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INSTABILITY AND NONLINEARITY IN THE EURO AREA PHILLIPS CURVE

by Alberto Musso,
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and Dick van Dijk

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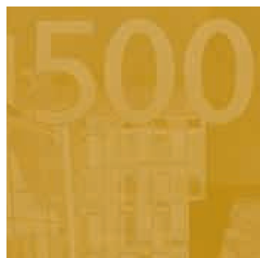

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INSTABILITY AND NONLINEARITY IN THE EURO AREA PHILLIPS CURVE[1]

by Alberto Musso[2],
Livio Stracca[3]
and Dick van Dijk[4]

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Abstract

This paper provides a comprehensive analysis of the functional form of the euro area Phillips curve over the past three decades. In particular, compared to previous literature we analyse the stability of the relationship in detail, especially as regards the possibility of a time-varying mean of inflation. Moreover, we conduct a sensitivity analysis across different measures of economic slack. Our main findings are two. First, there is strong evidence of time variation in the mean and slope of the Phillips curve occurring in the early to mid 1980s, but not in inflation persistence once the mean shift is allowed for. As a result of the structural change, the Phillips curve became flatter around a lower mean of inflation. Second, we find no significant evidence of non-linearity, in particular in relation to the output gap.

Keywords: Inflation, output gap, structural change, asymmetry, smooth transition model.
JEL Classification: E52, E58.

Non-technical summary

The dynamics of inflation have changed substantially in many if not all advanced economies over the past four decades. Several studies have documented significant changes in the average level of inflation, the degree of inflation persistence and the volatility of inflation, although the timing and extent of these changes varies across country. As a result of these changes, modelling and forecasting inflation dynamics has become an arduous task. The complexity in modelling inflation dynamics relates not only to the various types of above-mentioned structural changes in the statistical properties of inflation, but also to the fact that to some extent these changes are related to one another in various ways. For example, a key result of the Eurosystem Inflation Persistence Network (IPN) is that estimates of the euro area inflation persistence tend to be rather high unless shifts in the mean of inflation (for which there is clear statistical evidence) are allowed for. Hence, it is important to analyse these changes jointly. At the same time, modelling inflation is complicated also by the fact that in addition to its (potential) instability, different forms of nonlinearity can be relevant. For example, some studies have pointed out the possibility that the response of inflation to changes in economic activity may be asymmetric, with positive excess demand having a stronger impact on prices than negative excess demand (convex Phillips curve).

While much effort has been devoted to analysing the inflation process for the US economy, much less research has been undertaken for the euro area. As a result, it is still uncertain how to best model euro area inflation. Some efforts have been directed in recent years to analysing euro area inflation dynamics, especially in the context of the so-called New Keynesian Phillips Curve framework, with mixed results. As regards the traditional Phillips curve approach, relatively little has been done to assess its usefulness for the euro area. The few existing studies tend to include only a limited analysis of possible instability and nonlinearities. As a result, several questions remained unanswered regarding the most appropriate way to model inflation dynamics in the euro area. Although an assessment of the functional form of the Phillips curve is fraught with empirical difficulties, the policy implications of this question are extremely important. Therefore, a careful empirical modelling of the functional form of the Phillips curve is of paramount importance.

This paper provides a comprehensive analysis of euro area inflation dynamics, focusing on the functional form of the Phillips curve using quarterly data from 1970 to 2005. We explicitly and carefully address the stability of the relationship between inflation and economic activity, accounting for the possibility of structural change in the mean, persistence, and volatility of inflation, as well as in the slope of the curve. In addition, we examine the appropriate functional form of the curve by means of the methodology of smooth transition regression models, which allows for both convex and concave shapes of the curve. Although our main analysis is conducted on quarterly inflation based on the GDP deflator, we also analyse the price index that is preferred by the ECB, the Harmonised Index of Consumer Prices (HICP). For the latter indicator, we also analyse the possible presence of nonlinearity in the effect of additive price shocks stemming from oil and exchange rate developments. Finally, we conduct a thorough sensitivity analysis across different possible measures of economic slack.

The main results of the study are three:

- First, there is strong evidence, quite un-surprisingly, of a shift in the mean of euro area inflation, with the change occurring quite gradually towards the middle of the 1980s.
- Second, there is also strong evidence of a shift in the slope of the curve, again occurring in the 1980s but somewhat earlier and much more abruptly. As a result of this shift, the curve becomes significantly flatter, consistent with the idea that the frequency of price adjustment is negatively related to the mean of inflation.
- Third, once we correct for this time variation in the parameters we find no significant evidence of non-linearity in the curve. Hence, we conclude that the Phillips "curve" is, at least in the euro area, indeed a "line".

The main policy implication of our study is, therefore, that there is at least no convincing evidence of the existence of a "free lunch" for monetary policy, whereby the central bank is able to stimulate economic activity without creating inflationary pressure.

1 Introduction

The dynamics of inflation have changed substantially in many if not all advanced economies over the past four decades. For example, the average level of inflation has been subject to dramatic shifts over time (Cecchetti et al., 2007). Moreover, in recent years a number of studies have documented important changes also in the degree of inflation persistence (Cecchetti and Debelle, 2006). In addition, the volatility of inflation has changed during the past three decades, with a large decline observed since the mid-1980s to early 1990s, depending on the country (van Dijk et al. 2002a). As a result of these changes, modelling and forecasting inflation dynamics has become an arduous task. The complexity in modelling inflation dynamics relates not only to the various types of above-mentioned structural changes in the statistical properties of inflation, but also to the fact that to some extent these changes are related to one another in various ways. For example, a key result of the Eurosystem Inflation Persistence Network (IPN) is that estimates of the euro area inflation persistence tend to be rather high unless shifts in the mean of inflation (for which there is clear statistical evidence) are allowed for (Altissimo et al., 2006). Hence, it is important to analyse these changes jointly. At the same time, modelling inflation is complicated also by the fact that in addition to its (potential) instability, different forms of nonlinearity can be relevant. For example, some studies have pointed out the possibility that the response of inflation to changes in economic activity may be asymmetric, with demand increases having a stronger impact on prices than demand decreases (Laxton et al., 1999).

While much effort has been devoted to analysing the inflation process for the US economy, much less research has been undertaken for the euro area. As a result, it is still uncertain how to best model euro area inflation. This gap is rather unfortunate, given the mandate of the European Central Bank, whose primary objective is to ensure price stability at euro area aggregate level. Some efforts have been directed in recent years to analysing euro area inflation dynamics, especially in the context of the so-called New Keynesian Phillips Curve (NKPC) framework, with mixed results, as discussed in more detail below. As regards the traditional Phillips curve approach, relatively little has been done to assess its usefulness for the euro area. The few existing studies, such as Aguiar and Martins (2005), Dolado et al. (2005), Rudd and

Whelan (2005), and Baghli et al. (2007), include only a limited analysis of possible instability and nonlinearities. As a result, several questions remained unanswered regarding the most appropriate way to model inflation dynamics in the euro area.

Although an assessment of the functional form of the Phillips curve is fraught with empirical difficulties, the policy implications of this question are extremely important. Let us consider, for example, the situation of a policy-maker who is uncertain on whether the Phillips curve has a linear or alternatively a piecewise linear form as in Filardo (1998) and Barnes and Olivei (2003). In the first case, the policy-maker is confronted with a trade-off between stimulating demand and creating inflation, while in the latter case there is the possibility of pushing demand at least up to a certain limit without causing a significant increase in inflation. Therefore, a careful empirical modelling of the functional form of the Phillips curve is of paramount importance.

