# Nominal Frictions and Optimal Monetary Policy

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### **1. INTRODUCTION**

The modern modeling research on macroeconomics combines micro-foundations of both households and firms optimisation problems and with a large collection of both nominal and real (price/wage) rigidities that provide plausible short-run dynamic macroeconomic fluctuations with a fully articulated description of the monetary-cum-fiscal policy transmission mechanism; see, for instance, Christiano, et al. (2005) and Smets and Wouters (2003). The key advantage of this area of research over traditional reduce form macroeconomic models, is that the structural interpretation of their parameters allows to overcome the famous Lucas critique (1976). Traditional models contained equations linking variables of interest of explanatory factors such as economic policy variables. One of the uses of these models was therefore to examine how a change in economic policy affected these variables of interest, other things being equal. Based on these advantages there has been a growing interest in academics, international policy institutions and central banks in developing small-to-medium, even large-scale, both closed and open economy DSGE models based on new-Keynesian framework. In using DSGE models for practical purposes and to recommend how central banks and policy institutions should react to the short-run fluctuations, it is necessary to first examine the possible sources, as well as to evaluate the degree of nominal and real rigidities present in the economy. As price stability is the primary objective of every central bank so it is an important task to model inflation dynamics with its associated nominal rigidities using DSGE models carefully.

Therefore the core objective of this paper is to consider various nominal frictions, especially price stickiness with its alternative representations of the inflation dynamics, each one having formal microeconomic foundations. To learn dynamics of this friction associated with each representation we considered four competing closed economy DSGE models: a standard Calvo type pricing model; Hernandez's (2004) state-dependent pricing model; Mankiw and Reis (2002) standard sticky information model; and a mixed version of sticky price-information model. Each model incorporates various other standard New-Keynesian features such as habit formation, costs of adjustment in capital accumulation and variable capacity utilisation. While in the standard Calvo (1983) model, some prices are exogenously fixed for certain periods and the Phillips curve associated it performs badly to reproduce the gradual and delayed effects of monetary shocks on inflation. Mankiw and Reis (2002) propose to replace it with a Sticky

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information model. In that last specification, firms face some frictions while updating their information sets to determine the optimal flexible price.

However, in the two cases, the frequency of price revisions is constant and without cost. Price-setters cannot respond to shocks in the economy between price revisions. In such a context, literature on state-dependent pricing [e.g. Dotsey, *et al.* (1999)] allows firms either to evaluate in every period if it is convenient to change their price contracts or to keep them unchanged given a random cost. So we also simulate the performance of the Hernandez's (2004) model which combines state-dependent and time-dependent features in the firms pricing scheme is investigated as a natural extension of the Calvo model. Finally for each model, the Ramsey allocation has been computed, giving a natural benchmark for welfare comparisons.

The remainder of the paper is structured as follows. Section 2 gives an outline of Common theoretical framework. In Section 3 he main different responses observed across each specification essentially by the nature of nominal rigidities. The methodologies and empirical setup are discussed in Section 4. Section 5 describes the estimation results and finally we bring to a close in Section 6 with concluding remarks and possible model extensions.

#### 2. COMMON THEORETICAL FRAMEWORK

The following relationships are common to all models in the specification of the economy. These specifications are similar to Christiano, *et al.* (2005) and Smets and Wouters (2003). The main features of the closed economy DSGE model are habit formation in consumption, capital adjustment costs and a large number of shocks essential for the fit with data. Such a common framework is a mean to obtain comparable New Keynesian Phillips curves and to explain the main different responses observed across each specification essentially by the nature of nominal rigidities.

#### 2.1. Households Preferences

The economy is inhabited by a representative household (*h*) who derives its utility from consumption  $C_t$ , and leisure  $1-L_t$ . At time *t*, its preferences are described by an intertemporal utility function:

$$U_{t}(h) = E_{t}\left(\sum_{j=0}^{\infty} \beta^{j} [U_{1}(C_{t}, H_{t}) - U_{2}(L_{t})] \varepsilon_{t+j}^{B}\right)$$

Where,

$$U_{1}(C_{t}, H_{t}) = \frac{1}{1 - \varsigma_{c}} \left( C_{t+j}(h) - \upsilon C_{t+j-1}(h) \right)^{1 - \varsigma_{c}} \quad \text{and} \\ U_{2}(L_{t}) = \frac{\varepsilon_{t+j}^{L} \xi}{1 + \varsigma_{t}} \left( L_{t+j}(h) \right)^{1 + \varsigma_{L}}$$

Where  $\beta_t \in (0,1)$  is the intertemporal discount factor which describe rate of time preferences,  $\zeta_c$  is the inverse of the elasticity of intertemporal substitution in

consumption and  $\zeta_L$  is the inverse of wage elasticity of labour supply. We introduce external habit formation for the optimisation household as  $H_t = \upsilon C_{t+j-1}(h)$  with degree of intensity indexed by  $\upsilon$ , where  $C_{t+j-1}$  is the aggregate part of consumption index. Utility also incorporates a consumption preference shock  $\varepsilon_{t+j}^B$  and a labour supply shock  $\varepsilon_{t+j}^L$ .  $\xi$  is the scale parameter. As usual, it is assumed that,  $\zeta_c > 0$  and  $\zeta_L > 1$ .

Each household h maximises its utility function under the following budgetary constraint:

$$\frac{B_t(h)}{P_t(1+i_t)} + C_t(h) + I_t(h) = \frac{B_{t-1}(h)}{P_t} + \frac{(1-\tau_{w,t})W_t(h)L_t(h) + A_t(h) + T_t(h)}{P_t} + r_t^k u_t(h)K_t(h) - \Phi(u_t(h))K_t(h)$$

Where  $B_t(h)$  is a nominal bond,  $W_t(h)$  is the nominal wage,  $A_t(h)$  is a stream of income coming from state contingent securities,  $T_t(h)$  and  $\tau_{w,t}$  are government transfers and time-varying labour tax respectively, and  $r_t^k u_t(h)K_t(h) - \Phi(u_t(h))K_t(h)$  represents the return on the real capital stock minus the cost associated with variations in the degree of capital utilisation. As in Christiano, *et al.* (2005), the income from renting out capital services depends on the level of capital augmented for its utilisation rate. The cost of capacity utilisation is zero when capacity are fully used ( $\Phi(1) = 0$  and  $\Phi'(1), \Phi''(1) \ge 0$ ).

Separability of preferences and complete financial markets ensure that households have identical consumption plans. The first order condition related to consumption expenditures is given by:

$$\lambda_t = \varepsilon_t^B (C_t - \upsilon C_{t-1})^{-\varsigma_c} - \beta \upsilon E \bigg[ \varepsilon_t^B (C_{t+1} - \upsilon C_t)^{-\varsigma_c} \bigg] \qquad \dots \qquad \dots \qquad (1)$$

Where  $\lambda_t$  is the Lagrange multiplier associated with the budget constraint. First order conditions corresponding to the quantity of contingent bonds implies that:

$$\lambda_t = (1+i_t)\beta E_t \left[\lambda_{t+1} \frac{P_t}{P_{t+1}}\right] \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad (2)$$

Where  $i_t$  is the one-period-ahead nominal interest rate.

#### 2.2. Labour Supply and Staggered Wage Settings

Each household is a monopoly supplier of a differentiated labour service. For the sake of simplicity, we assume that he sells his services to a perfectly competitive firm which transforms it into an aggregate labour input using the following technology:

$$L_t = \left[ \int_0^1 \frac{h^{\frac{1}{\mu w}}}{t} dh \right]^{\mu w}$$

The household faces a labour demand curve with constant elasticity of substitution:

$$L_t(h) = \left[\frac{W_t(h)}{W_t}\right]^{\frac{-\mu w}{\mu w - 1}} L_t$$

Where:

$$W_t = \left[\int_0^1 W_t(h)^{\frac{1}{1-\mu w}} dh\right]^{1-\mu w}$$

is the aggregate wage rate.

