NOTES D'ÉTUDES

ET DE RECHERCHE

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December 2004

NER # 118

BANQUE DE FRANCE

DIRECTION GÉNÉRALE DES ÉTUDES ET DES RELATIONS INTERNATIONALES

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Partial Indexation, Trend Inflation, and the Hybrid Phillips Curve*

Jean-Guillaume Sahuc†
Banque de France
and EPEE, University of Evry

November 2004
(First draft: March 2004)

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*I would like to thank Eric Jondeau, Hervé Le Bihan, Julien Matheron, Tristan-Pierre Maury, Ferhat Mihoubi and Argia Sbordone for useful remarks. This paper represents the views of the author and should not be interpreted as reflecting those of the Banque de France.

†*Correspondence:* Banque de France, Centre de recherche, 31 rue Croix des Petits Champs, 75049 Paris, France. E-Mail: jean-guillaume.sahuc@univ-evry.fr.

Résumé :

Ce papier propose une description complète du modèle de fixation des prix à la Calvo fondé sur l'hypothèse d'indexation partielle des prix et étudie l'interaction entre l'indexation partielle et l'inflation tendancielle. Nous montrons qu'utiliser une version hybride de la courbe de Phillips diminue en partie les risques de surestimation dus à l'omission de l'inflation tendancielle. Nous fournissons également de nouveaux résultats concernant l'ajustement de la courbe de Phillips hybride sur la Zone Euro et les Etats-Unis au cours de la période 1970-2002. Les estimations à l'aide de la version des GMM proposée par West (1997) suggèrent (i) qu'une hypothèse d'indexation parfaite n'est pas compatible avec les données tandis qu'une hypothèse d'indexation partielle permet un bon ajustement et (ii) qu'oublier l'inflation tendancielle induit une surestimation d'approximativement 3-4 % de la probabilité de ne pas modifier les prix, pour des valeurs raisonnables de l'inflation tendancielle.

Mots-clés: Courbe de Phillips, inertie de l'inflation, inflation tendancielle, degré d'indexation.

Abstract:

This paper proposes a full description of the Calvo price-setting model based on partial prices indexation and studies the interaction between partial indexation and trend inflation. We show that using a hybrid version of the Phillips curve partly decreases the risks of overestimate due to the omission of trend inflation. We also provide new evidence on the fit of the hybrid Phillips curve for the Euro area and the United States over the period 1970-2002. The GMM-West estimates suggest that (i) a full indexation scheme is not data consistent whereas a partial indexation scheme allows a good fit and (ii) forgetting trend inflation induces overestimating by approximately 3-4 percent of the probability to not change the price, for reasonable values of trend inflation.

Keywords: Phillips curve, inflation inertia, trend inflation, degree of indexation.

JEL classification: E31, C22.

Résumé non technique :

Ce papier propose une extension du modèle de fixation des prix proposé par Calvo en 1983. Dans ce modèle, lorsque les entreprises ont l'opportunité de changer leur prix, elles le fixent au prix moyen souhaité jusqu'à leur prochaine opportunité. Cela permet d'étudier, entre autres, les interactions entre l'indexation partielle des prix et l'inflation tendancielle (niveau d'inflation à l'état stationnaire). Nous montrons que l'utilisation d'une courbe de Phillips (dite "hybride"), comportant à la fois l'inflation anticipée et l'inflation passée, permet de s'assurer en partie contre les risques de surestimation des durées de fixation des prix liés à l'omission de l'inflation tendancielle.

La courbe de Phillips Nouveaux Keynesiens, fondée sur des prix visqueux, a été intensément utilisée dans les travaux sur la politique monétaire. De fait, la majorité des modèles d'équilibre général intertemporel stochastique utilisent la formulation proposée par Calvo (1983). Malheureusement, elle entraîne deux problèmes récurrents. Premièrement, les travaux sont fondés sur l'hypothèse de log-linéarisation autour d'un état stationnaire avec une inflation nulle qui est cependant contrefactuelle. Ascari (2003) a montré qu'oublier l'inflation tendancielle n'est pas neutre et que les résultats tirés de modèles fondés sur cette hypothèse sont biaisés. Ensuite, la formulation de Calvo implique que, au niveau agrégé, l'inflation dépend des valeurs anticipées mais non de l'inflation passée. Cette spécification a été largement critiquée car elle ne reflète pas la persistance de l'inflation.

Ces deux faiblesses peuvent être en partie corrigées en utilisant un modèle dans lequel l'indexation sur l'inflation passée est autorisée (Woodford, 2003) . Dès lors, les prix augmenteront automatiquement en suivant une règle mécanique entre deux opportunités de changement de prix optimal. L'objectif de l'étude est d'étudier les interactions entre l'inflation tendancielle et le degré d'indexation dans un modèle de fixation des prix à la Calvo. Nous trouvons que plus le niveau de l'inflation tendancielle est élevé, plus la sensibilité de l'inflation au coût marginal est faible. Ceci confirme les résultats d'Ascari (lorsque le degré d'indexation des prix est nul). C'est une explication plausible des valeurs très élevées des durées de fixation des prix, souvent trouvées dans la littérature macroéconomique. Ce dernier résultat dépend cependant du degré d'indexation (caractère inertiel de l'inflation). En effet, lorsque le paramètre d'indexation tend vers 1, le coefficient associé au coût marginal devient stable. En d'autres termes, introduire plus d'inertie dans la courbe de Phillips la rend moins dépendante de l'inflation tendancielle. Pour des valeurs conventionnelles des paramètres structurels, avec une inflation tendancielle annualisée de 1 %, les simulations montrent que la réponse de l'inflation au coût marginal est réduite de 15 % lorsque le paramètre d'indexation est nul alors qu'elle n'est réduite que de 4 % lorsque le paramètre d'indexation vaut 0,75. Sur données européennes et américaines, ne pas tenir compte de l'inflation tendancielle surestimerait les durées de fixation des prix d'approximativement 3-4 % : elles seraient ainsi de 3 trimestres aux États-Unis et de 4,8 trimestres pour la Zone Euro.

