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Inflation Targets and Endogenous Wage Markups in a New Keynesian model[*]

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Abstract

Empirical contributions show that wage re-negotiations take place while expiring contracts are still in place. This is captured by assuming that nominal wages are pre-determined. As a consequence, wage setters act as Stackelberg leaders, whereas in the typical New Keynesian model the wage-setting rule implies that they play a Nash game. We present a DSGE New Keynesian model with pre-determined wages and money entering the representative household's utility function and show how these assumptions are sufficient to identify an inverse relationship between the inflation target and the wage markup (and thus employment) both in the short and the long run. This is due to the complementary effects that wage claims and the inflation target have on money holdings. Model estimates suggest that a moderate long-run inflation rate generates non-negligible output gains

Jel codes: E52, E58, J51, E24.
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1 Introduction

Recent developments in macroeconomics contradict the widely held belief that permanently higher inflation cannot affect output and employment. A long-run relationship between inflation and real activity is obtained in New Keynesian models based on price staggering, where inflation has adverse effects due to relative price dispersion and to the effect of expectations on mark-ups (Goodfriend

and King, 1997; Woodford, 2003; Schmitt-Grohè and Uribe, 2004). Other contributions point to the opposite direction. Benigno and Ricci (2011) resurrect the "grease in the wheels" argument, showing that low inflation rates disciplines monopolistic wage setters in case of downward nominal wage rigidity. In Graham and Snower (2008) the combination of staggered nominal wage contracts and hyperbolic discounting leads to a positive long-run effect of inflation on real variables.

We share the view that New Keynesian models may underestimate the beneficial effects of inflation on wage markups, but we highlight a different disciplining channel. According to recent empirical evidence, wage renegotiations take place while expiring contracts are still in place (Du Caju *et al.*, 2008), enabling wage setters to internalize the expected consequences of their actions over the life of the future contract. This feature of observed wage-setting practices plays a critical role in our model, because we are able to show that the anticipation of future inflation unambiguously disciplines wage markups.

The key innovation of the paper is that wage setters decisions anticipate the subsequent choices of price setters, consumers and policymakers. This is captured by assuming that nominal wages are pre-determined. As a consequence, in our model wage setters act as Stackelberg leaders, whereas in the typical New Keynesian model the wage-setting rule implies that they play a Nash game. For the model to replicate the degree of nominal wage inertia typically observed over the business cycle, we incorporate the assumption of pre-determined nominal wages into an otherwise standard sticky-wage model, based on Rotemberg (1982) quadratic adjustment cost. Another important feature of our model is that money enters the representative household's utility function. The pre-determined wages and money-in-the-utility-function assumptions are sufficient to identify an inverse relationship between the central bank long-run inflation target and the steady-state wage markup.

The rationale behind this result is simple. Both a positive inflation target and a consumption fall are associated to a higher marginal utility from real money balances (MUM in short). In the paper we show that wage setters internalize the adverse effect of a wage increase on consumption and are therefore induced to moderate their wage claims in order to limit the expected increase in MUM. Since the impact of a consumption fall on MUM grows with the expected inflation rate, we obtain a new justification for the existence of a non-vertical Phillips curve.

In order to assess the empirical relevance of our theoretical results we estimate the model for the US economy using Bayesian estimation techniques. We estimate a substantial disciplining effect on wage markups over the post-1983 sample, when average inflation has been relatively low. Further, the empirical performance of our model is strictly better than the standard alternative where wages are sticky but the predetermined wages assumption is ruled out.

The rest of the paper is organized as follows. The next section outlines our model. Section 3 discusses the steady state features of our model and, characterizes the wage moderation effect associated to a positive inflation rate. Section 4 takes the model to the data by using Bayesian estimation techniques. Section 5 characterizes our estimated long-run Phillips curve and presents the impulse response functions to an interest rate shock. Section 6 concludes.

2 The model

We consider a simple DSGE model without capital, where inertia is driven by consumption habits and by price and nominal wage rigidities. Monetary policy chooses the long-run inflation target and implements a Taylor rule. In addition, we nest the assumption of pre-determined nominal wages into a standard Rotemberg (1982) wage-setting rule.

2.1 Households

The representative household (i) maximizes a standard, separable money-in-the-utility function:[1]

$$U = \sum_{t=0}^{\infty} \beta^t \left(\ln \left(c_{t,i} - bc_{t-1,i} \right) - \frac{\eta}{1+\phi} l_{t,i}^{1+\phi} + \frac{\Gamma_t}{1-\varepsilon} \left(\frac{M_{t,i}}{P_t} \right)^{1-\varepsilon} \right) \tag{1}$$

where $\beta \in (0,1)$ is the intertemporal discount rate, $c_{t,i}$ is a consumption bundle, b denotes internal habits, $l_{t,i}$ is a differentiated labor type that is supplied to all firms, $M_{t,i}/P_t$ denotes real money holdings, Γ_t is a scale parameter. Following Neiss (1999), we set $\Gamma_t = \xi_m A_t^{\varepsilon-1}$, where A_t defines a non-stationary productivity factor. This guarantees that the model has a balanced growth path along which money velocity is constant even if $\varepsilon \neq 1$. The flow budget constraint is:

$$c_{t,i} + \frac{M_{t,i}}{P_{t,i}} + \frac{B_{t+1,i}}{P_t} = w_{t,i} l_{t,i} + \frac{M_{t-1,i}}{P_t} + \theta_t + \frac{\tau_t}{P_t} + R_t \frac{B_{t,i}}{P_t} \tag{2}$$

where $B_{t,i}$ denotes holdings of one-period bonds, $w_{t,i} = W_{t,i}/P_t$ is the real wage, θ_t denotes firms profits, τ_t is a lump-sum transfer from central bank profits, R_t is the nominal interest rate.