Households set their wage on a staggered basis. Each period, any household faces a constant probability  $1-\alpha_w$  of changing its wage. In such a case, the wage is set to  $\tilde{w}_t$  which is the same for all suppliers of labour services, taking into account that it will not be re-optimised in the near future. Otherwise, wages are adjusted following an indexation rule on past inflation and central bank objective:

$$W_t(h) = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\zeta_w} \left(\frac{\overline{P}_t}{\overline{P}_{t-1}}\right)^{1-\zeta_w} W_{t-1}^h$$

$$\pi_t = \frac{P_t}{P_{t-1}}$$
 denotes one plus the GDP deflator inflation rate while  $\overline{\pi}_t = \frac{P_t}{P_{t-1}}$  denotes one

plus the inflation objective of the central bank and  $\zeta_w$  is fraction of wage.

Notice that among the fraction of wage setters, which cannot re-optimise in period t; each nominal wage appears with the same frequency as in the t-1 distribution after controlling for the common indexation on inflation rates. This property crucially hinges on the fact that each wage has an equal probability of being adjusted in a given period.

Consequently, the dynamics of the aggregate wage index is given by:

$$\begin{split} & W_{t}^{\frac{1}{1-\mu w}} = \int_{0}^{1} W_{t}(h)^{\frac{1}{1-\mu w}} dh \\ & = \alpha_{w} \left[ \pi_{t-1}^{\zeta_{w}} \overline{\pi}^{1-\zeta_{w}} \right]^{\frac{1}{1-\mu w}} \int_{0}^{1} W_{t-1}(h)^{\frac{1}{1-\mu w}} dh + (1-\alpha_{w}) (W_{t}^{*})^{\frac{1}{1-\mu w}} \\ & = \alpha_{w} \left[ \pi_{t-1}^{\zeta_{w}} \overline{\pi}^{1-\zeta_{w}} W_{t-1} \right]^{\frac{1}{1-\mu w}} + (1-\alpha_{w}) (W_{t}^{*})^{\frac{1}{1-\mu w}} \end{split}$$

Each household chooses  $\tilde{W}_t$  in order to maximise:

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$$E_{t}\sum_{j=0}^{\infty}(\beta\alpha_{w})^{j} \left\{ (1-\tau_{w,t+j})L_{t+j}(h)\lambda_{t+j}\frac{W_{t}^{*}}{P_{t}}\frac{P_{t}}{P_{t+j}}\left(\frac{P_{t-1+j}}{P_{t-1}}\right)^{\zeta_{w}}\overline{\pi}^{j(1-\zeta_{w})} \right\} \\ -\varepsilon_{t+j}^{B}\varepsilon_{t+j}^{L}\xi\left(\frac{(L_{t+j}^{h})^{1+\varsigma_{L}}}{1+\varsigma_{L}}\right) \right\}$$

Given that the demand for differentiated labour service for wage setters who cannot re-optimise after period *t*, becomes:

$$\begin{split} L_{t+j}(h) &= \left[\frac{W_{t+j}(h)}{W_{t+j}}\right]^{\frac{-\mu w}{\mu w-1}} L_{t+j} \\ &= \left[\frac{W_t^*}{P_t}\right]^{\frac{-\mu w}{\mu w-1}} \left(\frac{P_t}{P_{t+j}} \left(\frac{P_{t-l+j}}{P_{t-1}}\right)^{\xi_w} \bar{\pi}^{f(l-\xi_w)}\right)^{\frac{-\mu w}{\mu w-1}} \left(\frac{W_{t+j}}{P_{t+j}}\right)^{\frac{-\mu w}{\mu w-1}} L_{t+j} \end{split}$$

Thus, the first order condition for the re-optimised wage verifies:

$$E_t \sum_{j=0}^{\infty} (\beta \alpha_w)^j \begin{cases} (1 - \tau_{w,t+j}) \lambda_{t+j} \frac{W_t^*}{P_t} \frac{P_t}{P_{t+j}} \left( \frac{P_{t-1+j}}{P_{t-1}} \right)^{\zeta_w} \overline{\pi}^{j(1-\zeta_w)} \\ -\mu_w \varepsilon_{t+j}^B \varepsilon_{t+j}^L \xi(L_{t+j}^h)^{\varsigma_L} \end{cases} = 0$$

Let us denote  $\tilde{w}_t$  as the real wage. The previous equation can therefore be rewritten as:

$$\frac{W_t^*}{P_t} = \left[\mu_w \frac{Z_{W1,t}}{Z_{W2,t}}\right]^{\frac{\mu w - 1}{\mu w (1 + \varsigma_K) - 1}}$$

With

$$Z_{W1,t} = \varepsilon_t^B \varepsilon_t^L L_t^{1+\varsigma_L} w_t + \alpha_w \beta E_t \left[ \left( \frac{\pi_{t+1}}{\pi_t^{\xi_w} \overline{\pi}^{1-\xi_w}} \right)^{\frac{\mu w(1+\varsigma_K)}{\mu w-1}} Z_{W1,t+1} \right] \qquad \dots \qquad \dots \qquad (3)$$

and

$$Z_{W2,t} = (1 - \tau_{w,t})\lambda_t L_t w_t^{\frac{\mu_w}{\mu_w - 1}} + \alpha_w \beta E_t \left[ \left( \frac{\pi_{t+1}}{\pi_t^{\xi_w} \overline{\pi}^{1 - \xi_w}} \right)^{\frac{1}{\mu_w - 1}} Z_{W2,t+1} \right] \qquad \dots \qquad \dots \qquad (4)$$

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Accordingly, the aggregate wage dynamics leads to the following relation.

$$w_t^{\frac{1}{1-\mu w}} = (1-\alpha_w) \left[ \mu_w \frac{Z_{W1,t}}{Z_{W2,t}} \right]^{\frac{-1}{\mu w(1+\zeta_K)-1}} + \alpha_w w_{t-1}^{\frac{1}{1-\mu w}} \left[ \frac{\pi_t}{\pi_{t-1}^{\xi_w} \pi^{1-\xi_w}} \right]^{\frac{-1}{1-\mu w}} \dots (5)$$

#### 2.3. Investment Dynamics

As in Smets and Wouters (2003), we introduce a delayed response of investment observed in the data. Capital producers combine existing capital,  $K_t$ , leased from the entrepreneurs to transform an input  $I_t$ , gross investment, into new capital according to:

$$K_{t+1} = (1-\delta)K_t + \left[1 - S\left(\frac{I_t E_t^I}{I_{t-1}}\right)\right]I_t \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad (6)$$

Where  $I_t$  is gross investment,  $\delta$  is the depreciation rate and the adjustment cost function  $S(\bullet)$  is a positive function of changes in investment.  $S(\bullet)$  equals zero in steady state with a constant investment level (S(1) = 0). In addition, we assume that the first derivative also equals zero around equilibrium, so that the adjustment costs will only depend on the second-order derivative ( $S''(\bullet)$  as in Christiano, *et al.* (2005). We also introduced a shock to the investment cost function, which is assumed to follow a first-order autoregressive process with an *IID*-Normal error term:  $E_t^I = \rho_I E_{t-1}^I + \eta_t^I$ .

Households choose the capital stock, investment and the capacity utilisation rate in order to maximise their intertemporal utility function subject to the intertemporal budget constraint and the capital accumulation. The first-order conditions result in the following equations for the real value of capital, investment and the capacity utilisation rate:

$$Q_{t} = E_{t} \left[ \beta \frac{\Lambda_{t+1}}{\Lambda_{t}} \left( Q_{t+1}(1-\delta) + R_{t+1}^{k} C U_{t+1} - \Phi(C U_{t+1}) \right) \right] E_{t}^{Q} \qquad \dots \qquad (7)$$

The value of installed capital depends on the expected future value taking into account the depreciation rate and the expected future return as captured by the rental rate times the expected rate of capital utilisation.

$$1 = Q_t \left[ 1 - S \left( \frac{I_t}{I_{t-1}} \right) - \frac{I_t}{I_{t-1}} S' \left( \frac{I_t}{I_{t-1}} \right) \right] E_t^I$$
  
+  $\beta E_t \left[ Q_{t+1} \frac{\Lambda_{t+1}}{\Lambda_t} \left( \frac{I_t + 1}{I_1} \right) S'' \left( \frac{I_t + 1}{I_1} \right) E_{t+1}^I \right]$  ... (8)

$$R_t^K = \Phi'(CU_t) \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad (9)$$

Where,  $R_t^K$  is rental rate of capital and  $E_t^I$  can be interpreted as a shock to the relative price of investment while  $E_t^Q$  accounts for fluctuations of the external finance risk premium.

