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Abstract

The euro area as a whole has experienced a marked downward trend in inflation over the past decades and, concomitantly, a protracted period of depressed activity. Can permanent and gradual shifts in monetary policy be held responsible for these dynamics? To answer this question, we embed serially correlated changes in the inflation target into a DSGE model with real and nominal frictions. The formal Bayesian estimation of the model suggests that gradual changes in the inflation target have played a major role in the euro area business cycle. Following an inflation target shock, the real interest rate increases sharply and persistently, leading to a protracted decline in economic activity. Counter–factual exercises show that, had monetary policy implemented its new inflation objective at a faster rate, the euro zone would have experienced more sustained growth than it actually did.

Keywords: Inflation target shocks, Gradualism, DSGE models, Bayesian econometrics
JEL Class.: E31, E32, E52

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Introduction

Inflation in the euro area fell dramatically from 12% in the early 1980's to 4% in the early 1990's. In spite of some differences, inflation rates in most member countries display a significant and very gradual downward trend over this period. These dynamics have followed purposeful monetary policies aimed at stabilizing inflation to lower levels (e.g., Germany in the early eighties, or the competitive disinflation in France and in Italy, in the mid eighties). At the very same time, these economies experienced protracted periods of recessions. Of course, the dynamics of macroeconomic variables might be due to other factors or shocks than monetary policy. However, a legitimate question is to assess whether permanent and gradual changes in monetary policy have significantly affected these dynamics over the past decades. If so, through which channels did these shocks propagate? This is the main question adressed in this paper.

As a matter of fact, in the main Continental European countries, disinflation policies have been implemented very gradually.[1] This might reflect either a purposeful choice of monetary policy or constraints imposed by European Monetary System (EMS) membership. The purposeful choice of monetary policy is clearly illustrated in Bundesbank (1995), which states that[2]

> " In view of the unfavorable underlying situation, the Bundesbank felt obliged until 1984 to include an "unavoidable" rate of price rises in its calculations. By so doing, it took due account of the fact that price increases which have already entered into the decisions of economic agents cannot be eliminated immediately, but only step by step. (...) The Bundesbank thereby made it plain that, by adopting an unduly "gradualist" approach to fighting inflation, it did not whish to contribute to strenghtening inflation expectations."
> Deutsche Bundesbank (1995), pp. 80-81.

Similarly, constraints on monetary policy imposed by EMS membership necessarily prevented the adoption of a shock therapy to fight inflation, due to exchange rate obligations.[3] This is typically the case for France and Italy, where a competitive disinflation policy was adopted (see De Grauwe, 1990, and Blanchard and Muet, 1993). Additionally, EMS countries had to maintain this policy for a long time in order to gain an anti–inflation reputation. This is clearly the position defended by French Minister Beregovoy, who consistently refused to devaluate

[1] As pointed out by Cogley and Sargent (2005) and Primiceri (2006), gradual disinflation was explicitly preferred by the Fed during the seventies, to prevent large sacrifice ratios.

[2] See Laubach and Posen (1997) for a thorough analysis of German monetary policy.

[3] This is in contrast to what UK did over the same period.

> "When it comes to France, its monetary policy is well known. It rests on the Franc–Deutsche Mark parity and the pursuit of the disinflation policy."
>
> Masset–Denèvre (2000), pp. 168.

To investigate quantitatively the dynamic effects of gradual disinflation, we summarize monetary policies in the euro area by permanent and gradual changes in the time–varying inflation target of a fictitious single European Central Bank. This inflation target is further embedded in a Dynamic Stochastic General Equilibrium (DSGE) model, imposing the Friedmanite premise that low frequency movements in inflation, if any, are necessarily due to this feature of monetary policy.[4]

As in the bulk of the literature, assuming a single central bank for euro zone countries is meant as a useful practical simplification of a much more complex decision making process (see, e.g., Smets and Wouters, 2003). This approach could be problematic when it comes to disinflation shocks. Indeed, it might be argued legitimately that European countries part of the EMS have faced heterogeneous disinflation experiences. However, based on the analysis conducted by Ball (1994) and Andersen and Wascher (1999), we find that disinflation episodes occurred approximately at the same dates in Belgium, France, Germany, and Italy.[5]

The main model features are the following. First and foremost, as in Ireland (2007), we assume that the inflation target follows a non–stationary process. In contrast with Ireland, though, we assume that changes in the inflation target are exogenous and serially correlated. Second, the DSGE model allows for various real and nominal frictions, such as habits in consumption, sticky prices, and sticky wages.[6] In the case of euro area data, gradual inflation target shocks and wage stickiness can be potentially crucial. Indeed, as argued by Blanchard (2003), two suspects for the protracted period of depressed economic activity in Europe over the eighties are: *(i)* excessive and persistent real wages and *(ii)* persistently high real interest rates. Allowing for sticky wages helps us quantify the importance of the first suspect. Considering gradual inflation target shocks can also help rationalize the observed inertial dynamics of the short–term nominal interest rate which remained above inflation for a very long period in the eighties and nineties.

In disentangling the respective roles of each suspect and the channels through which they contributed to propagate inflation target shocks, a formal econometric procedure is required. In this paper, the

[4]A number of recent papers have adopted time–varying inflation targets in DSGE models. See, among others, Adolfson et al. (2005, 2007), Cogley, Primiceri and Sargent (2008), Cogley and Sbordone (2007), Erceg and Levin (2003), Ireland (2007), Melecky et al. (2008), Smets and Wouters (2005), and de Walque et al. (2006).

[5]Throughout the paper, we endorse the working hypothesis that monetary policies are perfectly understood and credible, as in Ireland (2007). See Erceg and Levin (2003) for an alternative approach emphasizing credibility issues. Here, we stick to the specification adopted by Ireland to emphasize a single mechanism.

[6]Our setup also incorporates material goods and a production function à la Kimball (1995).

DSGE model is taken to the data by adopting a full system Bayesian estimation procedure. Using marginal likelihoods and posterior odds provides appropriate inputs for models comparison. This will prove particularly useful when assessing the importance of our assumption of gradual permanent inflation target shocks.

We find that inflation target shocks significantly contributed to aggregate fluctuations in the euro area. This result crucially depends on our assumption of gradual diffusion for these shocks. Ignoring this feature, these shocks are no longer essential in explaining fluctuations of real variables. At the same time, our hypothesis is strongly supported by the data. Indeed, a version of our model without gradual inflation target shocks has a much lower marginal likelihood than our benchmark model. Inspecting the impulse response functions, we also find that the real wage actually declines after an inflation target shock while the real interest rate persistently increases. This suggests that the main suspect accounting for the recessionary effects of disinflation shocks is the inertial behavior of monetary policy, in the form of both gradual disinflation shocks and an inertial interest rate rule.

These results are confirmed by a series of counterfactual exercises conducted with our estimated DSGE model. We find that, absent inflation target shocks, output would have been higher over the eighties than it actually was. This is a direct consequence of the high and persistent increase in the real interest rate triggered by negative inflation target shocks that would have otherwise been avoided. In addition, we perturb the parameters governing inertia and gradualism in monetary policy. We find that both stories have played a central role in propagating these shocks. These two features turn out to imply very long lasting increases in the real interest rate, translating into persistent output losses. Had monetary policy implemented its new inflation objective at a faster rate, the euro zone would have experienced more sustained growth than it actually did during the eighties.

The paper is organized as follows. A first section briefly expounds our theoretical model. Section 2 lays out our econometric procedure and comments on the estimation results. Counterfactual experiments are conducted in section 3. The last section offers concluding remarks.

1 The DSGE Model

We consider a discrete time economy, populated with a continuum of infinitely–lived households. Households are endowed with specific skills that are combined together in an aggregate labor index by an employment agency, as in Erceg et al. (2000). Perfectly competitive firms produce an aggregate good that can be either consumed or used as a production input. The aggregate good is produced by combining imperfectly substitutable intermediate goods, each of which is produced by monopolistic firms which combine aggregate labor and material goods according to a Leontief production function.

