Rotemberg) as the better fitting pricing scheme. In particular, when comparing the two models under the "no price-indexation" restriction, we verify the rejection of the indexation hypothesis by the Calvo framework. Interestingly, this result emerges in *absence* of any stochastic model for the low frequency of the inflation rate, i.e. without appealing to any exogenous process modeling the possibly time-varying trend inflation as in Ireland (2007) and Cogley and Sbordone (2008). Differently, shutting down indexation in the Rotemberg framework leads to a drop in the model's empirical fit, suggesting a lack of internal dynamics in comparison to Calvo. Third, conditional on *estimated* (as opposed to calibrated) frameworks, the determinacy area is shown to be strongly dependent on the choice of the price setting model. In particular, the set of implementable simple rules conditional on our estimated New-Keynesian model under positive trend inflation and Calvo price setting is substantially smaller than the one associated to the New-Keynesian framework derived under the standard zero steady-state assumption, and even smaller than that implied by the widely employed Rotemberg framework. Our empirical results points toward the Calvo mechanism as the better fitting pricing scheme. Thus, from a policy standpoint, they suggest that policymakers should refrain from loosening monetary policy and stay hawkish, i.e., they should keep reacting strongly to the evolutions of the inflation rate.

Other papers stress the importance of considering trend inflation in empirical work. Benati (2008) estimates a NKPC for a variety of countries, and shows that price-indexation à la Christiano, Eichenbaum, and Evans (2005) is not stable across different samples in countries that explicitly adopted an inflation targeting scheme. He relates this instability to different policy regimes, so demonstrating that indexation is "not structural in the sense of Lucas". Elaborating on this paper, Benati (2009) estimates different NKPCs derived under alternative pricing schemes. His results corroborate and extend his previous findings, i.e. the degree of price indexation is not invariant across different policy regimes, and it tends to zero under the more recent, stable regimes. Notably, Benati (2009) supports, among others, Ascari and Ropele's (2009) derivation of the Calvo model under trend inflation for a variety of countries.[5] He considers a step-function to model possible drifts in the inflation target. Differently from Benati (2009), who works with a fully-fledged New-Keynesian DSGE framework, Cogley and Sbordone (2008) estimate a NKPC embedding a drifting trend inflation coupled with a TVC-VAR model. They find that, once drifts in trend inflation are accounted for, price indexation in the U.S. is zero, i.e. a purely-forward looking NKPC fits the data well without the need for *ad-hoc* backward-looking components.[6] Coibion and Gorodnichenko (2009) estimate a Taylor rule with trend inflation for the post-WWII, and couple it with a calibrated New-Keynesian model derived under positive trend inflation. They show that the U.S. economy switched to determinacy during the Volcker disinflation because of changes in the Federal Reserve's response to macro variables *and* the decline in trend inflation.[7] Paciello (2009) estimates a Calvo-based NKPC with

[5] The list considered by Benati (2009) includes the Euro area, West Germany, Germany, France, Italy, U.K., Canada, Sweden, Australia, New Zealand, and Switzerland.

[6] Barnes, Gumbau-Brisa, Lie, and Olivei (2009) use a different estimation methodology and a more flexible indexation-scheme with respect to Cogley and Sbordone (2008), and show that indexation to past inflation may be substantial in the post-WWII sample.

[7] Schorfheide (2005) and Ireland (2007) also embed a time-varying inflation target in their models, but without consequences for the specification of the NKPC due to the assumption of full-indexation.

constant trend inflation for the post-WWII via indirect inference, and shows that such a model is able to match the dynamic responses of inflation to monetary policy and technology shocks even in absence of indexation, an ability not enjoyed by the standard, zero steady-state inflation framework.

Our investigation departs from the ones above along different dimensions. First and foremost, our paper focuses on the estimation of, and the empirical comparison between, two different frameworks, i.e. Calvo and Rotemberg. To our knowledge, this is the only contribution to date assessing the relative empirical relevance of these two very widely employed pricing schemes under trend inflation. Second, we focus on two models displaying a *constant* trend inflation rate, i.e. displaying no exogenous random-walk type of process for the Fed's inflation target. Still, the version of the Calvo model preferred by the data is that with no-price indexation. With respect to Benati (2009), we provide evidence for the U.S. case, therefore complementing his battery of estimates. With respect to Cogley and Sbordone (2008) and Paciello (2009), we consider a structural representation of the demand side of the economy, rather than a reduced-form TVC-VAR. This is obviously important from an econometric standpoint, because the identification of forward and backward looking terms in the NKPC also depends on how the remaining structural equations are modeled. When such equations are not specified, as in the NKPC-VAR approach, the meaning of the economic restrictions imposed to the estimation is unclear, as pointed out by Cogley and Sbordone (2008) themselves. Also from a theoretical point of view, our analysis shows the importance of estimating the full model equations, because the assumed pricing scheme may affect not only the supply side of the model, but also the other model equations, as in the case of the Rotemberg model. Moreover, differently from Paciello (2009), we conduct our empirical analysis with Bayesian techniques. Our choice is driven by the possibly superior performance against indirect inference (impulse response matching) as far as this class of DSGE models is concerned (Canova and Sala, 2009). Finally, we concentrate on a stable subsample (great moderation), which is likely to feature a unique equilibrium even under historically plausible values for trend inflation (Coibon and Gorodnichenko, 2009), and a more stable low-frequency component of inflation. This sample choice makes our assumption of a constant trend inflation more palatable. Moreover, it does not incorporate the real output losses caused by the "imperfect credibility" of the Volcker disinflation (Goodfriend and King, 2005), which is not modeled in this paper. We see our contribution as complementary to those presented above.

The paper is structured as follows. Section 2 describes the two frameworks we deal with and highlights the relevant differences. Section 3 presents and discusses our empirical findings, with particular emphasis on the estimated degree of price indexation. Section 4 compares the prescriptions of our estimated models in terms of implementable simple policy rules. Section 5 scrutinizes further the two pricing schemes, and discusses the reasons of Calvo's superiority. Section 6 concludes, and draws some directions for further research.

2 The theoretical models

In this section we sketch a small-scale New-Keynesian model in the two versions of the Rotemberg (1982) and the Calvo (1983) price setting scheme. The model economy is composed of a continuum of infinitely-lived consumers, producers of final and intermediate goods. Households have the following instantaneous and separable utility function:

$$U\left(C_t, N_t\right) = \frac{C_{t+j}^{1-\sigma}}{1-\sigma} - d_n \frac{N_{t+j}^{1+\varphi}}{1+\varphi},$$

where C_t is a consumption basket (with elasticity of substitution among goods ε) and N_t are labor hours.

Final good market is competitive and the production function is given by $Y_t =$

$\left[\int_0^1 Y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$. Final good producers demand for intermediate inputs is therefore equal to $Y_{i,t+j} = \left(\frac{P_{i,t}}{P_{t+j}}\right)^{-\varepsilon} Y_{t+j}$. The intermediate inputs $Y_{i,t}$ are produced by a continuum of firms indexed by $i \in [0,1]$ with the following simple constant return to scale technology $Y_{i,t} = A_t N_{i,t}$, where labor is the only input and $\ln A_t = a_t$ is an exogenous productivity shock, which follows an AR(1) process. The intermediate good sector is monopolistically competitive.