Non-technical summary:

The specification of the New Keynesian Phillips curve based on staggered prices has been intensively used in many recent discussions of monetary policy. Specifically, a host of dynamic stochastic general equilibrium models use Calvo's (1983) formulation: when firms have the opportunity to change their price they set this price equal to the average desired price until the next opportunity arises.

However, two main issues are still problematic. First, most of the papers in the sticky-price literature are based on a log-linearization around the zero inflation steady state but unfortunately this assumption is counterfactual. Ascari (2003) has clearly shown that disregarding *trend inflation* is quite far from being an innocuous assumption and that results obtained by models log-linearized around a zero inflation steady state are misleading. Second, at the aggregate level, current inflation will depend on future expected inflation but not on *lagged inflation*. However, this specification has been criticized on the ground that it does not fit very well the econometric evidence about co-movements of real and nominal variables: according to the New Keynesian Phillips curve, inflation should be a more forward-looking than seems to be.

This paper proposes a full explanation of the Calvo price-setting model based on partial prices indexation to derive a hybrid Phillips curve. In particular, we argue that these two problems can be partly mutually solved at once by resorting to a model where indexation on past inflation is allowed. This framework assumes that prices are automatically raised in accordance with some mechanical rule between the occasions on which they are reconsidered. Since assuming zero trend inflation can hardly be justified to describe and model post-war inflation, we take into account trend inflation and study the interaction between partial indexation and trend inflation. In particular, we analytically find that the higher the degree of indexation and the less trend inflation has an influence on the value of the parameters of the hybrid Phillips curve. Consequently, overestimate due to the omission of trend inflation disappears with the increase of the degree of indexation. We also proposed new empirical evidence about the properties of a hybrid Phillips curve based on partial price indexation. First, we initially cancel trend inflation in assuming that the prices that cannot be reset are indexed not only to a part of the past inflation rate but also to a part of trend inflation. Our results show that the extreme case with full indexation is data inconsistent and that the empirical model with partial indexation (and a degree of indexation around 0.5) appears to capture the inflation dynamics for the Euro area and the United States over the period 1970-2002. Second, we introduce trend inflation in the model and observe the theoretical awaited fall of the probability to not change the price : around 3-4% for reasonable values of trend inflation. The average duration of price rigidity would be thus 3 quarters for the U.S. and 4.8 quarters for the Euro area.

1 Introduction

The specification of the New Keynesian Phillips curve based on staggered prices has been intensively used in many recent discussions of monetary policy. Specifically, a host of dynamic stochastic general equilibrium models use Calvo's (1983) formulation: when firms have the opportunity to change their price they set this price equal to the average desired price until the next opportunity arises.

However, two main issues are still problematic. First, most of the papers in the sticky-price literature are based on a log-linearization around the zero inflation steady state but unfortunately this assumption is counterfactual. Ascari (2003) has clearly shown that disregarding *trend inflation* is quite far from being an innocuous assumption and that results obtained by models log-linearized around a zero inflation steady state are misleading.[1] Second, at the aggregate level, current inflation will depend on future expected inflation but not on *lagged inflation.* However, this specification has been criticized on the ground that it does not fit very well the econometric evidence about co-movements of real and nominal variables: according to the New Keynesian Phillips curve, inflation should be a more forward-looking than seems to be.

This paper reexamines the theoretical and empirical relevances of the New Keynesian Phillips curve for the Euro area and the United States. In particular, we argue that these two problems can be partly mutually solved at once by resorting to a model where indexation on past inflation is allowed. This framework, advocated by Christiano *et al.* (2003), Sbordone (2003), Smets and Wouters (2003), and Woodford (2003), assumes that prices are automatically raised in accordance with some mechanical rule between the occasions on which they are reconsidered.

The remainder of the paper is organized as follows. In section 2, we extend Woodford's (2003) exposition of *partial backward indexation* to an economy with positive trend inflation. In section 3, we study the interaction between trend inflation, degree of indexation and Calvo price-setting. In section 4, we provide evidence of this modified hybrid Phillips curve in conducting some instrumental variable estimations. Section 5 summarizes our main findings and concludes.

2 The Calvo model of sticky prices under partial price indexation

2.1 Optimal pricing decision

The forward-looking model of price setting due to Calvo (1983) is modified to allow for the possibility that firms that do not optimally set their prices may nonetheless adjust it to keep up with the previous period increase in the general price level. Although this seems to imply some sort of irrational behavior of the firms since inflation data is freely available, it is often argued that in low inflation environments this kind of behavior is normal.

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[1] In the same spirit, Bakhshi *et al.* (2003) build on the pure forward-looking work by Ascari (2003) in examining the interaction between strategic complementarity and trend inflation.

In each period, a firm faces a constant probability, $1-\phi$, of being able to reoptimize its nominal price and chooses a price $P_t^*(z)$ that maximizes the expected discounted sum of profits

$$\mathbb{E}_t \sum_{j=0}^{\infty} \phi^j \Lambda_{t,t+j} \left[P_t^*(z) X_{t,t+j} - MC_{t,t+j}\right] \frac{Y_{t+j}(z)}{P_{t+j}}, \tag{1}$$

subject to the sequence of demand constraints:

$$Y_{t+j}(z) = \left(\frac{P_t^*(z) X_{t,t+j}}{P_{t+j}}\right)^{-\varepsilon} Y_{t+j}, \tag{2}$$

where $\Lambda_{t,t+j} = \beta^j \left(U'(C_t)/U'(C_{t+j})\right)$ is the discount factor between time t and $t+j$, $U'(C_{t+j})$ is the marginal utility of consumption in $t+j$, $Y_t(z)$ is the level of output of firm z, $MC_{t,t+j}$ is the nominal marginal cost at $t+j$ of the firm that optimally set prices at time t, $\varepsilon > 1$ is the elasticity of substitution across goods, and[2]

$$X_{t,t+j} = \begin{cases} \prod_{k=0}^{j-1} \pi_{t+k}^{\xi} & j > 0 \\ 1 & j = 0 \end{cases} \tag{3}$$

$X_{t,t+j}$ describes the fact that if the firm z does not reoptimize its price, it updates it prices according to the rule:

$$P_t(z) = \pi_{t-1}^{\xi} P_{t-1}(z) \tag{4}$$

where $\pi_t = P_t/P_{t-1}$ is the gross inflation rate. As in Christiano *et al.* (2003), we interpret the Calvo price-setting mechanism as capturing firm's response to various costs of changing prices. The basic idea is that in the presence of these costs, firms fully optimize prices only periodically, and follow simple rules for changing their prices at other times. The coefficient $\xi \in [0,1]$ indicates the degree of indexation to past prices, during the periods in which firm is not allowed to reoptimize.