These firms face random nominal price reoptimization opportunities, according to the Calvo (1983) specification. Symmetrically, households reoptimize their nominal wage at random intervals.

In what follows, we briefly describe the log-linearized version of the model.[7] Since the inflation target changes permanently, all nominal variables are deflated by this variable. In addition, there are permanent productivity shocks. Thus to induce stationarity, real trending variables are divided by the productivity shock. All the resulting stationary variables are denoted, below, with the superscipt "s".

The *consumption* equations:

$$(1-\beta b)(1-b)\hat{\lambda}_t^s = \beta b \mathrm{E}_t\{\hat{y}_{t+1}^s - b\hat{y}_t^s\} - (\hat{y}_t^s - b\hat{y}_{t-1}^s) + b[\beta \mathrm{E}_t\{\Delta z_{t+1}\} - \Delta z_t] + \tilde{g}_t, \tag{1}$$

$$\hat{\lambda}_t^s = \hat{R}_t^s + \mathrm{E}_t\{\hat{\lambda}_{t+1}^s - \Delta z_{t+1} - \hat{\pi}_{t+1}^s - \Delta\hat{\pi}_{t+1}^\star\}, \tag{2}$$

The detrended marginal utility of wealth $\hat{\lambda}_t^s$ is a weighted average of present, past, and expected future detrended output ($\hat{y}_t^s$). It also depends on expected and present productivity growth Δz_t and on a preference shock $\tilde{g}_t$.[8] In turn, $\hat{\lambda}_t^s$ is linked to the ex-ante real interest rate $\hat{R}_t^s - \mathrm{E}_t\{\hat{\pi}_{t+1}^s + \Delta\hat{\pi}_{t+1}^\star\}$ and expected productivity growth. Here, $\hat{R}_t^s$ represents the nominal interest rate in deviation from the inflation target $\hat{\pi}_t^\star$ ($\hat{R}_t^s \equiv \hat{R}_t - \hat{\pi}_t^\star$). Similarly, $\hat{\pi}_t^s$ denotes the inflation gap ($\hat{\pi}_t^s \equiv \hat{\pi}_t - \hat{\pi}_t^\star$). The consumption equation incorporates a preference shock, which is assumed to obey the process

$$\tilde{g}_t = \rho_g \tilde{g}_{t-1} + \sigma_g \epsilon_{g,t}, \quad \epsilon_{g,t} \sim N(0,1), \quad \rho_g \in [0,1). \tag{3}$$

In turn, productivity growth evolves according to

$$\Delta z_t = (1-\rho_z)\log(\gamma) + \rho_z \Delta z_{t-1} + \sigma_z \epsilon_{z,t}, \quad \epsilon_{z,t} \sim N(0,1), \quad \rho_z \in [0,1). \tag{4}$$

The parameter $b \equiv \bar{b}/\gamma$, where $\bar{b}$ captures the degree of internal habit formation in consumption and γ is the average gross growth rate of technical progress. Finally β is the subjective discount factor.

The *price* equation:

$$\hat{\pi}_t^s - \gamma_p \hat{\pi}_{t-1}^s = \kappa_p (1-\mu_p s_x)\hat{w}_t^s + \beta \mathrm{E}_t\{\hat{\pi}_{t+1}^s - \gamma_p \hat{\pi}_t^s\} + \gamma_p \zeta_t + \tilde{\mu}_{p,t}. \tag{5}$$

The inflation gap $\hat{\pi}_t^s$ depends on its past and expected future values and on the current logdeviation of the detrended real wage $\hat{w}_t^s$. The residual variable ζ_t obeys the relation $\zeta_t \equiv \beta \mathrm{E}_t\{\Delta\hat{\pi}_{t+1}^\star\} - \Delta\hat{\pi}_t^\star$. Finally, the price equation includes a price–markup shock, which is assumed to obey the process

$$\tilde{\mu}_{p,t} = \rho_p \tilde{\mu}_{p,t-1} + \sigma_p \epsilon_{p,t}, \quad \epsilon_{p,t} \sim N(0,1), \quad \rho_p \in [0,1). \tag{6}$$

[7] See appendix **??** for a complete exposition of the model's details.

[8] Here and the remainder of the paper, a variable with a hat refers either to a percentage deviation from steady state or to the natural logarithm of a gross rate. With a slight abuse of notation, we also use hats to denote logarithms of non stationary variables.

The parameter γ_p is the degree of indexation of prices to past inflation, μ_p is the steady–state markup, and s_x is the share of material goods in gross output. The composite parameter κ_p is defined according to

$$\kappa_p \equiv \frac{(1-\beta\alpha_p)(1-\alpha_p)}{\alpha_p(1+\epsilon_\mu\theta_p)},$$

The parameter α_p is the probability that prices cannot be reset in a given period, θ_p is the price elasticity of demand, and ϵ_μ is the steady–state markup elasticity (e.g., Kimball, 1995).

The *wage inflation* equation:

$$\hat{\pi}^s_{w,t} - \gamma_w \hat{\pi}^s_{t-1} = \kappa_w(\omega\tilde{\mu}_p^{-1}\hat{y}^s_t - \hat{\lambda}^s_t - \hat{w}^s_t) + \beta \mathrm{E}_t\{\hat{\pi}^s_{w,t+1} - \gamma_w \hat{\pi}^s_t\} + \gamma_w \zeta_t + \tilde{\mu}_{w,t}, \tag{7}$$

where $\hat{\pi}^s_{w,t}$, the nominal wage inflation in deviation from the inflation target ($\hat{\pi}^s_{w,t} \equiv \hat{\pi}_{w,t} - \hat{\pi}^\star_t$), is a function of its expected future value, past and present inflation gaps, and the wage gap ($\omega\tilde{\mu}_p^{-1}\hat{y}^s_t - \hat{\lambda}^s_t - \hat{w}^s_t$). It also depends on a wage–markup shock $\tilde{\mu}_{w,t}$, which is assumed to obey

$$\tilde{\mu}_{w,t} = \rho_w\tilde{\mu}_{w,t-1} + \sigma_w\epsilon_{w,t}, \quad \epsilon_{w,t} \sim N(0,1), \quad \rho_w \in [0,1). \tag{8}$$

Here the parameter γ_w is the degree of indexation of nominal wages to lagged inflation. The composite parameters κ_w and $\tilde{\mu}_p$ are given by

$$\kappa_w \equiv \frac{(1-\beta\alpha_w)(1-\alpha_w)}{(1+\omega\theta_w)\alpha_w}, \quad \tilde{\mu}_p \equiv \frac{\mu_p(1-s_x)}{1-\mu_p s_x}.$$

The parameter α_w is the probability that nominal wages cannot be reset in a given period, while ω and θ_w denote the inverse elasticity of labor supply and the labor demand elasticity, respectively. Finally, inflation and wage inflation are linked together according to the identity $\hat{\pi}^s_{w,t} = \hat{\pi}^s_t + \hat{w}^s_t - \hat{w}^s_{t-1} + \Delta z_t$.