2.1 Firms and Price Setting: Rotemberg (1982) vs. Calvo (1983)

The Calvo model

The Calvo price setting scheme assumes that in each period there is a fixed probability $1-\theta$ that a firm can re-optimize its nominal price, i.e., $P^*_{i,t}$. With probability θ, instead, the firm automatically and costlessy adjust its price according to an indexation rule. The price setting problem is:

$$\max_{P^*_{i,t}} \quad E_t \sum_{j=0}^{\infty} \mathcal{D}_{t,t+j}\theta^j \left[\frac{P^*_{i,t}\left(\bar{\pi}^{\chi j}\right)^{1-\mu}\left(\Pi^{\chi}_{t,t+j-1}\right)^{\mu}}{P_{t+j}} Y_{i,t+j} - MC^r_{i,t+j} Y_{i,t+j} \right], \tag{1}$$

$$\text{s.t. } Y_{i,t+j} = \left[\frac{P^*_{i,t}\left(\bar{\pi}^{\chi j}\right)^{1-\mu}\left(\Pi^{\chi}_{t,t+j-1}\right)^{\mu}}{P_{t+j}} \right]^{-\varepsilon} Y_{t+j} \text{ and} \tag{2}$$

$$\Pi_{t,t+j-1} = \begin{cases} \left(\frac{P_t}{P_{t-1}}\right)\left(\frac{P_{t+1}}{P_t}\right) \times \cdots \times \left(\frac{P_{t+j-1}}{P_{t+j-2}}\right) & \text{for } j = 1, 2, \cdots \\ 1 & \text{for } j = 0. \end{cases} \tag{3}$$

where $\mathcal{D}_{t,t+j} \equiv \beta^j \frac{Y_t}{Y_{t+j}}$ represents firms' stochastic discount factor, $MC^r_{i,t+j} = \frac{W_{i,t+j}}{P_{t+j}A_{t+j}}$ is the real marginal cost function, and $\bar{\pi}$ denotes the central bank's inflation target and it is equal to the level of trend inflation. The indexation scheme in (1) is very general. In particular: (i) $\chi \in [0,1]$ allows for any degree of price indexation; (ii) $\mu \in [0,1]$ allows for any degree of (geometric) combination of the two types of indexation usually employed in the literature: to steady state inflation (e.g., Yun, 1996) and to past inflation rates (e.g., Christiano et al., 2005).

In the Calvo price setting framework, prices are staggered because firms charging prices at different periods will set different prices. Then, in each given period t, there will be a distribution of different prices. Price dispersion results in an inefficiency loss in aggregate production. Formally:

$$N_t^d = \frac{Y_t}{A_t} \underbrace{\int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\varepsilon} di}_{s_t} = s_t \frac{Y_t}{A_t}. \tag{4}$$

Schmitt-Grohé and Uribe (2007) show that s_t is bounded below at one, so that s_t represents the resource costs due to relative price dispersion under the Calvo mechanism. Indeed, the higher s_t, the more labor N_t^d is needed to produce a given level of output. Note that price dispersion creates a wedge between aggregate output and aggregate employment. To close the model, the aggregate resource constraint is simply given by:

$$Y_t = C_t. \tag{5}$$

The Rotemberg model

The Rotemberg model assumes that a monopolistic firm faces a quadratic cost of adjusting nominal prices, that can be measured in terms of the final-good and given by:

$$\frac{\varphi_p}{2} \left(\frac{P_{i,t}}{\left(\pi_{t-1}^{\chi}\right)^{\mu} \left(\bar{\pi}^{\chi}\right)^{1-\mu} P_{i,t-1}} - 1 \right)^2 Y_t, \tag{6}$$

where $\varphi_p > 0$ determines the degree of nominal price rigidity. As stressed in Rotemberg (1982), the adjustment cost seeks to account for the negative effects of price changes on the customer-firm relationship. These negative effects increase in magnitude with the size of the price change and with the overall scale of economic activity, Y_t. As for the Calvo model, (6) includes a general specification for the adjustment cost used by, e.g., Ireland (2007), among others. In particular, the adjustment cost will depend on the ratio between the new reset price and the one set during the previous period, adjusted by a (geometric) combination of steady state inflation and of past inflation. The parameters μ and χ play a parallel role as in the indexation scheme in the Calvo model.

The problem for the firm i is then:

$$\max_{\{P_{i,t}\}_{t=0}^{\infty}} E_t \sum_{j=0}^{\infty} \mathcal{D}_{t,t+j} \left\{ \frac{P_{i,t+j}}{P_{t+j}} Y_{i,t+j} - MC_{i,t+j}^r Y_{i,t+j} - \frac{\varphi_p}{2} \left(\frac{P_{i,t+j}}{\left(\pi_{t+j-1}^{\chi}\right)^{\mu} \left(\bar{\pi}^{\chi}\right)^{1-\mu} P_{i,t+j-1}} - 1 \right)^2 Y_{t+j} \right\}, \tag{7}$$

$$\text{s.t. } Y_{i,t+j} = \left[\frac{P_{i,t+j}}{P_{t+j}} \right]^{-\varepsilon} Y_{t+j}, \tag{8}$$

where the notation is as above. Firms can change their price in each period, subject to the payment of the adjustment cost. Therefore, all the firms face the same problem, and thus will choose the same price and output. In other words the equilibrium is symmetric: $P_{i,t} = P_t, Y_{i,t} = Y_t$, $W_{i,t} = W_t$ and $MC_{i,t}^r = MC_t^r$ $\forall i$. Given this symmetry, and differently with respect to the Calvo model, in the Rotemberg model the aggregate production function features no inefficiency due to price dispersion, therefore:

$$Y_t = A_t N_t. \tag{9}$$

In the Rotemberg model, the adjustment cost enters the aggregate resource constraint, which creates an inefficiency wedge between output and consumption:

$$Y_t = \left[1 - \frac{\varphi_p}{2} \left(\frac{P_t}{\left(\pi_{t-1}^{\chi}\right)^{\mu} \left(\bar{\pi}^{\chi}\right)^{1-\mu} P_{t-1}} - 1 \right)^2 \right]^{-1} C_t = \Psi_t \; C_t. \tag{10}$$

Some key-differences between the Calvo and the Rotemberg model arise. In the Calvo model, the cost of nominal rigidities, i.e., price dispersion, creates a wedge between aggregate employment and aggregate output, making aggregate production less efficient. In the Rotemberg model, instead, the cost of nominal rigidities, i.e., the adjustment cost, creates a wedge between aggregate consumption and aggregate output, because part of the output goes in the price adjustment cost. As shown in Ascari and Rossi (2009), and evident from (4) and (10), both these wedges are *non-linear functions of inflation* and they increase with trend inflation. However, both wedges take the same unitary value under two particular cases: (i) a net steady state inflation equals zero, and/or (ii) full indexation to past or trend inflation.

2.2 The log-linearized frameworks

We now present the log-linearized versions of the two pricing frameworks we deal with (for a full derivation, see Ascari and Ropele, 2007, 2009, and Ascari and Rossi, 2009). Again, we stress that the derivation allows for a non-zero value for the inflation rate in steady state, which may be interpreted as the target pursued by the Federal Reserve in conducting the U.S. monetary policy.

The Calvo model

The Calvo model is described by the following first-order difference equations:

$$
\begin{aligned}
\Delta_t &= \left[\beta\bar{\pi}^{1-\varepsilon} + \eta\left(\theta - 1\right)\right]\Delta_{t+1|t} + \kappa\hat{y}_t - \lambda\varphi a_t + \lambda\varphi\hat{s}_t + \eta\widehat{\phi}_{t+1|t}, && (11)\\
\widehat{\phi}_t &= \left(1-\sigma\right)\left(1 - \theta\beta\bar{\pi}^{(\varepsilon-1)(1-\chi)}\right)\hat{y}_t + \theta\beta\bar{\pi}^{(\varepsilon-1)(1-\chi)}\left[\left(\varepsilon-1\right)\Delta_{t+1|t} + \hat{\phi}_{t+1|t}\right], && (12)\\
\widehat{s}_t &= \xi\Delta_t + \varepsilon\bar{\pi}^{\varepsilon(1-\chi)}\widehat{s}_{t-1}, && (13)\\
\hat{y}_t &= \phi_y\hat{y}_{t+1|t} + (1-\phi_y)\hat{y}_{t-1} - \sigma^{-1}\left(\widehat{i}_t - \widehat{\pi}_{t+1|t}\right) + g_t, && (14)
\end{aligned}
$$

where $\Delta_t \equiv \widehat{\pi}_t - \chi\mu\widehat{\pi}_{t-1}$, $\hat{\pi}$ stands for the inflation rate, $\hat{y}$ for detrended output, a is the technological shock, g is the demand shock. Hatted variables indicate percentage deviations with respect to steady state values or, in case of output, from a trend. The notation $x_{t+1|t}$ indicates the expectation in t of x_{t+1}. σ is the relative risk aversion parameter, φ the labor supply elasticity, β the discount factor, ε the Dixit-Stiglitz elasticity of substitution among goods, θ the Calvo parameter, χ the degree of price indexation, μ the relative weight of indexation to past inflation vs. trend inflation, and