Consumption basket and price index are defined as follows: $c_t = \left(\int_0^1 c_t(j)^\rho di \right)^{\frac{1}{\rho}}$ and $P_t = \left(\int_0^1 P_t(j)^{\frac{\rho}{\rho-1}} dj \right)^{\frac{\rho-1}{\rho}}$, where ρ is a parameter that characterizes standard Dixit-Stiglitz preferences.

The first order conditions for consumption are:

$$c_{t,i}(j) = c_{t,i} \left(\frac{P_t(j)}{P_t} \right)^{\frac{1}{\rho-1}} \tag{3}$$

$$\lambda_t = \frac{1}{c_t - bc_{t-1}} - \frac{\beta b}{c_{t+1} - bc_t} \tag{4}$$

$$\lambda_t = \beta \frac{R_{t+1}}{\pi_{t+1}} \lambda_{t+1} \tag{5}$$

where $\pi_{t+1} = P_{t+1}/P_t$ denotes the gross inflation rate.

The money demand equation for the representative household is

$$\frac{M_{t,i}}{P_t} = \left(\frac{1}{\lambda_t} \frac{\Gamma_t}{1 - R_{t+1}^{-1}} \right)^{\frac{1}{\varepsilon}} \tag{6}$$

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[1] See Neiss (1999), Christiano *et al.* (2005) and Galì *et al.* (2007).

Here we assume $\varepsilon > 1$, which is sufficient to ensure that, *coeteris paribus*, the marginal cost to inflating is positive (see Neiss, 1999).

The optimal labor supply condition will be introduced at a later stage, when we consider the wage-setting regime.

2.2 Firms' pricing decisions

Each firm (j) produces a differentiated good using the production function:

$$y_{t,j} = A_t l_{t,j} \tag{7}$$

where $l_{t,j}$ is a standard labor bundle:

$$l_{t,j} = \left[\int_0^1 l_{t,j}(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}} \tag{8}$$

The productivity factor A_t is characterized by a stochastic trend[2]

$$\ln\left(\frac{A_t}{A_{t-1}} \right) = \ln\left(\gamma \right) + a_{a,t} \tag{9}$$

$$a_{a,t} = \rho_a a_{a,t-1} + \varepsilon_{a,t}$$

Firm (j) demand for labor type (i) is

$$l_{t,j}(i) = \left(\frac{W_{t,i}}{W_t} \right)^{-\sigma} l_{t,j} \tag{10}$$

where $W_t = \left[\int_0^1 W_{t,i}^{1-\sigma} di \right]^{\frac{1}{1-\sigma}}$ defines the wage index.

We assume a sticky price specification based on Rotemberg (1982) quadratic cost of price re-optimization:[3]

$$\frac{\xi_p}{2} \left(\Omega_t - 1 \right)^2 y_t \tag{11}$$

where $\Omega_t = \frac{\pi_t}{\pi_{t-1}^{\delta_p} \pi^{1-\delta_p}}$. In line with Ascari *et al.* (2010), the re-optimization cost is proportional to output[4] and depends on the ratio between the newly reset price and the previous-period price, adjusted by a geometric average ($\delta_p \in [0,1]$) of steady state inflation, π, and of past inflation.[5]

The price adjustment rule is:

$$\frac{\rho - mc_t}{1-\rho} + \xi_p \Omega_t \left(\Omega_t - 1 \right) = E_t \left\{ \left[\beta \xi_p \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} \left(\Omega_{t+1} - 1 \right) \right] \frac{y_{t+1}}{y_t} \right\} \tag{12}$$

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[2] Assumptions about the distribution of $\varepsilon_{a,t}$ are discussed in our empirical section.

[3] The cost of price adjustment is transferred to consumers through a reduction in profits.

[4] By making price adjustment costs proportional to current output we obtain that the output costs of inflation are constant along the balanced growth path.

[5] This assumption is common to several empirical contributions (Giannoni and Woodford, 2004; Christiano *et al.* 2005; Smets and Wouters, 2003, 2005, 2007; Jondeau and Sahuc, 2008; Coenen and Warne, 2008; Rabanal and Rubio-Ramirez, 2005; Levin *et al.*, 2006; Justiniano and Primiceri, 2008). It ensures that the Phillips curve is vertical in the long run. We make it here in order to sharpen the empirical analysis on the effectiveness of the wage-setting mechanism presented in this paper.

where

$$mc_t = \frac{w_t}{A_t} \tag{13}$$

defines real marginal costs.

2.3   Wage-setting decisions

Given (8), the labour market is characterized by monopolistic competition. From (10) each household i faces a downward-sloping demand curve

$$l_t(i) = \int_0^1 l_{t,j}(i)dj = \left(\frac{W_t(i)}{W_t}\right)^{-\sigma} l_t \tag{14}$$

Under flexible wages the standard wage-setting condition

$$w_t = \eta \mu^w \frac{l_t^{\phi}}{\lambda_t} \tag{15}$$

obtains, where $\mu^w = \sigma (\sigma - 1)^{-1}$ denotes the gross wage markup.