The *monetary policy reaction function*:

$$\hat{R}^\star_t = \hat{\pi}^\star_t + a_p(\hat{\pi}_t - \hat{\pi}^\star_t) + a_y\hat{\gamma}_{y,t}. \tag{9}$$

$$\hat{R}_t = \rho\hat{R}_{t-1} + (1-\rho)\hat{R}^\star_t + a_{\pi^\star}\Delta\pi^\star_t + \eta_{R,t}. \tag{10}$$

The central bank is assumed to set its nominal interest rate $\hat{R}_t$ according to a generalized Taylor rule. The target nominal interest rate $\hat{R}^\star_t$ is a function of the inflation target $\hat{\pi}^\star_t$, the inflation gap, and the growth rate of output $\hat{\gamma}_{y,t} \equiv \hat{y}^s_t - \hat{y}^s_{t-1} + \Delta z_t$. Here, a_p is the coefficient coding the responsiveness of the target rate to the inflation gap and a_y is the responsiveness to output growth, as in Coenen et al. (2008), Edge et al. (2007), and Laforte (2007). The target nominal interest rate $\hat{R}^\star_t$ is embedded in a partial adjustment model with autocorrelated shocks. Here, ρ is the degree of interest rate smoothing. In addition, we allow the nominal interest rate $\hat{R}_t$ to react to changes in the inflation target, with sensitivity parameter $a_{\pi^\star}$. This allows us to separate the consequences of monetary policy inertia from those of gradual disinflation. To see this most clearly, let us recast the above monetary policy rule in terms of the stationary variables. We obtain

$$\hat{R}^s_t = \rho \hat{R}^s_{t-1} + (1-\rho)[a_p \hat{\pi}^s_t + a_y \hat{\gamma}_{y,t}] + (a_{\pi^\star} - \rho)\Delta\hat{\pi}^\star_t + \eta_{R,t}, \tag{11}$$

This illustrates to what extent the coefficient $a_{\pi^\star}$ allows us to neutralize the effect of monetary policy inertia on the propagation of inflation target shocks. In the case when $a_{\pi^\star} = \rho$, the nominal interest rate reacts one for one to changes in the inflation target. To the contrary, suppose that $a_{\pi^\star} = 0$ and that ρ is close to one. In this case, the nominal interest rate is disconnected from $\pi^\star_t$ on impact. This specification is sufficiently flexible to let the data sort out which of these competing configurations has the better fit.[9]

In turn, the inflation target shock evolves according to

$$\Delta\hat{\pi}^\star_t = \rho_{\pi^\star}\Delta\hat{\pi}^\star_{t-1} + \sigma_{\pi^\star}\epsilon_{\pi^\star,t} \quad \epsilon_{\pi^\star,t} \sim N(0,1), \quad \rho_{\pi^\star} \in [0,1). \tag{12}$$

Thus, in an attempt to capture possible gradual shifts in the inflation target, we assume that changes in the inflation target are serially correlated. The autocorrelation coefficient $\rho_{\pi^\star}$ reflects the slow pace at which monetary authorities allegedly adjusted its inflation target. This is the key difference between our specification and previous works that allowed for a time–varying inflation target. Either the latter is assumed to be stationary (in which case, it is undistinguishable from a standard monetary policy shock), or it is assumed to follow a pure random walk, as in Ireland (2007), for example.[10]

Finally, we allow for a standard monetary policy shock $\eta_{R,t}$, which is assumed to evolve according to

$$\eta_{R,t} = \rho_R \eta_{R,t-1} + \sigma_R \epsilon_{R,t}, \quad \epsilon_{R,t} \sim N(0,1), \quad \rho_R \in [0,1). \tag{13}$$

We are a priori agnostic as to which feature of monetary policy (or combination thereof) accounts for its observed inertia. We leave it to the data to settle this question.

2 Empirical Results

In this section, our formal econometric procedure is expounded. We then discuss our results and detail various analyses designed to understand the transmission mechanisms of permanent inflation target shocks.

[9] We thank an anonymous referee for suggesting us this flexible specification of the monetary policy rule.

[10] Notice that our inflation target shock is exogenous, which precludes the study of what has been called the "opportunistic approach" to disinflation policy. Following Ireland (2007), this opportunistic approach could have been modelled by allowing the inflation target shock to covary with supply shocks. In our framework, as in Ireland (2007), this approach raises an econometric problem. See Cochrane (2007).

2.1 Data and Econometric Approach

The data used in our empirical analysis are extracted from the AWM database compiled by Fagan et al. (2005). These are area–wide data for the euro zone as a whole and cover the period 1970(1)–2004(4). The raw series used are the logarithm of per capita GDP, $\hat{y}_t$, the growth rate of the Harmonized Index of Consumer Prices, $\hat{\pi}_t$, the growth rate of nominal wages, $\hat{\pi}_{w,t}$, and the real ex–post interest rate (i.e. the difference between the short–term nominal interest rate and inflation), $\hat{R}_t - \hat{\pi}_t$.[11] The data are reported in figure **??**. The shaded area corresponds to the large recession period that European countries experienced during the eighties. Over the same period, notice that inflation and wage inflation sharply declined. At the same time, the real (ex–post) interest rate dramatically increased in a protracted fashion. Our main goal is now to investigate whether inflation target shocks can be held responsible for these dynamic patterns. To answer this question, a formal econometric approach is required.

Let $X_T \equiv \{x_t\}_{t=0}^T$ denote the sample of observable (demeaned) data, where

$$x_t = (\Delta\hat{y}_t, \Delta\hat{\pi}_t, \Delta\hat{\pi}_{w,t}, \hat{R}_t - \hat{\pi}_t)'.$$

Notice that the specification of observable data in X_t is compatible with the structural model. Conditional on a given model specification $\mathscr{M}_i$, the prior distribution for the vector of model's parameters θ is $p(\theta|\mathscr{M}_i)$ and the likelihood function associated to the observable variables is $L(X_T|\theta, \mathscr{M}_i)$. Then, from Bayes theorem, the posterior distribution of θ is given by

$$p(\theta|X_T, \mathscr{M}_i) \propto L(X_T|\theta, \mathscr{M}_i)p(\theta|\mathscr{M}_i).$$

This posterior distribution is evaluated numerically using the Metropolis–Hastings algorithm with 300,000 draws. The first 25% draws are discarded to eliminate dependence on the initializing values chosen for θ.

For the sake of comparing different model versions, we resort to the following two standard criteria. First, from $p(\theta|X_T, \mathscr{M}_i)$, one can compute the marginal likelihood of specification $\mathscr{M}_i$, which is defined by

$$L(X_T|\mathscr{M}_i) = \int L(X_T|\theta, \mathscr{M}_i)p(\theta|\mathscr{M}_i)\mathrm{d}\theta.$$

A benefit of resorting to this measure of fit is that it accounts for the effects of the prior distribution (An and Schorfheide, 2007). Second, given a prior probability p_i on a given model specification $\mathscr{M}_i$, the posterior odds ratio is defined as

$$\mathcal{P}_{i,T} = \frac{p_i L(X_T|\mathscr{M}_i)}{\sum_{j=0}^{M-1} p_j L(X_T|\mathscr{M}_j)} \quad \text{with} \quad \sum_{j=0}^{M-1} p_j = 1,$$

[11] The population series used to express output in per capita terms is the working age population from various issues of OECD's Economic Perspective.

where M is the number of model specifications considered.

2.2 Estimation Results

In the benchmark model version, labelled $\mathscr{M}_0$, the vector of estimated parameters is

$$\theta = (b, \omega, \gamma_p, \gamma_w, \alpha_p, \alpha_w, \rho, a_p, a_y, a_{\pi^\star}, \rho_z, \rho_p, \rho_w, \rho_g, \rho_R, \rho_{\pi^\star}, \sigma_z, \sigma_p, \sigma_w, \sigma_g, \sigma_R, \sigma_{\pi^\star})'.$$

We also consider two other model versions. In $\mathscr{M}_1$, we set $\rho_{\pi^\star} = 0$. Hence, in this model version, we assume that the inflation target follows a simple random walk, as in Ireland and Smets and Wouters. This allows us to assess the consequence of shutting down this channel of monetary policy inertia. Notice that this assumption affects only the propagation of inflation target shocks. In $\mathscr{M}_2$, we set $\rho = 0$. Thus nominal interest rate smoothing is ignored. This assumption impacts on the transmission of all the shocks included in the analysis. In both alternative model versions, all the remaining parameters are re-estimated. The choice of parameters priors is summarized in the left panel of table **??**.

For the benchmark specification, the estimation results, together with the priors, are graphically summarized in figure **??**.[12] In each case, the dark grey line is the posterior distribution while the light grey line corresponds to the prior distribution. Also, the vertical dashed line denotes the posterior mode. The results are also reported in the right panels of table **??**. For each model version, the table shows the posterior mean and the 95% HPD interval.

The mean habit parameter is $b = 0.82$. This value is higher than in Smets and Wouters (2003). This should come as no surprise given that we estimate a smaller model in which no formal distinction is established between output and consumption.[13] Concerning the utility parameter ω, we obtain a mean value of 2.10. Inspecting figure **??** reveals that the prior and posterior distributions are almost identical. This syndrom of a lack of identification is familiar in the literature (Smets and Wouters, 2003).