$\bar{\pi}$ the steady-state, trend inflation rate. Finally, λ, η, κ, and ξ in eqs. (11)-(14) are the following convolutions of parameters:

$$
\begin{aligned}
\lambda &\equiv \frac{\left(1-\theta\bar{\pi}^{(\varepsilon-1)(1-\chi)}\right)\left(1-\theta\beta\bar{\pi}^{\varepsilon(1-\chi)}\right)}{\theta\bar{\pi}^{(\varepsilon-1)(1-\chi)}}, \\
\eta &\equiv \beta\left(\bar{\pi}^{1-\chi}-1\right)\left[1-\theta\bar{\pi}^{(\varepsilon-1)(1-\chi)}\right], \\
\kappa &\equiv \left(\lambda_{(\bar{\pi},\varepsilon)}\left(\sigma+\varphi\right)+\eta_{(\bar{\pi},\varepsilon)}\left(1-\sigma\right)\right), \\
\xi &\equiv \frac{\varepsilon\theta\bar{\pi}^{(\varepsilon-1)(1-\chi)}\left(\bar{\pi}^{1-\chi}-1\right)}{1-\theta\bar{\pi}^{(\varepsilon-1)(1-\chi)}},
\end{aligned}
$$

Notably, all the convolutions of the log-linearized model are a function of the trend inflation rate $\bar{\pi}$, that generally tends to increase the coefficients on the forward-looking variables (see Ascari, 2004, Yun, 2005, Hornstein and Wolman, 2005 and Kiley, 2007). Moreover, the log-linearized NKPC is influenced by the price dispersion process s_t. Under Calvo, just a fraction $(1-\theta)$ of firms is allowed to reoptimize in each period, then price dispersion arises. Under a strictly positive trend inflation rate, price dispersion assumes a first-order relevance and influences the evolution of the log-linearized inflation rate. Moreover, price dispersion has a backward-looking dynamics. The forward looking auxiliary process ϕ_t also participates to the determination of inflation.

The aggregate demand equation (14) is expressed in hybrid terms à la Fuhrer and Rudebusch (2004), with the parameter ϕ_y identifying the relative weight of expected output. This semi-structural, flexible version of the IS curve have successfully been employed by, among others, Benati (2008, 2009) and Benati and Surico (2008, 2009).

The Rotemberg model

The Rotemberg model is characterized by the following difference equations:

$$
\begin{aligned}
\hat{\pi}_t &= \gamma_p\hat{\pi}_{t-1}+\gamma_f\beta\hat{\pi}_{t+1|t}+\gamma_{dy}\beta\left(1-\sigma\right)\Delta\hat{y}_{t+1|t}+\gamma_{mc}\widehat{mc}_t, && (15) \\
\widehat{mc}_t &= \left(\sigma+\varphi\right)\hat{y}_t-\varsigma_c\sigma\hat{\pi}_t+\varsigma_c\sigma\mu\chi\hat{\pi}_{t-1}-(1+\varphi)a_t, && (16) \\
\hat{y}_t &= \phi_y\hat{y}_{t+1|t}+(1-\phi_y)\hat{y}_{t-1}-\varsigma_c\Delta\hat{\pi}_{t+1|t}+\varsigma_c\mu\chi\Delta\hat{\pi}_t-\sigma^{-1}\left(\hat{\imath}_t-\hat{\pi}_{t+1|t}\right)+g_t, && (17)
\end{aligned}
$$

where $\widehat{mc}$ stands for marginal costs, and the notation has the same interpretation as in the previous Subsection. The coefficients γ_p, γ_f, γ_{dy}, γ_{mc}, and ς_c are convolutions of the structural parameters of the model:

$$
\begin{aligned}
\varsigma_c &= \frac{\varphi_p\left(\bar{\pi}^{1-\chi}-1\right)\bar{\pi}^{1-\chi}}{\left[1-\frac{\varphi_p}{2}\left(\bar{\pi}^{1-\chi}-1\right)^2\right]}, \\
\frac{C}{Y} &= \left(1-\frac{\varphi_p}{2}\left(\bar{\pi}-1\right)^2\right) \\
\varrho &\equiv \left(2\bar{\pi}^{2(1-\chi)}-\bar{\pi}^{(1-\chi)}\right)\left(1+\beta\chi\mu\right)\frac{C}{Y}+\beta\left[\left(\bar{\pi}^{1-\chi}-1\right)\bar{\pi}^{1-\chi}\right]^2\sigma\varphi_p\left(1+\mu\chi\right), \\
\gamma_p &= \frac{\left(2\bar{\pi}^{2(1-\chi)}-\bar{\pi}^{(1-\chi)}\right)\chi\mu\frac{C}{Y}+\beta\left[\left(\bar{\pi}^{1-\chi}-1\right)\bar{\pi}^{1-\chi}\right]^2\sigma\varphi_p\mu\chi}{\varrho}, \\
\gamma_f &= \frac{\left(2\bar{\pi}^{2(1-\chi)}-\bar{\pi}^{(1-\chi)}\right)\frac{C}{Y}+\left[\left(\bar{\pi}^{1-\chi}-1\right)\bar{\pi}^{1-\chi}\right]^2\sigma\varphi_p}{\varrho} \\
\gamma_{dy} &= \frac{\left(\bar{\pi}^{2(1-\chi)}-\bar{\pi}^{1-\chi}\right)\frac{C}{Y}}{\varrho}, \\
\gamma_{mc} &= \frac{\left(\varepsilon-1+\varphi_p\left(\bar{\pi}^{2(1-\chi)}-\bar{\pi}^{1-\chi}\right)\left(1-\beta\right)\right)\frac{C}{Y}}{\varphi_p\varrho}.
\end{aligned}
$$

As often assumed in the literature,[8] it is possible to draw a relationship between the Rotemberg adjustment cost φ_p and the Calvo parameter θ imposing the condition $\varphi_p = \frac{(\varepsilon-1)\theta}{(1-\theta)(1-\beta\theta)}$ that implies the same first order dynamics of the two models in the case of zero steady state inflation. Such relationship will enable us to indirectly estimate the Rotemberg adjustment cost by focusing on the Calvo parameter θ and to use the very same prior densities for the structural parameters of the two models we ultimately aim at comparing, i.e. Calvo and Rotemberg.[9]

A few comments are in order. First, the impact of trend inflation is evident when looking at eqs. (15)-(17) and their convolutions of parameters. As in the Calvo model, trend inflation alters the inflation dynamics by directly affecting the NKPC coefficients. Higher trend inflation increases the coefficient relative to expected and past inflation

[8] See Rotemberg (1987) or Lombardo and Vestin (2009) for details.

[9] We also estimated a version of the Rotemberg model in which the adjustment cost is a free parameter, and verified no appreciable variations in the marginal likelihood.

as well as the coefficient of real marginal costs (Ascari and Rossi, 2009). Notice that the presence of past inflation in (15) is due to indexation to past inflation. With no indexation to past inflation, i.e. with $\mu = 0$, however, the coefficient γ_p equals zero and the NKPC becomes completely forward looking. Recall that this is not the case in the Calvo model, because even if past inflation disappears when $\mu = 0$, price dispersion dynamics introduces a backward-looking component. Furthermore, the expected difference of detrended output appears in the NKPC, eq. (15), because of the influence that trend inflation exerts over firms' discount factor.

Second, because of the presence of the price adjustment cost, in the Rotemberg model the log-linearized resource constraint can be written

$$\hat{c}_t = \hat{y}_t - \frac{\varphi_p \left(\bar{\pi}^{1-\chi} - 1\right) \bar{\pi}^{1-\chi}}{\left[1 - \frac{\varphi_p}{2} \left(\bar{\pi}^{1-\chi} - 1\right)^2\right]} \hat{\pi}_t + \frac{\varphi_p \left(\bar{\pi}^{1-\chi} - 1\right) \bar{\pi}^{1-\chi} \mu\chi}{\left[1 - \frac{\varphi_p}{2} \left(\bar{\pi}^{1-\chi} - 1\right)^2\right]} \hat{\pi}_{t-1}. \tag{18}$$

This equation shows that to a first order approximation the Rotemberg model: (i) implies a wedge between output and consumption; (ii) this wedge depends positively on current and past inflation level; (iii) the coefficients of $\hat{\pi}_t$ and $\hat{\pi}_{t-1}$ in (18) increase with trend inflation; (iv) the wedge disappears with zero steady state inflation rate or with full indexation, i.e. with $\chi = 1$. Such a wedge affects also the amount of resources produced in the economy. Consequently, the IS, eq. (17), features the first difference in inflation rates. The price adjustment cost causes the real marginal cost to depend also on actual inflation and past inflation (see the additional term $\varsigma_c \sigma \hat{\pi}_t$ and $\varsigma_c \sigma \mu \chi \hat{\pi}_{t-1}$ in (16)).