Against this background, the aim of the present paper is to provide a comprehensive analysis of euro area inflation dynamics, focusing on the functional form of the Phillips curve. We explicitly and carefully address the stability of the relationship between inflation and economic activity, accounting for the possibility of structural change in the mean, persistence, and volatility of inflation, as well as in the slope of the curve. In addition, we examine the appropriate functional form of the curve by means of the methodology of smooth transition regression (STR) models, which allows for both convex and concave shapes of the curve. Although our main analysis is conducted on quarterly inflation based on the GDP deflator, we also analyse the price index that is preferred by the ECB, the Harmonised Index of Consumer Prices (HICP). For the latter indicator, we also analyse the possible presence of nonlinearity in the effect of additive price shocks stemming from oil and exchange rate developments. Finally, we conduct a thorough sensitivity analysis across different possible measures of economic slack.

The paper is structured as follows. In Section 2 we present a review of the literature. The data are described in Section 3. Section 4 presents the results for a linear Phillips curve specification for the euro area GDP deflator inflation. In Section 5 we assess the stability and linearity of this curve. In Section 6 we model the HICP inflation rate indirectly, by modelling the spread between the HICP and the GDP deflator. Finally, Section 7 concludes.

2 Literature review and modelling issues

2.1 Inflation modelling

The focus of this paper is on the general class of traditional backward looking Phillips curves. This choice is suggested by a number of considerations. First, survey-based inflation forecast data for the euro area starting from the 1970s are not available. Second, alternative estimation approaches based on the Generalised Method of Moments which abstract from inflation forecasts are surrounded by a number of controversial econometric aspects, limiting the reliability of NKPC estimates. Third, recent studies, in particular by Rudd and Whelan (2007), cast doubt on the ability of the NKPC (including its hybrid form, that is, with added lags of inflation) to provide a useful empirical characterisation of the inflation process and present evidence in support of the traditional Phillips curve for both the US and the euro area. While we do not take a stand on this debate, we note that it makes the estimation of a backward looking Phillips curve at least not a clearly sub-optimal choice. Finally, it should be emphasised that we conduct a thorough stability analysis in this paper, and in so doing we cater for the possible impact of the Lucas critique, which is often mentioned as the main shortcoming of backward looking macroeconomic models.

Although traditional Phillips curve relationships are building blocks of a number of macroeconomic models for the euro area, including the Area Wide Model (AWM), relatively few studies have provided a detailed modelling assessment of this key relationship. A number of studies providing estimates of the traditional Phillips curve in the euro area have been published in recent years.[1] However, no consensus seems to prevail as regards the most appropriate specification of the relationship. For example, Dolado et al. (2005) and Baghli et al. (2007) provide some evidence for the relevance of nonlinearity in the euro area Phillips curve, while Aguiar and Martins (2005) suggest that the empirical evidence against the linear specification is weak. Rudd and Whelan (2005) do not consider nonlinear specifications but conduct an extensive stability analysis of the linear Phillips relationship and find little evidence of instability. The main reasons of these contrasting results can be related to different

[1] Other papers include a euro area Phillips curve as a component of a broader, multivariate framework, such as Fagan et al . (2005), Proietti et al. (in press), Rünstler (2002) and Fabiani and Mestre (2004).

sample periods and different specifications, but possibly also data issues may play a role. In particular, the measures used for capturing economic slack tend to differ and range from output gap estimates based on simple filters (Rudd and Whelan, Dolado et al.) to estimates based on more structural unobserved components models (Aguiar and Martins, Baghli et al.). Sensitivity analysis to assess how results vary using alternative slack estimates is typically very limited or even missing in these studies. Given the uncertainty surrounding these estimates, this could turn out to be a significant limitation.

2.2 Instability

As discussed in the Introduction, various forms of instability in inflation dynamics have been documented for most advanced economies, including structural changes in the mean, persistence, and volatility of inflation. Focusing on the euro area, Corvoisier and Mojon (2005) find three breaks for the euro area inflation rate: in 1972 and 1985 with reference to the CPI/HICP and 1993 using the GDP deflator. Angeloni et al. (2006) present evidence of a permanent decline in the persistence of euro area after the mid-1990s, even after allowing for breaks in the mean of inflation.

While it is important to take into account these instabilities, it is questionable whether the most appropriate way to detect and model them is via structural breaks tests assuming *abrupt* changes. In particular, consistent with the idea that most regime changes tend to be gradual, several studies (especially on the US) adopt modelling approaches based on smoothly time-varying coefficients, rather than assuming abrupt changes (see for example Stock and Watson, 2007). We follow this suggestion here by adopting the smooth transition regression framework.

Several papers have found evidence of instability also in the slope of the Phillips curve, that is, on the response of inflation to demand pressures. In particular, some studies have highlighted the possibility that the Phillips curve may have flattened, i.e. the slope may have decreased, in several advanced economies (Borio and Filardo, 2007). The interpretation of this change in slope of the Phillips curve is still an open issue. A hypothesis which has received much attention is that the source of this flattening may be related to the process of globalisation (Melick and Galati, 2006). Other authors attribute the reduction in the slope to changes in monetary policy, such as Roberts (2006). However, there does not seem to be robust evidence for this

hypothesis, as recently shown by Ihrig et al. (2007).

Some evidence for significant changes over time has been uncovered also with regards to the impact of oil and exchange rate shocks to inflation. For example, a number of studies have documented a significant decline in the pass-through of oil prices to consumer price inflation in several advanced economies since the 1980s (De Gregorio et al., 2007). Blanchard and Galí (2007) confirm this findings and conclude that various forces have caused this decline, including improved monetary policy, more flexible labour markets and a smaller dependence on oil. Other studies have provided evidence for a reduced exchange rate pass-through to consumer price inflation in advanced economies after the 1980s, although this decline is not always statistically significant (Ihrig et al., 2006).

2.3 Nonlinearity and asymmetry

There is a long tradition of thought in monetary economics, going back at least to the times of John Maynard Keynes, suggesting that the Phillips curve may be nonlinear and in particular have a *convex* shape, reflecting the existence of discontinuity in firms' price adjustment costs, for example due to downward wage rigidity (e.g. Clark and Laxton, 1997). A convex Phillips curve implies that inflation may fail to decline in response to a shortfall of excess demand, but pick up significantly should demand exceed a certain threshold: the marginal reaction of inflation to a spending stimulus, for example coming from monetary policy, is therefore path-dependent. An extreme form of convexity is an *asymmetric* curve, where inflation reacts to excess demand only if the latter is above a certain level. It is worth noting that, in fact, the relationship initially proposed by Phillips was, indeed, a curve.

The existing empirical evidence for the US and other industrialised economies is, however, mixed. Akerlof, Dickens and Perry (1996) and Debelle and Laxton (1997), among others, suggest a convex Phillips curve is appropriate, while Gordon (1997) argues in favour of a linear curve and Stiglitz (1997) even of a concave one. The evidence on the functional form of the Phillips curve is particularly scant and controversial in the euro area, partly reflecting the challenges associated to gathering appropriately harmonised and long time series of data for this economy compared, for example, with the US. Interestingly, research conducted within the Eurosystem IPN has found that prices in the euro area appear to respond more strongly to cost

increases than to decreases, but at the same time more to a fall in demand than to a rise (Fabiani et al., 2006). Transposing this micro evidence to the macroeconomic level, the first bit of evidence would point to a convex Phillips curve, while the second bit suggests a concave curve. On the whole, therefore, the IPN evidence does suggest the existence of some interesting nonlinearity, but the implications at the aggregate level are unclear.