It follows that the aggregate price level can be expressed as:

$$P_t = \left[\phi \left(\pi_{t-1}^{\xi} P_{t-1}\right)^{1-\varepsilon} + (1-\phi)\left(P_t^*\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}. \tag{5}$$

Let us define the relative price by $p_t^*(z) = P_t^*(z)/P_t$ and using the fact that $X_{t,t+j} = \left(P_{t+j-1}/P_{t-1}\right)^{\xi}$, the first-order condition of this problem can be expressed as

$$p_t^*(z) = \left[\frac{\varepsilon}{\varepsilon-1} \frac{\mathbb{E}_t \sum_{j=0}^{\infty} \phi^j \Lambda_{t,t+j} MC_{t,t+j} \left(\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{\xi} \frac{P_t}{P_{t+j}}\right)^{-\varepsilon} Y_{t+j}}{\mathbb{E}_t \sum_{j=0}^{\infty} \phi^j \Lambda_{t,t+j} \left(\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{\xi} \frac{P_t}{P_{t+j}}\right)^{1-\varepsilon} Y_{t+j}}\right] \tag{6}$$

We show that the optimal relative price depends on current and future demand, aggregate inflation rates, and discount factors.

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[2] We do not index MC_t by z because we assume that all firms have identical marginal costs (*i.e.* strategic substitutability).

2.2 The hybrid Phillips curve under trend inflation

We log-linearize (6) around a steady state with generic trend inflation ($\bar{\pi}$) to get[3]

$$
\begin{aligned}
\hat{p}_t^* \;=\;& \left(1-\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\mathbb{E}_t\sum_{j=0}^{\infty}\left(\phi\beta\bar{\pi}^{-\varepsilon(\xi-1)}\right)^j \\
&\times\left[\hat{\Lambda}_{t,t+j}+\hat{y}_{t+j}+\widehat{mc}_{t,t+j}+\varepsilon\left(\sum_{k=1}^{j}\widehat{\pi}_{t+k}\right)-\varepsilon\xi\left(\sum_{k=0}^{j-1}\widehat{\pi}_{t+k}\right)\right] \\
&-\left(1-\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\mathbb{E}_t\sum_{j=0}^{\infty}\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)^j \\
&\times\left[\hat{\Lambda}_{t,t+j}+\hat{y}_{t+j}+(1-\varepsilon)\,\xi\left(\sum_{k=0}^{j-1}\widehat{\pi}_{t+k}\right)-(1-\varepsilon)\left(\sum_{k=1}^{j}\widehat{\pi}_{t+k}\right)\right] \qquad (7)
\end{aligned}
$$

In making use of mathematical properties concerning the double sum, we obtain equivalently,

$$
\begin{aligned}
\hat{p}_t^* \;=\;& -\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\left(\bar{\pi}^{(\xi-1)}-1\right)\left(1-\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\mathbb{E}_t\sum_{j=0}^{\infty}\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)^j \\
&\times\Bigg[\hat{y}_{t+j+1}+\frac{\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}{1-\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}\,((1-\varepsilon)\,\xi\widehat{\pi}_{t+j+1}+(\varepsilon-1)\,\widehat{\pi}_{t+j+2})\Bigg] \\
&+\left(\bar{\pi}^{(\xi-1)}-1\right)\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\left(\hat{y}_t-(1-\varepsilon)\,\xi\widehat{\pi}_t-(\varepsilon-1)\,\mathbb{E}_t\widehat{\pi}_{t+1}\right) \\
&+\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\left(\mathbb{E}_t\widehat{\pi}_{t+1}-\xi\widehat{\pi}_t\right)+\left(1-\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\right)\widehat{mc}_t \\
&+\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\mathbb{E}_t\hat{p}_{t+1}^* \qquad (8)
\end{aligned}
$$

Log-linearizing the aggregate price level (5) in the model gives

$$
\hat{p}_t^*=\frac{\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}}{1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}}\left[\widehat{\pi}_t-\xi\widehat{\pi}_{t-1}\right] \qquad (9)
$$

---

[3] Hat variables indicate log-deviations from steady-state levels.

Finally, using (8) and (5), we obtain the hybrid Phillips curve under trend inflation

$$
\begin{aligned}
\widehat{\pi}_t = {} & \frac{\xi}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]}\widehat{\pi}_{t-1} \\
& +\frac{\beta\left(1-\left(1-\bar{\pi}^{(1-\xi)}\right)\left(\varepsilon+\left(1-\varepsilon\right)\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\right)}{\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi}\mathbb{E}_t\widehat{\pi}_{t+1} \\
& +\frac{\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\right)}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}}\widehat{mc}_t \\
& +\frac{\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]} \\
& \times\left\{\hat{y}_t-\left(1-\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\mathbb{E}_t\sum_{j=0}^{\infty}\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)^j\right. \\
& \left.\times\left[\hat{y}_{t+j+1}+\frac{\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}{1-\left(\phi\beta\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)}\left(\left(1-\varepsilon\right)\xi\widehat{\pi}_{t+j+1}+\left(\varepsilon-1\right)\widehat{\pi}_{t+j+2}\right)\right]\right\} \qquad (10)
\end{aligned}
$$

The presence of trend inflation alters the structure of the standard hybrid Phillips curve in two ways. First, the coefficients on past and future inflation are functions of the degree of indexation and trend inflation. Second, there is a complex additional forward-looking structure.