Notably, under the peculiar case of zero trend inflation, i.e., $\bar{\pi} = 1$, both the Rotemberg and the Calvo frameworks lines up with the standard hybrid New-Keynesian formulation allowing for price indexation to past/steady state inflation. The same holds true in a full indexation scenario, i.e. when $\chi = 1$.

To sum up, the different wedges which characterize the Calvo and the Rotemberg model induce three main differences in the two log-linearized representations. First, the

Calvo model displays price dispersion, which enters the NKPC as endogenous predetermined variable. By contrast, given the symmetry in the Rotemberg economy, price dispersion is absent in the Rotemberg model. Second, the presence of the price adjustment cost in the Rotemberg model causes the real marginal cost to depend also on actual and past inflation. Finally, the price adjustment cost generates a wedge between output and consumption in the resource constraint (10), which is reflected in the IS curve (17). As shown by Ascari and Rossi (2009), these differences are relevant from a policy standpoint, because of their impact on the definition of the determinacy territory associated to simple, implementable Taylor-type rules.

2.3 Closing the models

The two models are closed by a common set of equations, i.e.

$$\hat{\imath}_t = \alpha_i \hat{\imath}_{t-1} + (1-\alpha_i)(\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t) + m_t, \tag{19}$$

$$z_t = \rho_z z_{t-1} + \varepsilon_{zt}, \varepsilon_{zt} \sim N(0, \sigma_z^2), z \in \{a, g, m\}. \tag{20}$$

Eq. (19) is a standard policy rule postulating a smoothed reaction of the policy rate $\hat{\imath}_t$ to fluctuations in inflation and output, with stochastic deviations driven by the monetary policy shock m_t. Eq. (20) defines the stochastic properties of the mutually uncorrelated shocks hitting the system.

3 Econometric exercise

Our investigation focuses on U.S. data. We employ three "observables", i.e. the quarterly net growth rate of the GDP deflator π_t^{obs}, the log-deviation of real GDP with respect to its long run trend y_t^{obs},[10] and the net Federal Funds Rate ι_t^{obs}.[11] Our measure of detrended output, being mainly statistical, is robust to model misspecification, and it is also justified by the absence in this model of physical capital, which would probably return a severely misspecified model-consistent measure of natural output. Output proxies robust to model misspecification have recently been employed by, among others, Lubik and Schorfheide (2004), Boivin and Giannoni (2006), Benati (2008, 2009) and Benati and Surico (2008, 2009).[12]

Several authors (Clarida, Galí and Gertler, 2000, Lubik and Schorfeide, 2004, Boivin and Giannoni, 2006, Benati and Surico, 2009, and Mavroeidis, 2009) document a break in the U.S. monetary policy conduct in correspondence to the advent of Paul Volcker as chairman of the Federal Reserve. Changes in the U.S. macro-dynamics possibly consequential to such a monetary policy shift have also been investigated by D'Agostino, Giannone, and Surico (2006), Benati and Surico (2008) and Cogley, Primiceri, and Sargent (2009), who document a variation in inflation predictability when entering the 1980s, and by Castelnuovo and Surico (2009), who show how VAR impulse response functions may be affected by a drift towards a more hawkish monetary policy. Importantly, Coibion and Gorodnichenko (2009) show that the switch from multiple equilibria to uniqueness is supported also in a context in which trend inflation is allowed to be positive. In particular, they show that the U.S. economy has entered the unique equilibrium territory at the end of the "Volcker experiment" because i) the Fed has engaged in

[10] We employ the Hodrick-Prescott detrended output (relative weight of the smoothing component: 1,600). We conducted a robustness check in which we modeled output's low-frequency component with a piecewise quadratic trend with break date in 1973:I as suggested by Perron and Wada (2009). Our results turn out to be robust to the employment of this alternative business cycle proxy. More information is reported in our Appendix.

[11] The source of the data is the Federal Reserve Bank of St. Louis' website, i.e. http://research.stlouisfed.org/fred2/. Quarterly observations of the federal funds rate were constructed as averages of monthly observations. The detrended output and the policy rate were demeaned prior to estimation.

[12] For an alternative approach, based on a model-consistent treatment of the real GDP trend, see Smets and Wouters (2007), Justiniano and Primiceri (2008), and Castelnuovo and Nisticò (2009).

a stronger systematic reaction against inflation fluctuations *and* ii) trend inflation has fallen. Moreover, Goodfriend and King (2005) convincingly argue that the real effects of the Volcker disinflation occurred in the early 1980s are mainly due to its imperfect credibility, which is not modeled in our frameworks. Therefore, we condition our analysis on the "great moderation" period 1984:I-2008:II. Our end-of-sample choice enables us to avoid dealing with the acceleration of the financial crises began with the bankruptcy of Lehman Brothers in September 2008, which triggered non-standard policy moves by the Fed (Brunnermeier, 2009).

3.1 Bayesian inference and priors

We estimate the Calvo (11)-(14), (19)-(20) and the Rotemberg (15)-(17), (19)-(20) models with Bayesian techniques (see e.g. An and Schorfheide, 2007). Canova and Sala (2009) show that this technique is less prone to identification issues with respect to alternatives in the context of DSGE models. The Technical Appendix offers details on our estimation strategy.

The following measurement equations link our observables to the latent factors of our models:

$$\begin{bmatrix} \pi_t^{obs} \\ y_t^{obs} \\ \iota_t^{obs} \end{bmatrix} = \begin{bmatrix} \bar{\pi} - 1 \\ \overline{y} \\ \overline{\iota} \end{bmatrix} + \begin{bmatrix} \widehat{\pi}_t \\ \widehat{y}_t \\ \widehat{\iota}_t \end{bmatrix} \tag{21}$$

where $\overline{y}$ and $\overline{\iota}$ are the sample means of, respectively, detrended output and the federal funds rate, and π_t^{obs} is the observed net inflation rate.

Eq. (21) identifies the quintessence of a trend inflation model, i.e., its ability to shape the steady-state inflation rate. Clearly, different trend inflation values will lead to different empirical performances of the different models we will investigate. Our empirical investigation exactly aims at discriminating such models on the basis of their ability to replicate inflation's long-run value on top of its dynamics. Our microfounded models, which are log-linearized around a general trend inflation level, can treat trend inflation in a model consistent way. This consideration is important when searching for the encompassed "baseline New-Keynesian model". Indeed, an obvious way to collapse to such model would be that of setting the gross trend inflation rate $\bar{\pi} = 1$, so reconstructing the "zero-steady state" assumption typically employed in the literature when deriving such model. However, eq. (21) makes it clear that, while being logically grounded, this choice would force us to leave the mean of observed inflation unmodeled, so condemning the standard New-Keynesian model to a poor empirical performance. To circumvent this issue, one could demean observed inflation prior to estimation. However, this would probably penalize, in relative terms, the trend inflation models, one of their edges being their ability to model the first moment of observed inflation. To estimate the encompassed baseline, "zero trend inflation" framework, we then set the indexation parameter $\chi = 1$, as in Christiano et al. (2005). In doing so, we switch off the trend inflation-related "extra terms", and we mute the impact of trend inflation on the relative weights of inflation expectations and marginal costs in the NKPC and IS schedules. We can then assign a positive trend inflation rate (with which we model the inflation mean) to the baseline New-Keynesian model in a theoretically-consistent manner.

