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Testing for a Forward-Looking Phillips Curve. Additional Evidence from European and US Data

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Abstract

The "New Keynesian" Phillips Curve (NKPC) states that inflation has a purely forward-looking dynamics. In this paper, we test whether European and US inflation dynamics can be described by this model. For this purpose, we estimate hybrid Phillips curves, which include both backward and forward-looking components, for major European countries, the euro area, and the US. Estimation is performed using the GMM technique as well as the ML approach. We examine the sensitivity of the results to the choice of output gap or marginal cost as the driving variable, and test the stability of the obtained specifications. Our findings can be summarized as follows. First, in all countries, the NKPC has to be augmented by additional lags and leads of inflation, in contrast to the prediction of the core model. Second, the fraction of backward-looking price setters is large (in most cases, more than 50 percent), suggesting only limited differences between the US and the euro area. Finally, our preferred specification includes marginal cost in the case of the US and the UK, and output gap in the euro area.

Keywords: Forward-looking Phillips curve, euro area, GMM estimator, ML estimator.
JEL classification: E31.

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1 Introduction

The traditional Phillips curve has recently been challenged in macroeconomic models by the "New Keynesian Phillips Curve" (NKPC), which states that inflation has a forward-looking dynamics. An appealing characteristic of the NKPC is that it can be derived under the optimizing behavior of firms in their price setting. As a consequence, this specification provides some immunity with respect to the Lucas critique. Estimated parameters are structural ones, so that they are not likely to change as the policy regime varies. This feature is essential in the case of the euro area, since some instability in the reduced-form parameters may arise as a consequence of the new policy regime which took place with the founding of the European Central Bank. Furthermore, the specification of the Phillips curve has dramatic implications from a central-bank perspective. As pointed by several authors (e.g. Ball, 1991), a fully credible central bank can engineer a disinflation at no cost in terms of output if inflation is a forward-looking phenomenon, whereas lowering steady-state inflation requires a recession in the context of a traditional Phillips curve.

A crucial issue is therefore whether the NKPC is empirically relevant. Recently, tests of the empirical validity of the NKPC have been conducted by different authors. These tests typically involve estimating a "hybrid" model, which incorporates, in addition to the forward-looking component, lags of inflation not predicted by the core theory. The hybrid model nests the traditional Phillips curve and the NKPC as special cases. Empirical estimates of the hybrid model have yielded very conflicting results. On one hand, Fuhrer (1997) found the forward-looking component in inflation to be essentially unimportant. Roberts (2001) also obtained an important backward-looking component on US data.[1] On the other hand, Galí and Gertler (1999), in the case of the US, and Galí, Gertler, and Lopez-Salido (2001), in the case of euro area, reported that the forward-looking component is dominant. In the same spirit, empirical evidence presented by Sbordone (1998) and Amato and Gerlach (2000) suggest that the baseline forward-looking NKPC provides a reasonably good description of US as well as European inflation dynamics. Rotemberg and Woodford (1997) also found empirical support for the NKPC, allowing for a serially correlated error term.

These conflicting results can be, to some extent, rationalized by the choice of the forcing variable in the Phillips curve. Galí and Gertler (1999), among others, pointed out that empirical evidence on the forward-looking Phillips curve with inflation driven by output gap is rather unsatisfactory, while a Phillips curve with marginal cost as a forcing variable is consistent with forward-looking behavior. They stressed that the relevant determinant of inflation is the marginal cost rather than the output gap. Indeed, theoretical models (as those developed by Calvo, 1983, and Rotemberg, 1982), indicate that firms subject to constraints on the frequency of price adjustment, or to adjustment costs, will set prices as a function of their expectations concerning future costs. Another explanation of the contrasting results may be found in the lag and lead structure of inflation dynamics. Fuhrer

[1] Estrella and Fuhrer (1998) also document the poor fit of a purely forward-looking Phillips curve.

and Moore (1995b) and Fuhrer (1997) provided empirical evidence that lags and leads of inflation have to be added to the baseline hybrid model to fit the data. Once sufficient inflation persistence is embedded in the model, the forward-looking component is found to be small.

Our purpose in this paper is to investigate the sources of the conflict between existing estimates, and to provide additional evidence on the empirical importance of the forward-looking component in inflation. As in previous studies, we estimate hybrid Phillips curves, in order to assess the relative weight of past and expected inflation, and we compare the ability of output gap and marginal cost to explain the dynamics of inflation. The distinctive features of our approach are the following. First, we extend the analysis to Europe, and we consider the four largest European countries (Germany, France, Italy, and the UK) as well as the euro area. Comparing results obtained at the euro-area level and at individual-country level is an important cross-check of the results obtained at the area level. Second, we systematically test for the stability of the estimated specifications. Stability tests provide indication of robustness with respect to the Lucas critique, and are helpful to discriminate among the alternative Phillips curve specifications. As stressed by Estrella and Fuhrer (1998) even optimization based models should be tested against the Lucas critique. Last, we investigate the influence of the estimation method in estimating the hybrid model. We implement the Generalized-Method-of-Moments (GMM) approach used by Galí and Gertler as well as the Maximum-Likelihood (ML) technique used by Fuhrer (1997). Whereas the former does not require strong assumptions on the innovation process, the latter provides model-consistent inflation expectations.

The paper is organized as follows. In section 2, we describe various specifications of the Phillips curve, including the traditional, the New Keynesian and the hybrid Phillips curves. A more detailed derivation of these specifications is presented in the Appendix. Section 3 is devoted to empirical issues, starting with a summary of the specifications tested. We also discuss the definition of the variables included in the model, and provide some details on the GMM and ML techniques. In section 4, estimation results are presented and discussed. As a robustness check of our estimations, we investigate for weak-instrument relevance in the case of GMM estimates, and we present stability tests of the hybrid equations. Section 5 summarizes our main findings and suggests topics for further investigation.

2 The traditional and the NK Phillips curves

2.1 The traditional Phillips curve

In the traditional Phillips curve, inflation is related to output gap and lagged values of inflation.[2] Such a relationship can be written as:

$$\pi_t = \sum_{k=1}^{K} \alpha_k \pi_{t-k} + \gamma \widehat{y}_t + \varepsilon_t \tag{1}$$

where π_t denotes the inflation rate, $\widehat{y}_t$ is the log deviation of output from its steady-state value, and ε_t is a random disturbance. Imposing $\sum_{k=1}^{K} \alpha_k = 1$ yields the accelerationist Phillips curve, so that there is no long-run trade-off between output and inflation. Such a backward-looking Phillips curve has been shown to fit the US postwar data very well (Fuhrer and Moore, 1995b, Fuhrer, 1997, Rudebusch and Svensson, 1998). The output term is found to be statistically significant and the sum of lagged inflation parameters is not significantly different from unity.

However, the traditional Phillips curve may be subject to the Lucas critique. Estimated parameters are likely to change as the policy regime varies. Since lagged inflation may embed expectations of future inflation, one may observe instability of the backward-looking Phillips curve.

2.2 The "Taylor" forward-looking Phillips curve

The explicit introduction of rational expectations is the main feature of the forward-looking Phillips curve. An early derivation was provided by the rational-expectation wage-staggering model of Taylor (1980). In the simplest nominal-wage contracting model of Taylor, nominal rigidities are introduced by assuming that wages are set for two periods. The inflation dynamics can be written in a forward-looking form, as:[3]

$$\pi_t = E_t \pi_{t+1} + \gamma \widehat{y}_t + \varepsilon_t \tag{2}$$

where E_t denotes expectation conditional to the information set available at time t. Such a specification has been estimated, for instance, by Galí and Gertler (1999), Galí, Gertler, and Lopez-Salido (2001), and Estrella and Fuhrer (2000). In most studies, the estimate of γ is found to be non-significant. Using the GMM approach, Galí and Gertler (1999) and Galí, Gertler, and Lopez-Salido (2001) report negative estimates of γ, for US as well as euro-area data.[4]

[2] For simplicity, we abstract from the "wage-price" form of the traditional Phillips curve.

[3] See Appendix 6.1. for derivation.

[4] Note, however, that using proxies for inflation expectations from surveys, Roberts (1995, 1997) obtains significant positive estimates of γ.

As argued by Fuhrer and Moore (1995a), this model is in fact not consistent with the degree of inflation persistence found in the data. Moreover, it is easy to show that this equation may be stated in a backward-looking form as:

$$\pi_{t+1} = \pi_t - \gamma \widehat{y}_t + \tilde{\varepsilon}_t \tag{3}$$

with $\tilde{\varepsilon}_t = -\varepsilon_t + (\pi_{t+1} - E_t\pi_{t+1})$, so that the effect of lagged output gap should be negative. However, this effect is generally found to be positive, a result which contradicts the forward-looking Phillips curve based on output gap.

2.3 The "two-sided" Phillips curve

In order to solve the lack of inflation persistence issue raised by the purely forward-looking model, Fuhrer and Moore (1995b) proposed a model of relative real wage contract, which is found to introduce sufficient inflation stickiness. Using two-period contracts, their key specification is written as a hybrid model of the form:[5]

$$\pi_t = \frac{1}{2}\left(\pi_{t-1} + E_t\pi_{t+1}\right) + \gamma \widehat{y}_t + \varepsilon_t. \tag{4}$$

This approach can be extended to multiple-period contracts, yielding a more general two-sided Phillips curve with lags and leads

$$\pi_t = \sum_{j=1}^{J} a_{-j}\pi_{t-j} + \sum_{h=1}^{H} a_h E_t \pi_{t+h} + \gamma \widehat{y}_t + \varepsilon_t \tag{5}$$

with some restrictions imposed on the parameters (see the Appendix 6.3 for an illustration).

Although this approach has been shown to explain the dynamics of observed inflation quite well (Chadha, Masson, and Meredith, 1992, Fuhrer and Moore, 1995a, Fuhrer, 1997, Coenen and Wieland, 2000, Roberts, 2001), it has been criticized on theoretical grounds. First, the staggered price setting of Taylor (1980) does not explicitly result from individual optimization. Second, the use of output gap as the driving term for inflation has no clear micro-foundations.

2.4 The core and hybrid NKPCs

In the core version of the NKPC, aggregate price is derived from the optimal individual behavior of firms. Combining nominal rigidities and an optimizing behavior produces a forward-looking dynamics of inflation. The main interest of this model is to embed nominal rigidities in the dynamic general equilibrium framework.

In the models developed by Rotemberg (1982) and Calvo (1983), firms set their price optimally, subject either to adjustment costs or to constraints on the frequency of price

[5] See Appendix 6.2 for derivation.

adjustment. Thus, they adjust their price to take into account expectations concerning future costs and future demand conditions. In both models, aggregating across firms provides the following Phillips curve equation:[6]

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \widehat{mc}_t, \tag{6}$$

where β denotes the discount factor, and $\widehat{mc}_t$ is the log deviation of average real marginal cost from its steady-state value. Parameter λ is shown to be a function of the parameters of the structural model (in particular, the demand elasticity and the adjustment cost). Note that, as shown for instance by Rotemberg and Woodford (1997), under some assumptions about the labor supply process, the output gap is linearly related to real marginal cost, so that equations (2) and (6) should provide similar results.

Equation (6) helps to understand why, over the recent period, the traditional Phillips curve has tended to overpredict inflation. Assuming that the NKPC given by equation (6) is the true model, past inflation enters the traditional Phillips curve (1) as a proxy for inflation expectations, and the output gap enters as a proxy for marginal cost. Therefore, the traditional Phillips curve may be subject to the Lucas critique for two reasons. First, the relationship between past inflation and expected future inflation may change over time. Second, the output gap may be a poor proxy for marginal cost. This may be the case, for instance, if productivity growth increased over the recent period. This would induce an increase in the measured output gap, whereas the true output gap should remain unchanged. Although there is no obvious choice between both interpretations, the use of the output gap as a proxy of the marginal cost appears clearly questionable. In the following section, we compare the ability of output gap and marginal cost to explain movements in inflation.