3 Quantitative investigations

We now seek to understand the respective effects of the degree of indexation and trend inflation on the dynamics of the hybrid Phillips curve. For that, one remarks that (10) can be written in a compact way:

$$
\begin{aligned}
\widehat{\pi}_t &= \alpha_b\left(\bar{\pi},\xi\right)\widehat{\pi}_{t-1}+\alpha_f\left(\bar{\pi},\xi\right)\mathbb{E}_t\widehat{\pi}_{t+1}+\lambda\left(\bar{\pi},\xi\right)\widehat{mc}_t \\
&\quad +\Omega\left(\bar{\pi},\xi\right)f\underset{\{i=1,\dots,\infty\}}{\left(\mathbb{E}_t\widehat{\pi}_{t+i},\mathbb{E}_t\hat{y}_{t+i}\right)} \qquad (11)
\end{aligned}
$$

where

$$
\begin{aligned}
\alpha_b\left(\bar{\pi},\xi\right) &= \frac{\xi}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]} \\
\alpha_f\left(\bar{\pi},\xi\right) &= \frac{\beta\left(1-\left(1-\bar{\pi}^{(1-\xi)}\right)\left(\varepsilon+\left(1-\varepsilon\right)\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\right)}{\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi}, \\
\lambda\left(\bar{\pi},\xi\right) &= \frac{\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\left(\phi\beta\bar{\pi}^{\varepsilon(1-\xi)}\right)\right)}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}}, \\
\Omega\left(\bar{\pi},\xi\right) &= \frac{\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta}{\left[\left(1+\xi\beta\bar{\pi}^{(1-\xi)}\right)+\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1-\xi)}\right)\beta\left(1-\varepsilon\right)\xi\right]}.
\end{aligned}
$$

Figure 1 shows the sensitivity of the values of coefficients on past (α_b) and future (α_f) inflation, the elasticity of inflation with respect to changes in the marginal cost (λ), and the coefficient before the additional forward-looking structure (Ω) to trend inflation ($1 \leq \bar{\pi} \leq 1.1$) and the degree of indexation ($0 \leq \xi \leq 1$). First, we observe that trend inflation has a low impact on α_b and α_f and that it is naturally the degree of indexation that governs their respective values. Second, Ω is negative, convex in $\bar{\pi}$ and very small (of order 10^{-3}). Ω tends naturally toward zero when ξ raises, so the additional forward-looking structure tends to disappear. Third, when $\xi = 0$, Ascari's result is found: the higher the level of trend inflation, the smaller the values of λ. It appears then that the dynamic response of inflation to marginal costs is then overestimated if trend inflation is not taken into account.

However, this last result is attenuated as the degree of indexation increases. Introducing an additional backward structure into the Phillips curve makes it automatically less dependent on trend inflation.[4] As shown in Table 1, whereas the model predicts that the dynamic response of inflation to marginal cost should be reduced by 15% if annualized trend inflation is 1% when $\xi = 0$, it would be reduced by only 4% when $\xi = 0.75$.

The preceding conclusions are reflected on the value of the crucial structural parameter ϕ. By disregarding additional term $f\left(\mathbb{E}_t\widehat{\pi}_{t+i}, \mathbb{E}_t\hat{y}_{t+i}\right)$ at first approximation and for a given λ, we obtain

$$\begin{aligned}
\phi \;=\; & -\left\{2\left[\left(\lambda\beta\xi\left(1-\varepsilon\right)-1\right)\bar{\pi}^{(1-2\varepsilon)(\xi-1)}+\left(\varepsilon-1\right)\lambda\beta\xi\bar{\pi}^{2(1-\varepsilon)(\xi-1)}\right]\right\}^{-1} \\
& \times\Big\{\left(1+\lambda\xi\varepsilon\right)\beta\bar{\pi}^{\varepsilon(1-\xi)}+\left(1+\lambda\left(1+\beta\xi-\beta\xi\varepsilon\right)\right)\bar{\pi}^{(1-\varepsilon)(\xi-1)} \\
& -\Big[\Big(\left(\lambda+1\right)^2+\lambda\beta\xi\left(\lambda\beta\xi+\lambda\beta\xi\varepsilon^2-2\left(\lambda\varepsilon+\lambda\beta\xi\varepsilon-\lambda-\varepsilon+1\right)\right)\Big)\bar{\pi}^{2(1-\varepsilon)(\xi-1)} \\
& +2\left(\beta\xi-1+\lambda\left(-\lambda\beta\xi^2\varepsilon^2+\lambda\xi\varepsilon+\lambda\beta\xi^2\varepsilon-\beta\xi\varepsilon+1+2\xi-\xi\varepsilon\right)\right)\beta\bar{\pi}^{(1-2\varepsilon)(\xi-1)} \\
& +\left(\lambda^2\xi^2\varepsilon^2+2\xi\varepsilon+1\right)\beta^2\bar{\pi}^{2\varepsilon(1-\xi)}\Big]^{1/2}\Big\} \qquad (12)
\end{aligned}$$

Figure 2 visualizes the sensitivity of this parameter to ξ and $\bar{\pi}$. We immediately notice that taking into account of trend inflation as well as increasing the degree of indexation reduce ϕ. However, just like for λ, this reduction attenuates with the increase in the degree of indexation. As summarized in Table 1, whereas the model predicts that the probability to not change the price should be reduced by 2% if annualized trend inflation is 1% when $\xi = 0$, it would be reduced by 0.6% when $\xi = 0.75$. We can see behind this phenomenon an explanation to the excessively high values of this parameter often obtained in the literature. Indeed, omitting trend inflation in a purely forward-looking Phillips curve would tend to bias upward the estimates whereas to specify a hybrid version of the Phillips curve prevents a too large error during estimation. Consequently, if we think that the inflation is very inertial (meaning a rather high degree of indexation), the estimation bias due to trend inflation will be weak even while using the following hybrid Phillips curve

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[4] This result is robust to different values for ε and ϕ.

$$\widehat{\pi}_t = \frac{\xi}{1+\xi\beta}\widehat{\pi}_{t-1} + \frac{\beta}{1+\xi\beta}\mathbb{E}_t\widehat{\pi}_{t+1} + \frac{(1-\phi)(1-\phi\beta)}{(1+\xi\beta)\phi}\widehat{mc}_t \tag{13}$$

For that, one must make the assumption that the prices that cannot be reset are indexed not only partially to past inflation rate but also partially to trend inflation.[5] But, if the empirical results conclude to a low value for ξ, it is then necessary to be careful on the validity of the estimates of ϕ.