#### 2.4. Firms Behaviour

Intermediate goods are produced with a Cobb-Douglas technology as follows:

$$Y_t(h) = E_t^A \left( CU_t(h) K_{t-1}(h) \right)^{\alpha} L_t(h)^{1-\alpha} - \Omega \qquad \forall h \in (0,1)$$

Where  $E_t^A$  is an exogenous technology parameter and  $\Omega$  is a fixed cost. Firms are monopolistic competitors and produce differentiated products an aggregate final good that may be used for consumption and investment. This production is obtained using a continuum of differentiated intermediate goods with the following Dixit and Stiglitz (1977) production technology:

Where  $\mu = \frac{\theta_P}{\theta_P - 1}$  and  $\theta_P > 1$  is the elasticity of substitution between differentiated

goods. The representative final good producer maximises profits  $P_t Y_t - \int_0^1 P_t(z) Y_t(z) dh$ 

subject to the production function (10), taking as given the final good price  $P_t$  and the prices of all intermediate goods. The first order condition for this problem is:

$$Y_t(z) = \left[\frac{P_t(z)}{P_t}\right]^{\frac{-\mu}{\mu-1}} Y_t \qquad \forall z \in (0,1) \qquad \dots \qquad \dots \qquad (11)$$

Finally, as the sector is perfectly competitive, the zero profit condition holds and the expression for  $P_t$  is:

$$P_t = \left[\int_0^1 P_t(z)^{1/1-\mu} dh\right]^{1-\mu}$$

### 2.5. Government

Public expenditures  $\overline{\overline{G}}^{G}$  are subject to random shocks  $E_t^G$ . The government finances public spending with labour tax, product tax and lump-sum transfers are expressed as:

$$P_t \overline{G} E_t^G - \tau_{W,t} W_t L_t - \tau_t P_t Y_t - P_t T T_t = 0 \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad (12)$$

The government also controls the short term interest rate  $R_t$ . Monetary policy is specified in terms of an interest rate rule: the monetary authority follows generalised Taylor rules which incorporate deviations of lagged inflation and the lagged output gap defined as the difference between actual and flexible-price output. Such reaction functions also incorporate a non-systematic component:  $E_t^G$ .

### 3. PRICE SETTING MODELS AND OPTIMAL MONETARY POLICY

This section presents the baseline version of the standard Calvo, State Dependent Pricing (SDP) and the Sticky Information (SI) models of price setting as different nominal rigidities modelling strategies. Furthermore, optimal monetary policy principle is also included in this section.

#### 3.1. Models Based on Price Stickiness

In this section we describe two competing models based on price stickiness; (a) a standard Calvo (1983) type price stickiness model, and (b) a recent extension by Hernandez's (2004): state dependent pricing model. Both these models capture the fundamental notion of staggered price mechanism and translate them into New Keynesian Phillips curve.

#### 3.1.1. Standard Calvo (1983) Model

In each period, firms receive a random signal with constant probability  $1 - \alpha_p$  that allows them to change the price  $p_t^*$ . This probability is independent across firms and time. The average duration of a rigidity period is  $\frac{1}{1-\alpha_p}$ . If a firm cannot re-optimise its price, the

price evolves according to the following simple rule:  $p_t(h) = \prod_{t=1}^{\xi_p} \overline{\Pi}_t^{1-\xi_p} p_{t-1}(h)$ .

Firms that are allowed to change their price maximise expected profit:

$$E_{t}\left[\sum_{j=0}^{\infty}\alpha_{p}^{j}\Xi_{t,t+j}\left((1-\tau_{t+j})\tilde{p}_{t}(h)Y_{t+j}(h)\left(\frac{P_{t-1+j}}{P_{t-1}}\right)^{\xi_{p}}\left(\frac{\overline{P}_{t-1+j}}{P_{t-1}}\right)^{1-\xi_{p}}\right)\right] -MC_{t+j}P_{t+j}\left(Y_{t+j}(h)+\Omega\right)\right]$$

Where,

$$Y_{t+j}(h) = \left(\frac{\overline{p}_t(h)}{P_t}\right)^{-\frac{\mu}{\mu-1}} \left[\frac{P_t}{P_{t+j}}\left(\frac{P_{t-1+j}}{P_{t-1}}\right)^{\xi_p} \left(\frac{\overline{P}_{t+j}}{\overline{P}_t}\right)^{1-\xi_p}\right]^{-\frac{\mu}{\mu-1}} Y_{t+j}$$

and

$$\Xi_{t,t+j} = \beta^j \frac{\Lambda_{t+j} P_t}{\Lambda_t P_{t+j}}$$

is the marginal value of one unit of money to the household.  $MC_{t+j}$  is the real marginal cost and  $\tau_t$  is a time-varying tax on firm's revenue. Due to our assumptions on the labour market and the rental rate of capital, the real marginal cost is identical across producers.

$$MC_t = \frac{W_{R,t}^{(1-\alpha)} R_t^{k\alpha}}{E_t^A \alpha^\alpha (1-\alpha)^{(1-\alpha)}}$$

The first order condition for the optimal nominal reset price  $p_t^*$  is:

$$E_{t}\left[\sum_{j=0}^{\infty}\alpha_{p}^{j}\Xi_{t,t+j}Y_{t+j}(h)P_{t+j}\left((1-\tau_{t+j})\frac{\tilde{P}_{t}(h)}{\bar{P}_{t}}\frac{P_{t}}{P_{t+j}}\left(\frac{P_{t-1+j}}{P_{t-1}}\right)^{\xi_{p}}\left(\frac{\bar{P}_{t-1+j}}{\bar{P}_{t-1}}\right)^{1-\xi_{p}}\right)\right]=0$$

In this study, the aggregate price level which incorporates rule of thumb price setters evolves according to:

$$P_t^{\frac{1}{1-\mu}} = \alpha_p \left( \prod_{t=1}^{\xi_p} \overline{\Pi}_t^{1-\xi_p} p_{t-1}(h) \right)^{\frac{1}{1-\mu}} + (1-\alpha_p) \left( \tilde{p}_t(h) \right)^{\frac{1}{1-\mu}}$$

This price setting scheme can be written in the following recursive form:

$$\frac{\tilde{p}_t(h)}{P_t} = \mu \frac{Z_{1,t}}{Z_{2,t}}$$

Where,

$$Z_{1,t} = \Lambda_t M C_t Y_t + \alpha_p \beta E_t \left[ \left( \frac{\Pi_{t+1}}{\Pi_t^{\xi_p} \overline{\Pi}_{t+1}^{1-\xi_p}} \right)^{\frac{\mu}{1-\mu}} Z_{1,t+1} \right] \qquad \dots \qquad \dots \qquad (13)$$

and

Accordingly, the aggregate price dynamics leads to the following relation:

The above specification of Calvo price for which,  $\xi_p$  equals to 0 is considered as a standard Calvo.

### 3.1.2. An Extension: State Dependent Pricing Model

Hernandez's (2004) model gives an explicit role for the average frequency of price revisions in the inflation-output relation, by including state dependent

fluctuations. To be more precise, it combines state-dependent and time-dependent features in the firms' pricing scheme. Firms are allowed to choose a higher probability of price revisions. In that case, they have to pay a lump sum cost which is random as in Dotsey, *et al.* (2004). There are two kinds of monopolistic firms  $j \in [L, H]$ . The first one revises prices with the lower probability  $(1 - \alpha_H)$  in each period but as soon as they receive the random signal of price revision, they have the possibility to benefit from faster price revisions  $(1 - \alpha_H)$  by paying the cost  $\xi$ , with the probability  $\lambda_t$ . If not, they can set a new price without cost but with the lower probability. The second one always adjusts prices with the higher probability and without cost.