The key innovation of the paper concerns the way we model nominal wage rigidity. Our approach is based on the conjecture that, when setting contracts, wage setters internalize the consequences of their choices for economic outcomes over the life of the contract. This is consistent with recent empirical micro-level evidence on wage bargaining, which shows that wage renegotiations take place while expiring contracts are still in place (Du Caju $et\ al.$, 2008). A standard way to capture this effect is to assume that in t nominal wages are pre-determined, i.e. they are set before shock realizations and the corresponding private sector and monetary policy responses are observed. More formally, this implies that $W_t(i)$ is set conditional to information available in $t-1$.[6]

To highlight the implications of our approach, we characterize the solution of the wage-setting problem when wages are pre-determined, abstracting from wage adjustment costs, which will be introduce shortly. In this case, the representative household sets the nominal wage rate, $W_t(i)$, that maximizes (1), conditional to the expected values for (14) (6), (4). The expected real wage is

$$w_t^e = E_{t-1}\left[\frac{\mu^w}{1 + \delta_{m.t}}\eta\frac{l_t^{\phi}}{\lambda_t}\right] \tag{16}$$

where

$$\delta_{m.t} = \frac{\Gamma_t}{\varepsilon}\left(\frac{M_t}{P_t^e}\right)^{1-\varepsilon} = \frac{\Gamma_t^{\frac{1}{\varepsilon}}}{\varepsilon}\left(\frac{1}{\lambda_t}\frac{1}{1 - R_{t+1}^{-1}}\right)^{\frac{1-\varepsilon}{\varepsilon}} \tag{17}$$

Relative to the case where wages are non-predetermined, $w_t^e = E_{t-1}\left[\frac{\mu^w \eta l_t^{\phi}}{\lambda_t}\right]$, the crucial difference is that households anticipate that real money balances will fall due to the adverse effect of the wage choice on consumption. This, in turn, has a disciplining effect on the real wage choice. The rationale for this result is as follows. Under flexible wages, the wage-setters' optimization problem is solved by choosing a real wage such that consumption falls below

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[6]This approach to modelling nominal wage rigidity in a static framework was popularized by standard Barro and Gordon models.

the perfectly competitive rate. This loss of utility is more than compensated for by the corresponding reduction in labor effort. When wages are predetermined, households also anticipate that real money balances fall due to the adverse effect of the wage choice on consumption. The term δ_m captures the impact of a real wage increase on expected real money holdings.

For the model to replicate the degree of nominal wage inertia typically observed over the business cycle, we incorporate this assumption into an otherwise standard sticky-wage model, based on Rotemberg (1982) quadratic adjustment cost:

$$\frac{\xi_w}{2} \left(\Omega_t^w - 1 \right)^2 A_t l_t \tag{18}$$

where $\Omega_t^w = \frac{\pi_t^w}{\left(\pi_{t-1}^w \right)^{\delta_w} (\pi^w)^{(1-\delta_w)}}$. In line with the assumptions made for the price-setting mechanism, the re-optimization cost is proportional to the product of labour[7] and depends on the ratio between the newly reset wage and the previous-period wage, adjusted by a geometric average ($\delta_w \in [0,1]$) of steady state wage inflation, π^w, and of past wage inflation π_{t-1}^w.[8]

When we introduce wage adjustment costs the solution to the wage-setting problem is:

$$E_{t-1} \left[\frac{w_t - \eta \frac{\mu^w}{1+\delta_m} \frac{l_t^\phi}{\lambda_t}}{\frac{\mu^w}{1+\delta_m} - 1} + \xi_w \Omega_t^w \left(\Omega_t^w - 1 \right) \right] =$$

$$= E_{t-1} \left\{ \left[\beta \xi_w \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1}^w \left(\Omega_{t+1}^w - 1 \right) \right] \frac{y_{t+1}}{y_t} \right\} \tag{19}$$

2.4 Aggregate resource constraint

The aggregate resource constraint accounts for price and nominal wage adjustment costs.

$$y_t = c_t + \frac{\xi_p}{2} \left(\Omega_t - 1 \right)^2 y_t + \frac{\xi_w}{2} \left(\Omega_t^w - 1 \right)^2 y_t \tag{20}$$

2.5 Monetary Policy

Monetary policy sets the long-run inflation target, π, and follows a Taylor rule

$$\frac{R_t}{R} = \left[\left(\frac{\pi_t}{\pi} \right)^{\psi_\pi} \left(\frac{A_{t-1} y_t}{A_t y_{t-1}} \right)^{\psi_{\Delta y}} \right]^{1-\rho_m} \left(\frac{R_{t-1}}{R} \right)^{\rho_m} \tag{21}$$

where parameter ρ_m captures interest rate smoothing, R defines the steady-state value of the nominal interest rate. Following Lubik and Schorfeide (2006) the interest rule reacts to inflation deviations from target (π) and to deviations of the actual growth rate from the growth rate of the productivity factor. According to (21) the interest rate therefore reacts to the growth rate gap instead of the standard output gap measure.

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[7]By making wage adjustment costs proportional to labour product we obtain that the output costs of wage inflation are constant along the balanced growth path.

[8]Indexation to wage inflation implies that nominal wage adjustment to long run productivity growth γ does not entail output costs.

3   Steady state

In steady state

$$\frac{c_{t+1}}{c_t} = \gamma \tag{22}$$

From (5), (7), (9), (21), (22) we get the solution for the real interest rate

$$\frac{R}{\pi} = \frac{\gamma}{\beta} \tag{23}$$

From the price adjustment rule (12) we get

$$\rho = \frac{w_t}{A_t} \tag{24}$$

where $\frac{1}{\rho} = \mu^p$ defines the flexible price markup. This implies that real wages grow with the productivity factor. Using (23), (24) and (20), the steady state solutions for (17) and employment are

$$\delta_m = \frac{\Gamma_t}{\varepsilon} \left(\frac{M_t}{P_t^e} \right)^{1-\varepsilon} = \frac{\xi^{\frac{1}{\varepsilon}}}{\varepsilon} \left(l \frac{\gamma - b}{\gamma - \beta b} \frac{\pi}{\pi - \frac{\beta}{\gamma}} \right)^{\frac{1-\varepsilon}{\varepsilon}} \tag{25}$$

$$l = l^{flex} \left[1 + \frac{\xi^{\frac{1}{\varepsilon}}}{\varepsilon} \left(l \frac{\gamma - b}{\gamma - \beta b} \frac{\pi}{\pi - \frac{\beta}{\gamma}} \right)^{\frac{1-\varepsilon}{\varepsilon}} \right]^{\frac{1}{1+\phi}} \tag{26}$$

where $l^{flex} = \left[\frac{\rho \gamma - \beta b}{\eta \mu^p \mu^w (\gamma - b)} \right]^{\frac{1}{1+\phi}}$ defines the employment level that would obtain if we removed the pre-determined wages assumption.