Recently, Galí and Gertler (1999) have introduced the following hybrid model:[7]

$$\pi_t = \omega_b \pi_{t-1} + \omega_f E_t \pi_{t+1} + \lambda \widehat{mc}_t + \varepsilon_t. \tag{7}$$

They propose a theoretical justification of this hybrid model based on the existence of two types of firms. A fraction of firms behave in a forward-looking way as in the NKPC. They set their price optimally, subject to the constraint on the frequency of price adjustment as in Calvo's (1983) model. The remaining firms use a rule of thumb, based on recent aggregate price developments, and therefore behave in a backward-looking fashion.[8]

Galí and Gertler (1999) and Galí, Gertler, and Lopez-Salido (2001) found empirical support of such a hybrid specification on US as well as European data. In both papers, a high weight (larger than 0.75) on the forward-looking component is reported. While these studies suggest that marginal cost is a more relevant driving variable for inflation than output gap, Roberts (2001) did not obtain conclusive results from his comparison of output gap and marginal cost in the case of the US.

[6]See Appendices 6.4 and 6.5 for alternative derivations. Note that Kiley (1997) and Chari, Kehoe, and McGrattan (2000) provide a derivation of such an equation under Taylor-type price staggering.

[7]See Appendix 6.6. for a derivation.

[8]Note that Brayton, Levin, Tryon, and Williams (1997) also justified the role of lagged inflation by a "polynomial adjustment cost" model, which allows a higher-order dynamics.

3 Empirical issues

3.1 Empirical specifications

Following the discussion of the previous section, we consider four alternative specifications in the empirical application. The first one is the hybrid model based on the output gap

$$\pi_t = \omega\pi_{t-1} + (1-\omega)\, E_t\pi_{t+1} + \gamma\widehat{y}_t + \varepsilon_t \tag{8}$$

where ω is the fraction of backward-looking agents in the population, with $0 \leq \omega \leq 1$. This model nests as special cases the traditional Phillips curve ($\omega = 1$) as well as the Taylor (1980) forward-looking Phillips curve ($\omega = 0$). It also nests the Fuhrer and Moore (1995b) model with two-period contracts ($\omega = 1/2$).

The second specification is the hybrid NKPC, based on the marginal cost, as in Galí and Gertler (1999):

$$\pi_t = \omega\pi_{t-1} + (1-\omega)\, E_t\pi_{t+1} + \lambda\widehat{mc}_t + \varepsilon_t. \tag{9}$$

Note that, in equation (7) resulting from Galí and Gertler (1999) model, the weights on lagged inflation and expected future inflation are not assumed to sum to one. In equation (9), we impose that weights on inflation terms sum to one, in order to obtain comparability with the Taylor-type specification. It is worth emphasizing that this assumption is not restrictive, since the sum of weights in the Galí and Gertler model should be very close to 1: It must lie between β (typically set equal to 0.99 in calibrated models) and 1. Furthermore, it appeared in our preliminary regressions that free estimation of the weight parameters almost exactly satisfied this constraint. Therefore, in the following empirical section, we only report estimates obtained with the constrained model, with ω denoting the weight on the backward-looking component.

The last two specifications we consider are hybrid versions of the Phillips curve, in which additional leads and lags of inflation are incorporated. We follow Fuhrer (1997) by replacing the single lag and lead of inflation with a three-quarter average of inflation. The output-gap model then becomes:

$$\pi_t = \omega\left(\frac{1}{3}\sum_{i=1}^{3}\pi_{t-i}\right) + (1-\omega)\left(\frac{1}{3}\sum_{i=1}^{3}E_t\pi_{t+i}\right) + \gamma\widehat{y}_t + \varepsilon_t. \tag{10}$$

While this specification has no exact micro-foundations, it can be related to the Fuhrer and Moore (1995b) model with multiple-period contracts. This specification with three lags and leads of inflation is consistent with wage contracts negotiated on a yearly basis. It allows to overcome multicolinearity between lags (or leads) of inflation and avoids relying too heavily on restrictions implied by a specific timing of expectations (see the Appendix 6.4 for details). Fuhrer (1997) and Roberts (2001) provided strong empirical support for this specification: Parameter estimates were found to be more precise than those obtained with the specification (8) with one lag and lead only.

A similar specification can be estimated, with the marginal cost as the driving term (as in Roberts, 2001):

$$\pi_t = \omega \left(\frac{1}{3} \sum_{i=1}^{3} \pi_{t-i} \right) + (1-\omega) \left(\frac{1}{3} \sum_{i=1}^{3} E_t \pi_{t+i} \right) + \lambda \widehat{mc}_t + \varepsilon_t. \quad (11)$$

Such a relation has been estimated,on US data, by Roberts (2001), who obtained significant estimates of the slope parameter, λ.

3.2 Data

We estimate the hybrid Phillips curves for the euro area, as well as four major European countries (Germany, France, Italy, and the UK). We also report results using US data for two purposes: First, we aim at explaining the conflicting results of Fuhrer (1997) and Galí and Gertler (1999). Second, we wish to examine whether similar results exist on European data. The sample period runs from 1970:1 to 1999:4 at a quarterly frequency. The data are drawn from OECD Business Sector Data Base for individual countries. As regards the euro area, we use the Area-Wide Model database from Fagan, Henry, and Mestre (2001).[9]

Figure 1 displays the historical path of the various series under consideration for each country or area. We measure inflation as the annualized quarterly percent change in the implicit GDP deflator. The interest rate is the three-month money-market rate. Output is simply defined as the real GDP. From a theoretical standpoint, potential output is the level that would prevail under fully flexible prices. It is well documented that the use of detrended GDP as a proxy for the output gap does not have strong theoretical grounds. Since estimating structural measure of potential output is beyond the scope of this paper, we concentrate on the output-gap measure computed with a Hodrick-Prescott filter.[10] It is likely, however, that detrended output fails to account adequately for supply shocks or labor market frictions, which affect marginal cost.

Real marginal cost is computed using deviation of the (log) labor income share from its average value or, equivalently, as the real unit labor cost. Such a proxy is obtained under the assumption of a Cobb-Douglas technology. This series is computed as the difference between the wage and labor productivity series. Wage is defined as the total compensation per employee, and labor productivity is the nominal GDP per employee.

[9] The database for the euro area covers the period from 1970:1 to 1998:4 only. Note also that, in the case of Germany, we corrected for the mechanical impact of re-unification on GDP and GDP deflator data using data for West Germany for the year 1991.

[10] We used the recommended value, $\lambda = 1600$, for the smoothness parameter. We also examined the output gap computed using the regression on a quadratic time trend or on a segmented trend as alternative indicators of excess demand. All statistical trends were computed over the 1965:Q1-1999:Q4 period. Using a Hodrick-Prescott filter provided more conclusive results, apparently because the resulting output gap displays a more stationary dynamics.

3.3 Methodology

In the various Phillips curves described above, current inflation depends on expected future inflation. Therefore, we need an expectation for π_{t+1}. Several approaches may be used to obtain inflation expectations. A first one relies on using genuine series of inflation expectations, which can be either collected using quantitative survey data (as in Roberts, 1995, 1997, or Rudebusch, 2000) or inferred on the basis of qualitative survey data (Reckwerth, 1998). The lack of long time series of inflation expectation surveys for the euro area precludes using this first approach here. A second approach, in the spirit of McCallum (1976), is the Instrumental Variables or, more generally, the GMM method. In this estimation procedure, expectational errors $(\pi_{t+1} - E_t\pi_{t+1})$ are assumed to be uncorrelated with all variables in the information set of agents available at date t. Another approach is the ML method. This approach requires specifying a process for the driving variable, i.e. the output gap or the marginal cost. The inflation expectation is implicitly obtained through solving a rational-expectation model (Fuhrer and Moore, 1995a, Fuhrer, 1997). An advantage of this method is that expectations are fully model-consistent.[11]

In the empirical analysis, we focus on the GMM and ML approaches. Both procedures assume rational expectations, but have very different informational assumptions and estimation properties. First, the GMM exploits the orthogonality conditions between the expectational error and the whole information set of agents. We adopt a baseline information set, which includes lags of inflation, output gap, marginal cost, and the short-term interest rate.[12] We use four lags of each instrument, a choice which appears to be sufficient to capture the economy's dynamics. We use the same information set for all specifications estimated in order to obtain comparable results.[13]

For estimating, say, specification (8) with output gap, we consider the q orthogonality conditions:

$$Em_t(\theta) = 0 \qquad \text{with} \qquad m_t(\theta) = \left(\pi_t - \omega\pi_{t-1} - (1-\omega)\,\pi_{t+1} - \gamma\widehat{y}_t\right)\mathbf{z}_{t-1}$$

where $\mathbf{z}_{t-1}$ denotes the $(q,1)$ vector of instruments available at time $t-1$ (with $q = 17$) and $\theta = \begin{pmatrix} \omega & \gamma \end{pmatrix}'$. The same approach applies for estimating other specifications described in section 3.1. The GMM weighting matrix is defined as the inverse of the asymptotic covariance matrix of orthogonality conditions $m_t(\theta)$. We estimate the asymptotic covariance

[11] Alternatively, Sbordone (1998) suggests to estimate, separately, a forecasting model for future values of the marginal cost. To simplify, she estimates the inflation dynamics, given by $\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k E_t\left[\widehat{mc}_{t+k}\right]$, where expectations of $\widehat{mc}_{t+k}$ are obtained from a VAR model. Other approaches have been recently proposed in a fully-specified model (Rotemberg and Woodford, 1997, Amato and Laubach, 1999, Coenen and Wieland, 2000).

[12] We also considered an extended information set, including, in addition to the baseline information set, lags of wage inflation and lags of productivity growth. We obtained empirical results very close to those reported in our Tables 1 and 2.

[13] Note, however, that this choice may have a drawback in the comparison of the GMM and ML procedures, since we use a rather large number of instruments. This is likely to introduce some dispersion in our estimates.

matrix using the estimator proposed by Newey and West (1987):

$$\widehat{S}_T = \widehat{\Sigma}_T + \widehat{\Lambda}_T + \widehat{\Lambda}'_T$$

with

$$\begin{aligned}
\widehat{\Sigma}_T &= \frac{1}{T}\sum_{t=1}^{T} m_t\left(\hat{\theta}\right) m_t\left(\hat{\theta}\right)' \\
\widehat{\Lambda}_T &= \frac{1}{T}\sum_{s=1}^{L} w(s,L) \sum_{t=s+1}^{T} m_t\left(\hat{\theta}\right) m_{t-s}\left(\hat{\theta}\right)'
\end{aligned}$$

where $w(s,L) = 1 - s/\left(L+1\right)$ is the Bartlett kernel and L the bandwidth parameter.

It has been shown that GMM estimators have poor small-sample properties. See, for instance, the July 1996 special issue of the *Journal of Business and Economic Statistics*, or Fuhrer, Moore, and Schuh, 1995, in the context of inventories. In small sample, GMM estimators are often found to be biased, widely dispersed, sensitive to the normalization of the orthogonality conditions, and to the choice of instrument set. Although there exist several GMM estimators, with similar asymptotic properties but contrasting small-sample properties, we use the two-step GMM estimator. This estimator has been found to be less sensible to small-sample biases.

The ML approach conditions upon forecasts of the driving variable, which are obtained from a prediction model. This may be a univariate relation, a VAR model, or a more sophisticated model. For instance, Fuhrer and Moore (1995b) estimate a forward-looking structural model, in which the output gap is a function of the long real rate (which is defined as the average of the sequence of expected short real rates) and the short rate is driven by a Taylor-rule type reaction function. In most cases, however, forecasts of the driving variable are obtained from a VAR-type approach (see Kozicki, Reifschneider, and Tinsley, 1995, Fuhrer and Moore, 1995a). It is worth emphasizing that this is not exactly a VAR model, since one of the equations (here, the Phillips curve) is a structural, forward-looking one. Our VAR-like model includes the driving variable (output gap or marginal cost) and the short nominal rate. Both variables depend on four lags of the inflation rate, the driving variable and the short nominal rate. This model is estimated using the AIM procedure developed by Anderson and Moore (1985). This procedure works as follows: First, the forward-looking model is written in the following general form

$$\sum_{i=1}^{\tau_B} H_{-i}X_{t-i} + H_0X_t + \sum_{j=1}^{\tau_F} H_jE_t\left(X_{t+j}\right) = \eta_t \tag{12}$$

where X_t contains all variables in the model, τ_B and τ_F denote the maximum number of lags and leads respectively, and η_t is the vector of error terms. Then, the procedure computes the autoregressive form of this model, using a generalized saddlepath procedure, which provides us with

$$\sum_{i=0}^{\tau_B} S_iX_{t-i} = \eta_t. \tag{13}$$

This so-called observable structure is then used to compute the log-likelihood function. See Anderson and Moore (1985) for additional details on the methodology.