The profit maximisation program respectively in the two cases is written as follows, supposing  $\tau_L > 0$  and  $\tau_H = 0$ :

If  $z \in L$  then:

$$\begin{aligned} \max_{p_{j,t}(z)} D_{0\,j,t} &= (1 - \tau_j) d(p_{j,t}(z), S_t) + \beta \alpha_j E_t \frac{\Lambda_{t+1}}{\Lambda_t} D_{1\,j,t+1}(p_{j,t}(z), S_{t+1}) \\ &+ \beta (1 - \alpha_j) E_t \frac{\Lambda_{t+1}}{\Lambda_t} \lambda_{t+1} (D_{0H,t+1}(S_{t+1}) - \Xi_{t+1}) \\ &+ \beta (1 - \alpha_j) E_t \frac{\Lambda_{t+1}}{\Lambda_t} (1 - \lambda_{t+1}) D_{0L,t+1}(S_{t+1}) \end{aligned}$$

Where;

$$\begin{split} D_{1j,t+i}(S_{t+i}) &= (1-\tau_j)d(p_{j,t}(z), S_{t+i}) + \beta \alpha_j E_t \frac{\Lambda_{t+1+i}}{\Lambda_{t+i}} D_{1j,t+1}(p_{j,t}(z), S_{t+1+i}) \\ &+ \beta (1-\alpha_j) E_t \frac{\Lambda_{t+1+i}}{\Lambda_{t+i}} \lambda_{t+1+i} (D_{0H,t+1+i}(S_{t+1+i}) - \Xi_{t+1+i}) \\ &+ \beta (1-\alpha_j) E_t \frac{\Lambda_{t+1+i}}{\Lambda_{t+i}} (1-\lambda_{t+1+i}) D_{0L,t+1+i}(S_{t+1+i}) \end{split}$$

and the real profits:

$$d(p_{j,t}(z), S_t) = \left[\frac{\tilde{p}_{j,t}(z)}{P_t} - \left(MC_t + \Omega\right)\right] \left(\frac{\tilde{p}_{j,t}(z)}{P_t}\right)^{-\frac{\mu}{\mu-1}} Y_t$$

If  $z \in H$  then:

$$\max_{p_{H,t}(z)} \overline{D}_{0H,t}(S_t) = (1 - \tau_H) d(p_{H,t}(z), S_t) + \beta \alpha_H E_t \frac{\Lambda_{t+1}}{\Lambda_t} \overline{D}_{1H,t+1}(p_{H,t}(z), S_{t+1}) + \beta (1 - \alpha_H) E_t \left[ \frac{\Lambda_{t+1}}{\Lambda_t} \overline{D}_{0H,t+1}(S_{t+1}) \right]$$

Where;

$$\begin{split} \overline{D}_{1H,t+i}(S_{t+i}) &= (1 - \tau_H) d(p_{H,t}(z), S_{t+i}) + \beta \alpha_H E_t \frac{\Lambda_{t+1+i}}{\Lambda_{t+i}} \overline{D}_{1H,t+1+i}(p_{H,t}(z), S_{t+1+i}) \\ &+ \beta (1 - \alpha_H) E_t \left[ \frac{\Lambda_{t+1+i}}{\Lambda_{t+i}} \overline{D}_{0H,t+1+i}(S_{t+1+i}) \right] \end{split}$$

The first order condition in both cases gives the same optimal price:

$$\tilde{p}_{j,t} = \mu \frac{Z_{1,t}}{Z_{2,t}}$$

Where;

$$Z_{1,t} = MC_t Y_t P_t^{\frac{\mu}{\mu-1}} + \alpha_j \beta \left[ \frac{\Lambda_{t+1}}{\Lambda_t} Z_{1,t+1} \right]$$

and

$$Z_{2,t} = Y_t P_t^{\frac{1}{\mu-1}} + \alpha_j \beta \left[ \frac{\Lambda_{t+1}}{\Lambda_t} Z_{2,t+1} \right]$$

Knowing that, the probability of j choosing $(1 - \alpha_H)$  is:

 $\lambda_t = 1 - \exp(-b[D_{0H,t} - D_{0L,t}])$ 

and the conditional expected random cost is:

$$E_{t}\Xi_{t+1} = E_{t} \frac{1}{\lambda_{t+1}} \left[ \frac{1}{b} - \left( \frac{1}{b} + D_{0H,t+1} - D_{0L,t+1} \right) \exp \left( -b[D_{0H,t+1} - D_{0L,t+1}] \right) \right]$$

Let  $V_t$  be the mass of all firms  $z \in L$  that chose before and up to  $t (1 - \alpha_H)$  and have not changes their price since that time. Consider  $\mu_t$ , the mass of firms that choose $(1 - \alpha_L)$  at t and  $\overline{\mu}$ , the mass of firms in L.

The dynamics of  $V_t$  and  $\mu_t$  is given by the following equations:

$$\begin{split} V_t = V_{t-1} + \lambda_t (1 - \alpha_L) \mu_{t-1} - (1 - \lambda_t) (1 - \alpha_H) V_{t-1} \\ \mu_t = \overline{\mu} - V_t \end{split}$$

With for initial conditions, the steady state values of  $\mu_t$  and  $V_t$ , respectively  $\mu_0$  and  $V_0$ .

In this standard version, the aggregate price level evolves according to:

$$P_t = \left[\int_0^1 (p_t(z))^{1/1-\mu} dz\right]^{1-\mu} = \left[\overline{\mu}_0 P_{L,t}^{1/1-\mu} + (1-\overline{\mu}_0) P_{H,t}^{1/1-\mu}\right]^{1-\mu}$$

Where;

$$P_{L,t} = \left[\frac{1}{\overline{\mu_0}} \int_{0}^{\mu_t} (P_t(s))^{1/1-\mu} ds\right]^{1-\mu} ds$$
$$\alpha_L P_{L,t-1}^{\nu_{l-\mu}} + \frac{1}{\overline{\mu_0}} \left[ (1-\alpha_L)\mu_{t-1} - (V_t - V_{t-1}) \right] (\tilde{p}_{L,t})^{\nu_{l-\mu}}$$

and

$$P_{H,t} = \left[\frac{1}{1-\overline{\mu}_0}\int_{\mu_t}^{1} (P_t(s))^{1/1-\mu} ds\right]^{1-\mu}$$
$$\alpha_H P_{H,t-1}^{\nu_{t-1}} + \frac{1}{1-\overline{\mu}_0} \left[(1-\alpha_H)(1-\mu_{t-1}) + (V_t - V_{t-1})\right] (\tilde{p}_{H,t})^{\nu_{t-\mu}}$$

With  $V_t - V_{t-1}$ , the mass of firms  $z \in L$  choosing  $(1 - \alpha_H)$  at *t*.

### 3.2. The Sticky Information Model

In each period, a randomly chosen fraction of agents updates their information set. To be more precise, prices are flexible in the sense that firms are allowed to change them in any periods, but at a different level than in a full information environment while they do not have the same information available about the state of the world. Therefore, prices fixed based on different information coexist in the economy. This model has the property that its modeling does not depend on the value of the steady state of inflation.

At *t*, firms choose the price  $p_t^*$  using all current information. Define  $P_t$ , the overall price index. The optimal price is determined by the solution of the profit maximisation problem:

$$\max_{p_t(h)} E_{t-j} \Big[ (1-\tau_t) p_t(h) Y_t(h) - M C_t P_t(Y_t(h) + \Omega) \Big]$$

where  $Y_t(h)$  is the demand schedule:

$$Y_t(h) = \left(\frac{p_t^*(h)}{P_t}\right)^{-\frac{\mu}{\mu-1}} Y_t$$

The first order condition of this program gives the following relationship between the optimal price  $p_t^*(h)$  and the real marginal cost  $MC_t$ :

$$p_t^*(h) = \frac{\mu}{1 - \tau_t} M C_t P_t$$

Lets consider the hybrid specification with backward looking agents as in Gali and Gertler (1999) by adding rule of thumb price setters.

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Then the aggregate price level is given by:

$$(P_t)^{1-\frac{\mu}{\mu-1}} = \alpha_p \left( P_{t-1} \Pi_{t-1}^{\xi_p} \overline{\Pi}^{1-\xi_p} \right)^{1-\frac{\mu}{\mu-1}} + (1-\alpha_p) \sum_{j=0}^{+\infty} \left( (1-\alpha)^j . E_{t-j} (p_t^*(h))^{1-\frac{\mu}{\mu-1}} \right)$$

In each period, firms face a constant probability  $(1-\alpha_p)$  of receiving a signal that allows them to change their price.