Finally, in the extreme case of a full indexation scheme ($\xi = 1$), the model predicts that the growth rate of inflation depends upon real marginal costs and the expected future growth rate of inflation. The appeal of this theoretical assumption is that the derivation of the hybrid Phillips curve is possible whatever the level of trend inflation. But a serious weakness is that coefficients on past and future inflation sum to 1, and, for β close to 1, they are approximately the same. Unfortunately, as we will see in the next section, this last point is rarely empirically verified.

4 Assessing the empirical properties of the hybrid Phillips curve

In this section, we assume strategic complementarity (a probably more realistic assumption) rather than strategic substitutability, and provide evidence of this modified hybrid Phillips curve in conducting some instrumental variable estimations. We now present estimates of the hybrid model with partial indexation for the Euro area and the United States. Under rational expectations, the set of orthogonality conditions is

$$\mathbb{E}\left\{\left[\hat{\pi}_t - \frac{\xi}{1+\beta\xi}\widehat{\pi}_{t-1} - \frac{\beta}{1+\beta\xi}\widehat{\pi}_{t+1} - \frac{(1-\phi\beta)(1-\phi)}{(1+\beta\xi)\phi(1+\omega\varepsilon)}\widehat{mc}_t\right] \times \mathbf{z}_t\right\} = 0 \tag{14}$$

where $\mathbf{z}_t$ denotes a $k \times 1$ vector of relevant instruments. It includes here four lags of inflation, real marginal cost, output gap (linearly detrended log output) and short interest rates.

Under the hypothesis of strategic complementarity, capital is not reallocated accross firms and $mc_{t,t+j}$ is in general different from the average marginal cost at time $t+j$. This is the reason of the presence of the term $(1+\omega\varepsilon)$ in (14) where ω is the output elasticity of real marginal cost for the individual firm.[6]

4.1 Data

All data are quarterly time series over the period 1970:1-2002:4. To measure inflation we use the GDP deflator. Our measure of average real marginal cost is the log of

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[5] Note that in this case the aggregate price level is given by $P_t = \left[\phi\left(\bar{\pi}^{1-\xi}\pi_{t-1}^{\xi}P_{t-1}\right)^{1-\varepsilon} + (1-\phi)\left(P_t^*\right)^{1-\varepsilon}\right]^{1/(1-\varepsilon)}$

[6] In a technical appendix available from the author upon request, we detail all the intermediate steps involved in deriving these results.

real unit labor costs. Accordingly, we use the log deviation of real unit labor costs from its mean as a measure of $\widehat{mc}_t$. Our data for the Euro area come from the updated database by Fagan *et al.* (2001). Unit labor costs are constructed as the ratio of compensation to employees (WIN) to GDP (YEN). Inflation is measured as the quarterly percent change in the GDP deflator (YED). The data for the U.S. come from the FRED II database. In particular, real unit labor costs are for the non-farm business sector. Figure 3 and 4 show the series used in this study.

4.2 GMM methodology

We present the limited information strategy to estimate the hybrid Phillips curve. Let define the random variable ε_t such that

$$\varepsilon_t = \left[\hat{\pi}_t - \frac{\xi}{1+\beta\xi}\widehat{\pi}_{t-1} - \frac{\beta}{1+\beta\xi}\hat{\pi}_{t+1} - \frac{(1-\phi\beta)(1-\phi)}{(1+\beta\xi)\,\phi(1+\omega\varepsilon)}\widehat{mc}_t \right] \tag{15}$$

Hansen (1982) provides conditions under which (14) can be used to consistently and efficiently estimate (ξ, β, ϕ) using Generalized Method of Moments (GMM). To discuss the procedure in our context we define the vector

$$g_T(\xi, \beta, \phi) = \frac{1}{T}\sum_{t=1}^{T} [\varepsilon_t(\xi, \beta, \phi) \times \mathbf{z}_t].$$

where T denotes the size of the sample. We also denote the true value of (ξ, β, ϕ) by (ξ_0, β_0, ϕ_0). The vector $g_T(\xi, \beta, \phi)$ is a consistent estimator of $\mathbb{E}[\varepsilon_t(\xi, \beta, \phi) \times \mathbf{z}_t]$. We estimate the parameter vector (ξ_0, β_0, ϕ_0) by choosing (ξ, β, ϕ) to make $g_T(\xi, \beta, \phi)$ as close as possible to zero as possible in the sense of minimizing

$$J_T = \{g_T(\xi, \beta, \phi)\}' W_T \{g_T(\xi, \beta, \phi)\}.$$

W_T is a symmetric positive definite matrix that can depend on sample information. A given choice of W_T implies that we are choosing (ξ, β, ϕ) to minimize the sum of squares of k linear combinations of the elements of $g_T(\xi, \beta, \phi)$.

Hansen (1982) shows that the choice of W_T that minimizes the asymptotic covariance matrix of our estimator depends on the serial correlation properties of the error term $\varepsilon_t(\xi, \beta, \phi)$. If the hybrid Phillips curve is well specified, the error term is serially uncorrelated and has a moving average representation. West (1997) proposed a long-run covariance matrix estimator that is positive semidefinite by construction and that is applicable when the disturbance follows a moving average (MA) process of known order, and the innovations in this MA process have zero mean conditional on past disturbances and current and past instruments.

Assuming the error term ε_t is driven by a $MA(q)$ process, it yields[7]

$$\varepsilon_t = \eta_t + \theta_1\eta_{t-1} + ... + \theta_q\eta_{t-q}$$

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[7] In our study, $q = 1$.

The $\hat{\theta}$'s and $\hat{\eta}$'s may be obtained by non linear least square applied to $\hat{\varepsilon}_t$. Then, for $t = 1, ..., T - q$, we can compute the weighting matrix

$$\Omega_T = \frac{1}{T-q} \sum_{t=1}^{T-q} \hat{d}_{t+q} \hat{d}'_{t+q}$$

where $\hat{d}_{t+q} = (z_t + z_{t-1}\theta_1 + ... + z_{t-q}\theta_q)\, \hat{\eta}_t$.