The wage indexation parameter is $\gamma_w = 0.37$, higher than $\gamma_p = 0.16$. Interestingly, the euro area data do not require too high a degree of price indexation. This result is now standard in the literature (Smets and Wouters, 2003, 2005, Rabanal and Rubio–Ramìrez, 2007). We obtain $\alpha_p = 0.82$, which is fairly high, especially when one acknowledges that our model incorporates many features devised to lower the estimated value of this parameter (material goods, variable elasticity of demand). The probability of no wage change is $\alpha_w = 0.77$.

[12] Details concerning the calibration and the prior distributions of the model parameters are provided in appendix **??**.

[13] Woodford (2003) discusses circumstances in which habit persistence in a small model like ours is compatible with an interpretation of y_t as private expenditures instead of consumption expenditures.

When it comes to the monetary policy rule, we obtain almost the same results as Smets and Wouters (2003) for ρ, a_p, and a_y. The new parameter $a_{\pi^\star} = 0.60$ suggests that the nominal interest reacts on impact to changes in the inflation target. However, the estimated value of $a_{\pi^\star}$ is lower than ρ, meaning that changes in the inflation target are not fully incorporated in the nominal interest rate on impact.

The marginal likelihoods show that the benchmark model version $\mathscr{M}_0$ is clearly favored by the data. This suggests that a scenario with both gradual changes in the inflation target and nominal interest rate inertia is preferred to each of the two alternative, in which one form of inertia has been shut down. The posterior odds ratios offer a complementary way of seeing this. Starting from a prior distribution on model versions with $p_j = 1/3$ for $j = 0, 1, 2$, one arrives at the following: $\mathcal{P}_0 = 99.32\%$, $\mathcal{P}_1 = 0.38\%$, and $\mathcal{P}_2 = 0.00\%$. Therefore, the prior distributions on model versions $\mathscr{M}_1$ and $\mathscr{M}_2$ are severely shifted towards model $\mathscr{M}_0$, which represents almost the whole probability mass.

2.3 Implications of Inflation Target Shocks

In this subsection, we use the estimated model to analyze the dynamic effects of an inflation target shock. To do so, we inspect the impulse response functions (IRFs) triggered by this particular shock. We also compute the contribution of inflation target shocks to aggregate fluctuations.

Before proceeding, it is interesting to compare actual inflation dynamics with the time profile of the unobserved inflation target that our estimation procedure reveals. As is customary, the latter is obtained using the full sample information contained in the smoothed inflation target shocks. Figure **??** reports in plain line the actual sample path of the cumulated demeaned first difference of inflation; the dotted line corresponds to the smoothed estimate of the inflation target. The grey area highlights the disinflation period experienced by the euro area in the eighties. As the figure makes clear, the inflation target tracks all the medium to low frequency movements of inflation. Interestingly, however, it does not fully capture the inflation peaks experienced over the seventies. Arguably, adverse supply shocks are to be held responsible for these peaks. In contrast, the inflation target mimicks well the sharp decline in inflation experienced in the early eighties.

Figure **??** reports the dynamic responses of aggregate variables after a one standard error percent, negative inflation target shock. For each variable, the figure includes the HPD intervals at different levels (95%, light gray, and 68%, dark gray). Also, the thick line is the mean impulse response function (IRF) while the dotted line is the median response.[14]

Annualized inflation displays a regular and slow decline to its new long–run value. The average long–run response is approximately equal to minus 1.6 percentage point. Notice that it takes more than 20

[14] All these IRFs are computed by drawing 5,000 values of the vector of model parameters in the posterior distribution.

quarters to approximately reach the new steady–state value. At the same time, the nominal interest rate is only mildly responsive on impact and then gradually declines. This implies a significant rise in the real interest rate in the immediate aftermath of the inflation target shock. In addition, the overall dynamics of the nominal interest rate appear significantly slower than for inflation. As a consequence, the rise in the real (ex–ante) interest rate turns out to be persistent. In turn, this implies a delayed, inverted–hump–shaped output response. Output reaches its lowest response after about height quarters. Finally, after twenty quarters, output reverts back to its initial response, suggesting a very long–lasting effect of the inflation target shock. To confirm this, it is instructive to inspect the sacrifice ratio implied by this shock, which we compute as the cumulated response of output divided by the annualized change in inflation. The traditional interpretation of this statistic is that it represents the total output loss consecutive to a purposeful disinflation. After twenty quarters, the sacrifice ratio is slightly higher than 4.62 with a 95% HPD interval delimited by 1.39 and 6.71. This is thus illustrative of the large effects of a negative inflation target shock on output.

In the short–run, wage inflation displays a similar pattern as that of inflation but since our estimates suggest greater price stickiness than nominal wage stickiness, the real wage decreases in a protracted fashion. The lowest response is reached after about 13 quarters. The real wage dynamics turn out to be even more persistent than that of output. This result is interesting because it suggests that the disinflation period in the euro area was not associated with excessively high real wages. Instead, our estimated model highlights the importance of real interest rate dynamics. This calls for a thorough assessment of the role of monetary policy in the depressed growth period experienced by the euro area in the eighties, to which we return in the next section.

To conclude this section, we assess the contribution of the inflation target shock to aggregate fluctuations. Table **??** reports the forecast error variance decomposition at different horizons. This exercise is conducted in all three estimated model versions discussed above.

In the benchmark specification, $\mathscr{M}_0$, the fluctuations of nominal variables (inflation, wage inflation and the nominal interest rate) are essentially explained by the inflation target shock, even in the short–run. For example, it accounts for 64% of inflation, 38% of wage inflation and 50% of the nominal interest rate after four quarters. At longer horizons, this shock explains by construction all the fluctuations in the nominal variables. Though the DSGE model implies long–run neutrality of monetary policy shocks, the inflation target shock has sizeable effects on real variables. For example, it account approximatively for 17% of the variance of output after twelve quarters. Additionally, it represents 13% of the variance of the real interest rate after twelve quarters. This contribution is smaller for the real wage.

These findings contrast with what obtains in model $\mathscr{M}_1$ ($\rho_{\pi^\star} = 0$). Indeed, in this case, the inflation target shock explains only a trivial portion of output dynamics. This is due to the fact that at medium to long horizons, this shock has a smaller contribution to fluctuations in the real interest rate when compared to the benchmark case. This result emphasizes the key role of gradual inflation target shocks. Notice that our results in $\mathscr{M}_1$ are very similar to what Ireland (2007) obtains on US data. Recall that in his specification, the inflation target follows a simple random walk. While this might be a defendible hypothesis for the US case, our empirical results suggest that it is less tenable for euro area data. Finally, in model $\mathscr{M}_2$ ($\rho = 0$), we obtain an even smaller contribution of inflation target shocks to all real variables. This indicates that the shape of monetary policy itself has played a significant role in the propagation of inflation target shocks.

3 Counterfactual Analysis on Monetary Policy

The preceeding section has highlighted the crucial role of gradual monetary policy in shaping the euro area business cycle. Armed with these empirical results, we now turn our attention to a counterfactual analysis of gradual monetary policy. All these quantitative experiments are conducted using our benchmark model specification $\mathscr{M}_0$.

3.1 What Happens When There Are No Inflation Target Shocks?

In order to assess the role played by the inflation target shock, we compute counterfactual sample pathes for inflation, output, real wage, the nominal interest rate, and the real (ex–ante) interest rate implied by the model, as in Ireland (2007). These samples are obtained using the following straightforward procedure. We first assume that no inflation target shocks whatsoever occured and feed the benchmark model with the remaining five smoothed shocks. The resulting sample pathes are reported in figure **??**. The solid line corresponds to the benchmark case. Because we simulate the model with smoothed shocks, these simulated data correspond to actual data. The dotted line is the counterfactual path, with inflation target shocks set to zero in each and every period. Finally, the figure also reports a shaded area corresponding to the disinflation period experienced by euro area countries.