Note that when $\varepsilon > 1$ the the marginal utility from holding real money balances increases with inflation and falls with employment. Under pre-determined wages, wage setters internalize the increase in the marginal utility of real money holdings which is associated to a positive variation of the real wage. Condition (26) shows that this effect unambiguously grows with the inflation target. In Appendix A we show that l is unambiguously increasing in π when $\varepsilon > 1$. This is the essence of our theoretical result.

4   Estimates and tests

In order to evaluate our results and compare our benchmark to alternative specifications we closely follow Lubik and Schorfheide (2006, LS henceforth), who apply Bayesian estimation techniques to a simple New Keynesian model by considering a parsimonious set of time series (specifically, they use observations from output growth, inflation, and nominal interest rate). Bayesian estimation for DSGE models is close in spirit to restricted full information maximum likelihood (FIML) estimation, since the subjective element is specified in both cases. The peculiarity of the Bayesian MCMC approach is that, instead of employing interval restrictions on parameters, it requires to nest formalized distributional priors on parameters with the conditional distribution (i.e., the likelihood) in order to obtain the posterior distribution. Operationally, we estimate the mode

of the posterior distribution by maximizing the log posterior function, which combines the prior information on the parameters with the likelihood of the data. The Metropolis-Hastings algorithm is then used to get a complete picture of the posterior distribution and to evaluate the marginal likelihood of the model.[9]

The model is estimated over the sample period 1983:1-2004:4 by using, as said, observations on output growth, inflation, and nominal interest rate series for the U.S.[10] Following LS, we log-linearize our model around the balanced growth steady state, and consider three shocks, a "habit" shock $a_{z,t}$, which affects dynamics of the Euler equation, a productivity shock $a_{a,t}$, which affects the production function and marginal costs, and a "demand" shock $a_{d,t}$, which affects (20) (See Appendix B for the details). Shocks dynamics are defined as follows

$$
\begin{aligned}
a_{z,t} &= \rho_z a_{z,t-1} + \varepsilon_{z,t} \\
a_{a,t} &= \rho_a a_{a,t-1} + \varepsilon_{a,t} \\
a_{d,t} &= \rho_d a_{d,t-1} + \varepsilon_{d,t}
\end{aligned}
$$

We also consider a monetary policy innovation, $\varepsilon_{R,t}$, which is added to the log-linearized version of (21).[11]

Priors for the shock distributions are provided by LS (2006), who extract them from pre-sample observations (1970:1 to 1982:4). The remaining priors are defined according to the results obtained in previous studies and to economic reasoning. When possible, distributions for structural parameters are those used by LS.

Priors for stickiness parameters ξ_p and ξ_w are based on previous evidence on the average frequency of price changes, typically obtained from estimates of the Calvo probabilities of resetting prices and the wages.[12] We assume Gamma distributions for stickiness parameters and set the prior mean at 9.90 for both ξ_p and ξ_w (corresponding to an average period of 3.3 months for resetting prices and wages),[13] standard deviations are set at 2.0. The beta-distributed priors for the degrees of price (δ_p) and wage (δ_w) indexation to past inflation are set at 0.5, with standard deviations at 0.15. The prior distribution for the inverse labor supply Frisch elasticity, ϕ, is assumed to follow a normal distribution centered around 2, a large standard deviation (0.8) accounts for uncertainty about its location; habit parameter b has a beta distribution, mean is set at 0.2 with a standard deviation equal to 0.15; parameter ε has a gamma distribution centered on 1.5 with a standard deviation equal to 0.15.

The priors for the coefficients in the monetary policy rule are loosely centered around values typically associated with the Taylor rule. Following LS, we assume

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[9] The Bayesian estimation methodology used here is extensively discussed in Smets and Wouters (2003, 2010) or An and Schorfheide (2007). Some limits and criticisms to this approach are described in Canova and Sala (2009).

[10] Data were extracted from the FRED 2 database maintained by the Federal Reserve Bank of St. Louis. Full details on the construction of the data set are provided in LS (2006).

[11] In this case the shock is not auto-correlated because persistence has already been introduced in equation (21).

[12] Rotemberg adjustment costs are obtained from Calvo probabilities of resetting prices by imposing the same first order dynamics for price- and wage-setting equations in the two models (for details, see Lombardo and Vestin, 2008).

[13] In the U.S. an average 26% of U.S. sectorial prices are changed every 3.3 months, (Bils and Klenow, 2004).

gamma distributions for ϕ_π and ϕ_y, respectively setting prior means at 1.5 and 0.5 and standard deviations at 0.25. In addition the interest rate smoothing parameter ρ_m has a beta distribution with 0.5 mean and 0.2 standard deviation. We also estimate the annual inflation target (π^A), and the real annual interest (r^A) and quarterly growth (g) rates.[14] Their prior distributions are taken from LS.

The remaining parameters are restricted before the estimation procedure. In line with our measurement equations we set $\beta = \left(1 + r^A/400\right)^{-1}$.[15] Similarly to Christiano *et al.* (2005), the scale parameter ξ_m in (1) was set to ensure that in steady state the consumption-based money velocity is 0.35, which is its observed average value over the sample period. Goods and labor-type elasticities are set at values consistent with $\mu^p = \mu^w = 1.2$. Finally, η is set to normalize hours to one in the efficient equilibrium.