4 Empirical results

4.1 GMM estimates

In this section, we present and discuss GMM estimates of the hybrid models described in the previous section. We considered different bandwidths (L) for the computation of the Newey-West covariance matrix. Computing the optimal bandwidth, as suggested by Den Haan and Levin (1996), we found that it ranges between 4 and 7, depending on the country considered. We thus report results for $L = 4$ and 12 lags. We note that the standard error of parameter estimates obtained for 12 lags is systematically lower than those obtained for 4 lags. Increasing the number of lags in the covariance matrix does not alter parameter estimates statistically, but allows to obtain, in a few cases, significant effects for the driving variable (for instance, in Germany, for the output-gap specification with a single lag and lead of inflation).

Table 1 reports GMM estimates of the hybrid version with a single lag and lead of inflation, as in equations (8) and (9). Table 2 uses the hybrid version which includes three-quarter average of lag and lead of inflation, as in equations (10) and (11). Standard errors are reported in italics. In both tables, Panel A is devoted to the case with output gap and Panel B to the case with marginal cost.

We begin with the model which includes a single lag and lead of inflation. A first forceful result is that the degree of backward-lookingness remains essentially unchanged for the two driving variables. Parameters ω are typically equal to 0.34 and 0.26 for the US and the euro area respectively. The estimates are very close to those obtained by Galí, Gertler, and Lopez-Salido (2001), when the marginal cost is used as a driving variable (0.39 and 0.20 respectively). In both regions, however, we find that the estimates of ω is strongly significant. This result suggests that, although forward-looking behavior is dominant, a significant backward-looking behavior does exist in these economies. Interestingly, we obtain very contrasting degrees of backward-lookingness in European countries. On one hand, Germany and the UK display a very low fraction of backward-looking price setters (about 15 percent of the population), whereas, in France and Italy, firms appear to behave in a strongly backward-looking fashion.

Second, in most cases, we obtain non-significant parameter estimates for the driving variable. On one hand, the effect of output gap is negative in the case of the US, France, and the UK. Since the work of Galí and Gertler (1999) and Roberts (2001), this result is not surprising for the US. Indeed, both papers highlighted the inability of output gap to explain the dynamics of inflation in a forward-looking or hybrid specification.[14] Note,

[14] For instance, Roberts obtains a significant negative estimate of γ for the detrended GDP when inflation is included in his information set (see his Table 1).

however, that introducing $L = 12$ lags in the Newey-West covariance matrix, we obtain a significant effect of output gap in the case of the euro area and Germany.

On the other hand, the marginal-cost parameter is not significant in the hybrid Phillips curve. But, contrary to the case of the output gap, estimates of λ are positive, with the exception of Italy. Point estimates of λ are very low in the euro area and in France. For the US, the parameter on marginal cost is 0.004 only. When the Newey-West covariance matrix is computed with $L = 12$ lags, we find $\lambda = 0.016$, a point estimate which is in the range obtained by Galí and Gertler (1999). In the UK, the reported value (0.033) is larger, but standard error is too large to provide a significant estimate. Galí and Gertler (1999), Roberts (2001) and Rudd and Whelan (2001) also obtained very low point estimates for the parameter on marginal cost. Some of these point estimates are not significantly different from 0. Depending on assumptions on the structural parameters and the orthogonalization conditions, Galí, Gertler, and Lopez-Salido (2001) obtained a wide range of the slope parameter for the US and the euro area, which includes our own point estimate.[15]

We turn now to the model with three lags and leads of inflation as in equations (10) and (11) (Table 2). Results obtained with this model differ from the model with a single lag and lead with different respects. First, in most countries, the degree of backward-lookingness is larger than in the previous specification. Interestingly, they are very close one to the other in the US, the euro area, and the UK (0.41, 0.36 and 0.38 respectively). We also find, in individual countries of the euro area, a large component of backward-looking price setters. It is as high as 0.46 in Italy, 0.58 in Germany, and 0.67 in France. This result is consistent with the finding of Roberts (2001), who obtained, for the US, an increase in the degree of backward-lookingness when he increased the number of lags and leads in the inflation dynamics. It is worth noting that the three largest countries of the euro area provide a strongest degree of backward-lookingness than the aggregated euro area. This can be explained by a larger forward-lookingness in small countries of the area. We do not see, however, why this is likely to be the case. Another possible explanation relies on an aggregation bias.

Second, estimates of the output-gap parameter are found to be much larger in European countries. The point estimate of γ is 0.28 for the euro area and it ranges between 0.16 (in France) and 0.46 (in Italy) for individual countries. Moreover, in most cases, the point estimate is strongly significant. By contrast, in the US and the UK, we find a negative, although non-significant, output-gap parameter.

Last, introducing the marginal cost in the hybrid model also provides very contrasting results. As predicted by the theory, the slope parameter is significantly positive in the US and the UK. It ranges between 0.037 and 0.068 in both countries. However, the slope parameter fails to be significant in the euro area and fails to be positive in individual European countries.

[15] The value reported for the reduced-form parameter λ in their Table 2 is not consistent with the definition of λ given by their equation (12). Applying this equation to estimates of ω, θ and β provides values for λ between 0.006 and 0.035 for the euro area and between 0.019 and 0.035 for the US.

To sum up, we obtain the following pattern: First, the model with a three-quarter average of lag and lead seems to dominate the model with a single lag and lead. Second, the marginal-cost model is more consistent with the US and UK data, whereas the output-gap model is more adapted for the euro area and individual countries.

4.2 Assessing the robustness of GMM estimates

4.2.1 Stability tests

As shown in section 2, the NKPC and the hybrid Phillips curve are, at least partially, theoretically grounded, since they are based on the underlying optimizing behavior of agents under rational expectations. However, these models can be claimed to be subject to the Lucas critique. Indeed, parameters may not be structural ones, if the model inaccurately reflects the true behavior of agents or the way they form expectations (see Estrella and Fuhrer, 1999). As shown by Favero and Hendry (1992) and Ericsson and Irons (1995), the Lucas critique can be seen as a testable hypothesis. A specification can be said to be structural, if it is policy-invariant. To address this issue, we formally test the stability of all hybrid models over time. We consider the Wald test for parameter stability with unknown break point, following the approach developed by Andrews (1993) and Andrews and Ploberger (1994).[16] Note, however, that such stability tests will not necessarily identify the more theoretically grounded model.

We consider a subsample $[\pi_0 T, (1-\pi_0) T]$, in which the break is allowed to occur, where π_0 represents a fraction of the sample and T is the sample size. Since our sample is fairly short, we choose a subsample covering 50 percent of the initial sample, so that $\pi_0 = 0.25$. Hence, for each date of this subsample (or for each fraction π, for simplicity), we sequentially estimate the hybrid Phillips curve for the period before and after the break. Then, the 'sup Wald' test statistic is defined as (Andrews, 1993):

$$Sup\text{-}W_T = \sup_{\pi \in [\pi_0, (1-\pi_0)]} W_T(\pi)$$

with

$$W_T(\pi) = T\left(\hat{\theta}_1(\pi) - \hat{\theta}_2(\pi)\right)' \left(\frac{\hat{V}_1(\pi)}{\pi} + \frac{\hat{V}_2(\pi)}{1-\pi}\right)^{-1} \left(\hat{\theta}_1(\pi) - \hat{\theta}_2(\pi)\right)$$

where $\hat{\theta}_1(\pi)$ and $\hat{\theta}_2(\pi)$ are the vectors of parameter estimates obtained over the first and second subsamples, respectively. The covariance matrix of parameter estimates is given by $\hat{V}_i(\pi) = \left(\hat{M}_i(\pi)' \widehat{S}_i^{-1}(\pi) \hat{M}_i(\pi)\right)^{-1}$, $i = 1, 2$, where

$$\hat{M}_1(\pi) = \frac{1}{\pi T} \sum_{t=1}^{\pi T} \frac{\partial m_t\left(\hat{\theta}_1(\pi)\right)}{\partial \hat{\theta}_1'}$$

[16] In the context of our model, the Wald test and the Lagrange-Multiplier test provide the same statistic.

$$\hat{M}_2(\pi) = \frac{1}{(1-\pi)T} \sum_{t=1}^{(1-\pi)T} \frac{\partial m_t\left(\hat{\theta}_2(\pi)\right)}{\partial \hat{\theta}_2'}$$

where $m_t\left(\hat{\theta}_i(\pi)\right)$ denotes the $(q,1)$ vector of orthogonality conditions at time t, evaluated at $\hat{\theta}_i(\pi)$. The Newey-West covariance matrix of errors is defined in the usual way:

$$\widehat{S}_1(\pi) = \widehat{\Sigma}_1(\pi) + \widehat{\Lambda}_1(\pi) + \widehat{\Lambda}_1(\pi)'$$

with

$$\widehat{\Sigma}_1(\pi) = \frac{1}{\pi T} \sum_{t=1}^{\pi T} \left(m_t\left(\hat{\theta}_1(\pi)\right) - \bar{m}_1(\pi)\right)\left(m_t\left(\hat{\theta}_1(\pi)\right) - \bar{m}_1(\pi)\right)'$$

$$\widehat{\Lambda}_1(\pi) = \frac{1}{\pi T} \sum_{s=1}^{L} w(s,L) \sum_{t=s+1}^{\pi T} \left(m_t\left(\hat{\theta}_1(\pi)\right) - \bar{m}_1(\pi)\right)\left(m_{t-s}\left(\hat{\theta}_1(\pi)\right) - \bar{m}_1(\pi)\right)'$$

where $\bar{m}_1(\pi) = \frac{1}{\pi T}\sum_{t=1}^{\pi T} m_t\left(\hat{\theta}_1(\pi)\right)$. $\widehat{S}_2(\pi)$ is defined in a similar way.

Andrews and Ploberger (1994) have proposed two other Wald statistics, called 'average' and 'exponential' statistics. Assuming that $\pi_0 T$ is an integer, these statistics are defined as

$$Avg\text{-}W_T = \frac{1}{T(1-2\pi_0)} \sum_{t=\pi_0 T}^{(1-\pi_0)T} W_T(t/T)$$

$$Exp\text{-}W_T = \ln\left(\frac{1}{T(1-2\pi_0)} \sum_{t=\pi_0 T}^{(1-\pi_0)T} \exp\left(\frac{1}{2}W_T(t/T)\right)\right).$$

The asymptotic distribution of these statistics is nonstandard, since the break-point parameter, π_0, appears under the alternative hypothesis only. Critical values of the test, which depend on the break-point parameter and on the number of shifting parameters, are reported in Andrews (1993) and Andrews and Ploberger (1994). As shown by Burnside and Eichenbaum (1996), the small-sample size of the Wald test exceeds its asymptotic size, so that the asymptotic distribution leads to reject the null hypothesis far too often. These authors claimed that the problem comes from the estimation of the Newey-West covariance matrix, suggesting the use of an estimator that imposes a priori information. Instead, we decided to compute critical values by Monte-Carlo simulations. The finite-sample distribution does not depend on the parameter values, but it depends on the number of lags and leads in the inflation dynamics.[17] We simulated $5,000$ samples of size T for each specification. For each sample, we computed the three Wald statistics for the model estimated by GMM (with $L = 4$ lags in the Newey-West covariance matrix). This allowed

[17] This occurs because the choice of the number of lags and leads directly affects the correlation between explanatory variables and the instruments and hence the Newey-West covariance matrix estimate.

us to obtain the empirical distribution for the Wald statistics under the null hypothesis of stability. Last, we defined the α percent critical value as the value of the statistic which is exceeded by α percent of the 5'000 samples.

Table 3 presents results of the stability tests for each country. We report $Sup\text{-}W_T$, $Avg\text{-}W_T$, and $Exp\text{-}W_T$ statistics. For the $Sup\text{-}W_T$ statistic, we also indicate the date for which the largest Wald statistic is obtained. First, we consider the model with a single lag and lead. Our results indicate that the hybrid Phillips curve with both forcing variables is unstable in three countries: Germany, France, and the UK. In Germany and the UK, the 'sup' statistic identifies a break in 1977, whereas the break is found to occur in 1989 in France. Such breaks are obtained at the same date for the models with output gap as well as with marginal cost.