Aguiar and Martins (2005) test the linearity of the euro area Phillips curve using data from 1970 to 2002 and find that there is not enough statistical evidence for rejecting the null of linearity. However, Dolado et al. (2005) suggest that nonlinearities may be present, working on data from 1984 to 2001. In particular, in their specification the square value of the output gap enters significantly and with a positive coefficient in the equation, suggesting a convex Phillips curve.

3 Data

The data for our empirical analysis is obtained from the Area Wide Model (AWM) database[2] and has quarterly frequency, spanning the period 1970:1 to 2005:4. We focus on the two main measures of inflation for the euro area, which are based on the GDP deflator and the Harmonised Index of Consumer Prices (HICP). Although the latter is the main indicator referred to by the ECB and is the ultimate target of our analysis, as discussed below there are certain benefits in starting from a model for the former and then analysing the link between these two price series.[3] Figure 1 shows the developments of the GDP deflator and the HICP over the sample period in terms of annualised quarter-on-quarter inflation rates. Although the two series move closely together[4] and follow broadly similar patterns, sizable deviations can be observed over some prolonged periods such as the late-1970s and mid-1980s. Moreover, while the GDP deflator also is available in seasonally adjusted form, the HICP only comes in seasonally unadjusted form, a fact which has to be borne in mind in the modelling process.

[2]For more details on the AWM database see Fagan et al. (2005). We make use of the database version released in September 2006, which extends to 2005:4.

[3]This approach is frequently adopted in several macroeconomic models which specify a Phillips type relationship, including the AWM.

[4]Over the complete sample period the correlation between GDP deflator and HICP inflation is 0.89.

- insert Figure 1 about here -

Typical measures of the output gap are surrounded by a large degree of uncertainty, see Orphanides and van Norden (2005) and Camba-Méndez and Rodriguez-Palenzuela (2003), among others. For that reason, we consider several alternative indicators of economic slack. First, we employ three alternative estimates of the output gap based on the multivariate unobserved components model of Proietti et al. (in press).[5] Second, we use three frequently used measures based on statistical filters applied to real GDP: the Baxter-King band-pass filter, the Hodrick-Prescott filter, and a univariate unobserved components model.[6]

- insert Figures 2 and 3 about here -

Figure 2 displays the output gap measures that we consider, while Table 1 reports summary statistics. From the graph it appears that, although all six variables are highly correlated, their amplitude tends to vary. The large positive cross-correlations in Table 1 confirm that there is a great deal of co-movement across the different output gap measures. At the same time, it is also clear that there is no perfect collinearity among them. To avoid the peculiarities of a specific output gap measure, in the empirical analysis in the following sections we will make use of their first principal component, which is shown in Figure 3. In Section 5.1 we conduct a sensitivity analysis where we consider the individual output gap estimates and an alternative summary measure based on their simple average.

[5]The three versions of the multivariate unobserved components model, based on the production function approach, consist of the common cycles (CC) version, the pseudo-integrated cycles (PIC) version, and the bivariate version (BIV). The CC specification is estimated under the assumption that all cyclical variables in the system (total factor productivity, unemployment, labour force participation) follow the relatively short cycle in capacity utilisation. The PIC specification is estimated under the assumption that the cycles in the labour variables are more persistent. The BIV specification is based on a bivariate system for inflation and output only. See Proietti et al. (in press) for more details.

[6]The three univariate filters are applied to real GDP, extended backwards (using a euro area aggregate based on OECD data) and projected forwards (with a simple autoregressive model) by three years. Subsequently, the first and last three years of the estimated cycles were discarded, as recommended by Baxter and King (1999) for the band-pass filter. The univariate unobserved components model was specified as a basic smooth unobserved components model (fixed level, stochastic slope) with a stochastic cycle (with damping factor equal to 0.9 and period equal to 20) and outlier corrections (found via tests based on the auxiliary residuals) in 1974:3, 1986:1, and 1987:1.

- insert Table 1 about here -

In part of the analysis also two common indicators of additive price shocks are included, namely the quarter-on-quarter growth rates in the euro nominal effective exchange rate (standardized to equal 100 in 1970:1) and the price of oil (in euros per barrel). The levels of these variables are plotted in Figure 4. The nominal effective exchange rate largely resembles the movements of European currencies against the US dollar, reaching a low value of 82 in 1985 followed by a rapid increase due to the Plaza agreement, and a substantial depreciation following the introduction of the euro in 1999 with the subsequent recovery during 2001-2003. The oil price clearly shows the OPEC-induced price jumps in 1973 and 1979, the rapid decline in 1985-1986 following the increase in production initiated by Saudi Arabia, as well as the price hikes around the turn of the millennium and in 2004-2005.

- insert Figure 4 about here -

4 Linear Phillips curve specification

The main conclusion that we draw from the literature review in Section 2 is that a comprehensive modelling strategy is required in order to discriminate among alternative specifications for euro area inflation dynamics and the Phillips curve, in particular to account for the possible presence of various types of instabilities and nonlinearity. We start from a generalised form of the Phillips curve estimated by O'Reilly and Whelan (2005):

$$\pi_t = \alpha + \rho\pi_{t-1} + \sum_{j=1}^{p} \psi_j \Delta\pi_{t-j} + \gamma x_t + \sum_{j=1}^{k} \lambda_j \Delta x_{t-j} + \delta' z_t + \varepsilon_t \qquad (1)$$

where quarterly inflation π_t (measured in annualised percentage points) is a function of its own lags (Δ denotes the first difference operator), the output gap x_t, and a vector of supply shocks z_t. For the latter we consider quarter-on-quarter growth rates of the oil price and of the nominal effective exchange rate of the euro, denoted as o_t and e_t, respectively.[7] These shocks are included in the same way as the output

[7]Some studies, including Aguiar and Martins (2005) and Rudd and Whelan (2005), have used the imported goods deflator (in its deviations from overall inflation) as a proxy for supply side shocks. However, for the euro area such variable is not available from 1970. The series for the import deflator which are available form 1970 (such as from the AWM database) include intra-euro area trade, while series for the extra-euro area import deflator are available only from the 1990s.

gap x_t, that is, z_t consists of contemporaneous levels and first differences up to orders l and m, such that $z_t = (o_t, \Delta o_t, \ldots, \Delta o_{t-l}, e_t, \Delta e_t, \ldots, \Delta e_{t-m})'$. Both e_t and o_t are demeaned prior to inclusion and given that the output gap measure has mean zero by construction, the long-run mean of inflation in (1) is given by $\alpha/(1-\rho)$. Following O'Reilly and Whelan (2005) and others, we interpret ρ as a measure of inflation persistence. Compared with O'Reilly and Whelan (2005), we allow for lags in the output gap variable and include a number of additive price shocks. Thus, the relationship resembles the triangle model advocated by Gordon (1997).

We specify the linear Phillips curve in (1) for both the GDP deflator and HICP inflation, including quarterly dummies for the latter inflation measure in order to capture its seasonal behaviour. Furthermore, we include an additive outlier dummy for 1976:2. For the output gap x_t we use the first principal component of six measures of economic slack, as described in the previous section. The maximum number of lags for all variables is four, with specific lag orders chosen by combining the information from the Akaike, Schwarz and Hannan-Quinn criteria, denoted as AIC, BIC and HQ. All models are estimated using an effective sample period from 1971:4-2005:4 ($T = 137$ observations).