Our dogmatic priors and prior densities read as follows. We assume standard values for a sub-set of parameters, i.e. we set the discount factor β to 0.99, the elasticity of substitution among goods $\varepsilon = 6$, and the inverse of the labor elasticity φ to 1. To favor a smooth convergence towards the ergodic distribution, we fix the relative degree of indexation μ to 1, i.e., we concentrate on indexation to past inflation, in line with Benati (2009). We calibrate the steady state inflation rate by appealing to inflation's sample mean, i.e., $\bar{\pi} = 1.0063$, which translates to a net annual inflation target of about 2.5%.[13], and set $\bar{y} = 0.0012$ and $\bar{\imath} = 0.0131$ (sample means of the corresponding

[13] We conducted a battery of econometric exercises in which we estimated also the trend inflation rate. Our results turned out to be virtually unchanged.

observables employed in the estimation). Table 1 reports the standard prior densities for the estimated parameters.

3.2 Posterior densities and model comparison

Figure 1 displays the posterior densities of the structural parameters across the three models we focus on, i.e. the "baseline" model (featuring full indexation to past inflation), the Calvo model, and the Rotemberg model.[14] First, the data appear to be quite informative as regards two key parameters in the pricing context, i.e. the degree of indexation in Calvo and Rotemberg, and the degree of price stickiness in our three models. Indeed, different frameworks return different indications as regards these key-parameters, with Calvo pointing towards a lower indexation and a higher stickiness than Rotemberg. In general, the likelihood function turns out to be informative for most of the structural parameters of interest, the only exception being the reaction to output in the Taylor rule.

Table 1 collects our posterior estimates. The posterior means of the Calvo parameter and the degree of relative risk aversion are very standard. Interestingly, the IS curve turns out to be (almost) fully forward looking. The estimated Taylor rule parameters suggest a strong long-run systematic reaction to the inflation gap - in line with recent estimates provided by Blanchard and Riggi (2009) - and a more moderate reactiveness to output, both tempered in the short run by a fairly large amount of policy gradualism. As in previous studies, (e.g., Smets and Wouters, 2007), the estimated persistence of the technological shock is large.

In terms of model comparison, the marginal likelihood (computed with the modified harmonic mean estimator developed by Geweke, 1998) points towards the superiority of trend inflation-equipped frameworks.[15] The Bayes factor involving the baseline and

[14] Details on our estimation strategy and results are reported in our Appendix.

[15] Recall that, to assess the standard New-Keynesian model, we set $\chi = 1$ and allowed for a positive trend inflation so to model the first moment of observed inflation. An alternative strategy, often

the Calvo models (unrestricted) reads $exp(4.57) \approx 96.54$, which suggests a "strong" support for the trend inflation model.[16] Interestingly, the Rotemberg model is also supported by the marginal likelihood comparison, even if the wedge with the baseline New-Keynesian model is much smaller.

Conditional on a positive trend inflation rate, one may also detect two important differences when contrasting Calvo and Rotemberg. First, a comparison based on their power of fit speaks in favor of the Calvo model, with a log-difference that translates into a Bayes factor of about 13.46. Second, while both models point towards a degree of indexation clearly lower than 1 (the calibration suggested by e.g., Christiano et al., 2005), there is a clear difference in the estimated degree of indexation χ, an object whose microfoundation is theoretically scant. The estimated posterior mean associated to the Calvo model clearly points towards a negligible value for price indexation (0.15), and the 5th percentile is virtually zero. By contrast, the Rotemberg model calls for a more than double posterior mean, 0.38, the zero value does not belong to the standard 90% credible set, and it calls for a very high 95th percentile reading 0.72.

As already stressed, the theoretical justification for the introduction of indexation in a macroeconomic model is somewhat questionable. Moreover, as shown by Benati (2008 and 2009) and Cogley and Sbordone (2008), such a parameter is hardly structural in the sense of Lucas, so that policy exercises conducted with models appealing to indexation may very well be misleading. Then, our posterior estimates point to the Calvo model as

followed by researchers when estimating zero steady state inflation models, would have been that of demeaning the observed inflation rate prior to estimation and let the indexation parameter free. Admittedly, when doing so, we obtained a marginal likelihood equal to -33.24, i.e., very close to our estimated trend inflation models. But demeaning inflation in an a-priori fashion is logically inconsistent in our context. In fact, with partial indexation the coefficients of the log-linearized model would depend on the level of trend inflation. A priori-demeaning, thus, just "kills" one of the implications of the microfounded restrictions imposed by positive trend inflation on the framework, i.e., that of *jointly* modeling inflation's first moment and its dynamics. Consequently, we intentionally stick to our theoretically-consistent strategy when conducting our model comparison.

[16] According to Kass and Raftery (1995), a Bayes factor between 1 and 3 is "not worth more than a bare mention", between 3 and 20 suggests a "positive" evidence in favor of one of the two models, between 20 and 150 suggests a "strong" evidence against it, and larger than 150 "very strong" evidence.

the more appealing from a "structural" standpoint. To gauge the statistical relevance of the difference in the estimated indexation parameters, Figure 2 displays the distribution obtained by plotting 10,000 pairwise *differences* computed by subtracting the draws sampled from the posterior of the χ parameter under Calvo from those sampled from the posterior under Rotemberg. Positive draws from this distribution suggests a higher degree of indexation associated to Rotemberg with respect to Calvo. Notably, the larger part of the mass is clearly associated to positive realizations, with a share of about 82%. While the standard [5th pct, 95th pct] credible set includes the zero value, the stricter [25th pct,75th pct] credible set - recently employed by e.g. Cogley, Primiceri, and Sargent (2009) - does not. Thus, the data support a lower indexation parameter called for by the Calvo model.

The estimation of a constrained version of the two models, i.e., with the degree of indexation χ set to zero, also confirms the superiority of the Calvo model. As shown by Table 2, all the structural parameters display an appreciable stability across the different model versions. Interestingly, the marginal likelihood gives an even more clear indication: the fit of the Calvo framework improves (suggesting that indexation is just unwarranted), while the one of the Rotemberg set up deteriorates (suggesting this model needs the indexation assumption to fit the data at hand). Consequently, the Bayes factor, which in this case reads 188.67, leads to a more solid preference in favor of the Calvo model, i.e., a "very strong" evidence in the language of Kass and Raftery (1995).

3.3 Robustness checks

In comparing Calvo and Rotemberg, our empirical exercises support (i) trend inflation equipped models, (ii) the empirical superiority of the Calvo model, and (iii) the lower degree of indexation to past inflation called for by the Calvo model. These conclusions have been drawn by relying on some assumptions whose relevance for our findings deserves further scrutiny. Therefore, we performed some robustness checks along different relevant dimensions. With respect to the exercises documented in this Section, we considered (a) alternative calibrations of the trend inflation rate, i.e. 2% and 3%; (b) indexation to trend inflation, i.e. $\mu = 0$; (c) a more informative prior for the indexation parameter, i.e. $\chi \sim Beta(0.25, 0.10)$; (d) a different measure of inflation, i.e. the "inflation gap" computed by taking raw inflation in deviations with respect to its Hodrick-Prescott "trend". This exercise is conducted to account for possible drifts in trend inflation in the sample at hand; (e) a different proxy of the business cycle, computed by modeling output's low-frequency component with a piecewise quadratic trend with a break in 1973:I as suggested by Perron and Wada (2009); (f) alternative calibrations of the Frisch labor supply elasticity φ drawn from the interval $[0.5, 1.5]$. Our findings (i)-(iii) turn out to be robust to these perturbations. Our robustness checks are reported in the Appendix.

4 Policy implications

In their theoretical paper, Ascari and Rossi (2009) show that trend inflation enlarges the determinacy region in the Rotemberg model. Differently, a positive inflation rate in steady state shrinks the determinacy region under Calvo pricing. This difference is clearly of great importance from a policymaking perspective, in that the set of optimal and implementable simple policy rules (rules which do rule out self-fulfilling expectations leading to inefficient macroeconomic fluctuations) is clearly different under the two pricing schemes in presence of trend inflation (for an analysis on implementable optimal policy rules in models with trend inflation, see Schmitt-Grohé and Uribe, 2007).