Turning to the model with three lags and leads, the evidence for the output-gap Phillips curve indicates that stability is rejected in two cases: in the euro area (with a break in 1976), for which the Wald statistics are significant at the 5 percent level, and in France (with a break in 1982), for which the Wald statistics are significant at the 1 percent level.[18] By contrast, Wald tests fail to reject the null hypothesis for the marginal-cost model.

On the whole, test evidence suggests that, for the specification with three lags and leads, the marginal-cost model has a slight edge over the output-gap model. But except for France, structural stability is not a major problem for the specifications with three lags and leads. In spite of their loose theoretical grounds, they exhibit some robustness to the Lucas critique. Evidence is more mixed as regards to the hybrid model with a single lag and lead, since it proves to be unstable in three cases out of six.

4.2.2 Instrument relevance

A general specification test for GMM estimation is Hansen's J statistic. However, in our estimates, this test statistics never points to rejection of the over-identifying assumptions, probably indicating lack of power (see Tables 1 and 2). To provide additional evidence on the robustness of GMM estimates, we investigate now the presence of a poor instrument-regressor correlation. The correlation between instruments and explanatory variables is indeed known to be the key determinant of the performance of the GMM estimator. Low relevance increases asymptotic standard errors and therefore reduces the power of hypothesis tests. As pointed out by Nelson and Startz (1990), poor instruments are likely to provide with biased parameter estimates. The instrument relevance is often measured by the standard R^2 from the regression of RHS variables X on instrument variables Z. (See, for instance, Miron and Zeldes, 1988, and Campbell and Mankiw, 1990.) However, Nelson and Startz (1990) have shown that such an approach may be misleading, when X contains more than one variable. This is because all RHS variables can be highly correlated

[18] Note that the rejection of the null hypothesis of parameter stability in France is not directly related to the outlier in the inflation series which occurs in 1982:Q3, in relation with the price and wage freeze (see Figure 1d). Even after correcting for this entries, we still reject parameter stability. We also reestimated the hybrid models over the period 1983-1999, but our empirical evidence was not significantly altered.

with one of the instruments only. In this case, only one of the parameters can be identified. Shea (1997) proposed an alternative measure of instrument relevance based on partial correlations between RHS variables and instruments.

In the case where X contains only one endogenous (forward-looking) variable X_1, with $X = \begin{pmatrix} X_1 & X_2 \end{pmatrix}'$, Shea's measure of instrument relevance is the squared correlation between the components of X_1 and $\hat{X}_1$ orthogonal to X_2, where $\hat{X}_1$ denotes the projection of X_1 on the instrument set. This statistic, named "partial R^2", is denoted R_p^2. To correct partial R^2 for degrees of freedom when instruments are added, one defines the corrected partial R^2 as $\bar{R}_p^2 = 1 - \left(1 - R_p^2\right)(T-1)/(T-q)$.

Table 4 reports standard R^2 and Shea's partial R^2 instrument-relevance measure for each model. As expected, the uncorrected standard R^2 is large. It is estimated to be between 0.64 and 0.89 for the model with a single lag and lead and between 0.75 and 0.90 for the model with three lags and leads.

The partial R^2 displays a somewhat different pattern. For the model with a single lag and lead, the partial R^2 decreases dramatically in all countries. It is lower than 0.4 for the output-gap model and lower than 0.5 for the marginal-cost model. The instruments therefore appear to be less relevant, once correlation between past explanatory variables and instruments has been taken into account, although this correlation appears to be at a reasonably high level. For the model with three lags and leads, partial R^2s are much more dispersed. A low partial R^2 (which indicates a weak instrument relevance for forecasting future inflation) is found in the US, Germany, France, and the euro area for the output-gap model and in France only for the marginal-cost model. Comparing both specifications is fairly easy, since the instrument set is the same, and therefore the two specifications differ by the choice of the driving variable only. This evidence suggests that GMM estimates are likely to be more strongly biased in the model with three lags and leads and, more particularly, in the model with output gap.

This does not necessarily mean that instruments are not relevant per se in forecasting inflation, but, instead, that the lack of structure prevents to identify model's parameters clearly. This provides some motivation for considering the ML approach implemented in next section.

4.3 ML estimates

We now consider results obtained with the ML estimation of the hybrid Phillips curve and the VAR model. As indicated beforehand, we adopted the following specification for modelling and thus forecasting the output gap and the marginal cost. Following most previous studies, we model the output gap using a IS curve, in which lagged output gap, interest rate, and inflation are introduced. Similarly, the short nominal rate is modeled as a reaction-function type equation, including lagged output gap, interest rate, and inflation. In addition to the hybrid Phillips curve, we thus estimate a VAR-like model for the output gap and the short nominal rate. We also introduce lagged inflation as additional explanatory variable. As far as the marginal-cost model is concerned, equations for marginal cost and short nominal rate can be seen as describing the dynamics of labor cost and capital cost, respectively.[19] We therefore estimate the following models:

$$\pi_t = \omega\pi_{t-1} + (1-\omega) E_t\pi_{t+1} + \gamma\widehat{y}_t + \varepsilon_t \tag{14}$$

$$\widehat{y}_t = \mu_1 + \sum_{k=1}^{4}\delta_{yk}\widehat{y}_{t-k} + \sum_{k=1}^{4}\delta_{ik}i_{t-k} + \sum_{k=1}^{4}\delta_{\pi k}\pi_{t-k} + u_{1t} \tag{15}$$

$$i_t = \mu_2 + \sum_{k=1}^{4}\theta_{yk}\widehat{y}_{t-k} + \sum_{k=1}^{4}\theta_{ik}i_{t-k} + \sum_{k=1}^{4}\theta_{\pi k}\pi_{t-k} + u_{2t} \tag{16}$$

and

$$\pi_t = \omega\pi_{t-1} + (1-\omega) E_t\pi_{t+1} + \lambda\widehat{mc}_t + \varepsilon_t \tag{17}$$

$$\widehat{mc}_t = \nu_1 + \sum_{k=1}^{4}\varphi_{mk}\widehat{mc}_{t-k} + \sum_{k=1}^{4}\varphi_{ik}i_{t-k} + \sum_{k=1}^{4}\varphi_{\pi k}\pi_{t-k} + v_{1t} \tag{18}$$

$$i_t = \nu_2 + \sum_{k=1}^{4}\psi_{mk}\widehat{mc}_{t-k} + \sum_{k=1}^{4}\psi_{ik}i_{t-k} + \sum_{k=1}^{4}\psi_{\pi k}\pi_{t-k} + v_{2t}. \tag{19}$$

We also estimate the same specifications with three lags and leads in the hybrid Phillips curve, so that we replace equations (14) and (17) by equations (10) and (11) respectively.

Models (14)-(16) and (17)-(19) were estimated using two approaches. The baseline estimate was performed in two steps:[20] First, we estimated the "VAR" component. Then, we estimated the hybrid Phillips curve, conditional on the VAR parameter estimates obtained in the previous step. With this approach, we did not had problem to obtain a convergence of the optimization algorithm. We also adopted a FIML approach, in which all equations were estimated simultaneously. This approach allows the full covariance matrix of errors to be freely estimated. However, in a few cases, we had some difficulties to obtain convergence of VAR models with this approach, presumably because of near-nonstationarity of the model. In those cases, we proceeded iteratively by estimating the VAR and the Phillips curve parameters until convergence. Since the results obtained with both approaches were very close, we only report results of the two-step approach.

Empirical results are reported in Table 5 for the model with a single lag and lead and in Table 6 for the model with three lags and leads. To save space, we do not report parameters of the VAR models. We first comment the empirical evidence obtained with the output gap as the driving variable in the model with a single lag and lead (Table 5). First, the degree of backward-lookingness is found to be much larger with the ML approach than the

[19] Amato and Gerlach (2000) estimate a model in which the marginal cost is defined as the difference between the real wage and the labor productivity. They therefore estimate a VAR model, which includes the real wage change and the labor productivity change. We also estimated such a model and did not find strong differences between their approach and ours.

[20] Fuhrer and Moore (1995b) used the same approach.

one obtained with GMM. The smallest estimate of ω is 0.42 for the UK (against 0.13 with GMM) and the largest estimate is 0.51 for the euro area (whereas we previously obtained 0.26). It is worth emphasizing that the fraction of backward-looking price setters is now similar for the US and the euro area, at about 50 percent.

Second, in most countries, the point estimate of the output-gap parameter is found to be zero. In Germany, France, and the UK, it has been constrained to zero to obtain convergence.[21] In other countries, we obtain a positive, although non significant, parameter estimate. This result confirms the low ability of output gap to explain the dynamics of inflation with the specification with a single lag and lead, as noted above.

Using marginal cost in place of the output gap as the driving variable improves the fit of the data significantly. The degree of backward-lookingness remains essentially unaltered, since it is estimated to be between 0.29 and 0.46. But, the slope parameter is now significantly positive in most countries. It is particularly high in Germany and the UK (with $\lambda = 0.15$ and 0.39, respectively). Moreover, the standard error of estimate decreases in all cases. These results contrast with those obtained with the GMM approach, since most GMM estimates of the slope parameter failed to be significant.

We turn now to the hybrid Phillips curve with a three-quarter average of lag and lead of inflation (Table 6). The backward-looking component of inflation is increased as compared with the case with one lag and one lead. The fraction of backward-looking price setters is as high as 0.64 for the euro area, 0.73 for the US, and even 0.86 for the UK. In all countries, the backward-looking component is larger than one half and we are able to reject the null hypothesis that $\omega = 0$. By contrast, we cannot reject the null that $\omega = 1$ for the US, France, and the UK. This result is consistent with Fuhrer (1997) as regards the US. The output-gap parameter is now found to be positive in all cases. The point estimate ranges between 0.11 and 0.75. It is significantly positive in the euro area, Germany, and Italy. The model with three lags and leads appears to dominate the model with a single lag and lead in terms of fit. The former model provides a smaller standard error of estimate than the latter in all countries but Italy. In some cases (Germany, the UK, and, to a lesser extent, France), the standard error of estimate reduces dramatically, suggesting that the model with three lags and leads is likely to be more consistent with the data.

Last, it is worth emphasizing that the model with marginal cost remains basically unchanged, when we introduce additional lags and leads in the Phillips curve. Parameter estimates are fairly close to those displayed in Table 5. The backward-looking component of inflation has a weight close to 0.5. The slope parameter is particularly high, and significant, in the US, the UK, and Germany.

To sum up, our estimates provide additional support in favor of the model with three lags and leads. On one hand, the model with three lags and leads provides closer GMM and ML estimates than the model with a single lag and lead. On the other hand, it generally

[21] For these countries, the estimate of γ was spontaneously negative. A negative estimate is preclude with the ML approach, because the whole model would then be nonstationary.

offers a better fit of the data. This result confirms previous tests performed on US data, for instance by Fuhrer (1997) and Roberts (2001). Another important feature is that ML estimates point to a large weight of the backward-looking component, especially in the case of the output-gap model. On the whole, two kinds of specification emerge: In the first one, inflation is related to output gap with a large degree of backward-lookingness (above 50 percent); In the second one, inflation is related to marginal cost, with a lower fraction of backward-looking price setters (below 50 percent). While the former model seems to be more relevant in the case of continental European countries, and the latter in the case of the US and the UK, it seems hazardous to distinguish further between both specifications. An exception is the euro area, for which the output-gap model clearly dominates the marginal-cost model.

5 Conclusion

This paper has investigated the importance of the forward-looking component in the inflation dynamics of four European countries as well as the euro area and the US, over the 1970-1999 period. Our starting point was the conflicting results obtained by Fuhrer (1997) and Galí and Gertler (1999). Whereas the former found the forward-looking component to be empirically unimportant, the latter found inflation to be essentially forward-looking.

Our main findings are the following. First, conflicting results arise for each of the European countries, as well as for the euro area as a whole, when we control for the forcing variable in the Phillips curve, for the dynamic structure, and for the estimation method. We find that the contrasting conclusions of Fuhrer (1997) and Galí and Gertler (1999) are not directly related to the choice of the driving variable, but instead to the lag and lead structure of inflation dynamics. Although less theoretically grounded, the model with three lags and leads provides a better fit of the data and allows to obtain a significant slope parameter. Our empirical evidence confirms, on US data, results obtained by Roberts (2001). The estimation methods used in the two studies also appear to be, to a lesser extent, responsible for the conflicting results.