The following table summarizes our priors and displays our results.[16]

Table 1 – Parameters and stochastic structure

	Prior			Posterior		
	Distr.	Mean	St.Dev.	Mean	5%	95%
δ_p	Beta	0.50	0.15	0.18	0.06	0.28
δ_w	Beta	0.50	0.15	0.28	0.10	0.44
b	Beta	0.20	0.10	0.61	0.42	0.79
ξ_p	Gamma	9.90	2.00	10.34	7.01	13.53
ξ_w	Gamma	9.90	2.00	10.90	7.81	14.01
ϕ	Normal	2.00	0.80	1.91	0.77	2.90
ε	Gamma	1.50	0.20	1.53	1.23	1.84
ϕ_π	Gamma	1.50	0.25	1.66	1.31	1.99
ϕ_y	Gamma	0.50	0.25	0.55	0.30	0.80
π^A	Gamma	7.00	2.00	3.36	2.80	3.88
r^A	Gamma	0.50	0.50	0.53	0.01	0.96
γ^Q	Normal	0.40	0.20	0.41	0.16	0.63
ε^a	Invgamma	1.25	0.66	1.59	0.75	2.84
ε^d	Invgamma	1.25	0.66	0.45	0.37	0.52
ε^z	Invgamma	0.63	0.33	0.29	0.20	0.37
ε^R	Invgamma	0.50	0.26	0.17	0.14	0.20
ρ_a	Beta	0.80	0.10	0.87	0.78	0.96
ρ_d	Beta	0.80	0.10	0.88	0.79	0.98
ρ_z	Beta	0.66	0.15	0.85	0.76	0.94
ρ_m	Beta	0.50	0.20	0.78	0.72	0.84

From the mean posterior estimates reported in Table 1 we obtain that in steady state $\delta_m = 0.026$. This, in turn, implies that we estimate a wage disciplining effect of about 3% by reducing the wage markup from 1.20 to 1.17.

Finally, to provide a formal evaluation of the importance of our results we compare our results with the case where we neglect pre-determined wages

[14] Parameters π^A, r^A, γ^Q are linked to the model steady state values for inflation, growth and the real interest rate by using: $\pi = 1+\pi^A/400$; $\gamma = 1+\gamma^Q/100$; $R = 1+r^A/400+\pi^A+4\gamma^Q$.

[15] See LS (2006).

[16] The results reported in this paper have been computed using the Matlab-based Dynare package. Markov chain Monte Carlo methods are used to generate draws (500.000) from the posterior distribution of the model parameters. The summary statistics (posterior means and 90% probability intervals) reported are computed by using these draws.

$(\delta_m = 0).$[17] The relative performance of our model specification is measured by comparison of log data densities.[18] Bayesian model selection analysis allows us formally to compare the two specifications. Following Riggi and Tancioni (2010), by considering the Laplace approximation,[19] the posterior log-likelihood of including and excluding pre-set wages is -296.49 and -297.33, respectively.[20] The Bayes factor is thus 2.08, a value which indicates an evidence in favor of the specification that includes anticipation effects (i.e., pre set wages and money in the utility function, $\delta_m \neq 0$) .

5 The long-run Phillips curve and the IRFs to a monetary shock

Given our estimates for ε, γ, b, ϕ and the values chosen for $\mu^p \mu^w$, we are able to characterize a long-run Phillips curve, illustrated in Figure 1.

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[17] The alternative model has been estimated by using the same prior distributions described in Table 1. Posterior means are very similar. The full outcome of the estimations is available upon request.

[18] See LS (2006) or Riggi and Tancioni (2010). Sims (2006) discusses the methodology vis a vis existing alternatives. Specifically, he discusses in favour of likelihood-based methods for fitting and comparing model specifications, as opposed to single-equation or impulse-response matching approaches.

[19] Similar results can be obtained by using log marginal data densities computed on Geweke's modified harmonic mean estimator. We report Laplace approximation as they are more robust in our framework, where we test consistency with respect to a large set of parameters in a small scale model. It is also worth noticing that there is ad adverse effect on our exercise as that estimation of more parsimonious model are more likely to be preferred. See Riggi and Tancioni (2010).

[20] The alternative model has been estimated by using the same prior distributions described in Tables 1 and 2. Posterior means are very similar. The full outcome of the estimations is available upon request.
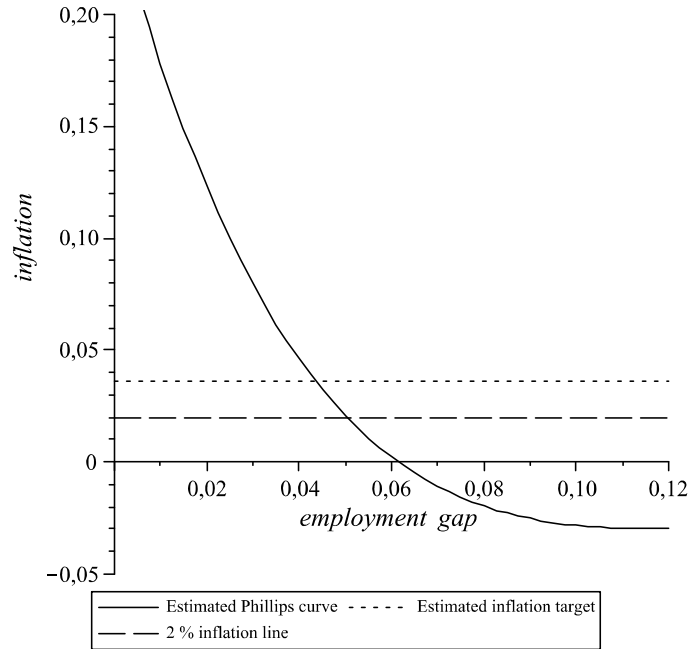
Figure 1 – Long run Phillips curve

The curve describes the relationship between long-run inflation (i.e., central bank's targets) and the employment loss, defined as the per cent gap between actual hours and their efficient level. Our results show that the estimated inflation target (3.36%) implies an employment gap equal to 4.3%, whereas the gap would grow to 5% and 6.1% if the inflation target fell to 2% and to zero, respectively. A 1% reduction in the net inflation target relative to the 3.36% value estimated over the sample period would cause a 0.4% employment loss. Approximately we find a one to two relationship between the gap and the inflation rate.