Of course, different regions would emerge if different model calibrations were used. However, not all the possible regions enjoy the same likelihood from an empirical point of view. Then, we plot the determinacy regions conditional on our *estimated* models. We do so by calibrating each model we focus on with its estimated posterior means, with the exception of the Taylor parameters α_π and α_y, which we vary in order to explore each model's determinacy territory. This is equivalent to conditioning our exercise to the most plausible calibration (given the sample at hand) among the set of infinite parameterizations available. Our aim is to understand how relevant the difference in terms of determinacy regions is from an empirical standpoint.

We consider the best fitting versions of the Calvo and Rotemberg models, i.e. (i) the Calvo model with $\mu = 1$ and $\chi = 0$, and the (ii) the Rotemberg model with $\mu = 1$ and $\chi = 0.38$. To have a sense of the impact that trend inflation actually exerts on the determinacy regions, we also consider (iii) the baseline New-Keynesian model with $\chi = \mu = 1$, our "baseline" model. It is useful to recall that, under full indexation, Calvo and Rotemberg collapse to the same reduce-form dynamics, then the differences in terms of determinacy region disappear.

Figure 3 plots the determinacy regions of the three models. The baseline model, which is conditional on full indexation, recovers the standard Taylor principle to have a unique equilibrium under rational expectations: $\alpha_\pi > 1$. Our estimates, however, suggests that the degree of indexation is full neither under Calvo nor under Rotemberg pricing. Consequently, the determinacy regions under these two estimated frameworks look quite different. Indeed, the estimated Calvo model delivers a quite smaller determinacy region. This translates into a substantial reduction of the set of implementable rules, and calls for a hawkish behavior by monetary policymakers not to trigger self-fulfilling fluctuations. This prediction is in stark contrast with the one coming from the Rotemberg model, which suggests a counter-clockwise rotation conditional on the estimated degree of indexation (as well as the remaining structural parameters), and an enlargement of the set of policy rules which guarantee equilibrium uniqueness.

The stark difference in the determinacy regions naturally leads to a key policy-question: should the Fed's conduct return to be as hawkish as it used to be during the great moderation (before the advent of the recent financial turmoil)? Given the inflation-output volatility trade-off, an hawkish conduct may induce business cycle fluctuations which could be dampened under an alternative, more dovish policy behavior. The determinacy region associated to Rotemberg suggests that this behavior would not lead (to some extent) to indeterminacy. However, our empirical evidence offer stronger empirical support in favor of the Calvo model, which associate a higher likelihood of falling into a multiple equilibria scenario than Rotemberg. Unfortunately, under indeterminacy both inflation and output volatilities may increase (with respect to uniqueness) because of distortions in the monetary policy transmission mechanism (Lubik and Surico, 2008). Therefore, our empirical exercise offers a clear policy implication. Given that Calvo proves to be empirically superior to Rotemberg, policymakers should beware self-fulfilling fluctuations and stay hawkish.

5 Understanding the superior empirical performance of the Calvo model

The differences between Calvo and Rotemberg are fundamentally three: (i) the different order of the dynamics because of the presence of price dispersion $\widehat{s}_t$ and the auxiliary process $\widehat{\phi}_t$ in Calvo but not in Rotemberg; (ii) the different non-linear impact of trend inflation on the convolutions of the two systems; (iii) the different structure ("regressors") in the NKPC and IS schedules of the two models. We discuss each element in turn.

Price dispersion is an autoregressive process that might in principle explain the lower "request for price indexation" by Calvo. The auxiliary process, even if purely forward looking, might in principle be important in shaping the dynamics of the system. Figure

4 contrasts observed inflation with these two latent processes. When looking at the two top panels, which display raw processes, one may easily realize that such latent processes are hardly responsible for the superiority of the Calvo framework. Indeed, the price dispersion volatility (left column) is way lower than that of raw inflation. In contrast, the auxiliary process (right column) is extremely volatile. Of course, this does not imply that these processes are uncorrelated with raw inflation. The two bottom panels, which show standardized processes, make us appreciate the correlations between price dispersion and raw inflation (0.80) and the auxiliary process and inflation (0.60). Nevertheless, given the very different volatilities characterizing these processes, the explanatory power of these two processes is likely to be very low.[17] However, further investigations conducted over these latent processes to isolate their contribution for the description of the U.S. inflation rate turn out to be inconclusive. In particular, when switching these latent processes off and re-estimating our models, we do not observe any clear impact on the estimated parameters or a deterioration of the marginal likelihoods. Clearly, one should take this exercise with a grain of salt. Indeed, given the structure of the Calvo-model at hand, it is not possible to "mute" these latent processes in a theoretically coherent manner. We then leave the attempt to identify the role played by price dispersion for the description of raw inflation to future research.

The impact of trend inflation on the convolutions of our structural models is also unlikely to be responsible of the different between Calvo and Rotemberg. Cogley and Sbordone (2008) perform an exercise in which they shut down the impact of trend inflation on the convolutions of a NKPC estimated with U.S. data. They show that this restricted version of the NKPC tracks U.S. inflation equally well. Then, the edge of the Calvo model over Rotemberg is likely not to be given by the impact of trend

[17] Of course, a more volatile price dispersion process, possibly stochastic, could very well turn out to be a determinant of raw inflation. We leave the development of a model with a stochastic price dispersion process to future research.

inflation on the convolutions of the NKPC and the IS curve.

We are then left with the distinct structures of the two models. Recall that the two pricing schemes under scrutiny have different implications also as for the IS curves. This is due to the different implications on the relationship between consumption and output. We then implement an exercise to investigate if the difference between the two IS curves is responsible for the fit of the overall frameworks. In particular, we "swap" the different, theoretically based IS structures between the two models to check the consequences on the price indexation estimate and the model fit. To be clear, we estimate the "Calvo NKPC - Rotemberg IS" model set up, composed by eqs. (11)-(13), (17), (19), and (20), and the "Rotemberg NKPC - Calvo IS" model, which consists by eqs. (15)-(16), (14), (19), and (20).

This "swap" leads to some interesting findings. First, the estimated indexation parameter for the "Calvo NKPC - Rotemberg IS" turns out to be $\chi = 0.36$ $[0.03, 0.68]$ (posterior mean and 90% credible set), i.e., the indexation parameter more than double with respect to the trend inflation Calvo model. Moreover, the empirical fit deteriorates, with the marginal likelihood reading -35.52. On top of that, we detect a deterioration of about one log-point in the marginal likelihood when imposing the no-indexation constraint $\chi = 0.36$. Contrasting results emerge when moving to the estimation of the "Rotemberg NKPC - Calvo IS" set up, which returns $\chi = 0.17$ $[0, 0.35]$, with a marginal likelihood equal to -33.12, higher than the "Calvo NKPC - Rotemberg IS" framework. The imposition of the $\chi = 0$ constraint on this latter framework leaves the marginal likelihood basically unchanged.[18] These findings suggest that the assessment of the empirical abilities of the Calvo vs. Rotemberg frameworks must involve *all* the model equations, i.e. the study on the NKPCs *per se* is not exhaustive.

[18] We omit the presentation of the whole set of "Calvo NKPC - Rotemberg IS" and "Rotemberg NKPC - Calvo IS" estimates for the sake of brevity, but these results are available upon request.

6 Conclusions

This paper compares two New-Keynesian DSGE monetary models of the business cycle derived under different pricing schemes - Calvo (1983) and Rotemberg (1982) - and a positive trend inflation rate. We exploit the different reduced-form dynamics of the two models, derived in Ascari and Rossi (2009), to assess their relative empirical fit for the 1984:I-2008:II U.S. data.

Several findings arise. First, we find empirical support in favor of trend inflation-endowed models as opposed to models derived under the commonly used "zero inflation in steady state" assumption. Second, the data support the Calvo model as the better fitting pricing scheme as opposed to Rotemberg. This superiority is suggested both by comparisons based on marginal likelihoods and by the economic plausibility of the estimates we obtain. In particular, we find the estimated degree of indexation in the Calvo model to be statistically zero, in line with the results in Cogley and Sbordone (2008) and Benati (2009). This is a *plus* of the Calvo model with trend inflation, in that price indexation is theoretically questionable and empirically at odds with micro-data evidence (Bils and Klenow, 2004, and Nakamura and Steinsson, 2008). Interestingly, Calvo's superior empirical performance is related to the different cross-equation restrictions affecting the demand-side of the economy with respect to Rotemberg's. This result stresses the importance of conducting empirical investigations with a fully structural system, rather than only with a NKPC generated from a particular price setting mechanism. Third, we show that the sets of implementable rules ruling out self-fulfilling fluctuations are different between the two models. In particular, the indeterminacy region associated to the Calvo model is significantly smaller than that associated to Rotemberg. A clear policy implication arises: given that Calvo proves to be empirically superior to Rotemberg, policymakers should beware self-fulfilling fluctuations and stay hawkish.