Second, in all cases, the backward-looking component as well as the forward-looking component are significant, with roughly equal weights, in line with the results found by Roberts (2001). Therefore, US and European inflation dynamics seem to be more accurately described by a hybrid model than by a pure NKPC or a pure backward-looking model.

Third, augmenting the hybrid one lead-one lag specification with additional lags and leads results in a significantly better fit of the data, as pointed out by Fuhrer (1997) and Roberts (2001). Although the model with three lags and leads lacks theoretical foundations, it performs much better when submitted to stability tests, indicating some robustness with respect to the Lucas critique.

Fourth, our estimates provide mixed results as regards whether the output gap or the marginal cost should enter the hybrid Phillips curve as the driving variable. Among the models with three lags and leads, combining the criteria of significance of the slope parameter and of parameter stability produces the following preferred specifications: the marginal-cost model in the US and the UK, and the output-gap model in Germany, Italy and the euro area. Results are inconclusive in the case of France, since the output-gap specification is unstable, while the marginal-cost specification has a wrongly signed, insignificant, slope parameter.

This empirical analysis suggests several topics for future investigation. The empirical evidence concerning the euro area and the individual countries of the area should be rationalized. In many cases, the backward-looking component appears to be too small in the euro area, as compared to the weight obtained in individual countries. A first avenue to address this issue would be to analyze, from a theoretical point of view, the possible consequences of the aggregation bias. Another option would be to use the system estimation proposed by Turner and Seghessa (1999), in the context of partially forward-looking Phillips curve.

The model with three lags and leads has been found to fit the data much better than the more theoretically grounded model with a single lag and lead. This result has also to be rationalized. In the model of relative real wage contract, for instance, the multiple-period contract does not allow a simple three-quarter average of lag and lead to be obtained. More generally, the strong persistence in actual inflation appears difficult to explain from a theoretical viewpoint.

6 Appendix: Alternative derivations of the Phillips curve

This appendix summarizes the most common derivations of the New Keynesian and hybrid versions of the Phillips curve. We do not aim at providing strong theoretical grounds to the hybrid Phillips curve, since it appears to be based, at least partially, on the non-optimizing behavior of a fraction of agents. Instead, we wish to justify the specifications estimated in this paper, with output gap or marginal cost as driving term. Let P_t be the price level, W_t the level of nominal wages, R_t the cost of capital, Y_t the level of output, N_t the level of employment, and K_t the stock of capital. Lower-case letters indicate logarithms; Δ is the first-difference operator; $\widehat{x}_t$ is the log deviation of variable x from its steady-state value. $\pi_t = \Delta p_t = p_t - p_{t-1}$ is the inflation rate and y_t is the output gap or an indicator of excess demand.

6.1 The Taylor (1980) staggered wage model

In this model, only a fraction of wages is reset in a given period. Contract wages x_t are assumed to be set for a fixed number of period. In the simplest two-period model, half of the wages are reset at a given date, for two periods. The average wage at time t is then $w_t = \frac{1}{2}(x_t + x_{t-1})$. Assuming prices to be set by a simple mark-up over average wage further implies:

$$p_t = \frac{1}{2}\left(x_t + x_{t-1}\right). \tag{20}$$

The contract wage is assumed to be proportional to the expected average price level over the lifetime of a contract and also influenced by the degree of labor-market pressure:

$$x_t = \frac{1}{2}\left(p_t + E_t p_{t+1}\right) + \frac{\gamma}{2} y_t + \eta_t. \tag{21}$$

This formulation is equivalent to Taylor's (1980) original formulation, which expresses the current contract wage as a function of past and expected contract wages. Combining equations (20) and (21) yields the following expression for the contract wage:

$$x_t = \frac{1}{2}\left(x_{t-1} + E_t x_{t+1}\right) + \gamma y_t + 2\eta_t.$$

The model is solved by using equation (21) to substitute for x_t in equation (20). Rearranging terms gives:

$$\pi_t = E_t \pi_{t+1} + \gamma\left(y_t + y_{t-1}\right) + 2\left(\eta_t + \eta_{t-1}\right) - \left(p_t - E_{t-1} p_t\right).$$

Last, defining $\widehat{y}_t = (y_t + y_{t-1})$ and $\varepsilon_t = 2\left(\eta_t + \eta_{t-1}\right) - (p_t - E_{t-1} p_t)$, we obtain the following expression, which corresponds to the forward-looking Phillips curve

$$\pi_t = E_t \pi_{t+1} + \gamma \widehat{y}_t + \varepsilon_t.$$

6.2 The Fuhrer and Moore (1995b) two-sided Phillips curve

Fuhrer and Moore (1995b) have introduced a variant of Taylor's model, which allows not only price-level persistence but also inflation persistence. The model is based on the assumption that workers are concerned about their relative real wage. Let v_t be the average real contract wage in effect at a given time t:

$$v_t = \frac{1}{2}(x_t - p_t) + \frac{1}{2}(x_{t-1} - p_{t-1}). \tag{22}$$

The nominal contract wage is now set so that the real contract wage is equal to the expected average real wage over the lifetime of the contract, plus an effect of labor-market pressure:[22]

$$x_t - p_t = \frac{1}{2}(v_t + E_t v_{t+1}) + \frac{\gamma}{2} y_t + \eta_t. \tag{23}$$

The price behavior remains described by equation (20) above. Substituting for v_t in expression (23) and rearranging terms, we obtain:

$$x_t = \frac{1}{4}\left(-p_{t-1} + 4p_t + E_t p_{t+1}\right) + \frac{\gamma}{2} y_t + \eta_t. \tag{24}$$

[22] Note that the formulation relies on some simplifications, as discussed by Fuhrer and Moore (1995b) and Coenen and Wieland (2000). For instance, in equation (22), it is arguably theoretically preferable to define the agent's objective in terms of the real contract wage expected to prevail over the life of the contract, i.e. $x_t - \frac{1}{2}(p_t + E_t p_{t+1})$, rather than $x_t - p_t$.

Taking the average of equation (24) at time t and equation (24) at time $t-1$, and using equation (20), we can state this equation in terms of inflation:

$$\Delta p_t = \frac{1}{2}\left(\Delta p_{t-1} + E_t \Delta p_{t+1}\right) + \gamma(y_t + y_{t-1}) + 2(\eta_t + \eta_{t-1}) - \frac{1}{2}\left(p_t - E_{t-1} p_t\right).$$

This relation can be rewritten as the following "hybrid Phillips curve":

$$\pi_t = \frac{1}{2}\left(\pi_{t-1} + E_t \pi_{t+1}\right) + \gamma \widehat{y}_t + \varepsilon_t,$$

with the error term defined as $\varepsilon_t = 2(\eta_t + \eta_{t-1}) - \frac{1}{2}\left(p_t - E_{t-1} p_t\right)$.

6.3 The two-sided Phillips curve with more lags and leads

In real world, contracts are likely to last for more than two periods. As a benchmark, we consider the case of a one-year average. Thus, the aggregate price index in the current quarter is a weighted average of the log contract wages which were negotiated in the current and the preceding quarters and are still in effect:

$$p_t = \frac{1}{4}(x_t + x_{t-1} + x_{t-2} + x_{t-3}). \tag{25}$$

In the model proposed by Taylor (1980), the weights (0.25) are consistent with the fact that 25 percent of workers sign a new contract each quarter. Fuhrer and Moore (1995b) proposed a more general specification, but we adopt this assumption in order to simplify exposition.

The index of real contract wages negotiated on the contracts which are currently in effect is given by:

$$v_t = \frac{1}{4}\sum_{i=0}^{3}\left(x_{t-i} - p_{t-i}\right).$$

Last, the nominal contract wage is set so that the real contract wage is equal to the expected average real wage over the lifetime of the contract, plus an effect of labor-market pressure:

$$x_t - p_t = \frac{1}{4} E_t \sum_{i=0}^{3} v_{t+i} + \frac{\gamma}{4} y_t + \eta_t. \tag{26}$$

Substituting for v_t in expression (26) and rearranging terms, we obtain:

$$x_t = \frac{1}{16}\left[-p_{t-3} - 2p_{t-2} - 3p_{t-1} + 16p_t + E_t\left(p_{t+1} + 2p_{t+2} + 3p_{t+3}\right)\right] + \frac{\gamma}{4} y_t + \eta_t. \tag{27}$$

Taking the average of equation (27) between t and $t-3$, we obtain, using equation (25), the following "two-sided" Phillips curve:

$$\begin{aligned} \pi_t &= \frac{1}{28}\left[\pi_{t-5} + 4\pi_{t-4} + 10\pi_{t-3} - 12\pi_{t-1} + E_t\left(14\pi_{t+1} + 8\pi_{t+2} + 3\pi_{t+3}\right)\right] \\ &\quad + \frac{\gamma}{7}\left(y_t + y_{t-1} + y_{t-2} + y_{t-3}\right) + \varepsilon_t \end{aligned} \tag{28}$$

where ε_t depends on the error term and expectations errors.

Note that Fuhrer and Moore (1995b) and Coenen and Wieland (2000) discussed another formulation, in which the agent's objective is defined in terms of the real contract wage expected to prevail over the life of the contract. In this case, the index of real contract wages negotiated on the contracts which are currently in effect is be given by

$$v_t = \frac{1}{4}\sum_{i=0}^{3}(x_{t-i} - E_t\bar{p}_{t-i})$$

where $\bar{p}_t = \frac{1}{4}\sum_{i=0}^{3} p_{t+i}$ denotes the average of current and future price indices prevailing over the life of the contracts currently in effect. Moreover, the nominal contract wage is defined as

$$x_t - E_t\bar{p}_t = \frac{1}{4}E_t\sum_{i=0}^{3} v_{t-i} + \frac{\gamma}{4}y_t + \eta_t.$$

The resulting "hybrid Phillips curve" is then given by

$$\begin{aligned}\pi_t \quad = \quad & \frac{1}{86}\left[\pi_{t-5} + 5\pi_{t-4} + 15\pi_{t-3} + 3\pi_{t-2} - 30\pi_{t-1}\right. \\ & \left. + E_t\left(86\pi_{t+1} + 30\pi_{t+2} - 3\pi_{t+3} - 15\pi_{t+4} - 5\pi_{t+5} - \pi_{t+6}\right)\right] \\ & + \frac{16}{86}\gamma\left(y_t + y_{t-1} + y_{t-2} + y_{t-3}\right) + \varepsilon_t.\end{aligned} \tag{29}$$

Although specifications (28) and (29) fulfill the restriction that lag and lead parameters sum to one, the resulting "hybrid Phillips curves" display a rather complicated dynamics of inflation. Fuhrer (1997) and Roberts (2001) have suggested a simplification of the inflation persistence model. They replaced the lag and lead structure of inflation with a three-quarter average of inflation.