The covariance matrix is minimized when $W_T = \Omega_T^{-1}$ and the standard errors of the optimal GMM estimator are calculated as the square roots of the diagonal elements of $\frac{1}{T} \left(\Gamma'_T \Omega_T^{-1} \Gamma_T \right)^{-1}$, where $\Gamma_T = \mathbb{E} \left(\dfrac{\partial \left[\varepsilon_t \left(\xi, \beta, \phi \right) \times \mathbf{z}_t \right]}{\partial \left(\xi, \beta, \phi \right)'} \right)$.

4.3 Empirical results

We begin by analyzing results based on reduced form of the hybrid Phillips curve. The estimated coefficients

$$\begin{aligned} \alpha_b &= \frac{\xi}{(1+\beta\xi)}, \\ \alpha_f &= \frac{\beta}{(1+\beta\xi)}, \\ \text{and } \lambda &= \frac{(1-\phi\beta)(1-\phi)}{(1+\beta\xi)\,\phi(1+\omega\varepsilon)} \end{aligned}$$

are given in Table 3.[8] Overall, the empirical hybrid model works reasonably well in both cases. The slope coefficient on marginal cost is positive in each case, as implied by the theory. The standard errors suggest some imprecision in the point estimate, but the coefficient in each case are significantly different from zero. These estimates imply that backward looking behavior is slightly less important than forward looking behavior in the Euro area as well as in the United States. Just like Gali *et al.* (2001) or Jondeau and Le Bihan (2001), we find that inflation dynamics in the Euro area appears to have a stronger forward-looking component than in the United States. It is noticed finally, that the sum of the backward and forward parameters is very close to one (but strictly lower) and that the distribution is far from being equal as it is supposed in many works.

We next estimate the structural parameter ξ, β and ϕ. Table 4 summarizes the results. We first impose the full indexation scheme ($\xi = 1$) considered for example in Christiano *et al.* (2003). The model predicts that the growth rate of inflation depends upon real marginal costs and the expected future growth rate of inflation. In this case, coefficients on past and future inflation sum to 1, and, for β close to 1, they are approximately the same. Unfortunately this scheme is not consistent with the data since it implies values of β that are implausible. One can even say that there is more evidence against the model for the Euro area, based on the J-stat. Conversely from the structural model with partial indexation, we see that all parameters are

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[8] We set $\varepsilon = 10$ and $\omega = 1.25$ as is conventionally assumed in the literature (see Woodford, 2003).

estimated with relatively small standard errors. Especially, we find degrees of inertia significant with $\xi = 0.408$ for the Euro area and $\xi = 0.639$ for the United States. Prices appear to be more flexible in the U.S. than in the Euro area, *i.e* the average duration of price rigidity is shorter: 3 quarters for the U.S. and 4.8 quarters for the Euro area. To impose β to be equal to 0.99, as the theory suggests it, increases at the same time the degree of indexation and the probability to not change the price.

We now check the recommendations concerning the omission of trend inflation. Although Ascari (2003) affirms that the omission of trend inflation involves an overestimate of the parameter ϕ, we have seen that this omission may be neglected for a rather strong value of ξ. In Section 2, we derived the expression of the hybrid curve with trend inflation under strategic substitutability and shows that its presence alters the structure of the curve in two ways. First, the coefficients on past and future inflation are functions of the degree of indexation and trend inflation. Second, there is a complex additional forward-looking structure. The additional forward-looking term is very difficult to apprehend, we ignore it at first approximation in order to concentrate us on the other variables. In the present case of strategic complementarity (14) becomes

$$\mathbb{E}\left\{\left[\widehat{\pi}_t - \frac{\left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\phi\beta\bar{\pi}^{(\varepsilon+\omega\varepsilon)(1-\xi)}\right)}{\Phi_1\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\left(1+\omega\varepsilon\right)}\widehat{mc}_t \right.\right.$$
$$\left.\left. -\frac{\xi}{\Phi_1}\widehat{\pi}_{t-1} - \frac{\Phi_2}{\Phi_1}\mathbb{E}_t\widehat{\pi}_{t+1}\right] \times \mathbf{z}_t\right\} = 0.$$

where $\Phi_1 = 1 + \xi\beta\bar{\pi}^{(1+\omega\varepsilon)(1-\xi)} + \left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1+\omega\varepsilon)(1-\xi)}\right)\left(1-\varepsilon\right)\beta\xi$ and $\Phi_2 = \beta\left[\bar{\pi}^{(1+\omega\varepsilon)(1-\xi)} + \left(1-\phi\bar{\pi}^{(1-\varepsilon)(\xi-1)}\right)\left(1-\bar{\pi}^{(1+\omega\varepsilon)(1-\xi)}\right)\left(1-\varepsilon\right)\right]$.

Table 5 reports estimates of the structural parameters ξ, β and ϕ in function of $\bar{\pi}$. We estimate the model for three values of $\bar{\pi}$: (i) the mean level of inflation over the period $\left(1.0148^{\frac{1}{4}}\right.$ for the Euro area and $\left.1.0098^{\frac{1}{4}}\right.$ for the United States$\left.\right)$, (ii) a low level of 2% annually and (iii) a high level of 5% annually. One clearly observes in both cases a reduction in ϕ when inflation is increased but this fall is all the more weak than one finds a high degree of indexation. For example, the model predicts that ϕ is reduced by 3.4% (resp. 4.8% and 2.5%) in the Euro area and 1.8% (resp. 3.8% and 9.5%) in the United States if annualized trend inflation is $\tilde{\pi}$ (resp. 2% and 5%).