In Figure 2 we report the impulse response functions to the interest rate shock $\varepsilon_{R,t}$.
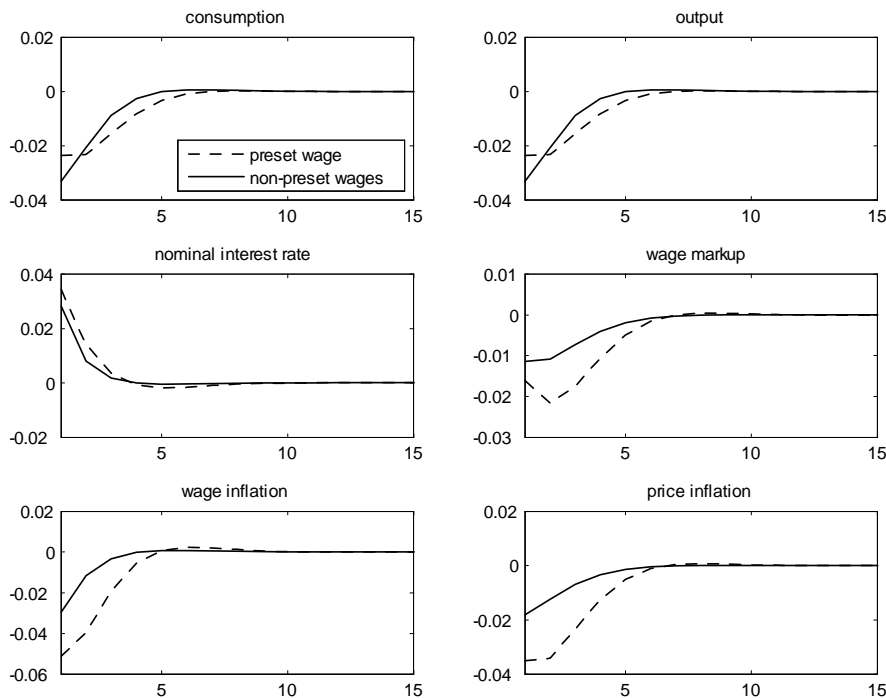
Figure 2 - IRFs

We comment on the dynamic performance of our model relative to the restricted version where wages are sticky but they non-preset. From (17) it is clear that the real interest rate increase is associated to a reduction in real money holdings and to an increase in their marginal utility. This, in turn disciplines wage claims, i.e. the wage markup falls. As a result we observe a stronger fall in both wage and price inflation, whereas consumption is stabilized.

6   Conclusions

Empirical micro evidence about wage-setting behavior inspires the key innovation of our paper, that is, the pre-set wages assumption is nested into an otherwise standard Rotemberg sticky wage model. The pre-determined wages and money-in-the-utility-function assumptions are sufficient to identify a non vertical long-run Phillips curve. Model estimates suggest that the disciplining effect associated to a moderate inflation rate could be substantial. In addition, the dynamic adjustment to an interest rate shock is characterized by stronger wage (price) adjustment and relative stability of output and consumption.

We consider our investigation successful, but an important caveat is that our approach should be tested within richer medium-scale models that, e.g., account for a characterization on the money market. For instance, one should introduce the cash in advance constraint that generates the working capital channel of monetary policy, as described in Christiano *et al.* (2005). In addition, it would

be interesting to estimate the empirical relevance of our wage-setting mechanism for different countries and over different sample periods. All this is left for future research.

Appendix A − Wage moderation effect

Totally differentiating (26) we obtain

$$
\begin{aligned}
\frac{\partial l\left\{\pi\right\}}{\partial \pi} &= \frac{l^{flex}}{1+\phi}\left[1+\frac{\xi_m^{\frac{1}{\varepsilon}}}{\varepsilon}\left(\frac{\gamma-b}{\gamma-\beta b}\frac{\pi}{\pi-\frac{\beta}{\gamma}}l\left\{\pi\right\}\right)^{\frac{1-\varepsilon}{\varepsilon}}\right]^{\frac{1}{1+\phi}-1} \times \\
&\times l^{flex}\frac{1-\varepsilon}{\varepsilon}\left[1+\frac{\xi_m^{\frac{1}{\varepsilon}}}{\varepsilon}\left(\frac{\gamma-b}{\gamma-\beta b}\frac{\pi}{\pi-\frac{\beta}{\gamma}}l\left\{\pi\right\}\right)^{\frac{1-\varepsilon}{\varepsilon}-1}\right] \times \\
&\times \frac{\xi_m^{\frac{1}{\varepsilon}}}{\varepsilon}\frac{\gamma-b}{\gamma-\beta b}\left[\frac{\pi}{\pi-\frac{\beta}{\gamma}}\frac{\partial l\left\{\pi\right\}}{\partial \pi}-\frac{\frac{\beta}{\gamma}l\left\{\pi\right\}}{\left(\pi-\frac{\beta}{\gamma}\right)^2}\right] \quad (27)
\end{aligned}
$$

Under the assumption that $\varepsilon > 1$, $\partial l(\pi)/\partial \pi$ is unambiguously positive.