6.4 The NKPC based on Rotemberg (1982) model

The model developed by Rotemberg (1982) is based on profit maximization by firms operating under monopolistic competition. The production function of each firm is given by

$$Y_t = AN_t^a K_t^{1-a}. \tag{30}$$

Each firm faces the demand curve:

$$Y_t = \left(\frac{P_t}{\overline{P}_t}\right)^{-\theta}\overline{Y}_t, \tag{31}$$

where $\overline{P}_t$ and $\overline{Y}_t$ denote aggregate price and output ($\overline{Y}_t = \left[\int_0^1 (Y_t(i))^{\frac{\theta-1}{\theta}}\, di\right]^{\frac{\theta}{\theta-1}}$ for a continuum of firms indexed by i). Furthermore, when changing price, the firm experiences a cost of adjustment, which depends on the change in price:

$$C_t = \frac{c}{2}\overline{P}_t\overline{Y}_t\left[\ln\left(\frac{P_t}{P_{t-1}}\right)\right]^2.$$

Therefore, for a given discount rate β, the program of the firm is the following:

$$\max E_t \sum_{k=0}^{\infty} \beta^k \left(P_{t+k} \left(\frac{P_{t+k}}{\overline{P}_{t+k}} \right)^{-\theta} \overline{Y}_{t+k} - W_{t+k}N_{t+k} - R_{t+k}K_{t+k} - C_{t+k} \right)$$

$$\text{s.t.} \quad \left(\frac{P_{t+k}}{\overline{P}_{t+k}} \right)^{-\theta} \overline{Y}_{t+k} \leqslant AN_{t+k}^{a} K_{t+k}^{1-a} \qquad \text{for each } k \geq 0.$$

Let $\beta^k \lambda_{t+k}$ be the Lagrange multiplier associated with the constraint on time $t+k$. The first-order condition w.r.t employment indicates that $\lambda_{t+k} = \frac{W_{t+k}N_{t+k}}{aY_{t+k}}$. Therefore, λ_{t+k} can be seen as the nominal marginal cost at time $t+k$. The first-order condition of maximization w.r.t price, for $k = 0$, yields, after substituting for λ_t:

$$\frac{W_t N_t}{aP_t Y_t} = \frac{\theta - 1}{\theta} + \frac{c}{\theta} \left(\frac{\overline{P}_t \overline{Y}_t}{P_{t-1} Y_t} \right) \ln \left(\frac{P_t}{P_{t-1}} \right) - \frac{\beta c}{\theta} \left(\frac{\overline{P}_{t+1} \overline{Y}_{t+1}}{P_t Y_t} \right) \ln \left(\frac{P_{t+1}}{P_t} \right). \tag{32}$$

In the case with no adjustment cost ($c = 0$), we recover the traditional monopolistic competition mark-up condition $\frac{W_t N_t}{aP_t Y_t} = \frac{\theta - 1}{\theta}$. This condition also gives the long-run expression for the real marginal cost: $mc_t = \frac{W_t N_t}{aP_t Y_t}$.

Linearizing expression (32) around steady-state output and price level at the symmetric equilibrium, and assuming a zero inflation steady state, we obtain:

$$\begin{aligned} \widehat{mc}_t &= \widehat{w}_t + \widehat{n}_t - \widehat{y}_t - \widehat{p}_t \\ &= \frac{c}{\theta - 1} \left(1 + \widehat{p}_t - \widehat{p}_{t-1}\right) \ln \left(1 + \widehat{p}_t - \widehat{p}_{t-1}\right) \\ &\quad - \frac{\beta c}{\theta - 1} E_t \left(1 + \widehat{p}_{t+1} - \widehat{p}_t + \widehat{y}_{t+1} - \widehat{y}_t\right) \ln \left(1 + \widehat{p}_{t+1} - \widehat{p}_t\right). \end{aligned}$$

Neglecting second-order terms, we get:

$$\widehat{p}_t - \widehat{p}_{t-1} = \beta E_t \left(\widehat{p}_{t+1} - \widehat{p}_t\right) + \frac{\theta - 1}{c} \widehat{mc}_t$$

which is the NKPC:

$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + \lambda \widehat{mc}_t$$

with $\lambda = (\theta - 1)/c$.

6.5 The NKPC based on Calvo (1983) constant hazard model

The framework is similar to the previous model: Firms operate under monopolistic competition with production function (30) and demand function (31). However, at time t, each firm is allowed to reset its price with probability $(1-\alpha)$. Let X_t be the price set by the firms which receive the signal allowing them to change price. The Lagrangean corresponding to the firm's program is now

$$\begin{aligned} L &= E_t \sum_{k=0}^{\infty} (\alpha\beta)^k \left[X_t \left(\frac{X_t}{\overline{P}_{t+k}} \right)^{-\theta} \overline{Y}_{t+k} - W_{t+k}N_{t+k} - R_{t+k}K_{t+k} \right] \\ &\quad + E_t \sum_{k=0}^{\infty} (\alpha\beta)^k \lambda_{t+k} \left[AN_{t+k}^{a} K_{t+k}^{1-a} - \left(\frac{X_t}{\overline{P}_{t+k}} \right)^{-\theta} \overline{Y}_{t+k} \right], \end{aligned}$$

where $(\alpha\beta)^k\lambda_{t+k}$ is the Lagrange multiplier for period $t+k$. Note that each term is weighted not only by the discount factor β^k but also by the probability α^k that the price set in period $t\,(X_t)$ is still unchanged in period $t+k$.

As above, the first-order condition w.r.t to employment yields: $\lambda_{t+k} = \frac{W_{t+k}N_{t+k}}{aY_{t+k}}$. To simplify, we assume that the marginal cost at time $t+k$ of a firm which has reset price at time t is equal to the average mark-up at time $t+k$ (see Sbordone, 2000, and Woodford, 1996, for a more careful treatment).

Solving the first-order condition w.r.t prices, we obtain the following expression for the reset price at the symmetric equilibrium:

$$X_t = \frac{\theta}{\theta-1} E_t \frac{\sum_{k=0}^{\infty}(\alpha\beta)^k W_{t+k}N_{t+k}}{\sum_{k=0}^{\infty}(\alpha\beta)^k aY_{t+k}}.$$

We notice that the steady state is $X^* = \dfrac{\theta}{\theta-1}\dfrac{W^*N^*}{aY^*}$ as in the flexible-price model. Linearizing around the steady state, we obtain:

$$\widehat{x}_t = (1-\alpha\beta)E_t \sum_{k=0}^{\infty} (\alpha\beta)^k \left(\widehat{w}_{t+k} + \widehat{n}_{t+k} - \widehat{y}_{t+k}\right). \tag{33}$$

The average price level at time t is given by

$$P_t = \left[(1-\alpha)X_t^{1-\theta} + \alpha P_{t-1}^{1-\theta}\right]^{\frac{1}{1-\theta}}.$$

Taking the logarithm of this expression and linearizing around the steady state, $X_t^* = P_t^* = P_{t-1}^*$, we obtain

$$\widehat{p}_t = (1-\alpha)\widehat{x}_t + \alpha\widehat{p}_{t-1}. \tag{34}$$

Combining equations (33) and (34), we can write

$$\widehat{p}_t - \alpha\widehat{p}_{t-1} = (1-\alpha)(1-\alpha\beta)E_t \sum_{k=0}^{\infty} (\alpha\beta)^k \left(\widehat{w}_{t+k} + \widehat{n}_{t+k} - \widehat{y}_{t+k}\right).$$

Quasi-differencing this formula (substracting $\beta\,(E_{t+1}\widehat{p}_t - \alpha\widehat{p}_t)$ from the latter expression) and rearranging terms, it can be shown that

$$\Delta\widehat{p}_t = \beta E_t \Delta\widehat{p}_{t+1} + \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\left(\widehat{w}_t + \widehat{n}_t - \widehat{y}_t - \widehat{p}_t\right)$$

which is the NKPC

$$\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} + \lambda\widehat{mc}_t$$

with $\lambda = (1-\alpha)(1-\alpha\beta)/\alpha$.

6.6 The Galí and Gertler (1999) hybrid model

We assume, as in the baseline Calvo model, that, at each date, only a fraction of firms is allowed to reset their price. However, among the firms which are able to change their price, we distinguish between forward-looking firms (which set price $\widehat{x}_t^f$ in log-deviation from equilibrium) and backward-looking firms (which set price $\widehat{x}_t^b$). Therefore, forward-looking firms use rule given by equation (33) whereas backward-looking firms use the rule of thumb: $\widehat{x}_t^b = \widehat{x}_{t-1} + \Delta\widehat{p}_{t-1}$. Newly set prices are a weighted average of prices set by backward and forward-looking firms: $\widehat{x}_t = (1-\omega)\widehat{x}_t^f + \omega\widehat{x}_t^b$, and the average price level is given by: $\widehat{p}_t = (1-\alpha)\widehat{x}_t + \alpha\widehat{p}_{t-1}$.

Combining these expressions yields

$$\pi_t = \left(\frac{1-\alpha}{\alpha}\right)\left[(1-\omega)(\widehat{x}_t^f - \widehat{p}_t) + \omega(\widehat{x}_t^b - \widehat{p}_t)\right]. \tag{35}$$

The first term in the weighted average between brackets can be expressed as

$$\widehat{x}_t^f - \widehat{p}_t = (1-\alpha\beta)E_t\sum_{k=0}^{\infty}(\alpha\beta)^k\widehat{mc}_{t+k} + E_t\sum_{k=0}^{\infty}(\alpha\beta)^k\widehat{\pi}_{t+k},$$

which simplifies to, after quasi-differentiating this expression:

$$(\widehat{x}_t^f - \widehat{p}_t) - \alpha\beta E_t(\widehat{x}_{t+1}^f - \widehat{p}_{t+1}) = (1-\alpha\beta)\widehat{mc}_t + \alpha\beta E_t\pi_{t+1}. \tag{36}$$

The second term in the weighted average is:

$$\widehat{x}_t^b - \widehat{p}_t = \left(\frac{1}{1-\alpha}\right)\pi_{t-1} - \pi_t. \tag{37}$$

Using equations (35), (36), and (37), we obtain the following expression for the quasi-difference in π_t:

$$\begin{aligned}\pi_t - \alpha\beta E_t\pi_{t+1} \;=\; & \left(\frac{1-\alpha}{\alpha}\right)(1-\omega)\left[(1-\alpha\beta)\widehat{mc}_t + \alpha\beta E_t\pi_{t+1}\right] \\ & + \left(\frac{1-\alpha}{\alpha}\right)\omega\left[\left(\frac{1}{1-\alpha}\right)\pi_{t-1} - \pi_t - \left(\frac{\alpha\beta}{1-\alpha}\right)\pi_t + \alpha\beta E_t\pi_{t+1}\right].\end{aligned}$$

After rearranging terms, we recover the following hybrid equation:

$$\pi_t = (\phi^{-1}\omega)\widehat{\pi}_{t-1} + (\phi^{-1}\beta\alpha)E_t\widehat{\pi}_{t+1} + (1-\alpha)(1-\omega)(1-\alpha\beta)\phi^{-1}\widehat{mc}_t$$

where $\phi = [\alpha + (1-\alpha)\omega + \omega\alpha\beta]$. Note that the sum of the backward and forward-looking terms is equal to $\left(1 + (1-\beta)\alpha\frac{(1-\omega)}{(\omega+\alpha\beta)}\right)^{-1}$, an expression which lies between β and 1 and therefore is very close to 1 for any plausible value of β.

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Captions

Table 1: This table reports GMM estimates of the hybrid model with a single lag and lead. Panel A corresponds to the output-gap specification (equation (8)) and Panel B to the marginal-cost specification (equation (9)). L denotes the bandwidth parameter for the Newey-West covariance matrix. Column 's.d.' reports the standard error of parameter estimates and the p-value of the Hansen's J statistics. 'see' is the standard error of estimate.

Table 2: This table reports GMM estimates of the hybrid model with three lags and leads. Panel A corresponds to the output-gap specification (equation (10)) and Panel B to the marginal-cost specification (equation (11)). L denotes the bandwidth parameter for the Newey-West covariance matrix. Column 's.d.' reports the standard error of parameter estimates and the p-value of the Hansen's J statistics. 'see' is the standard error of estimate.

Table 3: This table reports Wald test statistics for the test of the null hypothesis of parameter stability. These statistics are defined in section 4.2.1. Panel A is devoted to the output-gap specification, whereas Panel B is devoted to the marginal-cost specification. The top of the table corresponds to the model with a single lag and lead. The bottom of the table corresponds to the model with three lags and leads. Below the $Sup\text{-}W_T$ statistics is reported the breaking date. [a] and [b] indicate that the statistics is significant at the 1 and 5 percent levels respectively. The critical values are obtained using Monte-Carlo simulations, as described in section 4.2.1.

Table 4: This table reports standard R^2 and Shea's (1997) partial R^2 instrument-relevance measures. These statistics are defined in section 4.2.2. Panel A is devoted to the output-gap specification, whereas Panel B is devoted to the marginal-cost specification. The top of the table corresponds to the model with a single lag and lead. The bottom of the table corresponds to the model with three lags and leads.

Table 5: This table reports ML estimates of the hybrid model with a single lag and lead. Panel A corresponds to the output-gap specification (equation (8)) and Panel B to the marginal-cost specification (equation (9)). Column 's.d.' reports the standard error of parameter estimates. 'see' is the standard error of estimate. 'log-lik' is the sample log-likelihood of the model.

Table 6: This table reports ML estimates of the hybrid model with three lags and leads. Panel A corresponds to the output-gap specification (equation (10)) and Panel B to the marginal-cost specification (equation (11)). Column 's.d.' reports the standard error of parameter estimates. 'see' is the standard error of estimate. 'log-lik' is the sample log-likelihood of the model.