5 Conclusion

This paper proposes a full explanation of the Calvo price-setting model based on partial prices indexation to derive a hybrid Phillips curve. Since assuming zero trend inflation can hardly be justified to describe and model post-war inflation, we take into account trend inflation and study the interaction between partial indexation and trend inflation. In particular, we analytically find that the higher the degree of indexation and the less trend inflation has an influence on the value of the parameters of the hybrid Phillips curve. Consequently, overestimate due to the omission of trend inflation disappears with the increase of the degree of indexation. We also proposed new empirical evidence about the properties of a hybrid Phillips curve based on partial price indexation. First, we initially cancel trend inflation in assuming that the prices that cannot be reset are indexed not only to a part of the past inflation rate but also to a part of trend inflation. Our results show that the extreme case with full indexation is data inconsistent and that the empirical model with partial indexation (and a degree of indexation around 0.5) appears to capture the inflation dynamics for the Euro area and the United States over the period 1970-2002. Second, we introduce trend inflation in the model and observe the theoretical awaited fall of the probability to not change the price (around 3-4% for reasonable values of $\bar{\pi}$).

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Table 1. Values of $\left[\lambda\left(1,\xi\right)-\lambda\left(\bar{\pi},\xi\right)\right]/\lambda\left(1,\xi\right)$ as a function of $\bar{\pi}$ and ξ

	$\bar{\pi}=(1.01)^{\frac{1}{4}}$	$\bar{\pi}=(1.02)^{\frac{1}{4}}$	$\bar{\pi}=(1.05)^{\frac{1}{4}}$	$\bar{\pi}=(1.08)^{\frac{1}{4}}$	$\bar{\pi}=(1.1)^{\frac{1}{4}}$
$\xi=0$	15%	30%	63%	86%	95%
$\xi=0.25$	12%	23%	51%	72%	83%
$\xi=0.5$	8%	16%	36%	53%	63%
$\xi=0.75$	4%	8%	19%	29%	35%

Parameter configuration: $\beta=0.99,\phi=0.75,\varepsilon=10.$

Table 2. Values of $\left[\phi\left(1,\xi\right)-\phi\left(\bar{\pi},\xi\right)\right]/\phi\left(1,\xi\right)$ as a function of $\bar{\pi}$ and ξ

	$\bar{\pi}=(1.01)^{\frac{1}{4}}$	$\bar{\pi}=(1.02)^{\frac{1}{4}}$	$\bar{\pi}=(1.05)^{\frac{1}{4}}$	$\bar{\pi}=(1.08)^{\frac{1}{4}}$	$\bar{\pi}=(1.1)^{\frac{1}{4}}$
$\xi=0$	2%	5%	11%	17%	20%
$\xi=0.25$	2%	4%	8%	13%	16%
$\xi=0.5$	1%	2%	6%	9%	11%
$\xi=0.75$	0.6%	1%	3%	5%	6%

Parameter configuration: $\beta=0.99,\varepsilon=10,\lambda=0.086.$

Table 3. Reduced form estimates

Euro area

α_b	α_f	λ	J-stat
0.292 (0.049)	0.691 (0.051)	0.003 (0.002)	18.845 (0.171)

United States

α_b	α_f	λ	J-stat
0.408 (0.029)	0.567 (0.036)	0.010 (0.005)	19.366 (0.151)

Table 4. Structural estimates

Euro area

ξ	β	ϕ	J-stat
1	1.220 (0.242)	0.819 (0.163)	25.525 (0.043)
0.408 (0.097)	0.963 (0.056)	0.791 (0.082)	18.845 (0.171)
0.533 (0.085)	0.99	0.821 (0.027)	24.186 (0.057)

United States

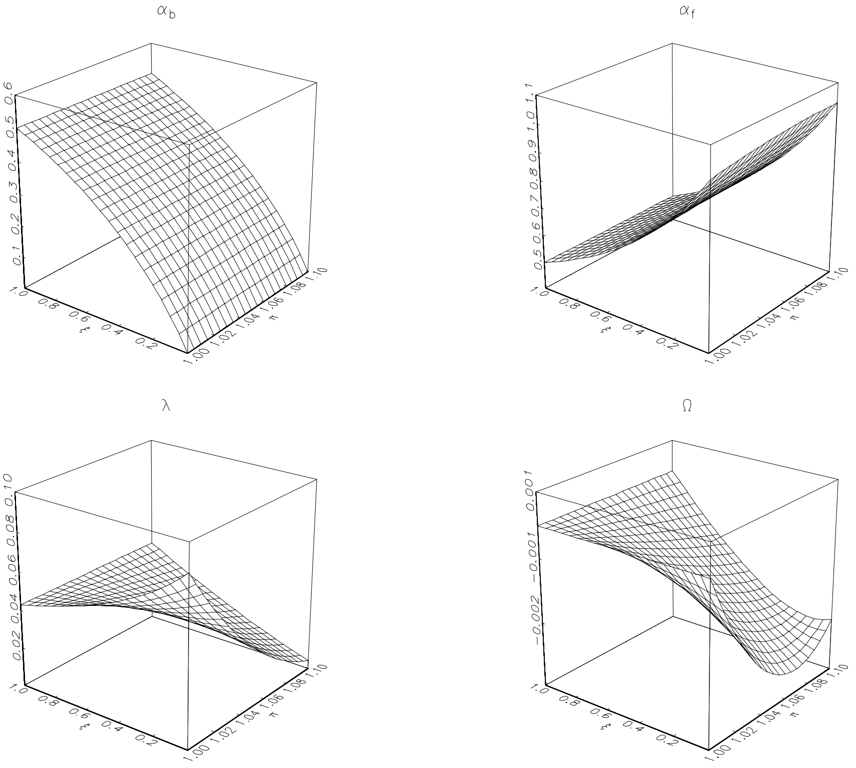
ξ	β	ϕ	J-stat
1	1.478 (0.179)	0.676 (0.082)	21.907 (0.110)
0.639 (0.065)	0.901 (0.066)	0.664 (0.062)	19.366 (0.151)
0.665 (0.080)	0.99	0.759 (0.081)	21.488 (0.122)