The last equation can be rewritten as follows:

$$(P_t)^{1-\frac{\mu}{\mu-1}} = \alpha_p \left( P_{t-1} \prod_{t-1}^{\xi_p} \overline{\Pi}^{1-\xi_p} \right)^{1-\frac{\mu}{\mu-1}} + (1-\alpha_p) \alpha \sum_{j=0}^{+\infty} \left( (1-\alpha)^j \left[ \mu E_{t-j} \left( \frac{P_t M C_t}{(1-\tau_t)} \right) \right]^{1-\frac{\mu}{\mu-1}} \right)^{1-\frac{\mu}{\mu-1}} \right)^{1-\frac{\mu}{\mu-1}}$$

Some manipulations allow us to obtain the stationary version of the previous equation which symbolises the non linear Sticky information Phillips curve:

$$\left(\frac{P_{t}}{P_{t-J}}\right)^{1-\frac{\mu}{\mu-1}} = \alpha_{p} \left(\frac{P_{t-1}}{P_{t-J}} \prod_{t=1}^{\xi_{p}} \overline{\Pi}^{1-\xi_{p}}\right)^{1-\frac{\mu}{\mu-1}} + (1-\alpha_{p})\alpha \sum_{j=0}^{+\infty} \left((1-\alpha)^{j} \cdot \left[\mu E_{t-j}\left(\frac{MC_{t}}{(1-\tau_{t})} \cdot \frac{P_{t}}{P_{t-J}}\right)\right]^{1-\frac{\mu}{\mu-1}}\right)$$

Knowing that:

$$\frac{P_t}{P_{t-J}} = \prod_{s=0}^{J-1} \Pi_{t-s}$$

For computational reasons, the scheme truncates the infinite horizon in the age distribution of information sets, such as agents set their prices based on information outdates by J=12 periods (that is to say 3 years). Therefore, this parameterisation leads us

to divide the previous Phillips curve by the parameter:  $\omega = \sum_{j=0}^{J} \alpha (1-\alpha)^j$ 

### 3.3. Market Equilibrium

Aggregate demand is given by:

$$Y_t = C_t + I_t + \overline{\overline{G}}\varepsilon_t^G + \Psi(u_t)K_{t-1}$$

Market clearing condition on goods market is given by:

$$\int_{0}^{1} Y_{t}(z) dz = \varepsilon_{t}^{A} \int_{0}^{1} (u_{t} K_{t-1}(z))^{\alpha} (L_{t}(z))^{1-\alpha} dz - \Omega$$
$$= \varepsilon_{t}^{A} (u_{t})^{\alpha} \int_{0}^{1} (K_{t-1}(z)) \left(\frac{L_{t}(z)}{K_{t-1}(z)}\right)^{1-\alpha} dz - \Omega$$

Or

$$\Delta_{p,t} Y_t = \varepsilon_t^A (u_t K_t)^\alpha (L_t)^{1-\alpha} - \Omega$$
  
With:  $\Delta_{p,t} = \int_0^1 \left(\frac{p_t(z)}{P_t}\right)^{-\frac{\mu}{\mu-1}} dz$ 

It measures the price dispersion due to the staggered price setting. As in the case of the aggregate price index, we can show that this price dispersion index under Calvo contracts and sticky information (SI) contracts has respectively the following dynamics:

$$\begin{split} \Delta_{p,t}^{Calvo} &= \alpha_p \int_0^1 \left( \frac{p_{t-1}(z)}{P_{t-1}} \frac{P_{t-1}}{P_t} \pi_{t-1}^{\xi_p} \pi^{1-\xi_p} \right)^{-\frac{\mu}{\mu-1}} dz + (1-\alpha_p) \left( \frac{p_t^*}{P_t} \right)^{-\frac{\mu}{\mu-1}} \\ &= \alpha_p \Delta_{p,t-1} \left( \frac{\pi_t}{\pi_{t-1}^{\xi_p} \pi^{1-\xi_p}} \right)^{\frac{\mu}{\mu-1}} + (1-\alpha_p) \left( \mu \frac{Z_{1,t}}{Z_{2,t}} \right)^{-\frac{\mu}{\mu-1}} \\ \Delta_{p,t}^{SDP} &= \left[ \overline{\mu}_0 \left( \frac{P_{L,t}}{P_t} \right)^{-\frac{\mu}{\mu-1}} + (1-\overline{\mu}_0) \left( \frac{P_{H,t}}{P_t} \right)^{-\frac{\mu}{\mu-1}} \right] \\ \Delta_{p,t}^{SI} &= \alpha_p \Delta_{p,t-1} \left( \frac{\pi_t}{\pi_{t-1}^{\xi_p} \pi^{1-\xi_p}} \right)^{\frac{\mu}{\mu-1}} + (1-\alpha_p) \frac{P_{t-J}}{P_t} \alpha_{j=0}^J (1-\alpha) E_{t-j} \left( \mu M C_t \frac{P_t}{P_{t-J}} \right)^{-\frac{\mu}{\mu-1}} \end{split}$$

The aggregate unconditional welfare is defined by:

$$u_t = \int_0^1 u_t(h) dh$$

We already mentioned that all household have the same consumption plans. Consequently:

$$u_t = E_t \sum_{j=0}^{\infty} \beta^j \left[ \frac{1}{1 - \varsigma_C} \left( C_{t+j} - \upsilon C_{t-l+j} \right)^{1 - \varsigma_C} - \frac{\varepsilon_{t+j}^L \zeta}{1 + \varsigma_L} L_{t+j}^{1 + \varsigma_L} \Delta_{w,t+j} \right] \varepsilon_{t+j}^B \qquad \dots \quad (16)$$

Where;

$$\Delta_{w,t} = \int_0^1 \left(\frac{W_t(h)}{W_t}\right)^{-\frac{(1+\varsigma_L)\mu w}{\mu w - 1}} dh$$

As for the price dispersion index:

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$$\Delta_{w,t} = \alpha_w \Delta_{w,t-1} \left( \frac{w_t}{w_{t-1}} \frac{\pi_t}{\pi_{t-1}^{\xi_w}} \right)^{\frac{(1+\zeta_L)\mu_W}{\mu_{w-1}}} + (1-\alpha_w) w_t \left( \mu_W \frac{Z_{W1,t}}{Z_{W2,t}} \right)^{-\frac{(1+\zeta_L)\mu_W}{\mu_W(1+\zeta_L)-1}}$$
(17)

#### 3.4. Optimal Monetary Policy (Main Principle)

The optimal monetary policy or the Ramsey policy under commitment consists in maximising the intertemporal households' welfare  $(U_t)$  subject to a set of non-linear structural constraints of the model.

To be more precise, a Ramsey equilibrium is a competitive equilibrium such that:

(i) Given a sequence of shocks, prices, policy instrument and quantities  $P_t$ ;  $R_t$ ;

 $Q_{tt=0}^{\infty}$  it maximises the representative agent lifetime utility,  $U_{t.}$ 

(ii)  $i_t > 0$ .

In order to analyse essentially the macroeconomic stabilisation properties of the monetary policy, we assume subsidies on labour and goods markets are offsetting first order distortions. In that case, the flexible price equilibrium is Pareto optimal. The Ramsey policy problem is written using an infinite horizon Lagrangian:

$$L = U_t + E_t \lambda_r \sum_{j=0}^J \beta^j (i_{t+j} - \overline{i})^2 + \lambda \text{ (Model Constraints)} \qquad \dots \qquad (18)$$

Where  $\lambda_r$  is the weight associated to the cost on nominal interest rate fluctuations. We introduce an interest rate objective in this problem in order to make the Ramsey policy operational. The first order conditions to this problem are obtained using the symbolic toolbox of Matlab 2008.

#### 4. THE EMPIRICAL SETUP

This section briefly outlines the empirical setup by illustrating data, choice of priors and estimation methodology used in this paper. We adopted the empirical approach outlined in Smets and Wouters (2003) and estimate our augmented DSGE models with sticky prices-information and wages employing Bayesian inference methods. This involves obtaining the posterior distribution of the parameters of the model based on its log-linear state-space representation and assessing its empirical performance in terms of its marginal likelihood. In the following we briefly sketch the adopted approach and describe the data and the prior distributions used in its implementation. We then present our estimation results in next coming section.