In this counterfactual experiment, the long–run and non–stationary component of inflation is eliminated. As a consequence, the large downswing in inflation that occured in the 1980's is absent from the simulated path. Notice that, in spite of this, inflation continues to exhibit a substantial amount of low frequency movements, reflecting the high degree of nominal rigidities found in the estimated model. Another interesting feature is the time profile of the stochastic growth component of output (i.e. that portion of output dynamics not explained by the deterministic part of exogenous productivity). During the seventies, shuting the inflation target shock down does not alter the dynamics of output significantly. On the contrary, during the eighties (shaded area), the euro zone would have experienced more sustained growth than it actually did, had it not been hit by negative inflation target shocks. The traditional explanations for the protracted period of depressed growth in the euro area consecutive to disinflation policies are *(i)* too high a real wage (due to nominal wage rigidities) and *(ii)* too high a real interest rate. Given that our model attributes a large part of the decline in output to negative inflation target shocks, it is interesting to study what would have been the dynamics of the real wage and the real interest rate absent these shocks. As was to be expected from the previous section, we find that the real wage is hardly affected by the omission of the inflation target shock. Real wages would have been slightly higher in the mid eighties had it not been for the disinflation shocks. Our main finding in this exercise is that the dynamics of the real (ex–ante) interest rate is much more affected by omitting the inflation target shocks. Indeed, the real interest rate would have fallen in the early eighties and remained below its actual path during the eighties if inflation target shocks had not hit the economy.

3.2 Consequences of Alternative Monetary Policies

The previous exercise suggests a non trivial role of monetary policy in our sample. To investigate further this issue, we use our estimated version of the DSGE model to perform counterfactual analyses focused only on the shape of monetary policy. These exercises are meant to shed additional light on the main mechanisms at work after a permanent change in the inflation target. In each experiment, the estimated model is used as our benchmark. We modify the two key parameters $\rho_{\pi^\star}$ and ρ capturing the observed persistence in monetary policy. At the same time, we keep $a_{\pi^\star}$ unchanged (recall that this parameter allows us to separate the consequences of gradual changes in the inflation target from nominal interest rate inertia). These counterfactual experiments about monetary policy are investigated by inspecting how the dynamic responses of inflation, output, the real wage, the nominal interest rate, and the real (ex–ante) interest rate differ from the benchmark responses. All the results are reported in figure **??**.

Immediate Diffusion of Inflation Target Shocks. We first investigate whether the persistence in the inflation target has played a sizeable role in the depressive effect of disinflation policies. The idea is to assess whether a faster adjustment of the inflation target to its new value could have altered the dynamic responses of aggregate variables in the Euro zone. This quantitative analysis echoes previous debates about the optimal speed of disinflation (see Taylor, 1983, and Sargent, 1983). It is worth noting that empirical studies suggest that a higher disinflation speed often results in a lower output loss (see Ball, 1994, and Boschen and Weise, 2001). To investigate this, we set $\rho_{\pi^\star} = 0$ in our first experiment.

As shown in figure **??**, inflation drops very quickly to its new long–run value (in approximately 3 periods). At the same time, the response of the real wage and output are smaller than what obtained in the benchmark case. The decline in output follows from the response of the real interest rate. To understand this, notice that, after eliminating inessential terms, equations (**??**) and (**??**) can be combined together to yield the forward solution

$$\hat{y}_t^s = b\hat{y}_{t-1}^s - \frac{(1-\beta b)(1-b)}{\beta b}\mathrm{E}_t\left\{\sum_{j=0}^{\infty}\hat{r}_{t+j}\right\}, \tag{14}$$

where $\hat{r}_t \equiv \hat{R}_t - \mathrm{E}_t\{\hat{\pi}_{t+1}\}$ is the real ex–ante interest rate. As in Boivin and Giannoni (2006), we interpret the term in curly brackets as the long–term real interest rate, the latter being simply the infinite cumulated sum of ex–ante real short–term rates. Thus, output negatively responds to this long–term real rate. As a consequence, if monetary policy induces persistent increases in the real interest rate, the negative output response will be more pronounced and more persistent.

In order to understand the dynamics of the real (ex ante) interest rate, it is important to inspect the dynamics of the nominal interest rate and expected inflation. Recall that in this first experiment, the remaining monetary policy parameters are left unchanged. In the $\rho_{\pi^\star} = 0$ scenario, expected inflation almost instantly jumps to its new steady–state value. Given our specification of monetary policy, this is not completely refelcted in the nominal interest rate insofar as $a_{\pi^\star} < \rho$. As a conserquence, the real interest rate increases on impact. Given the estimated degree of interest rate smoothing, this increase turns out to be persistent, though less pronounced than in the benchmark. Thus, output indeed falls. Notice that, given the forward–looking nature of equation (**??**), what appears to be a small difference in the dynamics of the real interest rate (when one compares the benchamrk model with the $\rho_{\pi^\star} = 0$ case), turns out to imply fairly large differences in output dynamics.

To see this even more clearly, let us consider the following counterfactual exercise, reported in figure **??**. Here, we compare the outcome of three alternative model versions. The first one is the benchmark model with gradual changes in the inflation target. The second is the same model but with inflation target shocks set to zero in each and every period, as in the previous subsection. The last one is similar to the benchmark, except that gradualism is shut down, i.e. we assume $\rho_{\pi^\star} = 0$. To make this illustration even more striking, we focus only on the eighties. As is clear, output has noticeably different dynamics when $\rho_{\pi^\star} = 0$ and in the benchmark. This suggests that gradual disinflation has ended up in large output losses in the eighties. This obtains for very small differences in the real interest rate. Even more interesting, the figure shows that the eurozone would have experienced almost identical output dynamics with an immediate disinflation ($\rho_{\pi^\star} = 0$) or without any negative changes in the inflation target ($\pi_t^\star = 0$). This finding is in sharp contrast with what would obtain in an old fashioned Keynesian model (Okun, 1978, Gordon and King, 1982). In such a setup, the relative gradualism of economic policy does not matter, since private expectations are backward–looking. Thus, whether or not disinflation is gradual is relatively irrelevant in old Keynesian models.

No Nominal Interest Rate Inertia. In a second experiment, we consider the adjustment speed of the nominal interest rate. Monetary policy inertia is somewhat akin to the gradual diffusion of inflation target shocks in terms of adjustment speed of nominal variables. However, it acts differently in that a higher nominal interest rate inertia can disconnect the nominal rate from inflation in the short–run . For example, if the nominal interest rate is almost unresponsive in the short–run whereas the inflation target reaches its new (lower) long–run value, one should expect a persistent increase in the real interest rate translating into a sizeable output loss. Thus, in this second experiment, we set $\rho = 0$.

We see from figure **??**, that this new form of monetary policy has strong implications on the dynamic responses of output and the real interest rate. At the same time, the response of inflation is almost unaffected in comparison to the benchmark case and the real wage is almost unresponsive. These results suggest that the speed of adjustment to the targeted nominal interest rate governs a large part of the model's dynamics. Here, since monetary policy displays no inertia, the nominal interest rate follows closely the inflation rate. As a consequence, the real interest rate is almost unresponsive and thus the output loss consecutive to a disinflation shock is very small. This finding suggests that the form of monetary policy, namely monetary policy inertia, has played an important role in the large and persistent increase of the real interest rate and the sizeable output loss that have followed from disinflation policies in the eighties.

No Diffusion – No Inertia. The last experiment mixes the previous two, *i.e.* an immediate adjustment of the inflation target combined with no monetary policy inertia ($\rho = \rho_{\pi^\star} = 0$). In this situation, inflation adjusts very quickly to its new long–run value and the disinflation shock has almost no effect on output. Once again, this obtains because the real interest rate is almost unresponsive to this shock.

This exercise is a further illustration of the familiar "disinflation without recession" phenomenon. Recall that despite some form of backward–lookingness in the private sector behavior (habit persistence, indexation), the model remains forward–looking. When the inflation target is expected to adjusts immediately to its new steady–state level and the nominal interest is allowed to respond one for one to changes in the inflation target, the real interest rate has a flat dynamic path. Thus, output does not react to the target shock. Once again, this is in contrast with what can happen in an old–fashioned Keynesian model. In such a setup, even when gradualism and inertia are shut down, a disinflation shock entails a large sacrifice ratio (though smaller that what obtains with both inertia and gradualism).