Figure 1: This figure illustrates the historical path of the various series under considerations for each country or area: 'QQ inflation' is the annualized quarterly percent change in the implicit GDP deflator, 'short rate' is the three-month money-market rate, 'output gap' is the percent deviation of real GDP from its trend computed using the Hodrick-Prescott filter, 'marginal cost' is the percent deviation of the real unit labor cost from its sample average value.

Table 1: Hybrid model with 1 lag and lead estimated by GMM

	Panel A: Output gap					Panel B: Marginal cost			
	L =4		*L* =12			*L* =4		*L* =12	
	parameter	*s.e.*	parameter	*s.e.*		parameter	*s.e.*	parameter	*s.e.*
The US					**The US**				
ω	0.344	*0.051*	0.344	*0.033*	ω	0.369	*0.051*	0.373	*0.026*
γ	-0.039	*0.027*	-0.039	*0.019*	λ	0.004	*0.028*	0.016	*0.018*
see	1.004		1.004		see	0.997		0.996	
J-stat	10.356	*0.736*	7.292	*0.923*	J-stat	11.042	*0.683*	7.390	*0.919*
Euro area					**Euro area**				
ω	0.266	*0.071*	0.255	*0.045*	ω	0.231	*0.059*	0.230	*0.034*
γ	0.071	*0.056*	0.063	*0.037*	λ	0.000	*0.010*	0.001	*0.007*
see	1.161		1.165		see	1.171		1.171	
J-stat	10.612	*0.716*	6.826	*0.941*	J-stat	11.242	*0.667*	7.461	*0.915*
Germany					**Germany**				
ω	0.105	*0.089*	0.128	*0.068*	ω	0.099	*0.088*	0.123	*0.065*
γ	0.058	*0.056*	0.073	*0.034*	λ	0.011	*0.019*	0.005	*0.012*
see	1.762		1.749		see	1.755		1.739	
J-stat	11.641	*0.635*	7.350	*0.920*	J-stat	11.689	*0.631*	7.494	*0.914*
France					**France**				
ω	0.379	*0.051*	0.340	*0.036*	ω	0.384	*0.050*	0.351	*0.032*
γ	-0.020	*0.098*	-0.085	*0.064*	λ	0.002	*0.018*	0.011	*0.011*
see	1.994		2.011		see	1.993		2.007	
J-stat	10.540	*0.722*	6.139	*0.963*	J-stat	10.690	*0.710*	6.811	*0.942*
Italy					**Italy**				
ω	0.490	*0.031*	0.498	*0.020*	ω	0.491	*0.031*	0.499	*0.020*
γ	0.039	*0.082*	0.031	*0.049*	λ	-0.006	*0.009*	-0.003	*0.006*
see	2.082		2.083		see	2.085		2.085	
J-stat	14.679	*0.400*	8.147	*0.882*	J-stat	14.723	*0.397*	8.118	*0.883*
The UK					**The UK**				
ω	0.171	*0.049*	0.180	*0.035*	ω	0.181	*0.049*	0.190	*0.034*
γ	-0.138	*0.109*	-0.083	*0.075*	λ	0.033	*0.025*	0.027	*0.017*
see	4.321		4.321		see	4.337		4.317	
J-stat	8.239	*0.877*	6.514	*0.952*	J-stat	7.387	*0.919*	5.977	*0.967*

Note: standard errors in italics.

Table 2: Hybrid model with 3 lags and leads estimated by GMM

	Panel A: Output gap					Panel B: Marginal cost			
	$L=4$		$L=12$			$L=4$		$L=12$	
	parameter	*s.e.*	parameter	*s.e.*		parameter	*s.e.*	parameter	*s.e.*
The US					**The US**				
ω	0.407	*0.071*	0.393	*0.042*	ω	0.462	*0.047*	0.441	*0.029*
γ	-0.037	*0.047*	-0.038	*0.032*	λ	0.037	*0.042*	0.068	*0.029*
see	1.035		1.037		see	1.028		1.028	
J-stat	10.682	*0.711*	7.009	*0.934*	J-stat	11.386	*0.655*	7.158	*0.928*
Euro area					**Euro area**				
ω	0.360	*0.082*	0.391	*0.048*	ω	0.253	*0.069*	0.267	*0.038*
γ	0.229	*0.082*	0.279	*0.056*	λ	0.000	*0.017*	0.004	*0.011*
see	1.145		1.140		see	1.186		1.179	
J-stat	13.691	*0.473*	8.320	*0.872*	J-stat	12.906	*0.534*	8.185	*0.879*
Germany					**Germany**				
ω	0.581	*0.118*	0.624	*0.074*	ω	0.505	*0.114*	0.523	*0.069*
γ	0.163	*0.059*	0.193	*0.043*	λ	-0.009	*0.023*	-0.013	*0.015*
see	1.291		1.296		see	1.293		1.294	
J-stat	11.850	*0.618*	7.575	*0.910*	J-stat	11.331	*0.660*	7.390	*0.919*
France					**France**				
ω	0.668	*0.068*	0.665	*0.049*	ω	0.621	*0.078*	0.641	*0.050*
γ	0.157	*0.153*	0.165	*0.110*	λ	-0.013	*0.028*	-0.019	*0.017*
see	1.921		1.921		see	1.912		1.915	
J-stat	12.790	*0.543*	7.319	*0.922*	J-stat	11.565	*0.641*	6.564	*0.950*
Italy					**Italy**				
ω	0.460	*0.060*	0.420	*0.032*	ω	0.443	*0.049*	0.435	*0.028*
γ	0.456	*0.106*	0.462	*0.060*	λ	-0.021	*0.020*	-0.014	*0.011*
see	2.525		2.538		see	2.628		2.632	
J-stat	13.021	*0.525*	7.742	*0.902*	J-stat	13.856	*0.461*	7.574	*0.910*
The UK					**The UK**				
ω	0.381	*0.047*	0.402	*0.036*	ω	0.382	*0.041*	0.376	*0.031*
γ	-0.033	*0.154*	0.046	*0.116*	λ	0.061	*0.035*	0.059	*0.025*
see	3.595		3.595		see	3.608		3.611	
J-stat	12.851	*0.538*	8.139	*0.882*	J-stat	10.358	*0.736*	7.383	*0.919*

Note: standard errors in italics.

Table 3: Wald tests for stability

	Panel A: Output gap			Panel B: Marginal cost		
Test	*Sup-W* $_T$	*Exp-W* $_T$	*Avg-W* $_T$	*Sup-W* $_T$	*Exp-W* $_T$	*Avg-W* $_T$
		1 lag - 1 lead			**1 lag - 1 lead**	
The US	10.45	2.15	2.57	10.27	2.10	2.22
	1977:3			*1977:3*		
Euro area	12.25	3.59	4.73	11.13	3.31	3.38
	1989:2			*1988:2*		
Germany	24.23 [a]	9.18 [a]	13.30 [a]	25.74 [a]	9.46 [a]	13.67 [a]
	1977:3			*1977:3*		
France	36.82 [a]	14.44 [a]	4.16	25.11 [a]	8.59 [a]	3.98
	1989:4			*1989:4*		
Italy	10.03	2.28	2.96	11.41	2.69	2.65
	1980:1			*1980:1*		
The UK	32.01 [a]	12.29 [a]	7.12 [a]	37.24 [a]	15.02 [a]	7.37 [a]
	1977:1			*1977:3*		
		3 lags - 3 leads			**3 lags - 3 leads**	
The US	17.95	5.47	4.50	7.76	1.68	2.00
	1989:4			*1986:4*		
Euro area	27.41 [b]	10.05 [b]	13.60 [b]	15.69	4.13	3.36
	1976:3			*1976:3*		
Germany	25.44	9.22	9.39 [b]	11.81	3.69	4.06
	1988:1			*1985:2*		
France	49.27 [a]	20.70 [a]	12.23 [b]	23.86	8.03	5.26
	1982:2			*1986:3*		
Italy	21.28	7.51	8.50	7.31	1.54	2.35
	1976:4			*1984:2*		
The UK	18.09	5.62	4.04	17.86	5.04	3.68
	1980:4			*1980:4*		

Table 4: Standard R^2 and Shea's partial R^2 instrument relevance measures

	Panel A: Output gap			Panel B: Marginal cost		
	R^2	R^2_p	corrected R^2_p	R^2	R^2_p	corrected R^2_p
	1 lag - 1 lead			**1 lag - 1 lead**		
The US	0.844	0.381	0.279	0.844	0.492	0.408
Euro area	0.887	0.418	0.317	0.887	0.464	0.370
Germany	0.647	0.389	0.288	0.647	0.431	0.337
France	0.812	0.455	0.363	0.812	0.482	0.394
Italy	0.791	0.434	0.334	0.791	0.389	0.281
The UK	0.741	0.470	0.382	0.741	0.548	0.474
	3 lags - 3 leads			**3 lags - 3 leads**		
The US	0.887	0.217	0.085	0.887	0.628	0.565
Euro area	0.896	0.356	0.241	0.896	0.514	0.428
Germany	0.751	0.223	0.092	0.751	0.447	0.353
France	0.882	0.307	0.187	0.882	0.300	0.178
Italy	0.832	0.618	0.549	0.832	0.538	0.453
The UK	0.848	0.489	0.403	0.848	0.746	0.704

Table 5: Hybrid model with 1 lag and lead estimated by ML

	Panel A: Output gap			Panel B: Marginal cost	
	parameter	*s.e.*		parameter	*s.e.*
The US			**The US**		
ω	0.473	*0.026*	ω	0.458	*0.029*
γ	0.001	*0.013*	λ	0.063	*0.059*
see	1.211		see	1.155	
log-lik.	-446.655		log-lik.	-420.558	
Euro area			**Euro area**		
ω	0.513	*0.153*	ω	0.399	*0.041*
γ	0.033	*0.136*	λ	0.036	*0.010*
see	1.380		see	1.308	
log-lik.	-343.959		log-lik.	-341.024	
Germany			**Germany**		
ω	0.436	*0.019*	ω	0.438	*0.019*
γ	0.000	--	λ	0.152	*0.014*
see	1.728		see	1.639	
log-lik.	-451.350		log-lik.	-476.420	
France			**France**		
ω	0.462	*0.013*	ω	0.458	*0.021*
γ	0.000	--	λ	0.013	*0.019*
see	2.311		see	2.279	
log-lik.	-455.527		log-lik.	-475.361	
Italy			**Italy**		
ω	0.472	*0.012*	ω	0.460	*0.090*
γ	0.002	*0.010*	λ	0.012	*0.002*
see	2.753		see	2.721	
log-lik.	-507.427		log-lik.	-562.228	
The UK			**The UK**		
ω	0.418	*0.016*	ω	0.285	*0.054*
γ	0.000	--	λ	0.385	*0.090*
see	4.414		see	3.972	
log-lik.	-639.102		log-lik.	-656.344	

Note: standard errors in italics.

Table 6: Hybrid model with 3 lags and leads estimated by ML

	Panel A: Output gap			Panel B: Marginal cost	
	parameter	*s.e.*		parameter	*s.e.*
The US			**The US**		
ω	0.725	*0.192*	ω	0.478	*0.100*
γ	0.181	*0.113*	λ	0.097	*0.023*
see	1.152		see	1.173	
log-lik.	-440.921		log-lik.	-422.402	
Euro area			**Euro area**		
ω	0.645	*0.040*	ω	0.465	*0.092*
γ	0.318	*0.066*	λ	0.025	*0.041*
see	1.200		see	1.321	
log-lik.	-329.069		log-lik.	-341.000	
Germany			**Germany**		
ω	0.512	*0.055*	ω	0.528	*0.037*
γ	0.115	*0.028*	λ	0.032	*0.009*
see	1.433		see	1.424	
log-lik.	-424.657		log-lik.	-459.746	
France			**France**		
ω	0.728	*0.384*	ω	0.514	*0.165*
γ	0.288	*0.331*	λ	-0.002	*0.024*
see	2.051		see	2.068	
log-lik.	-442.260		log-lik.	-463.560	
Italy			**Italy**		
ω	0.520	*0.025*	ω	0.481	*0.053*
γ	0.210	*0.078*	λ	0.013	*0.002*
see	2.978		see	3.008	
log-lik.	-517.183		log-lik.	-575.298	
The UK			**The UK**		
ω	0.857	*0.283*	ω	0.399	*0.026*
γ	0.754	*0.597*	λ	0.143	*0.017*
see	3.947		see	3.937	
log-lik.	-626.478		log-lik.	-654.416	

Note: standard errors in italics.