Appendix B − The estimated model.

In order to take the model to the data we follow Lubik and Schorfeide (2005). In particular, we impose the same stochastic structure imposed by them and use their prior to estimate our model, which is a generalization of LS (2005) to imperfect labor markets. It is worth to noticing that a different stochastic structure does not affect any of the theoretical results reported in the paper as all of them are derived for the long run (steady state).

B1. Stochastic structure

Following LS (2005), we introduce two shocks in the production function,

$$
Y_t = A_{a,t}A_t^z L_t \quad (28)
$$

where A_t is a canonical productivity shock and A_t^z is a non stationary disturbance, which determines the growth rate γ (i.e., $A_t^Z/A_{t-1}^Z = \gamma$). Specifically, we consider $A_{a,t}$ and $A_{z,t} = A_t^Z/\gamma A_{t+1}^Z$ (thus along the balanced growth path $A_z = 1$), in log they are assumed to behave as an $AR(1)$ process:

$$
\begin{aligned}
a_{z,t} &= \rho_z a_{z,t-1} + \varepsilon_{z,t} \\
a_{a,t} &= \rho_a a_{a,t-1} + \varepsilon_{a,t}
\end{aligned}
$$

Households whose preferences are described by

$$
U = \sum_{t=0}^{\infty} \beta^t \left(\ln\left(\frac{h_{t,i}}{A_t^z}\right) - \frac{\eta}{1+\phi}l_{t,i}^{1+\phi} + \frac{\Gamma_t}{1-\varepsilon}\left(\frac{M_{t,i}}{P_t}\right)^{1-\varepsilon}\right) \quad (29)
$$

where $h_{t,i} = c_{t,i} - b\gamma c_{t-1,i}$ is effective consumption under habit formation. The presence of the term A_t^z in the above expression implies that households derive utility from effective consumption relative to the level of technology and guarantees that the model has a balanced growth path along which hours worked are stationary even if more general preference function for consumption are considered. It follow that marginal utility of income is

$$A_t^z \lambda_t = \frac{A_t^z}{c_t - bc_{t-1}} - \frac{\beta b\gamma A_t^z}{c_{t+1} - bc_t} \tag{30}$$

i.e.

$$A_t^z \lambda_t = \frac{1}{h_t/A_t^z} - \frac{\beta b}{h_{t+1}/A_{t+1}^z} \frac{1}{A_{z,t+1}} \tag{31}$$

It is worth noticing that $A^z\lambda$ and h/A^z are stationary along the balanced growth path and that A_z is an habit-driven shock to the marginal utility of consumption. If $b = 0$, marginal utility of consumption no longer depends on A_z.

The remaining two shocks affect the aggregate resource constraint and the Taylor rule. Regarding the former, $A_{d,t}$, we have that

$$y_t = A_{d,t} \left[c_t + \frac{\xi_p}{2} \left(\Omega_t - 1 \right)^2 y_t + \frac{\xi_w}{2} \left(\Omega_t^w - 1 \right)^2 y_t \right] \tag{32}$$

with $A_{d,t}$ in log deviations

$$a_{d,t} = \rho_d a_{d,t-1} + \varepsilon_{d,t} \tag{33}$$

Regarding the latter we just consider an innovation, $\varepsilon_{R,t}$, in the log linear Taylor rule, where persistence is already modelled by interest rate inertia.

B2. Habits equation

The habits equation is:
$$h_t = c_t - b\gamma c_{t-1} \tag{34}$$

Note that
$$\frac{h_t}{A_t^z} = \frac{c_t}{A_t^z} - b\gamma \frac{c_{t-1}}{A_t^z} \tag{35}$$

i.e.,
$$\frac{h_t}{A_t^z} = \frac{c_t}{A_t^z} - b\frac{c_{t-1}}{A_{t-1}^z} \frac{1}{A_{z,t+1}} \tag{36}$$

in steady state thus
$$\frac{h}{A^z} = \frac{c}{A^z} \left(1 - b \right) \tag{37}$$

Log linearization of (34) thus implies

$$\hat{h}_t = \frac{\hat{c}_t}{1 - b} - \frac{b}{1 - b} \left(\hat{c}_{t-1} - a_{z,t} \right) \tag{38}$$

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B3. Marginal utility of income

The marginal utility of income is

$$A_t^z \lambda_t = \frac{1}{h_t/A_t^z} - \frac{\beta b}{h_{t+1}/A_{t+1}^z} \frac{1}{A_{z,t+1}} \tag{39}$$

In the steady state (by using (37)), it implies

$$A^z \lambda = \frac{1}{h/A^z} (1 - \beta b) = \frac{1 - \beta b}{1 - b} \frac{1}{c/A^z} \tag{40}$$

We log linearize (39) and get

$$\hat{\lambda}_t = -\frac{1}{1 - \beta b} \hat{h}_t + \frac{\beta b}{1 - \beta b} \left(\hat{h}_{t+1} + a_{z,t+1} \right) \tag{41}$$

B4. Euler equation

The Euler equation is

$$\frac{1}{R_t} = \beta \frac{1}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \tag{42}$$

i.e.,

$$\frac{1}{R_t} = \beta \frac{1}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \frac{A_{t+1}^z}{A_{t+1}^z} \frac{A_t^z}{A_t^z} \frac{\gamma}{\gamma} = \beta \frac{1}{\pi_{t+1}} \frac{\lambda_{t+1} A_{t+1}^z}{\lambda_t A_t^z} \frac{1}{\gamma A_{z,t+1}} \tag{43}$$

In the steady state

$$\frac{1}{R} = \frac{\beta}{\gamma} \frac{1}{\pi} \Rightarrow R = \frac{\gamma}{\beta} \pi \tag{44}$$

Log linearization of (43) is

$$-\hat{\lambda}_t = -\hat{\lambda}_{t+1} - \left(\hat{R}_t - \hat{\pi}_{t+1} \right) + a_{z,t+1} \tag{45}$$

B5. Price equation

The price equation is

$$\frac{\rho - mc_t}{1 - \rho} + \xi_p \Omega_t (\Omega_t - 1) = E_t \left[\beta \xi_p \frac{\lambda_{t+1}}{\lambda_t} \Omega_{t+1} (\Omega_{t+1} - 1) \right] \frac{y_{t+1}}{y_t} \tag{46}$$

In steady state $mc = \rho$.