4 Concluding Remarks

In this paper, we have attempted to quantify the importance of gradual inflation target shocks in the euro zone business cycle. To do so, we formulated a DSGE model with various real and nominal frictions. Our main results are that these shocks are important insofar as changes in the inflation target are gradual. This hypothesis is strongly supported by the data, based on marginal likelihood rankings. In addition, our framework enables us to disentangle the respective roles of excessive and persistent real wages and real interest rates in explaining the protracted period of depressed economic activity in the euro area over the eighties. Our findings suggest that real wages played a minor role while real interest rates seem to be the essential part of the story. Running several counterfactual experiments, we find that monetary policy itself, due to gradualism and inertia, is responsible for the observed dynamics of the real interest rate.

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Table 1. Structural parameter estimates, 1970(1)–2004(4)

	Prior distribution			**Posterior distribution**								
				$\mathscr{M}_0$			$\mathscr{M}_1$			$\mathscr{M}_2$		
	Type	Mean	S.E.	5%	Mean	95%	5%	Mean	95%	5%	Mean	95%
b	beta	0.7000	0.0500	0.7726	0.8240	0.8730	0.7995	0.8455	0.8958	0.8770	0.9005	0.9272
ω	normal	2.0000	0.5000	1.2982	2.0948	2.8951	1.3455	2.0897	2.9095	1.7924	2.5527	3.2596
γ_p	beta	0.5000	0.1500	0.0573	0.1620	0.2607	0.0640	0.1898	0.3186	0.1158	0.1772	0.2372
γ_w	beta	0.5000	0.1500	0.1718	0.3727	0.5690	0.1989	0.3951	0.6009	0.7058	0.8114	0.9293
α_p	beta	0.7500	0.0500	0.7588	0.8179	0.8855	0.7353	0.8037	0.8714	0.6823	0.7178	0.7510
α_w	beta	0.7500	0.0500	0.6954	0.7740	0.8423	0.6674	0.7508	0.8280	0.6363	0.7021	0.7650
ρ	beta	0.7500	0.1000	0.8663	0.8971	0.9281	0.8264	0.8644	0.9126	—	—	—
a_p	normal	1.7000	0.1500	1.3393	1.5889	1.8320	1.3044	1.5450	1.8049	1.3047	1.5270	1.3047
a_y	normal	0.1250	0.0500	0.0799	0.1591	0.2414	0.0913	0.1737	0.2539	0.0072	0.0455	0.0072
$a_{\pi^\star}$	normal	0.7500	0.2500	0.3856	0.6015	0.8023	-0.2152	0.3608	0.8341	-0.2152	0.3608	0.8341
ρ_z	beta	0.2500	0.0500	0.1656	0.2407	0.3142	0.1649	0.2384	0.3165	0.1536	0.2314	0.3016
ρ_p	beta	0.7500	0.1500	0.0878	0.2262	0.3599	0.0987	0.2905	0.4637	0.1345	0.2781	0.4218
ρ_w	beta	0.7500	0.1500	0.7388	0.8184	0.9057	0.7737	0.8452	0.9238	0.7342	0.8143	0.8976
ρ_g	beta	0.7500	0.1500	0.1892	0.4215	0.6309	0.3479	0.5552	0.7419	0.1851	0.3203	0.4590
ρ_R	beta	0.7500	0.1500	0.1920	0.3153	0.4328	0.2621	0.4314	0.5718	0.9562	0.9657	0.9757
$\rho_{\pi^\star}$	beta	0.7500	0.1500	0.5858	0.7392	0.9064	—	—	—	0.6376	0.7611	0.8912
σ_z	inv. gamma	0.2500	2.0000	0.4543	0.5298	0.6033	0.4438	0.5229	0.6018	0.4970	0.5718	0.6392
σ_p	inv. gamma	0.2500	2.0000	0.1650	0.2011	0.2365	0.1382	0.1921	0.2522	0.0346	0.0429	0.0516
σ_w	inv. gamma	0.2500	2.0000	0.0515	0.0848	0.1159	0.0518	0.0828	0.1141	0.0503	0.0828	0.1158
σ_g	inv. gamma	0.2500	2.0000	0.2102	0.2967	0.3856	0.2110	0.2881	0.3630	0.3188	0.3812	0.4483
σ_R	inv. gamma	0.2500	2.0000	0.1087	0.1258	0.1437	0.1063	0.1303	0.1534	0.4155	0.5072	0.5940
$\sigma_{\pi^\star}$	inv. gamma	0.2500	2.0000	0.0643	0.0916	0.1196	0.0764	0.1351	0.1869	0.0563	0.0820	0.1065
Marginal likelihood					-246.8950			-252.4741			-305.7210	
Posterior odds ratio					0.9962			0.0038			0.0000	

Notes: The posterior distribution is obtained using the Metropolis–Hastings algorithm. Model codes: $\mathscr{M}_0$: benchmark model; $\mathscr{M}_1$: $\rho_{\pi^\star} = 0$; $\mathscr{M}_2$: $\rho = 0$. The posterior odd ratios are obtained under a uniform prior on model versions.

Table 2. Forecast Error Variance Decomposition

	Forecast Horizon					
	1	4	8	12	20	40
Model $\mathscr{M}_0$						
Output	7.78	14.61	17.77	17.23	13.76	8.34
Inflation	10.18	63.72	85.85	91.79	95.64	98.01
Wage Inflation	8.41	38.34	66.69	78.74	87.56	93.79
Nominal Interest Rate	21.06	50.27	72.91	83.05	91.03	96.18
Real Interest Rate	0.58	5.39	10.59	13.24	14.77	14.83
Real Wage	0.17	0.48	0.96	1.48	2.40	3.21
Model $\mathscr{M}_1$						
Output	0.41	0.73	0.99	1.01	0.82	0.49
Inflation	12.70	37.68	53.67	62.55	72.91	84.16
Wage Inflation	7.28	17.55	28.30	36.99	48.56	64.17
Nominal Interest Rate	19.87	19.36	28.50	37.94	52.38	71.12
Real Interest Rate	1.66	3.82	4.01	4.06	4.04	3.96
Real Wage	0.06	0.02	0.06	0.10	0.16	0.20
Model $\mathscr{M}_2$						
Output	0.03	0.07	0.08	0.07	0.06	0.04
Inflation	2.20	10.74	20.09	26.12	33.61	45.84
Wage Inflation	0.67	4.58	11.43	17.11	25.46	39.72
Nominal Interest Rate	21.40	35.21	45.01	49.24	53.40	61.57
Real Interest Rate	0.68	0.42	0.29	0.24	0.21	0.20
Real Wage	1.09	1.29	0.86	0.58	0.32	0.15

Notes: Model codes: $\mathscr{M}_0$: benchmark model; $\mathscr{M}_1$: $\rho_{\pi^\star} = 0$; $\mathscr{M}_2$: $\rho = 0$.

Figure 1: Data Used in Estimation

Notes: The shaded area indicates the large recession period experienced by Euro area countries in the 1980's.

Figure 2: Parameter Prior and Posterior Distribution

Notes: The vertical line denotes the posterior mode, the light grey line is the prior distribution, and the black line is the posterior distribution.

Figure 3: Annualized Inflation and Inflation Target

Notes: The series are demeaned. Actual inflation: solid line; inflation target: dotted line. The shaded area indicates the large recession period experienced by Euro area countries in the 1980's.

Figure 4: Impulse Response Functions to an Inflation Target Shock

Notes: Impulse response to a one standard error % shock. The light gray and dark gray areas correspond to the 95% and 68% HPD intervals, respectively. The thick line and the dotted line correspond to the mean and median IRFs, respectively.

Figure 5: Counterfactual Analysis, $\hat{\pi}_t^{\star} = 0$

Notes: The series are demeaned. Actual variable: solid line; counterfactual variable: dotted line. The shaded area indicates the large recession period experienced by Euro area countries in the 1980's.