In the process of developing a linear Phillips curve equation for the GDP deflator and HICP inflation, it turns out that the resulting specification for the former inflation measure is considerably simpler, in the sense that the supply shocks z_t do not enhance the explanatory power of the model while they are important for HICP inflation. For that reason we proceed by first considering a Phillips curve specification for the GDP deflator, excluding the additive price shocks, and subsequently modelling the relationship between the GDP deflator and HICP inflation using a bridge equation, which also takes into account the additive price shocks.

The appropriate lag orders are selected by varying $p \in \{0, \ldots, 4\}$ and $k \in \{-1, 0, \ldots, 4\}$, where $p = 0$ ($k = -1$) indicates that no first differences of inflation (the output gap) are included in the model. AIC selects $p = 3$ and $k = 3$, while both BIC and HQ select $p = 3$ and $k = -1$. Upon estimating both specifications, we find that the first differences of the output gap do not add substantially to the model fit, such that we settle for the more parsimonious model which only includes its contemporaneous level. The resulting model is given by:

$$\hat{\pi}_t = \underset{(0.151)}{0.053} + \underset{(0.029)}{0.978}\,\pi_{t-1} - \underset{(0.080)}{0.493}\,\Delta\pi_{t-1} - \underset{(0.090)}{0.314}\,\Delta\pi_{t-2} - \underset{(0.100)}{0.370}\,\Delta\pi_{t-3} + \underset{(0.067)}{0.280}\,x_t, \quad (2)$$

$\hat{\sigma}_\pi = 3.96$, $\hat{\sigma}_\varepsilon = 1.20$, SK $= 0.38$, EK $= 1.43$, LJB $= 15.1(5.0 \times 10^{-4})$, ARCH(1) $=$ $0.23(0.63)$, ARCH(4) $= 7.12(0.13)$, $\text{LM}_{\text{SI}}(1) = 0.29(0.59)$, $\text{LM}_{\text{SI}}(4) = 1.47(0.22)$, AIC $= 0.483$, BIC $= 0.654$,

where heteroskedasticity-consistent standard errors are given in parentheses below the parameter estimates, $\hat{\sigma}_\pi$ is the standard deviation of the dependent variable, $\hat{\sigma}_\varepsilon$ is the residual standard deviation, SK and EK are residual skewness and excess kurtosis, respectively, LJB is the Lomnicki-Jarque-Bera test of normality of the residuals, ARCH(q) is the LM test of no ARCH effects up to order q in the residuals, and $\text{LM}_{\text{SI}}(m)$ is the Breusch-Godfrey test for no residual autocorrelation up to and including lag m. The numbers in parentheses following the test statistics are p-values.

The linear model seems adequate in that the errors are serially uncorrelated and homoskedastic, whereas the skewness and excess kurtosis are caused entirely by large residuals in 1973:1 and 1992:1. From this linear specification inflation appears to be highly persistent with $\hat{\rho} = 0.978$. The coefficient of the output gap level has the expected positive sign with $\hat{\gamma} = 0.280$.

5 Instability and nonlinearity

In this section we assess the stability and linearity of the Phillips curve specification for the GDP deflator discussed above. A relevant issue in this analysis is that nonlinearity and time-varying parameters generally are difficult to distinguish. In addition, instability in one part of the model may spuriously suggest instability of other parts as well. For example, a structural change in the mean of inflation, when neglected, may give the impression that inflation persistence has changed. In sum, analysing the linearity and stability of the Phillips curve requires a well-structured and comprehensive approach. For that purpose, we adopt the methodology underlying the time-varying smooth transition (TV-STR) models as developed in Lundbergh et al. (2003). TV-STR models allow for nonlinearity and time-varying parameters simultaneously, while a modelling procedure is available for arriving at the most

appropriate empirical specification, see also van Dijk et al. (2002b) for detailed discussion. This involves the application of a battery of diagnostic tests to a given model specification, including tests for nonlinearity and time-varying parameters, and expanding the model in the direction for which the statistical evidence is most convincing.

We start from the linear specification for the GDP deflator as given in (2). Among other misspecification tests, we separately test the stability and linearity of the intercept α, the persistence parameter ρ, and the output gap coefficient γ as follows.

Stability of a given coefficient θ for a given variable v_t in the model is tested against the alternative of a single, gradual structural change of the form

$$\theta_t = \theta_1(1 - G(t; \xi, \tau)) + \theta_2 G(t; \xi, \tau), \tag{3}$$

where $G(t; \xi, \tau)$ is the logistic function

$$G(t; \xi, \tau) = \frac{1}{1 + \exp(-\xi(t - \tau))}, \qquad \xi > 0, \tag{4}$$

which changes monotonically from 0 to 1 as t increases such that θ_t changes from θ_1 to θ_2. The restriction on the parameter ξ, which governs the smoothness of the parameter change, is for identification purposes only. The parameter τ determines the location of the shift in θ_t, in the sense that $G(t; \xi, \tau) = 0.5$ when $t = \tau$. The null hypothesis of stability can be formulated as either $\xi = 0$ or $\theta_1 = \theta_2$. In both cases, the testing problem is non-standard due to the presence of unidentified nuisance parameters under the null hypothesis. This can be remedied by approximating the logistic function $G(t; \xi, \tau)$ by means of a low-order Taylor approximation around the point $\xi = 0$, giving rise to an auxiliary regression including terms $v_t t$, $v_t t^2$, $v_t t^3, \ldots$. This can be estimated using least squares and a standard F-test for the joint significance of the coefficients of the auxiliary regressors provides a test for stability.

Linearity of the relationship between π_t and v_t is tested against the same alternative (3), except that in the logistic function $G(\cdot)$ in (4) time t is replaced by another observable variable s_t, which then governs the switching of θ_t between its two extreme values θ_1 and θ_2. Here we consider nonlinear specifications with the first lag of the level and first difference of inflation, and the current level and change of the slack measure as transition variables, that is, $s_t \in \{\pi_{t-1}, \Delta\pi_{t-1}, x_t, \Delta x_t\}$. More

details about the diagnostic tests for time-varying parameters and nonlinearity can be found in Eitrheim and Teräsvirta (1996). Medeiros and Veiga (2003) develop analogous test statistics for examining the constancy and linearity of the residual variance σ_ε^2, which we also employ here.

- insert Table 2 about here -

Table 2 reports p-values of the diagnostic tests of stability and linearity applied to the different components in the linear specification for the GDP deflator. We observe that several null hypotheses are rejected, in particular stability of the intercept α, the persistence parameter ρ, and the slope of the curve γ. The evidence for structural change in the conditional variance σ_ε^2 is less convincing. All three types of possible structural change signalled by the diagnostic tests seem plausible and have been documented in previous literature, see Section 2. Given that the p-value of the stability tests for α are smallest, we proceed with estimating a model that incorporates a change in the intercept, thereby allowing for a shift in the long-term mean of inflation. This appears plausible given the substantial changes in monetary policy regimes and in particular in the level of inflation targets experienced by euro area countries over the course of the past three decades. The specification of the model thus is as follows

$$\pi_t = \alpha_t + \rho\pi_{t-1} + \sum_{j=1}^{p} \psi_j \Delta\pi_{t-j} + \gamma x_t + \sum_{j=1}^{k} \lambda_j \Delta x_{t-j} + \varepsilon_t, \qquad (5)$$