#### 4.1. Data

We consider 7 key macro-economic quarterly time series from 1973q1 to 2004q4: output, consumption, investment, hours worked, real wages, GDP deflator inflation rate, and 3 month short-term interest rate. Euro area data are taken from Smets and Wouters (2003) and Euro-stat official website. Concerning the euro area, employment numbers

replace hours. Consequently, as in Smets and Wouters, hours are linked to the number of people employed  $e_t$  with the following dynamics:

$$e_{t} = \beta E_{t} e_{t+1} + \frac{(1 - \beta \alpha_{e})(1 - \alpha_{e})}{\alpha_{e}} (l_{t}^{*} - e_{t})$$

Aggregate real variables are expressed per capita by dividing with working age population. All the data are detrended before the estimation. Since the model has implications for the log-deviations from the steady-state of all these variables, so we preprocess the data before the estimation stage.

### 4.2. Choice of Priors

In the overall, the set of priors corresponds to the ones in Smets and Wouters (2003) (see Tables 2 to 5).

#### 4.2.1. Common Parameters

The discount factor  $\beta$  is calibrated to 0.99, which implies annual steady state real interest rates of 4 percent. The depreciation rate  $\delta$  is equal to 0.0025 per quarter. Markups are 1.3 in the goods market and 1.5 in the labour market. The steady state is consistent with labour income share in total output of 70 percent. Shares of consumption and investment in total output are respectively 0.65 and 0.18.

### 4.2.2. Calvo and State Dependent Pricing based Model Parameters

Two additional parameters ( $\alpha_p$  and  $\xi_p$ ). The parameter  $\alpha_p$  which determines the probability that firms are allowed to change their price, has a prior mean of 0.75 and a standard deviation of 0.0084. Regarding the hybrid specification, the parameter of partial indexation to lagged inflation follows a Beta-distribution.

#### 4.2.3. Sticky Information based Model Parameters

Lets suppose the same prior for the previous parameters in that case and consider  $\alpha$  which is the probability to receive new information about the state of the economy, follows a Beta-distribution with the mean of 0.75 and the standard deviation of 0.0512. This parameter value is also consistent with Mankiw and Reis (2002).

#### 4.3. Bayesian Estimation Approach

In empirical literature, there are numerous strategies used to determine the parameters of new-Keynesian DSGE models. These ranging from pure calibration, e.g., Kydland and Prescott (1982), Monacelli (2003), over generalised method of moments (GMM) for estimation of general equilibrium relationships, e.g., Christiano and Eichenbaum (1992), to full-information based maximum likelihood estimation as in Altug (1989), Mcgrattan (1994), Leeper and Sims (1994), Kim (2000) and Irland (2000). Other studies also proposed mixed strategies like limited-information based methods to explore a key question whether a DSGE model matches the data with some certain dimensions. For example, Canova (2002) and Christiano, *et al.* (2005) used minimum

distance based criterion to estimate VAR and DSGE model impulse response functions. Further methodological debate can be referred using the following studies by Diebold (1998), Ruge-Murcia (2003) and Tovar (2008).

Other than these proposed estimation and calibration strategies, this study uses another estimation approach called Bayesian estimation approach. This alternative approach is a combination of calibration and estimation of selected model parameters. The fundamental advantage of this approach is a batter adoption of the model to the conditions in the given economy, [see e.g., Smets and Wouters (2003)].

In any empirical modeling exercise, there are three possible sources of uncertainty; the model itself; the parameterisation condition of the model and the data. The debate on the issue of uncertainty is the most important as it provide a difference between frequentist (classical) and Bayesian approach. In classical approach the probability of the occurrence of an event, i.e., the measurement of uncertainty is associated with its frequency. However, in Bayesian approach, the probability of an event is determined by two components; the subjective believe (prior) and the frequency of that event. For further detail on this notion, [see for instance Gelman (2006) and Koopman, *et al.* (2007)].

The seminal work on DSGE modeling used this approach started with the study by Landon-Lane (1998), DeJong, *et al.* (2000), Schorfheide (2000) and Otrok (2001). This approach has been generalised by Lubik and Schorfheide (2005) who estimate a DSGE model without providing restrictions to the determinacy region of the parameter space. Almost all recent studies on DSGE model has been used this approach, e.g., Smets and Wouters (2003), Laforte (2004), Onatski and Williams (2004), Ratto, *et al.* (2008), Adolfson, *et al.* (2008) and Kolasa (2008).

In practical sense, we try to fit out referenced model, which consists in placing a prior distribution  $p(\Gamma)$  on structural parameters  $\Gamma$ , the estimate of which are then updated using the data  $Y^T$  according to the Bayes rule:

$$p(\Gamma/Y^T) = \frac{p(Y^T/\Gamma)}{p(Y^T)} \propto L(\Gamma/Y^T)p(\Gamma) \qquad \dots \qquad \dots \qquad \dots \qquad (19)$$

Where  $p(Y^T / \Gamma) = L(\Gamma / Y^T)$  is the likelihood function  $p(\Gamma / Y^T)$  is the posterior distribution of parameters and  $p(Y^T)$  is the marginal likelihood defined as:

$$p(Y^T) = \int p(Y^T / \Gamma) p(\Gamma) d\Gamma \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad \dots \qquad (20)$$

Any DSGE model forms a linear system with rational expectations, the solution to which is of the form:

$$\mu_t = B_3(\Gamma)\mu_{t-1} + B_4(\Gamma)\varepsilon_t$$
 ... ... (22)

Where  $R_t$  is a vector of endogenous variables,  $\mu_t$  is a vector of stochastic disturbances and  $\varepsilon_t$  is a vector of innovations to stochastic shocks and coefficient matrices  $A_i$  depending on

the parameters of the model. The measurement Equations (21) and (22) linking observable variables used in the estimation with endogenous variables can be written as:

$$Y^{I} = CR_{t}$$
 ... ... ... ... ... ... ... (23)

Where, *C* is the deterministic matrix. The Equations (21), (22) and (23) form the statespace representation of the model. The likelihood of which can be evaluated using Kalman filter. The analytical solution of the whole system may not be obtain in general, however the sequence of posterior draws can be obtain using Markov-Chain-Monte-Carlo (MCMC) simulation methodology. This methodology is briefly discussed in Lubik and Schorfheide (2005), Gelman, *et al.* (2006) and Koopman, *et al.* (2007). For our estimation setup the random walk Metropolis-Hastings algorithm is used to generate Morkov-Chains (MC) for the model parameters.

### 5. EMPIRICAL RESULTS

The Bayesian framework as discussed in previous section is used in order to compare the purely forward looking and hybrid Calvo to the baseline and the hybrid specifications of a truncated Sticky Information model, under the assumption that the models have equal prior probabilities.

#### 5.1. Model Comparison Based on Marginal Densities

The following Table 1 reports the marginal densities for the all pricing models. The model with the highest marginal density is the standard Calvo model over the other specifications. In the overall, it dominates the sticky information for all specifications in terms of marginal densities.

Model Comparison			
Marginal Density	Laplace Appr.	Metropolis	Acceptation Rates
Model			
State-Dependent	-467.549	-466.673	0.36954
Standard Calvo	-472.703	-471.660	0.28976 - 0.28845
Hybrid Calvo	-473.223	-472.247	0.27243 - 0.27305
Mixed Standard Sticky Info (J=12)	-514.784	-515.292	0.23582
Mixed Hybrid Sticky Info (J=12)	-518.912	-519.466	0.19194
Standard Sticky Info (J=12)	-591.869	-592.952	0.21310
Hybrid Sticky Info (J=12)	-515.399	-515.796	0.28529

Table 1

Table Key: The Mixed Hybrid SI with 22 lags gives the Marginal Density -514.2014 (Laplace Approximation).

In the literature, the motivation for including inertia is largely empirical and justified theoretically with an assumption that a fixed proportion of firms has backwardlooking price setting behaviour. Empirically the adequacy of this model, which nests the pure forward-looking sticky price model and inherits the good properties of backwardlooking behaviour, to data is controversial. In this study using Bayesian estimation, the introduction of indexation to lagged inflation is not a necessary condition to reproduce

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plausible inflation dynamics as in the standard Calvo model, [see for instance Laforte (2004); Paustian and Pytlarczyk (2006)].