Table 5. Structural estimates under trend inflation

	Euro area				*United States*			
$\bar{\pi}$	ξ	β	ϕ	J-stat	ξ	β	ϕ	J-stat
$\tilde{\pi}$	0.416 (0.101)	0.982 (0.060)	0.765 (0.078)	18.845 (0.171)	0.650 (0.067)	0.904 (0.069)	0.652 (0.061)	19.366 (0.151)
	0.529 (0.085)	0.99	0.766 (0.021)	23.580 (0.073)	0.660 (0.080)	0.99	0.720 (0.069)	20.602 (0.150)
$(1.0200)^{\frac{1}{4}}$	0.419 (0.103)	0.989 (0.062)	0.755 (0.077)	18.845 (0.171)	0.662 (0.068)	0.920 (0.073)	0.640 (0.060)	19.366 (0.151)
	0.526 (0.085)	0.99	0.749 (0.020)	23.034 (0.083)	0.656 (0.080)	0.99	0.686 (0.062)	19.730 (0.183)
$(1.0500)^{\frac{1}{4}}$	0.439 (0.113)	1.036 (0.075)	0.703 (0.067)	18.845 (0.171)	0.698 (0.072)	0.971 (0.089)	0.606 (0.056)	19.366 (0.151)
	0.507 (0.086)	0.99	0.669 (0.016)	20.382 (0.158)	0.654 (0.082)	0.99	0.610 (0.055)	17.653 (0.281)

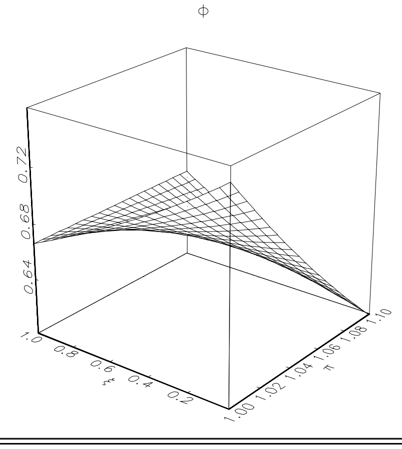
$\tilde{\pi} = (1.0148)^{\frac{1}{4}}$ for the Euro area and $\tilde{\pi} = (1.0098)^{\frac{1}{4}}$ for the United States.

Figure 1. Values of $\alpha_b, \alpha_f, \lambda, \Omega$ as a function of $\bar{\pi}$ and ξ



Parameter configuration: $\beta = 0.99, \phi = 0.75, \varepsilon = 10$.

Figure 2. Values of ϕ as a function of $\bar{\pi}$ and ξ



Parameter configuration: $\beta = 0.99, \varepsilon = 10, \lambda = 0.086$.

Figure 3. The Euro Area Data

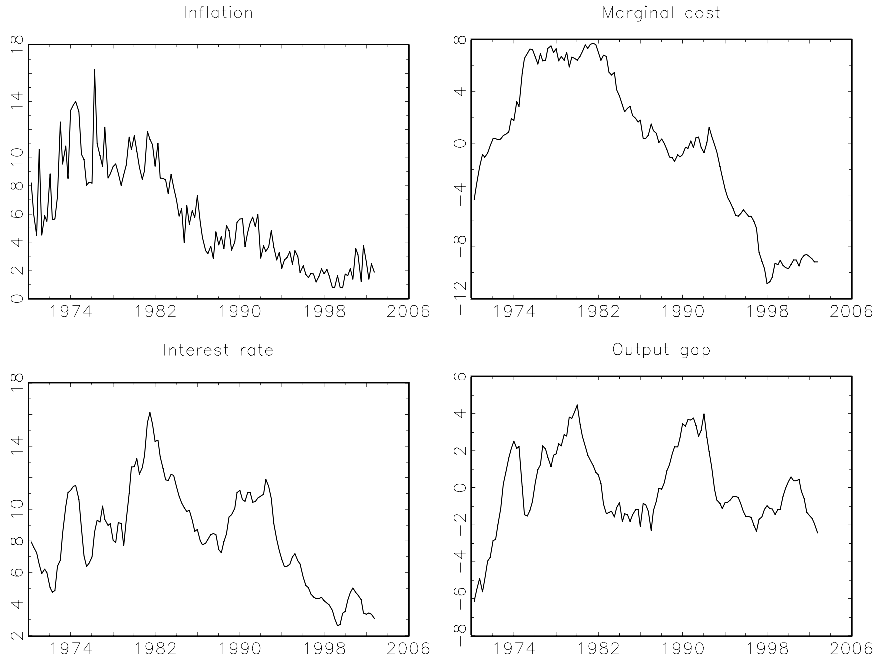
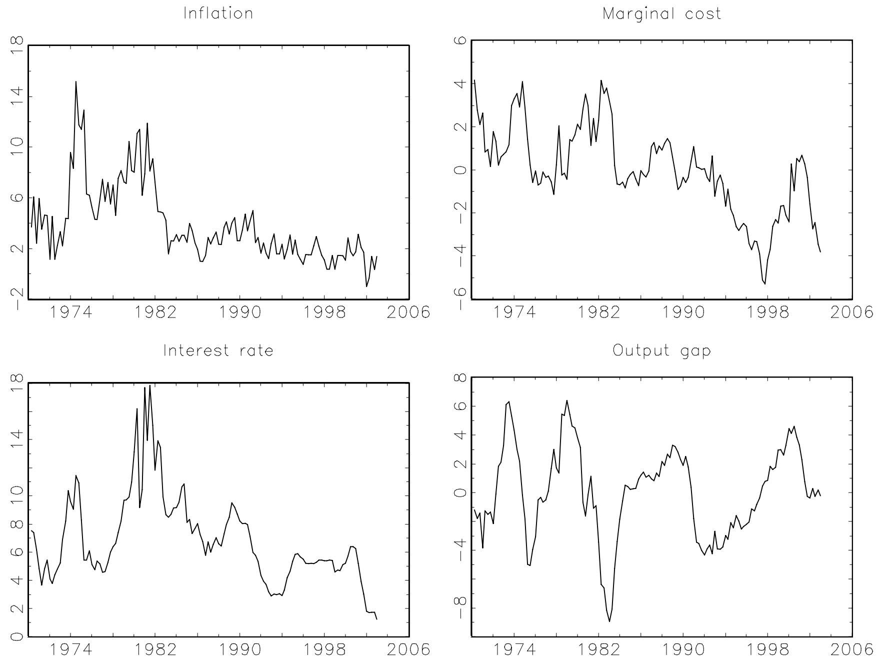


Figure 4. The United States Data



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