where α_t is now time-varying according to (3), that is

$$\alpha_t = \alpha_1(1 - G(t;\xi,\tau)) + \alpha_2 G(t;\xi,\tau), \qquad (6)$$

with $G(t;\xi,\tau)$ given by (4), such that $\alpha_1/(1-\rho)$ and $\alpha_2/(1-\rho)$ are the long-run means of inflation before and after the change, respectively, and can be interpreted as the central bank inflation targets during those periods. The lag orders p and k are, once again, selected on the basis of the Akaike, Schwarz and Hannan-Quinn information criteria, all of which indicate that $p = 3$ and $k = -1$ is the preferred specification. The model is estimated with nonlinear least squares, which yields the following results:

$$\hat{\pi}_t = \underset{(0.950)}{3.247}\,(1 - G(t;\hat{\xi},\hat{\tau})) + \underset{(0.219)}{0.643}\,G(t;\hat{\xi},\hat{\tau}) + \underset{(0.086)}{0.694}\,\pi_{t-1}$$

$$- \underset{(0.101)}{0.330}\,\Delta\pi_{t-1} - \underset{(0.097)}{0.176}\,\Delta\pi_{t-2} - \underset{(0.085)}{0.291}\,\Delta\pi_{t-3} + \underset{(0.065)}{0.275}\,x_t, \tag{7}$$

with

$$G(t;\hat{\xi},\hat{\tau}) = (1+\exp(-\underset{(0.061)}{0.138}\,(t-\underset{(3.72)}{60.8})))^{-1}, \tag{8}$$

$\hat{\sigma}_\pi = 3.96$, $\hat{\sigma}_\varepsilon = 1.12$, SK $= 0.34$, EK $= 0.55$, LJB $= 4.34(0.11)$, ARCH(1) $= 0.55(0.46)$, ARCH(4) $= 14.9(0.01)$, $\text{LM}_{\text{SI}}(1) = 0.12(0.73)$, $\text{LM}_{\text{SI}}(4) = 1.62(0.17)$, AIC $= 0.344$, BIC $= 0.514$.

The reduction in the intercept α_t is large from $\alpha_1 = 3.247$ to $\alpha_2 = 0.643$, implying a decline in the long-run mean of annualised inflation from 10.6% before the change to 2.1% thereafter. The time-varying inflation mean is plotted in Figure 5, showing that the decline occurred rather gradually during the 1980s. This is broadly in line with existing literature, which dates the Great Disinflation in the early 1980s, see Cecchetti et al. (2007), among others. The second prominent feature of this specification is that allowing for a time-varying mean substantially reduces inflation persistence. The estimate of ρ in (5) is 0.694 compared to 0.978 in the specification with constant mean in (2), implying a reduction in the half-life of shocks to inflation from 31 to just 2 quarters. Finally, note that the estimated coefficient of the slack measure, $\hat{\gamma} = 0.275$, is essentially unchanged compared to the linear specification.

- insert Figure 5 about here -

Table 2 reports diagnostic tests for the model with time-varying inflation mean, including tests for remaining nonlinearity and time-varying parameters. Several interesting results emerge. First, the previous evidence for time-variation in inflation persistence has disappeared completely, which is in line with results of the IPN (see Altissimo et al., 2006). Second, the single monotonic change in the intercept appears sufficient to capture the changes in the mean of inflation as we find no statistical evidence for additional instability in the intercept. This result is somewhat surprising as Figure 5 suggests that after the large decline during the 1980s, inflation increased again during a short period around 1990, which was followed by a further downward shift to the current level of around 2% due to the implementation of the Maastricht Treaty and the convergence towards EMU. Third, the null hypothesis of stability of the slope parameter γ continues to be strongly rejected. This is in line with

theoretical priors indicating a possible link between the level of inflation and the frequency of price adjustment, which affects the slope of the Phillips curve (Dotsey, King and Wolman 1999). Based on the results from the various diagnostic tests, we proceed with estimating the following model, which allows for a change in slope, in addition to the change in intercept:

$$\pi_t = \alpha_t + \rho\pi_{t-1} + \sum_{j=1}^{p} \psi_j \Delta\pi_{t-j} + \gamma_t x_t + \sum_{j=1}^{k} \lambda_j \Delta x_{t-j} + \varepsilon_t, \tag{9}$$

where α_t evolves according to (6), and the slope coefficient γ_t is now time-varying and follows

$$\gamma_t = \gamma_1(1 - G(t;\zeta,\kappa)) + \gamma_2 G(t;\zeta,\kappa). \tag{10}$$

We obtain the following estimation results for this model:

$$\hat{\pi}_t = \underset{(0.916)}{2.742}\,(1 - G(t;\hat{\xi},\hat{\tau})) + \underset{(0.207)}{0.454}\,G(t;\hat{\xi},\hat{\tau}) + \underset{(0.084)}{0.748}\,\pi_{t-1} - \underset{(0.099)}{0.408}\,\Delta\pi_{t-1}$$

$$- \underset{(0.107)}{0.259}\,\Delta\pi_{t-2} - \underset{(0.080)}{0.327}\,\Delta\pi_{t-3} + [\,\underset{(0.109)}{0.466}\,(1 - G(t;\hat{\zeta},\hat{\kappa})) + \underset{(0.060)}{0.134}\,G(t;\hat{\zeta},\hat{\kappa})\,]\,x_t, \tag{11}$$

with

$$G(t;\hat{\xi},\hat{\tau}) = (1 + \exp(-\underset{(0.042)}{0.081}\,(t - \underset{(0.69)}{57.1})))^{-1}, \tag{12}$$

$$G(t;\hat{\zeta},\hat{\kappa}) = (1 + \exp(-\underset{(0.048)}{4.20}\,(t - \underset{(0.050)}{39.6})))^{-1}, \tag{13}$$

$\hat{\sigma}_\pi = 3.96$, $\hat{\sigma}_\varepsilon = 1.07$, SK $= 0.19$, EK $= 0.79$, LJB $= 4.44(0.11)$, ARCH(1) $= 0.39(0.53)$, ARCH(4) $= 13.6(0.01)$, $\text{LM}_{\text{SI}}(1) = 0.20(0.65)$, $\text{LM}_{\text{SI}}(4) = 6.37(0.17)$, AIC $= 0.272$, BIC $= 0.464$.

Two features of the model are striking. First, the reduction in the output gap coefficient is substantial, with the slope after the break being approximately one third of the slope before the break ($\hat{\gamma}_2 = 0.134$ compared to $\hat{\gamma}_1 = 0.466$). Second, the change in slope occurs rather abruptly, as indicated by the large estimate of ζ, and in 1979:4, prior to the change in the mean of inflation. Note that the timing and speed of the change in the intercept α_t are comparable to the estimates found before in (7), as shown in Figure 5. The restriction that the timing and speed of the transitions of the intercept and slope are in fact identical is convincingly rejected on the basis of a likelihood ratio test. One might conjecture that the transition in the

frequency of price adjustment may have taken place as soon as the shift in monetary policy regime, already evident in 1980, was introduced, well before actual inflation started to fall and converge to lower levels as from the mid 1980s.[8]

Table 2 reports diagnostic tests for remaining instability and nonlinearity for this model with time-varying intercept and slope. For most tests, the p-values are well above conventional significance levels. As regards nonlinearity, we find statistically insignificant test statistics when the forcing variables is the output gap in level or first difference, i.e. x_t or Δx_t. This implies that we find no evidence of a nonlinear relationship of the type usually studied in the literature (i.e. convex or concave, asymmetric). However, we find some indications for the presence of nonlinearity in the relationship between inflation and the output gap, as the p-value of the linearity tests with $s_t = \pi_{t-1}$ are below 10%. We attempted to estimate a smooth transition regression model accordingly, but this did not give meaningful results. Hence, such that we accept the specification in (11) as an adequate representation of the Phillips curve dynamics over the period 1970-2005.