Some researchers criticise all models built on the sticky price hypothesis because they would not be at odds with the facts and the hybrid models would be even worse than the standard ones [see for example, Mankiw and Reis (2002)]. They advise to replace this specification by Sticky Information contracts that prevent inflation to jump immediately after shocks. However under such pricing, the fit is poor and regarding the Hybrid curve, all expected inflation is integrated in the price path such as the scheme of indexation is again of little interest. Moreover, the extension of the maximum age of outdated information sets from 12 to 22 quarters does not improve very much the performance of the Sticky Information models such as we consider 12 quarters represent a good approximation of the infinite sum in terms of contracts duration. In the overall, the introduction of indexation, under mixed SI models, does not by itself add more persistence in the two specifications and basically, the choice of the price structure seems to be much more important.

#### 5.2. Model Comparison Based on Posterior Distribution

Tables A1 to A7 of Appendix-A,<sup>\*</sup> present information about the posterior distributions of the two pricing schemes, under different assumptions. In the standard case (without indexation), while most of estimated parameters are quite similar, the estimated degree of wage indexation is significantly high in the Sticky Information model under Calvo wage contracts (0.76) and low in the Calvo model (0.21).

In the same way, the variance of wage markup is 0.40 in SI model vs 0.19 in Calvo model. We can also note an important difference across the pricing regarding the persistence degree of the preference shock and its variance (respectively in Calvo and SI : 2.54 vs 1.95 and 5.30 vs 9.34).

As a result, the Sticky information assumption has different implications for some key parameters including the ones in the policy instrument. The degree of inertia is slightly smaller in that this model as opposed to the Calvo specification. This shows that model parameters are highly sensitive to both specifications; therefore, it is difficult to conclude the degree of robustness of each model specification. As both models can produce an important degree of persistence such as the choice of Sticky Price against Sticky Information is not sufficient to determine dynamics properties of two key variables inflation and output.

### 5.3. Model Comparison Based on Impulse Responses

Figures B1 to B8 of Appendix-B compare the models' estimated impulse responses of main variables after one percent increase in key structural shocks, showing the 90 percent posterior bands and the median of the posterior densities. Figures B1 show the responses after a productivity shock. Across both Calvo models, the propagation of the shock is consistent, though in the hybrid version, the inflation displays a 'hump-shaped' curvature after the few initial impact. As opposed to the SI model, the Calvo models can

For detail results of this Appendix (Tables A1 to A7) please contact the authors via email: rdrissi@esg.fr

bring down the policy instrument slightly longer below its steady state in the short run. In the overall, the short run responses are much stronger under the Sticky information pricing due to its volatile short run dynamics for the nominal variables. Indeed, after an initial boost, the variables more quickly come back towards the long-run values.

Regarding the responses of output and inflation to a Monetary Policy shock (Figure B2), both specifications lead to a hump-shaped response of inflation (except for the pure FL Calvo model). First of all, the standard Calvo model exposes an immediate response of inflation. Mankiw and Reis (2002) criticise in the fixed prices models, the absence of delay in the inflation reaction. While it seems to be only a feature related to the fixed prices forward looking models, the hybrid Calvo reproduce a reaction of inflation less delayed than the response of the Sticky Information model. Moreover, this last specification respect the condition of a more delayed response of inflation than Output while in the Calvo models the response of inflation is faster. Indeed, the peak slightly occurs before the one of Output.

Besides, in the Smets andWouters (2003) model under Calvo contracts, the price markup shock is dominant in the inflation driving. In the Sticky Information models, such shocks lead to responses less persistent into the main selected variables, returning more quickly to their Steady State than in the Calvo models (Figures B3 and B4). Paustian and Pytlarczik (2006) show the estimation of a Calvo model without markup shock induces a marginal likelihood lower and advance one explanation for the poor fit could be the inability of Sticky Information models to match the volatility of inflation as well as the persistence of inflation and real wages. Indeed, such non structural shocks play an important role in the inflation persistence, in particular for the model comparison.

#### 5.4. Welfare Comparison Based on Optimal Monetary Policy

In this section, the Ramsey allocation is computed by solving the first order approximation of the equilibrium conditions. Figures B1 and B2 refer to the responses of aggregates after an efficient supply shock. Concerning the productivity shock, the Ramsey allocation generates a stronger and faster response of real variables and real wage in the Calvo Model but weaker and slower in the SI model. The associated interest rate path is much more accommodative in the short term but reverts very quickly to its initial level.

In the overall, for both models, over longer horizons, the response of real variables becomes significantly closer in both monetary regimes. Regarding the labour supply shock, in the Calvo model, the hump-shaped downward under the Ramsey policy stimulated output, consumption and investment and leaves quasi-unchanged inflation and real wages. Under Sticky Information pricing, the effect is weaker and the hump-shaped stimulates all the aggregates. By contrast, the estimated rule is not supportive enough to prevent a decrease in real wage and inflation, above all in the SI model where the interest rate is close to the steady state value.

Turning now to efficient demand shocks, the increase in consumption after a preference shock, is more limited under the Ramsey policy than the alternative rule, and the contraction in investment is stronger. In the Calvo model, the output decreases in short term under the Ramsey allocation while inflation and real wage are almost fully stabilised while in the SI model, the output is stabilised and the real wage decreases in short term. Under estimated rule, such a shock is expansionary on output and upward pressures emerge on real wages and inflation.

For the others demand shocks, the differences noted above are less pronounced. The responses of output, consumption, investment and real wages to an investment shock or a government spending shock are relatively similar under Ramsey policy and he estimated rule, even if the inflation response is much more muted in the Ramsey allocation (see Figures B4 and B5 in Appendix).

Figures B6 to B8 refer to inefficient shocks. The transmission of price markup shocks to the economy is not strongly different under both monetary regimes which suggest a similar inflation/output tradeoff for this type of shock. However, in the case of wage markup and external finance premium shocks, the Ramsey policy is much more restrictive. It delivers lower real variables and more stable inflation. In the overall, compared with the estimated Taylor rule, the Ramsey policy accommodates more strongly the efficient supply shocks, leans more against efficient demand shocks. In addition, the optimal policy is much more responsive to labour market shocks than the estimated rule which incorporates only goods market variables such as inflation and output.

### 6. CONCLUSION

This paper considers a closed economy version of DSGE model with various nominal frictions vis-à-vis monetary-cum-fiscal blocks to seek the basic query that how monetary policy impacts while in the presence of nominal frictions, like price stickiness, staggered wages, etc. Using Bayesian Simulation techniques, we estimate the model for the closed economy. Our simulation results show that despite the apparent similarities these frictions, their responses to shocks and fit to data are quite different and there is no agreement on their relative performance. Both these hypotheses can produce an important degree of persistence such as the choice of Sticky Price against Sticky Information is not sufficient to determine dynamics properties of two key variables inflation and output. Hence, as a result, monetary authorities cannot afford to rely on a single reference model which contains few nominal frictions of the economy but need to model a large number of alternative ways available when they take their decision of optimal monetary policy.

Appendices

### **APPENDIX B**

### MODEL IMPULSE RESPONSES

## Fig. B1. Dynamic Responses to a Productivity Shock



Fig. B2. Dynamic Responses to a Labour Shock







Fig. B4. Dynamic Responses to a Price Markup Shock



Fig. B5. Dynamic Responses to a Wage Markup Shock



Output Consump Investment 0.2 0.5 2 Calvo 0 o -0.5 -0.2 -2L 20 20 40 20 40 0.5 0.1 2 0 55 0 0 -0.1 -0.5 -20 20 Inflation 20 Real Wage 20 Interest Rate 40 0.01 0.1 0.2 Callo 0 0 0 -0.01 -0.1 L -0.2 20 20 40 20 40 40 0.05 0.02 0.5 55 0 0 0 -0.05 L 0.02 -0.50 20 40 20 ão 20 40