Figure 1a: The US data

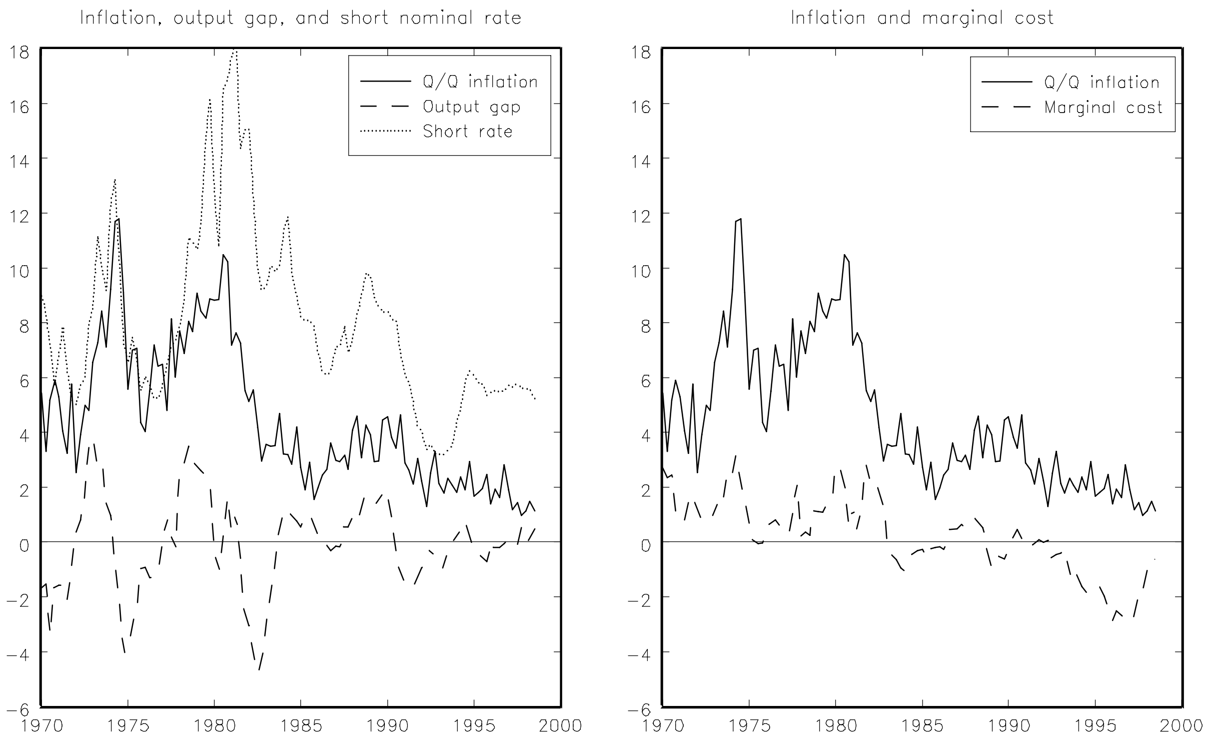

Figure 1b: The euro−area data

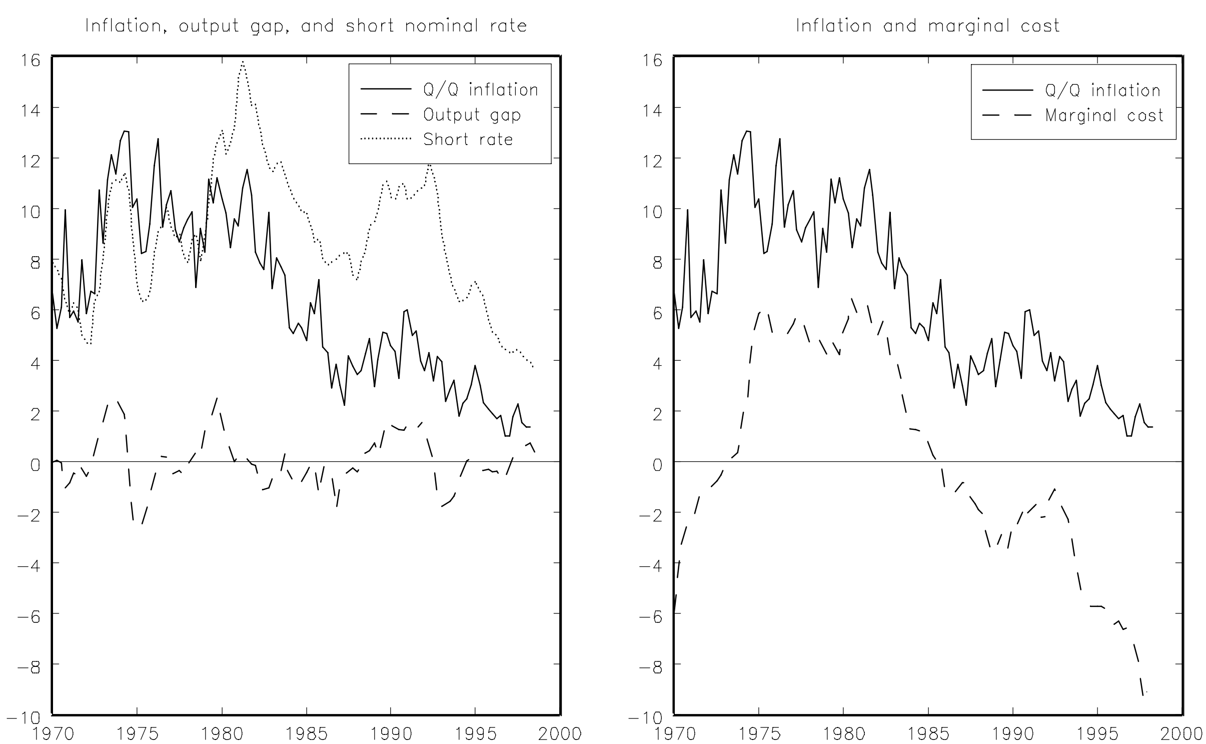

Figure 1c: The data for Germany

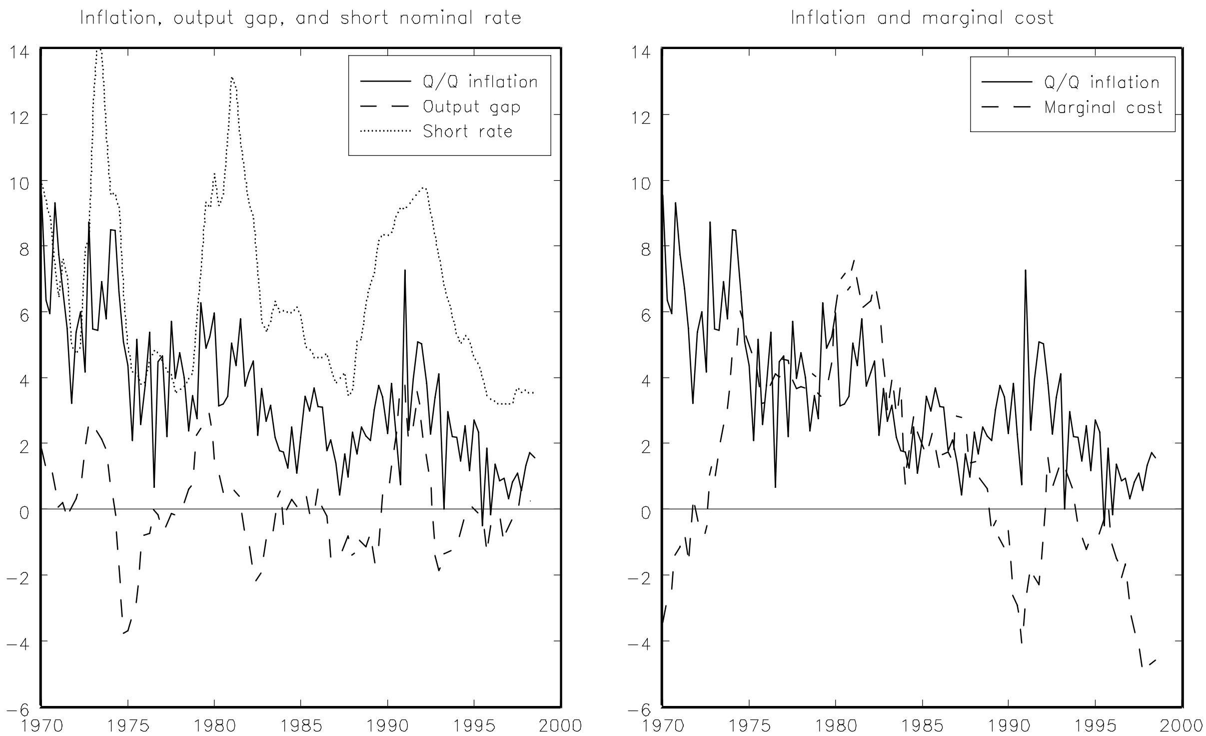

Figure 1d: The data for France

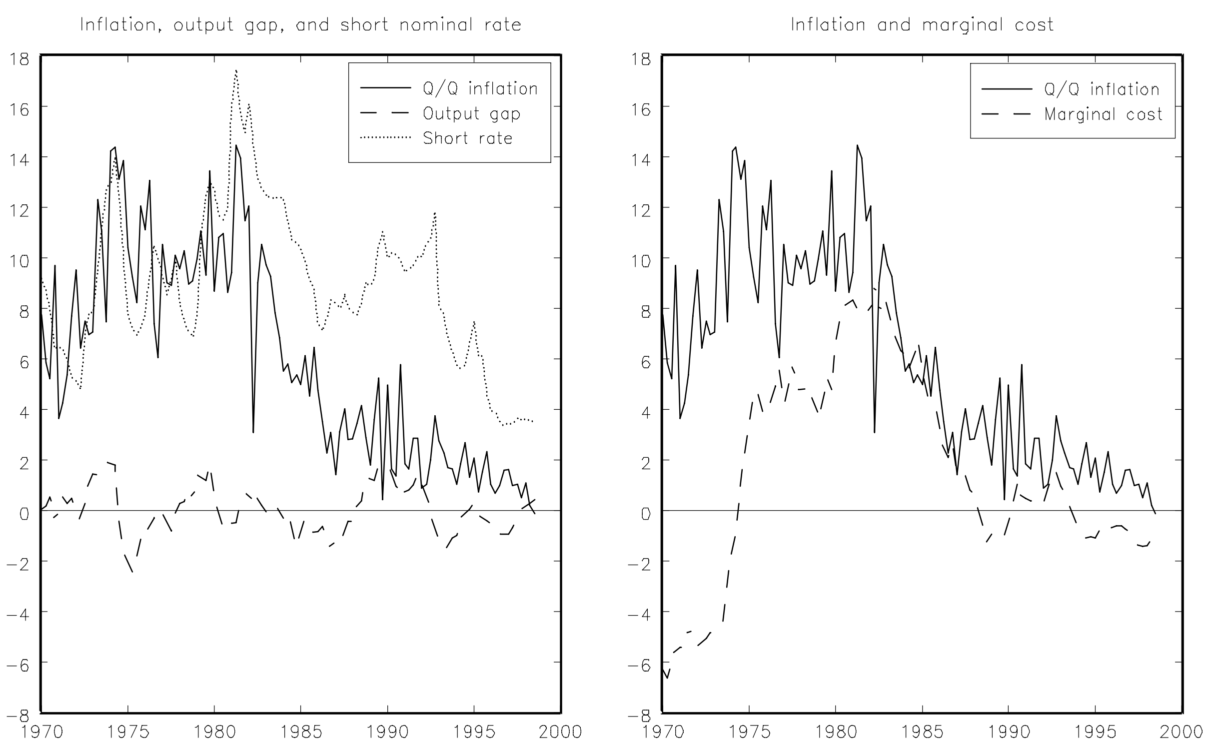

Figure 1e: The data for Italy

Figure 1f: The UK data