5.1 Sensitivity analysis

We perform two types of sensitivity analysis to examine the robustness of our results. First, we include the price shocks z_t in the Phillips curve specification as in (1). The information criteria suggest to include only the contemporaneous level of the oil price shock o_t and the contemporaneous level and one lagged first difference of the exchange rate shock e_t. As already noted in Section 4, we find very little role for these additive price shocks in the equation for the GDP deflator and, not surprisingly the main results concerning the changes in mean and slope of the Phillips curve remain practically unchanged.[9]

Second, we re-estimate the model in (11) by substituting each of the six individual measures of the output gap discussed in Section 3 as well as their arithmetic average for the summary measure based on the first principal component used before. Table 3 presents estimates of the parameters determining the time-varying slope γ_t as defined

[8]This may imply that a model in which the change in the slope of the curve is driven by the level of (trend) inflation, as in De Veirman (2007) for Japan, may not be very appropriate in the euro area.

[9]Results are not reported for brevity but are available from the authors upon request.

in (10) for the different choices of the output gap measure x_t. To account for the different amplitude of the slack measures, we report scaled coefficients $\gamma_i^* = \gamma_i \times \sigma_x$, $i = 1, 2$, where σ_x denotes the sample standard deviation of x_t. The table shows that the coefficient estimates for the principal component and the arithmetic average are very close, both for the timing and speed of the structural change of the slope coefficient as well as its magnitude before and after the change. The same holds for the three gap measures based on the multivariate unobserved components model of Proietti et al. (in press). Larger differences are observed for the univariate measures based on statistical filters applied to real GDP. In particular, when using the Baxter-King band-pass filter or the Hodrick-Prescott filter, the timing of the change is dated a full decade later compared to the univariate unobserved components model or any of the other gap measures ($\hat{\kappa} \approx 80$ as opposed to 40).

- insert Table 3 about here -

6 Modelling HICP inflation

Although the rate of inflation derived from the GDP deflator is of great interest, the ECB's monetary policy objective of price stability is defined in terms of HICP inflation. For that reason, in this section we develop a model for HICP inflation, linking it to the GDP deflator using a so-called 'bridge equation' which has the difference between the HICP and GDP deflator inflation measures as dependent variable. As discussed in Sections 3 and 4, HICP inflation moves closely together with the GDP deflator inflation, but with two important differences. First, while GDP deflator inflation appears not to be affected by our measures of additive price shocks, HICP inflation is. Second, while the GDP deflator is seasonally adjusted, the HICP is not.

Figure 6 plots the difference between the annualised quarter-on-quarter rate of change in the HICP and in the GDP deflator, denoted d_t. The difference between the two inflation measures appears to be stationary over the sample period that we cover, although an increase in the level seems to have occurred since 1990, approximately. Some seasonality also appears to be present in the series. The effects of price shocks become clear from Figure 7, showing scatter plots of the quarterly changes in the euro nominal effective exchange rate and in the oil price against d_t. As expected,

the inflation differential is negatively related to exchange rate shocks and positively to oil price shocks.

- insert Figures 6 and 7 about here -

An appropriate model for d_t is developed using the same procedure applied to the Phillips curve specification for the GDP deflator as discussed in Sections 4 and 5. That is, we start with a linear specification of the form (1), but for d_t instead of π_t and not including the terms involving the output gap x_t. We do include the price shocks $z_t = (o_t, \Delta o_t, \ldots, \Delta o_{t-l}, e_t, \Delta e_t, \ldots, \Delta e_{t-m})'$ and, in addition, a set of centered seasonal dummies $D_t = (D^*_{1,t}, D^*_{2,t}, D^*_{3,t})' \equiv (D_{1,t} - D_{4,t}, D_{2,t} - D_{4,t}, D_{3,t} - D_{4,t})'$, where $D_{s,t}$, $s = 1, \ldots, 4$ are quarterly dummy variables, with $D_{s,t} = 1$ when time t corresponds with quarter s and $D_{s,t} = 0$ otherwise. Finally, additive outlier dummies are included for 1976:2 as before, as well as for 1974:1 to handle the extremely large oil price shocks that occurred at that time.

Based on the information criteria, the lag orders are set equal to $p = 4$, $l = 0$ and $m = -1$, that is, we include the contemporaneous level and first difference of the oil price shock o_t and only the contemporaneous level of the exchange rate shock e_t. The estimated model[10] is subjected to the usual misspecification tests for nonlinearity and parameter instability. The test results indicate instability in the intercept of the model, reflecting the change in level of d_t, as well as instability in the coefficients of the quarterly dummies D_t, suggesting that the seasonal pattern also may have changed. No signs for instability or nonlinearity in the effects of the shocks o_t and e_t are found. (Sequentially) Incorporating the change in intercept and seasonality into the model, we finally arrive at the following estimated model:

$$\hat{d}_t = \underset{(0.317)}{-0.812}\,(1 - G(t;\hat{\xi},\hat{\tau})) + \underset{(1.397)}{0.637}\,G(t;\hat{\xi},\hat{\tau}) + \underset{(0.158)}{0.047}\,d_{t-1} - \underset{(0.143)}{0.075}\,\Delta d_{t-1} - \underset{(0.129)}{0.029}\,\Delta d_{t-2}$$

$$+ \underset{(0.117)}{0.074}\,\Delta d_{t-3} + \underset{(0.082)}{0.224}\,\Delta d_{t-4} + \underset{(0.0012)}{0.0045}\,o_t + \underset{(1.5\times 10^{-4})}{9.4 \times 10^{-5}}\,\Delta o_t - \underset{(0.011)}{0.042}\,e_t$$

$$+ [\underset{(1.268)}{-2.362}\,D^*_{1,t} - \underset{(0.866)}{1.019}\,D^*_{2,t} + \underset{(0.835)}{2.412}\,D^*_{3,t}](1 - G(t;\hat{\zeta},\hat{\kappa}))$$

[10]Results are not reported for brevity but are available from the authors upon request.

$$+[\underset{(0.262)}{0.679}\, D^*_{1,t} + \underset{(0.229)}{0.499}\, D^*_{2,t} - \underset{(0.193)}{0.868}\, D^*_{3,t}]G(t;\hat{\zeta},\hat{\kappa}), \tag{14}$$

with

$$G(t;\hat{\xi},\hat{\tau}) = (1+\exp(-\underset{(0.075)}{0.055}\,(t-\underset{(1.99)}{113.6})))^{-1}, \tag{15}$$

$$G(t;\hat{\zeta},\hat{\kappa}) = (1+\exp(-\underset{(0.039)}{20.00}\,(t-\underset{(0.005)}{13.9})))^{-1}, \tag{16}$$

$\hat{\sigma}_d = 1.73$, $\hat{\sigma}_\varepsilon = 1.17$, SK $= -0.19$, EK $= 0.35$, LJB $= 1.49(0.47)$, ARCH(1) $= 0.72(0.40)$, ARCH(4) $= 5.16(0.27)$, $\text{LM}_{\text{SI}}(1) = 1.12(0.29)$, $\text{LM}_{\text{SI}}(4) = 0.67(0.61)$, AIC $= 0.583$, BIC $= 0.966$.