Fig. B6. Dynamic Responses to an External Finance Premium Shock





Fig. B8. Dynamic Responses to a Government Spending Shock



#### REFERENCES

- Adolfson, M., S. Laséen, J. Linde, and M. Villani (2007a) RAMSES: A New General Equilibrium Model for Monetary Policy Analysis. Risksbank, *Economic Review* 2.
- Adolfson, M., S. Laséen, J. Linde, and M. Villani (2007b) Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through. *Journal of International Economics* 72, 481–511.
- Adolfson, M., S. Laséen, J. Linde, and M. Villani (2008) Evaluating an Estimated New Keynesian Small Open Economy Model. *Journal of Economic Dynamics and Control* 32, 2690–2721.
- Altug, S. (1989) Time-to-Build and Aggregate Fluctuations: Some New Evidence. International Economic Review 30, 889–920.
- Calvo, G. A. (1983) Staggered Price Setting in a Utility-Maximising Framework. *Journal of Monetary Economics* 12, 383–398.
- Canova, F. (2007) *Methods for Applied Macroeconomic Research*. Princeton University Press.
- Christiano, L. J., M. Eichenbaum, and C. L. Evans (1997) Sticky Price and Limited Participation Models Of Money: A Comparison. *European Economic Review* 41, 1201–1249.
- Christiano, L. J., M. Eichenbaum, and C. L. Evans (1998) Monetary Policy Shocks: What Have We Learned And To What End? In J. B. Taylor and M. Woodford (eds.) Handbook of Macroeconomics. Amsterdam, North-Holland.
- Christiano, L., and M. Eichenbaum (1992) Current Real-Business Cycle Theories and Aggregate Labour-Market Fluctuations. *American Economic Review* 82, 430–45.
- Christiano, L., M. Eichembaum and C. Evans (2005) Nominal Rigidities and the Dynamic Effects to a Shock of Monetary Policy. *Journal of Political Economy* 113, 1–45.
- Clarida, R., J. Gali and M. Gertler (1999) The Science of Monetary Policy: A New Keynesian Perspective. *Journal of Economic Literature* 37, 1661–1707.
- Dejong, D., B. Ingram, and C. Whiteman (2000) A Bayesian Approach to Dynamic Macroeconomics. *Journal of Econometrics* 98, 201–223.
- Dib, A., M. Gammoudi and K. Moran (2008) Forecasting Canadian Time Series with the New Keynesian Model. Canadian Economics Association. *Canadian Journal of Economics* 41, 138–165.
- Diebold, F. X. (1998) The Past, Present, and Future of Macroeconomic Forecasting. Journal of Economic Perspectives 12, 175–192.
- Dotsey, M., R. King and A. Wolman (1999) State Dependent Pricing and General Equilibrium Dynamics of Money and Output. *Quarterly Journal of Economics* 114, 655–690.
- Gali, J. and M. Gertler (1999) Inflation Dynamics: A Structural Econometric Analysis. *Journal of Monetary Economics* 44, 195–222.
- Gali, J. and M. Gertler (2007) Macroeconomic Modeling for Monetary Policy Evaluation. *Journal of Economic Perspectives* 21, Fall Issue.
- Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin (2006) *Bayesian Data Analysis*. (Second Edition) Text in Statistical Science, Chapman and Hall.
- Geweke, J. (1995) Monte Carlo Simulation and Numerical Integration. Federal Reserve Bank of Mineapolis. (Research Department Staff Report 192).

- Geweke, J. (1999) Using Simulation Methods for Bayesian Econometric Models: Inference, Development and Communication. *Econometric Reviews* 18, 1–73.
- Goodfriend, M. (2007) How the World Achieved Consensus on Monetary Policy. *Journal of Economic Perspectives* 21, Fall Issue.
- Goodfriend, M. and R. King (1997) The New Neoclassical Synthesis and the Role of Monetary Policy. NBER Macroeconomics Annual Vol. 1997.
- Haider, A. and S. U. Khan (2009) A Small Open Economy DSGE Model for Pakistan. *The Pakistan Development Review* (Forthcoming).
- Hernandez, K. (2004) Inflation and Output Dynamics with State Dependent Frequency of Price Change. Boston College, USA. (Working Paper).
- Ireland, P. N. (2004) Technology Shocks In The New Keynesian Model. (NBER Working Paper No. W10309).
- Justiniano, A. and B. Preston (2004) Small Open Economy DSGE Models: Specification, Estimation and Model Fit. Columbia University. (Manuscript).
- Keen, B. D. (2006) Sticky Price and Sticky Information Price Setting Models: What is the Difference? University of Oklahoma. (Working Paper).
- Kiley, M. T. (2007) A Quantitative Comparison of Sticky-Price and Sticky-Information Models of Price Setting. *Journal of Money, Credit and Banking* 39:S1, 101–125.
- Kim, J. (2000) Constructing and Estimating a Realistic Optimising Model of Monetary. *Journal of Monetary Economics* 45, 329–359.
- Kolasa, M. (2008) Structural Heterogeneity or Asymmetric Shocks? Poland and the Euro Area Through the Lens of a Two-Country DSGE Model. National Bank of Poland. (Working Paper No. 49).
- Koop, G., D. J. Poirier, and J. L. Tobias (2007) *Bayesian Econometric Methods*. Cambridge University Press.
- Kwapil, C., J. Baumgartner, and J. Scharler (2005) The Price-Setting Behaviour of Austrian Firms Some Survey Evidence. European Central Bank. (Working Paper Series No. 464).
- Kydland, F. E. and E. C. Prescott (1982) Time to Build and Aggregate Fluctuations. *Econometrica* 50, 1345–1370.
- Kydland, F. E. and E. C. Prescott (1996) The Computational Experiment: An Econometric Tool. *Journal of Economic Perspectives* 10, Winter Issue.
- Landon-Lane, J. (1998) Bayesian Comparison of Dynamic Macroeconomic Models. PhD Dissertation, University of Minnesota.
- Leeper, E. and C. Sims (1994) Toward a Modern Macroeconomic Model Usable for Policy Analysis. In Stanley Fischer and Julio Rotemberg (eds.) NBER Macroeconomics Annual. Cambridge, MA.: MIT Press.
- Liu, P. (2006) A Small New Keynesian Model of the New Zealand Economy. Reserve Bank of New Zealand. (Discussion Paper Series, No. 03/06).
- Lubik, T., and F. Schorfheide (2005) A Bayesian Look at New Open Economy Macroeconomics. In M. Gertler, and K. Rogoff (eds.) NBER Macroeconomics Annual 313–336.
- Lucas, J. R. (1976) Econometric Policy Evaluation: A Critique. In K. Brunner and A. Meltzer (eds.) *The Phillips Curve and Labour Markets*. North Holland.
- Lucas, J. R. and T. J. Sargent (1979) After Keynesian Macroeconomics. Federal Reserve Bank of Minneapolis. *Quarterly Review* 3, 1–16.

- Mankiw, G. N. (2006) The Macroeconomist as Scientist and Engineer. Journal of Economic Perspectives Fall Issue, 20, 29–461.
- Mankiw, N. G., and R. Reis (2002) Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve. *Quarterly Journal of Economics* 117, 1295–1328.
- Mcgrattan, E. (1994) The Macroeconomic Effects of Distortionary Taxation. Journal of Monetary Economics 33, 573–601.
- Monacelli, T. (2003) Monetary Policy in a Low Pass-Through Environment. European Central Bank, (Working Paper No. 227).
- Onatski, A. and N. Williams (2004) Empirical and Policy Performance of a Forward-Looking Monetary Model. Princeton University. (Mimeographed.)
- Otrok, C. (2001) On Measuring the Welfare Cost of Business Cycles. Journal of Monetary Economics 47, 61–92.
- Paustian, M. and E. Pytlarczik (2006) Sticky Contracts or Sticky Information? Evidence from an Estimated Euro Area Model. (Mimeographed.)
- Ratto, M., W. Roeger and In 'T Veld (2008) QUEST III: An Estimated Open-Economy DSGE Model of the Euro Area with Fiscal and Monetary Policy. *Economic Modeling* (Forthcoming Issue).
- Romer, D. (1993) The New Keynesian Synthesis. American Economic Association, Journal of Economic Perspective 7, 5–22.
- Romer, D. (2006) Advanced Macroeconomics. Third Edition. New York .: Mcgraw-Hil.
- Ruge-Murcia, F. (2003) Methods to Estimate Dynamic Stochastic General Equilibrium Models. Cahier 17–2003.
- Smets, F., and R. Wouters (2003) Monetary Policy in an Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association* 1, 1123–1175.
- Tovar, E. C. (2008) DSGE Models and Central Banks. Bank for International Settlements, (BIS Working Paper No. 258.)
- Woodford, M. (2003) *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton University Press.