As above $\frac{\lambda_{t+1}}{\lambda_t} = \frac{\lambda_{t+1}}{\lambda_t} \frac{A_{t+1}^z}{A_{t+1}^z} \frac{A_t^z}{A_t^z} \frac{\gamma}{\gamma} = \frac{\lambda_{t+1} A_{t+1}^z}{\lambda_t A_t^z} \frac{1}{\gamma A_{z,t+1}}$, equation (46) can be rewritten as

$$\frac{\rho - mc_t}{1 - \rho} + \xi_p \Omega_t (\Omega_t - 1) = E_t \left[\beta \xi_p \frac{\lambda_{t+1} A_{t+1}^z}{\lambda_t A_t^z} \frac{\Omega_{t+1} (\Omega_{t+1} - 1)}{\gamma A_{z,t+1}} \right] \frac{y_{t+1}}{y_t} \tag{47}$$

It follows that the log linearization of (47) is

$$\frac{\rho}{1 - \rho} \widehat{mc}_t + \xi_p (\hat{\pi}_t - \delta_p \hat{\pi}_{t-1}) = \beta \xi_p (\hat{\pi}_{t+1} - \delta_p \hat{\pi}_t) \tag{48}$$

as in steady state $\Omega = 1$ and $\Omega(\Omega - 1) = 0$, which also implies that $\frac{\lambda_{t+1} A_{t+1}^z}{\lambda_t A_t^z}$ and $A_{z,t+1}$ do not affect the dynamics,

It is worth noticing that from (28) the marginal cost is:

$$MC_t = \frac{W_t/P_t}{A_t^z} \frac{1}{A_{a,t}} = \frac{w_t}{A_t^z} \frac{1}{A_{a,t}} \tag{49}$$

After log linearization it becomes:

$$\widehat{mc}_t = \hat{w}_t - a_{a,t} \tag{50}$$

B6. Wage equation

Similarly, the wage equation can be written as

$$E_{t-1}\left[\frac{1}{y_t\lambda_t} \frac{w_t\lambda_t - \eta\frac{\mu^w}{1+\delta_{m,t}}l_t^\phi}{\frac{\mu^w}{1+\delta_{m,t}} - 1} + \xi_w\Omega_t^w\left(\Omega_t^w - 1\right)\right] =$$

$$= E_{t-1}\left[\beta\xi_w \frac{\lambda_{t+1}A_{t+1}^z}{\lambda_t A_t^z} \frac{\Omega_{t+1}^w\left(\Omega_{t+1}^w - 1\right)}{\gamma A_{z,t+1}}\right]\frac{y_{t+1}}{y_t} \tag{51}$$

In steady state

$$
\begin{aligned}
w\lambda &= \eta\frac{\mu^w}{1+\delta_m}l^\phi \\
y\lambda &= \frac{c}{A^z}\lambda A^z \tag{52}
\end{aligned}
$$

Log linearization of (51) is

$$w\lambda\left(\hat{w}_t + \hat{\lambda}_t - \phi\hat{l}_t + \frac{\delta_m}{1+\delta_m}\hat{\delta}_{m,t}\right) + \xi_w\left(\hat{\pi}_t^w - \delta_w\hat{\pi}_{t-1}^w\right) = \beta\xi_w\left(\hat{\pi}_{t+1}^w - \delta_w\hat{\pi}_t^w\right) \tag{53}$$

where wage moderation follows from the log linearization of (17):

$$\hat{\delta}_{m,t} = \frac{\varepsilon - 1}{\varepsilon}\left(\frac{\beta}{\pi - \beta}\hat{R}_t + \hat{\lambda}_t\right) \tag{54}$$

B7. Other equations

Aggregate resource constraint (28) implies

$$\hat{y}_t = \hat{c}_t + a_{d,t} \tag{55}$$

Production function (32) implies

$$\widehat{y}_t = \hat{l}_t + a_{a,t} \tag{56}$$

The log linearization of the Taylor rule (21) is

$$\hat{R}_t = \rho_m\hat{R}_{t-1} + (1 - \rho_m)\left[\psi_\pi\hat{\pi}_t + \psi_{\Delta y}\left(\Delta\hat{y}_t + \hat{z}_t\right)\right] + \hat{\varepsilon}_{Rt} \tag{57}$$

B8. Measurement equations

Measurement equations relate the net annualized per-cent inflation (π^{Obs}) and nominal interest rate (R^{Obs}), and the quarterly net per-cent growth rate (g^{Obs}) to the model as follows:[21]

$$
\begin{align}
\pi_t^{Obs} &= \pi^A + 4\pi_t \tag{58}\\
R_t^{Obs} &= r^A + \pi^A + 4\gamma^Q + 4R_t \tag{59}\\
g_t^{Obs} &= \gamma^Q + y_t + y_{t-1} + z_t \tag{60}
\end{align}
$$

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[21]See LS (2006).

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