Figure 6: Counterfactual IRFs

Notes: In each case, the shock is normalized so as to generate the same long–run effect on inflation.

Figure 7: Counterfactual Pathes

Notes: The plain line is the benchmark path, the dashed line corresponds to the no–disinflation case, and the line with stars corresponds to the shock–therapy case ($\rho_{\pi^\star} = 0$).

A Model's Details

A.1 Households and Wage Setting

The typical household υ seeks to maximize

$$\mathrm{E}_t \sum_{T=t}^{\infty} \beta^T \{ \mathrm{e}^{g_T} \log(c_T - \bar{b} c_{T-1}) - V(h_T(\upsilon) \},$$

where $\beta \in [0,1)$ is the subjective discount factor, $\bar{b} \in [0,1)$ is the degree of habit formation in consumption, c_t is consumption, $h_T(\upsilon)$ is the supply of labor of type υ, and $V(h_T(\upsilon))$ is the associated disutility. Finally, g_t is a consumption–preference shock, the dynamics of which will be specified later. The household faces the sequence of constraints

$$P_T c_T + B_{T+1}/R_T = W_T(\upsilon) h_T(\upsilon) + \mathrm{Prof}_T + B_T,$$

where P_t is the aggregate price level, B_{t+1} is the quantity of nominal government bonds acquired at t, maturing at $t+1$, and paying the gross nominal interest rate R_t. $W_t(\upsilon)$ is the nominal wage paid to labor of type υ. Finally Prof_t denotes profits redistributed by monopolistic firms.

Each household supplies labor to a competitive employment agency which combines the differentiated labor inputs $\{h_t(\upsilon), \upsilon \in [0,1]\}$ into an aggregate labor index h_t according to

$$h_t = \left(\int_0^1 h_t(\upsilon)^{(\theta_{w,t}-1)/\theta_{w,t}} \mathrm{d}\upsilon \right)^{\theta_{w,t}/(\theta_{w,t}-1)},$$

where $\theta_{w,t} > 1$ is the stochastically varying elasticity of substitution between any two labor types, the dynamics of which will be specified later. Associated with this technology is the demand for labor of type υ, which obeys

$$h_t(\upsilon) = \left(\frac{W_t(\upsilon)}{W_t} \right)^{-\theta_{w,t}} h_t,$$

where the aggregate wage index W_t is defined by

$$W_t = \left(\int_0^1 W_t(\upsilon)^{1-\theta_{w,t}} \right)^{1/(1-\theta_{w,t})}.$$

It is assumed that at each point in time, a typical household can reoptimize its wage with probability $1 - \alpha_w$, irrespective of the elapsed time since it last revised its age. The remaining households simply revise their wage according to the rule

$$W_t(\upsilon) = \gamma (\pi_t^\star)^{1-\gamma_w} (\pi_{t-1})^{\gamma_w} W_{t-1}(\upsilon),$$

where γ is the steady–state gross growth rate of technical progress, $\gamma_w \in [0,1]$ is the degree of indexation to the most recently available inflation measure, $\pi_t^\star$ is the gross inflation target (to be defined later), and π_t is gross inflation.

Let us now turn our attention to the wage setting decision and define $h_{t,T}^\star(\upsilon)$ the supply of hours at T by household υ if it last reoptimized its wage at t. In period t, if drawn to reoptimize, household υ chooses his wage rate $W_t^\star(\upsilon)$ so as to solve

$$\max_{W_t^\star(\upsilon)} \mathrm{E}_t \sum_{T=t}^{\infty} (\beta\alpha_w)^{T-t} \left\{ \lambda_T \frac{\gamma^{T-t}\delta_{t,T}^w W_t^\star(\upsilon)}{P_T} - V(h_{t,T}^\star(\upsilon)) \right\},$$

subject to

$$h_{t,T}^\star(\upsilon) = \left(\frac{\gamma^{T-t}\delta_{t,T}^w}{\pi_{t,T}^w} \frac{w_t^\star(\upsilon)}{w_t} \right)^{-\theta_{w,t}} h_t,$$

where $w_t^\star(\upsilon) \equiv W_t^\star(\upsilon)/P_t$, $\pi_{t,T}^w \equiv W_T/W_t$, and the factor $\delta_{t,T}^w$ obeys

$$\delta_{t,T}^w = \begin{cases} \prod_{j=t}^{T-1} (\pi_{j+1}^\star)^{1-\gamma_w} (\pi_j)^{\gamma_w} & \text{if } T > t \\ 1 & \text{otherwise} \end{cases},$$

For later reference, it is convenient to define the "wage markup"

$$\mu_{w,t} \equiv \frac{\theta_{w,t}}{\theta_{w,t}-1}.$$

A.2 Production Side and Price Setting

There is a unique aggregate good, d_t, which can be either consumed, y_t, or used as an input in production, x_t. Thus, $d_t = y_t + x_t$. The aggregate good is produced by competitive firms according to the Kimball (1995) type technology

$$\int_0^1 G\left(\frac{d_t(\varsigma)}{d_t}; \mathrm{e}^{\varphi_t} \right) \mathrm{d}\varsigma = 1,$$

where φ_t is a price–elasticity shock, the dynamics of which will be specified later, $G(\cdot;\mathrm{e}^{\varphi_t})$ is increasing and strictly concave, is such that $G_{12}(1;1) = 0$, and satisfies the normalization $G(1,\mathrm{e}^{\varphi_t}) = 1$, and $d_t(\varsigma)$ is the input of intermediate good ς, with $\varsigma \in [0,1]$. Here and in the remainder, G_i is the partial derivative of G with respect to its ith argument and G_{ij} is the cross partial derivative of G with respect to arguments i and j. Similarly, $(G_i)^{-1}$ will denote the reciprocal of G_i, taken as a function of its first argument. The Kimball (1995) type technology is a theoretical device that allows for a small slope of the Phillips curve without assuming too high a degree of nominal price rigiditiy (see, e.g., Woodford, 2003).

The associated demand function for good ς is

$$d_t(\varsigma) = d_t(G_1)^{-1}\left(\frac{P_t(\varsigma)}{P_t}\Upsilon_t; \mathrm{e}^{\varphi_t}\right), \quad \text{where} \quad \Upsilon_t \equiv \int_0^1 \frac{d_t(\varsigma)}{d_t} G_1\left(\frac{d_t(\varsigma)}{d_t}; \mathrm{e}^{\varphi_t}\right) \mathrm{d}\varsigma.$$

$P_t(\varsigma)$ is the nominal price of good ς and P_t is the aggregate price level, which is implicitly defined by the relation

$$\int_0^1 \frac{P_t(\varsigma) d_t(\varsigma)}{P_t d_t} \mathrm{d}\varsigma = 1.$$

Associated with the above technology is $\theta_p(e_t(\varsigma), \mathrm{e}^{\varphi_t})$ the elasticity of demand for a given intermediate good whose relative demand is equal to $e_t(\varsigma)$. Formally

$$\theta_p(e_t(\varsigma), \mathrm{e}^{\varphi_t}) = -\frac{G_1(e_t(\varsigma); \mathrm{e}^{\varphi_t})}{e_t(\varsigma) G_{11}(e_t(\varsigma); \mathrm{e}^{\varphi_t})}.$$

From this, we can also define the price markup $\mu_p(e_t(\varsigma); \mathrm{e}^{\varphi_t})$ through the familiar expression

$$\mu_p(e_t(\varsigma); \mathrm{e}^{\varphi_t}) = \frac{\theta_p(e_t(\varsigma); \mathrm{e}^{\varphi_t})}{\theta_p(e_t(\varsigma); \mathrm{e}^{\varphi_t}) - 1}.$$

For later reference, it is also convenient to define $\mu_p \equiv \mu_p(1; 1)$ the steady–state markup as well as

$$\hat{\mu}_{p,t} \equiv \frac{D_2 \mu_p(1; 1)}{\mu_p} \varphi_t$$

where $D_2\mu_p(1;1)/\mu_p$ is the steady–state elasticity of μ_p with respect to e^{φ_t}, and where a hat denotes logdeviation from steady state.