All in all, this paper offers support to the Calvo pricing scheme for the modeling of inflation dynamics from a macroeconomic perspective. Admittedly, the Calvo-parameter is hardly structural, and the policy implications stemming from the Calvo-world should be carefully assessed. While offering some empirical support to the Calvo-mechanism conditional on their micro-data analysis, Costain and Nakov (2008) call for further explorations of state-dependent pricing models, which can potentially provide policy-makers with more reliable policy suggestions. We are sympathetic with this call, and welcome contributions engaging in the design of more realistic pricing schemes.

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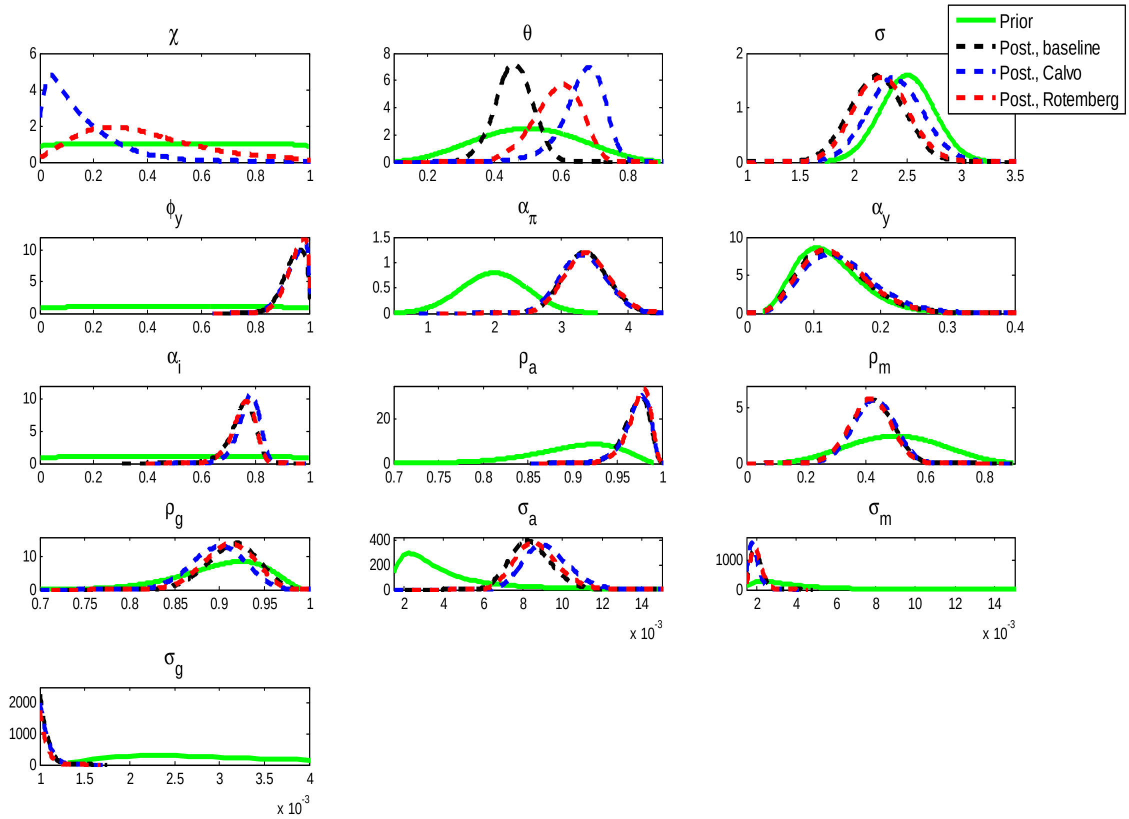

Figure 1: **Prior and posterior densities.** 'Baseline' model: Full indexation. 'Calvo' and 'Rotemberg': See description in the text. Models estimated under a 2.5 per cent trend inflation net rate (yearly rate, percentualized) and indexation to past inflation.

Param.	*Description*	*Prior Distr.*	*Prior Mean* (*St.dev.*)	*Posterior Mean* [5th pct, 95th pct]				
				NK χ=1	*Calvo*	*Rotemb.*	*Calvo* χ=0	*Rotemb.* χ=0
χ	Indexation	Beta	0.50 (0.285)	1.00 [–]	0.15 [0.00,0.34]	0.38 [0.03,0.72]	0.00 [–]	0.00 [–]
θ	Calvo	Beta	0.50 (0.15)	0.46 [0.37,0.54]	0.66 [0.56,0.76]	0.59 [0.48,0.70]	0.70 [0.63,0.77]	0.65 [0.58,0.72]
σ	Risk aversion	Normal	2.50 (0.25)	2.21 [1.80,2.61]	2.38 [1.97,2.81]	2.25 [1.85,2.67]	2.43 [2.01,2.83]	2.23 [1.83,2.62]
ϕ_y	Euler eq. f. look.	Beta	0.50 (0.285)	0.94 [0.89,1.00]	0.94 [0.89,1.00]	0.95 [0.90,1.00]	0.95 [0.89,1.00]	0.96 [0.92,1.00]
α_π	T. rule inflation	Normal	2.00 (0.50)	3.36 [2.79,3.88]	3.32 [2.75,3.87]	3.39 [2.85,3.96]	3.31 [2.73,3.87]	3.46 [2.90,4.00]
α_y	T. rule output	Gamma	0.125 (0.05)	0.13 [0.05,0.20]	0.14 [0.06,0.22]	0.13 [0.05,0.21]	0.14 [0.06,0.23]	0.13 [0.05,0.21]
α_i	T. rule smooth.	Beta	0.50 (0.285)	0.75 [0.68,0.83]	0.77 [0.71,0.84]	0.75 [0.69,0.82]	0.78 [0.73,0.84]	0.75 [0.69,0.82]
ρ_a	Tech. shock pers.	Gamma	0.90 (0.05)	0.97 [0.94,0.99]	0.97 [0.95,0.99]	0.97 [0.95,0.99]	0.97 [0.95,0.99]	0.98 [0.96,0.99]
ρ_m	M. pol. shock pers.	Beta	0.50 (0.15)	0.42 [0.31,0.53]	0.42 [0.32,0.54]	0.41 [0.30,0.52]	0.42 [0.31,0.53]	0.37 [0.30,0.47]
ρ_g	IS shock pers.	Gamma	0.90 (0.05)	0.91 [0.87,0.96]	0.90 [0.85,0.95]	0.90 [0.87,0.95]	0.89 [0.84,0.94]	0.91 [0.87,0.96]
σ_a	Tech. shock std	IGamma	0.005 (2.00)	0.0084 [0.0067,0.0101]	0.0092 [0.0095,0.0111]	0.0087 [0.0070,0.0105]	0.0094 [0.0075,0.0113]	0.0087 [0.0070,0.0103]
σ_m	M. pol. shock std	IGamma	0.005 (2.00)	0.0020 [0.0015,0.0025]	0.0019 [0.0014,0.0023]	0.0020 [0.0015,0.0025]	0.0018 [0.0014,0.0022]	0.0020 [0.0016,0.0025]
σ_g	IS shock std	IGamma	0.005 (2.00)	0.0009 [0.0007,0.0011]	0.0009 [0.0007,0.0011]	0.0008 [0.0007,0.0010]	0.0009 [0.0007,0.0011]	0.0008 [0.0007,0.0010]
Marg.Lik.				−37.54	−32.97	−35.57	−31.29	−36.53

Table 1: **Priors and posteriors for structural parameters.** Models estimated under a 2.5 per cent trend inflation net rate (yearly rate, percentualized) and indexation to past inflation. The Table reports the posterior means and the [5th,95th] percentiles. The Marginal Likelihood are computed with the modified harmonic mean estimator by Geweke (1998). Details on the model estimation are reported in the text.