Several features of the model are noteworthy. First, the model explains more than half of the variation in the inflation differential and appears adequate, as the usual diagnostic tests do not indicate any obvious misspecification. Second, the change in mean occurs gradually and is centered around 1997, see also Figure 6. The mean inflation differential changes from -0.85% before the change to 0.67% after. The latter should be interpreted with caution, however, as the function $G(t;\hat{\xi},\hat{\tau})$ only takes the value 0.85 at the end of our sample period such that the change is not completed. Third, the estimates of the parameters in the second logistic function $G(t;\hat{\zeta},\hat{\kappa})$ indicate that the change in seasonality occurs rapidly at the end of 1972. Hence, the instability in the seasonal pattern appears to be due to a few erratic observations early in the sample period. Fourth, the oil price shock o_t has a significant positive effect on the inflation differential, consistent with the idea that an oil price increase leads to higher consumer prices but does not affect the GDP deflator. Similarly, the significantly negative coefficient for the exchange rate shock e_t suggests that consumer prices are influenced by changes in the euro exchange rate.

It is worth mentioning that the finding of no evidence of a *direct* asymmetric impact of oil price shocks *on inflation* is not necessarily inconsistent with an *overall* asymmetric impact once the transmission channel through the output gap is taken into account, if oil prices do have an asymmetric impact on demand conditions.

7 Conclusions

This paper has aimed at providing a comprehensive analysis of the stability and linearity of the euro area Phillips curve, a question that is of obvious policy relevance

in Europe where a stable rate of inflation appears to coexist with a seemingly high level of spare capacity. The main results of the study are three. First, there is strong evidence, quite un-surprisingly, of a shift in the mean of euro area inflation, with the change occurring quite gradually towards the middle of the 1980s. Second, there is also strong evidence of a shift in the slope of the curve, again occurring in the 1980s but somewhat earlier and much more abruptly. As a result of this shift, the curve becomes significantly flatter, consistent with the idea that the frequency of price adjustment is negatively related to the mean of inflation. Third, once we correct for this time variation in the parameters we find no significant evidence of non-linearity in the curve, in particular in relation to the output gap. Hence, we conclude that the Phillips “curve” is, at least in the euro area, indeed a “line”. The main policy implication of our study is, therefore, that there is at least no convincing evidence of the existence of a ”free lunch” for monetary policy, whereby the central bank is able to stimulate economic activity without creating inflationary pressure.

Further analysis at the level of the individual countries in the euro area could be useful, in order to ascertain whether there is any interesting heterogeneity in the stability and functional form of the Phillips curve. In particular, it appears interesting to compare low inflation (e.g. Germany) and high inflation (e.g. Italy) countries over a longer sample period, before the start of the monetary union. This appears to be an interesting avenue for future research.

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Table 1: Output gap measures - summary statistics

	Mean	St.dev.	Skewness	Kurtosis	Correlation					
					CC	PIC	BIV	BK	HP	UC
CC	−0.01	1.07	−0.22	2.78		0.87	0.61	0.75	0.74	0.63
PIC	−0.03	1.42	0.03	2.62			0.83	0.81	0.82	0.59
BIV	−0.06	1.76	0.15	2.16				0.82	0.79	0.52
BK	0.11	0.92	0.43	3.39					0.97	0.81
HP	0.02	0.97	0.25	3.06						0.83
UC	−0.01	0.63	−0.01	4.07						

Note: The table presents summary statistics for quarterly output gap measures for the Euro area for the period 1970:1-2005:4. CC, PIC and BIV are obtained from the common cycles, the pseudo-integrated cycles, and the bivariate versions, respectively, of the multivariate unobserved components model of Proietti et al. (in press). BK denotes the Baxter-King band-pass filter, HP the Hodrick-Prescott filter, and UC a univariate unobserved components model applied to quarterly real GDP.

Table 2: LM-type tests for nonlinearity and time-varying parameters in Phillips curve specifications for GDP deflator

Transition variable s_t	$k =$	Linear model 1	2	3	Model with change in mean 1	2	3	Model with change in mean and slope 1	2	3
					Intercept α					
π_{t-1}		-	0.599	0.790	-	0.200	0.174	-	0.242	0.163
$\Delta\pi_{t-1}$		-	0.953	0.772	-	0.431	0.408	-	0.194	0.355
x_t		-	0.355	0.190	-	0.998	0.823	-	0.385	0.245
Δx_t		0.266	0.433	0.299	0.510	0.667	0.295	0.688	0.667	0.239
t		0.000	0.000	0.000	0.860	0.928	0.607	0.982	0.909	0.983
					Persistence ρ					
π_{t-1}		0.175	0.307	0.026	0.173	0.063	0.097	0.133	0.072	0.064
$\Delta\pi_{t-1}$		0.586	0.790	0.162	0.417	0.239	0.176	0.396	0.386	0.179
x_t		0.008	0.008	0.019	0.052	0.095	0.196	0.369	0.156	0.083
Δx_t		0.289	0.445	0.336	0.462	0.704	0.630	0.195	0.366	0.444
t		0.001	0.001	0.003	0.525	0.393	0.602	0.734	0.548	0.731
					Slope γ					
π_{t-1}		0.007	0.023	0.057	0.047	0.141	0.167	0.625	0.051	0.032
$\Delta\pi_{t-1}$		0.008	0.028	0.067	0.052	0.149	0.217	0.560	0.090	0.090
x_t		0.355	0.190	0.340	0.998	0.823	0.823	0.385	0.245	0.459
Δx_t		0.851	0.091	0.110	0.903	0.468	0.437	0.748	0.662	0.238
t		0.001	0.002	0.001	0.004	0.011	0.028	0.993	0.994	0.914
					Residual variance σ_ε^2					
π_{t-1}		0.100	0.103	0.160	0.047	0.026	0.025	0.142	0.115	0.117
$\Delta\pi_{t-1}$		0.119	0.171	0.111	0.049	0.018	0.025	0.147	0.115	0.117
x_t		0.213	0.164	0.304	0.466	0.302	0.304	0.249	0.300	0.176
Δx_t		0.964	0.026	0.038	0.368	0.036	0.060	0.588	0.137	0.244
t		0.106	0.127	0.080	0.067	0.074	0.027	0.178	0.164	0.119

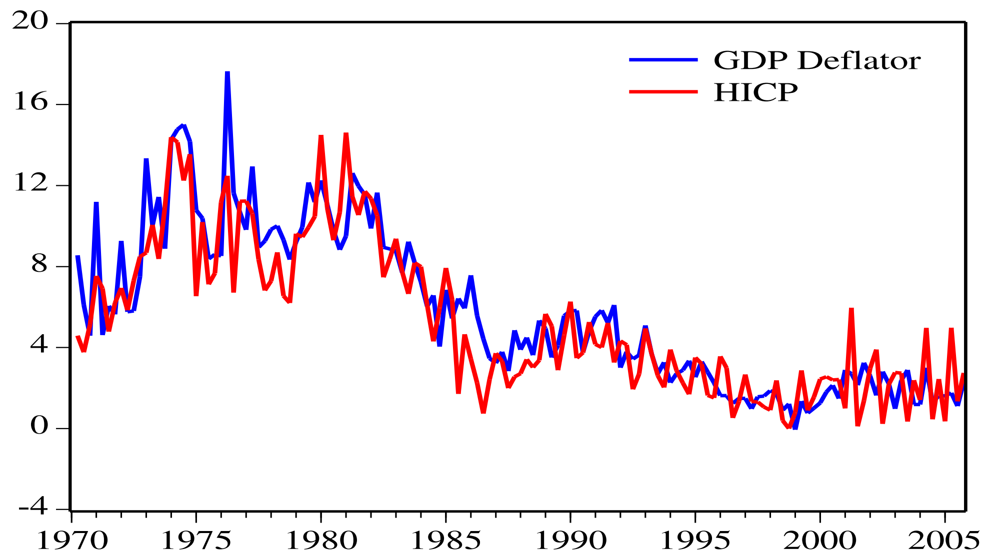
Note: The table presents p-values of F-tests for (remaining) nonlinearity and instability in Phillips curve specifications for quarterly inflation based on the euro area GDP deflator for the period 1971:4-2005:4. The headings 'Linear', 'Model with change in mean', and 'Model with change in mean and slope' refer to the specifications in (2), (7), and (11), respectively. Tests are conducted for the intercept α (first panel), the persistence parameter ρ (second panel), the slope coefficient γ (third panel), and the residual variance σ_ε^2 (fourth panel). Tests are based on auxiliary regressions involving terms $v_t s_t$, $v_t s_t^2$, $\ldots$, $v_t s_t^k$, where v_t is a constant, lagged inflation π_{t-1} or the output gap x_t and s_t is the transition variable in the logistic function (4) under the alternative.