Each intermediate good $\varsigma \in [0, 1]$ is produced by a monopolistic firm with the same index. Firm ς has technology

$$d_t(\varsigma) = \min\left\{\frac{\mathrm{e}^{z_t} n_t(\varsigma) - \kappa \mathrm{e}^{z_t}}{1 - s_x}, \frac{x_t(\varsigma)}{s_x}\right\},$$

where $n_t(\varsigma)$ and $x_t(\varsigma)$ are the inputs of aggregate labor and material goods, respectively, and z_t is a permanent productivity shock. Here, $\kappa \mathrm{e}^{z_t}$ is a fixed production cost which grows at the same rate as technical progress. This assumption ensures the existence of a well–defined balanced growth path. The fixed cost will be pinned down so that aggregate profits are zero in the deterministic steady state. The real marginal cost associated with the above technology is

$$s_t = (1 - s_x) w_t \mathrm{e}^{-z_t} + s_x,$$

where $w_t \equiv W_t / P_t$ is the real wage rate paid to aggregate labor.

We assume that in each period of time, a monopolistic firm can reoptimize its price with probability $1 - \alpha_p$, irrespective of the elapsed time since it last revised its price. If the firm cannot reoptimize its price, the latter is rescaled according to the simple revision rule

$$P_t(\varsigma) = (\pi_t^{\star})^{1-\gamma_p} (\pi_{t-1})^{\gamma_p} P_{t-1}(\varsigma)$$

where $\gamma_p \in [0,1]$ measures the degree of indexation to the most recently available inflation measure. Let $d^\star_{t,T}(\varsigma)$ denote the production of firm ς at T if it last revised its price in period t. Then, if drawn to reoptimize at t, firm ς sets its new price $P^\star_t(\varsigma)$ so as to solve

$$\max_{P^\star_t(\varsigma)} \mathrm{E}_t \sum_{T=t}^{\infty} (\beta\alpha_p)^{T-t} \frac{\lambda_T}{\lambda_t} \left\{ \frac{\delta^p_{t,T} P^\star_t(\varsigma)}{P_t} d^\star_{t,T}(\varsigma) - s_T d^\star_{t,T}(\varsigma), \right\},$$

subject to

$$d^\star_{t,T}(\varsigma) = d_T (G_1)^{-1} \left(\frac{\delta^p_{t,T} P^\star_t(\varsigma)}{P_t} \Upsilon_T; \mathrm{e}^{\varphi_T} \right),$$

where

$$\delta^p_{t,T} = \begin{cases} \prod_{j=t}^{T-1} (\pi^\star_{j+1})^{1-\gamma_p} (\pi_j)^{\gamma_p} & \text{if } \; T > t \\ 1 & \text{otherwise} \end{cases}.$$

A.3 Technicalities

Before loglinearizing the equilibrium conditions implied by the above model, we must appropriately get rid of the stochastic trends included in our specification. To do so, all real trending variables are divided by e^{z_t}, while π_t, $\pi_{w,t} \equiv W_t/W_{t-1}$, and R_t are divided by $\pi^\star_t$. At this stage, it is convenient to define

$$\pi^s_{w,t} \equiv \pi_{w,t}/\pi^\star_t, \quad \pi^s_t \equiv \pi_t/\pi^\star_t, \quad R^s_t \equiv R_t/\pi^\star_t.$$

Similarly, we define

$$y^s_t \equiv y_t/\mathrm{e}^{z_t}, \quad w^s_t \equiv w_t/\mathrm{e}^{z_t}, \quad \lambda^s_t \equiv \lambda \mathrm{e}^{z_t}.$$

The stochastic shocks $\tilde{g}_t$, $\tilde{\mu}_{p,t}$, and $\tilde{\mu}_{w,t}$ are defined in terms of the structural shocks g_t, φ_t and $\theta_{w,t}$ according to the formulas

$$\tilde{g}_t = (1-b)[g_t - \beta b \mathrm{E}_t\{g_{t+1}\}], \quad \tilde{\mu}_{p,t} = \kappa_p \hat{\mu}_{p,t}, \quad \tilde{\mu}_{w,t} = \kappa_w \hat{\mu}_{w,t}.$$

B Prior Distributions

B.1 Calibration

We partition the model parameters into two groups. Let $\theta^c \equiv (\beta, s_x, \gamma, \theta_p, \theta_w, \epsilon_\mu)'$ denote the vector of calibrated parameters. We set $\beta = 0.99$. The growth rate of technical progress is set to the mean gross growth rate of output, $\gamma = 1.0045$. We impose $s_x = 0.5$, which matches the euro area figure reported by Jellema et al. (2006). We chose to calibrate θ_p, θ_w and ϵ_μ because these parameters cannot be separately identified as long as we want to estimate the probabilities of price and wage fixity, namely α_p and α_w. Note that α_w and θ_w appear only in the definition of κ_w. The data allow us only to estimate the partial elasticity of wage inflation with respect to the labor disutility wedge, and many combinations of α_w and θ_w are compatible with a given estimate of this partial elasticity (see Rotemberg and Woodford, 1997, and Amato and Laubach, 2003). We encountered similar difficulties when trying to estimate α_p, ϵ_μ, and θ_p. Since we estimate α_p and α_w, the other parameters are calibrated prior to estimation. As in Rabanal and Rubio–Ramírez (2007), we set $\theta_p = 6$ and $\theta_w = 11$. Finally, we set $\epsilon_\mu = 1$. As argued by Chari et al. (2000), it is important that this value be set to generate a reasonable curvature of the demand function faced by a monopolist. With the chosen value, we obtain that a 2% increase in relative prices results in a 14.8% decline in demand, similar to the 11.2% decline in demand that obtains under $\epsilon_\mu = 0$.

B.2 Choice of Prior Distributions

In the benchmark version, the priors for the utility parameters are based on the belief that it takes a high degree of habit formation and a low elasticity of labor supply to match the data (see, e.g., Smets and Wouters, 2003, Rabanal and Rubio–Ramírez, 2007). At the same time, previous results in the literature suggest that ω is difficult to estimate precisely. Thus, we must combine our prior belief that ω is high with the fact that relatively little is known on this parameter at the aggregate level. Accordingly, we adopt a normal distribution for ω, with a prior mean set to 2 and a standard error set to 0.5. While still informative, this prior distribution is dispersed enough to allow for a wide range of possible and realistic values to be considered. For the habit parameter, we adopt a Beta prior, ensuring that this parameter belongs to $[0, 1]$. The prior mean is set to 0.7, with a standard error of 0.05.

We adopt Beta prior distributions for α_p, α_w, γ_p, and γ_w. For the Calvo probabilities, our priors are based on the thorough studies conducted by the ECB's *Inflation Persistence Network*, as summarized by Dhyne et al. (2006), and *Wage Dynamics Network*, as summarized by Druant et al. (2008). We thus set both prior means to 0.75 with a low standard error of 0.05. We adopt less strict priors for the indexation parameters, with prior means set to 0.5 and standard errors set to 0.15.

We adopt analog priors as those used by Smets and Wouters (2003) for the monetary policy parameters, namely a_p, a_y and ρ. More precisely, a_p and a_y are assumed to be normally distributed, with means 1.7 and 0.125, respectively and associated standard errors of 0.15 and 0.05, respectively. For the degree of nominal interest rate smoothing, ρ, we adopt a Beta distribution, with mean set to 0.75

and standard error set to 0.1. The new parameter $a_{\pi^\star}$ has a normal distribution centered on 0.75, as for ρ, but with a larger standard error, set to 0.25.

All the standard errors of shocks are assumed to be distributed according to inverted Gamma distributions, with prior means 0.25 and standard error 0.25. The autoregressive parameters are all assumed to follow Beta distributions. Except for technology shocks, all these distributions are centered on 0.75. For technology shocks, a much lower mean of 0.25 is adopted. This reflects our prior belief that TFP growth is only mildly serially correlated, if ever. We assume a common standard error of 0.15, slightly larger than that assumed by Smets and Wouters (2003). We allow for a lower standard error for the prior distribution of ρ_z.