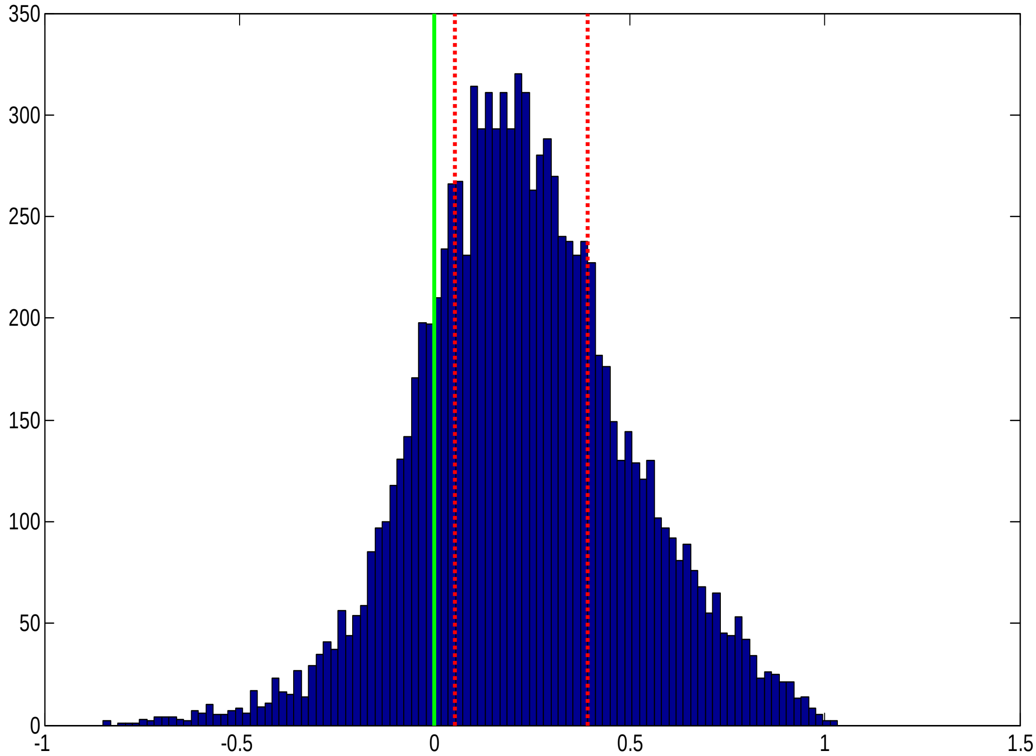

Figure 2: **Indexation: Difference between densities.** Green vertical line: zero line. Red dotted vertical lines: 25th and 75th percentiles.

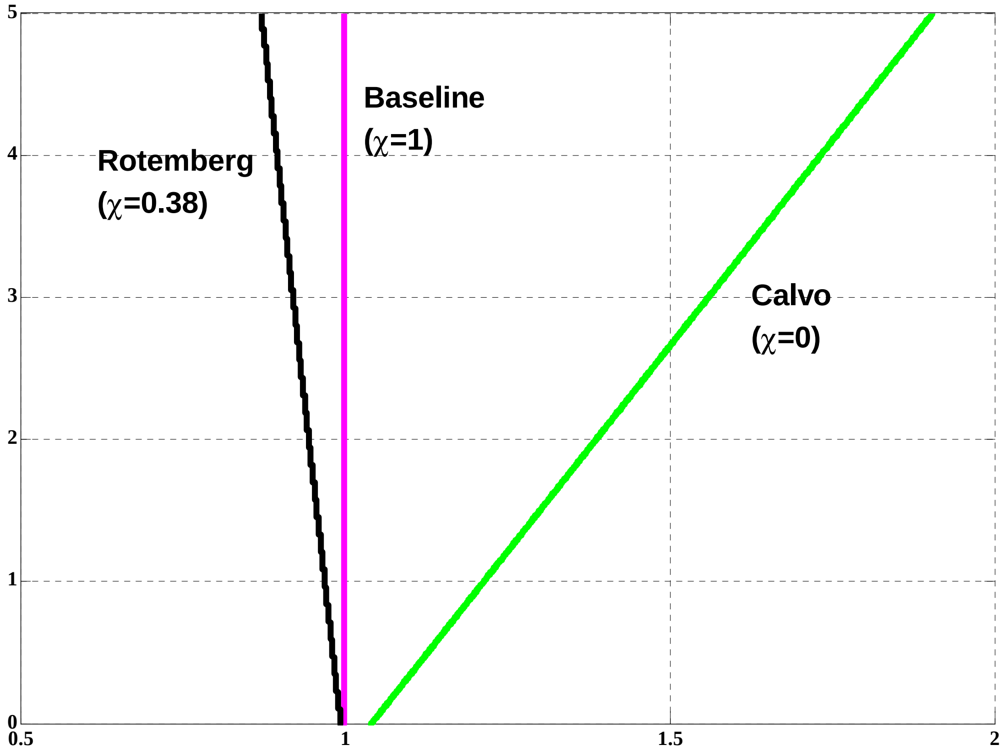

Figure 3: **Determinacy under different frameworks.** Determinary regions lie at the right of the model-consistent boundaries.

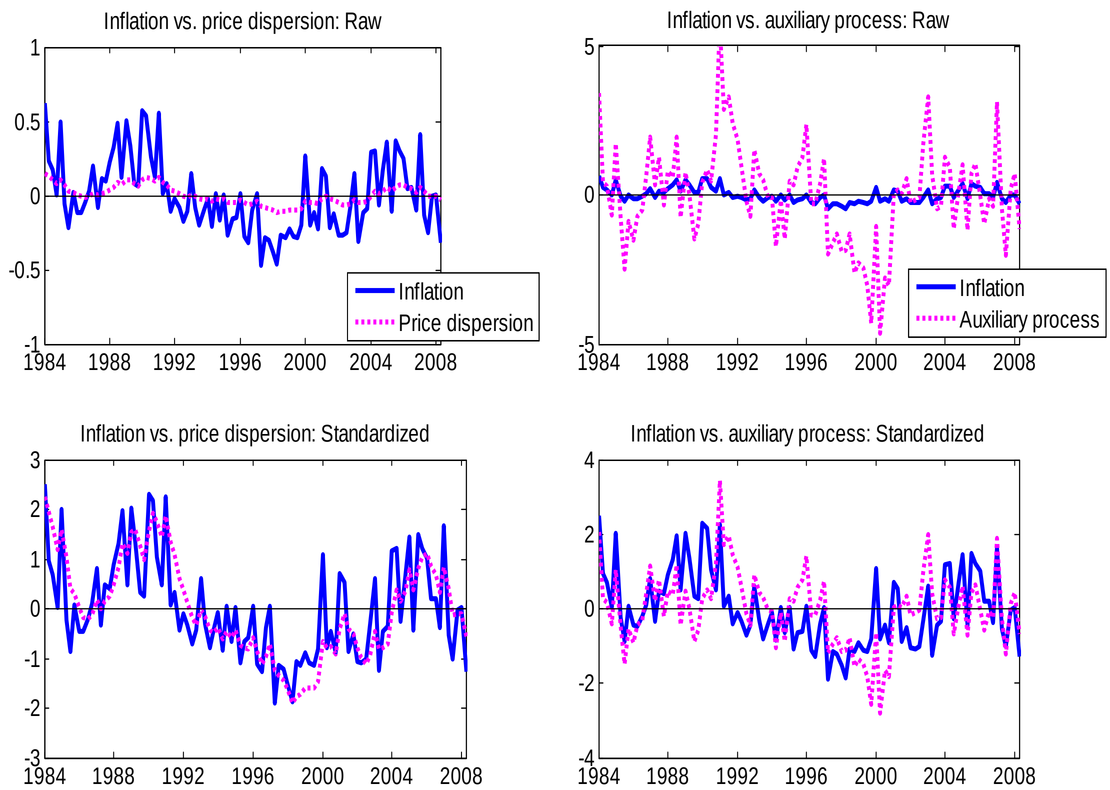

Figure 4: **Calvo model: Inflation vs. latent factors.** Filtered factors estimated under 2.5 per cent trend inflation and zero indexation.