Table 3: Output gap measures - sensitivity analysis

	PC	AVG	CC	PIC	BIV	BK	HP	UC
γ_1^*	1.042	1.115	1.384	1.495	1.546	0.855	0.830	0.833
γ_2^*	0.300	0.304	0.311	0.179	0.369	0.222	0.154	0.102
ζ	4.20	3.75	4.20	20.0	0.207	20.0	0.526	20.0
κ	39.6	39.6	39.3	42.8	34.0	80.4	79.6	40.1

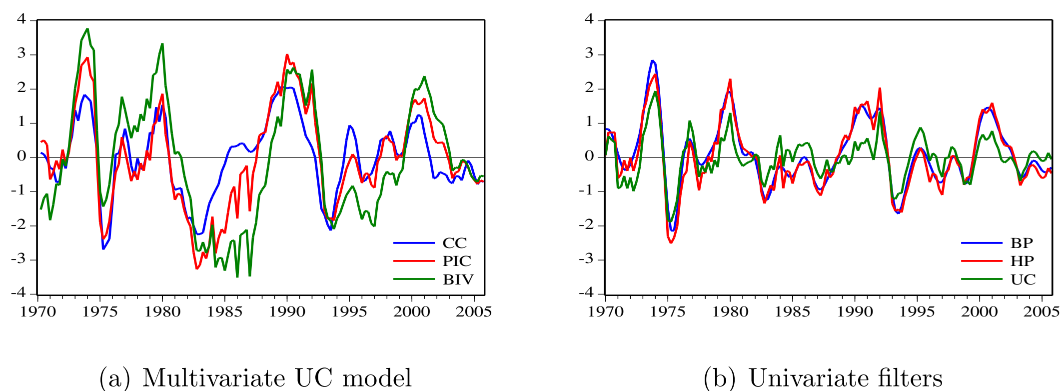
Note: The table presents estimates of the parameters in the time-varying slope γ_t defined in (10), which is used in the Phillips curve specification given in (9) for different choices of the output gap measure x_t. $\gamma_i^* = \gamma_i \times \sigma_x$, $i = 1, 2$, where σ_x denotes the sample standard deviation of x_t. CC, PIC and BIV are obtained from the common cycles, the pseudo-integrated cycles, and the bivariate versions, respectively, of the multivariate unobserved components model of Proietti et al. (in press). BK denotes the Baxter-King band-pass filter, HP the Hodrick-Prescott filter, and UC a univariate unobserved components model applied to quarterly real GDP. PC denotes the first principal component of these six measures, while AVG denotes their simple average.

Figure 1: GDP deflator and HICP inflation



Note: The graph shows annualised quarter on quarter inflation rates for the euro area GDP deflator and HICP for the period 1970:2-2005:4.

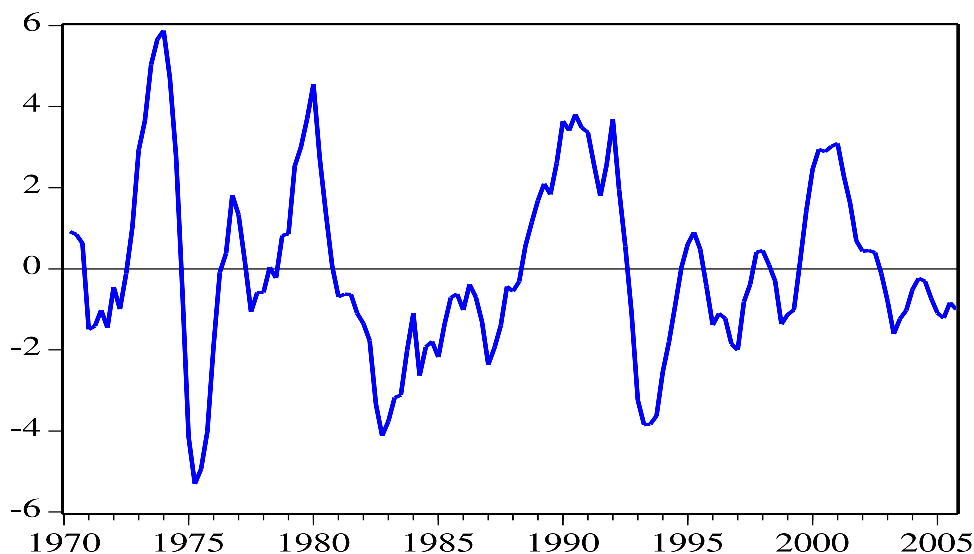
Figure 2: Output gap measures



(a) Multivariate UC model (b) Univariate filters

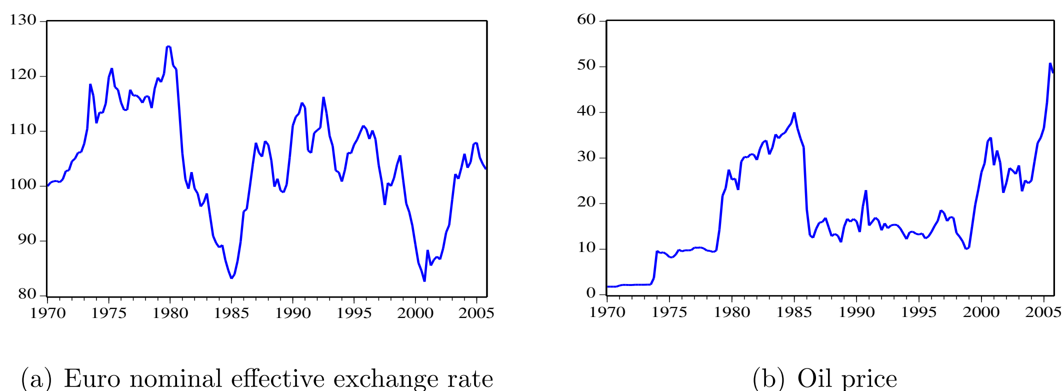
Note: The graphs show measures of the quarterly output gap. In Panel a), CC, PIC and BIV denote measures are obtained from the common cycles, the pseudo-integrated cycles, and the bivariate versions, respectively, of the multivariate unobserved components model of Proietti et al. (in press). In Panel b), BK denotes the Baxter-King band-pass filter, HP the Hodrick-Prescott filter, and UC a univariate unobserved components model applied to quarterly real GDP.

Figure 3: Principal component of output gap measures



Note: The graph shows the first principal component of the six output gap measures for the period 1970:1-2005:4.

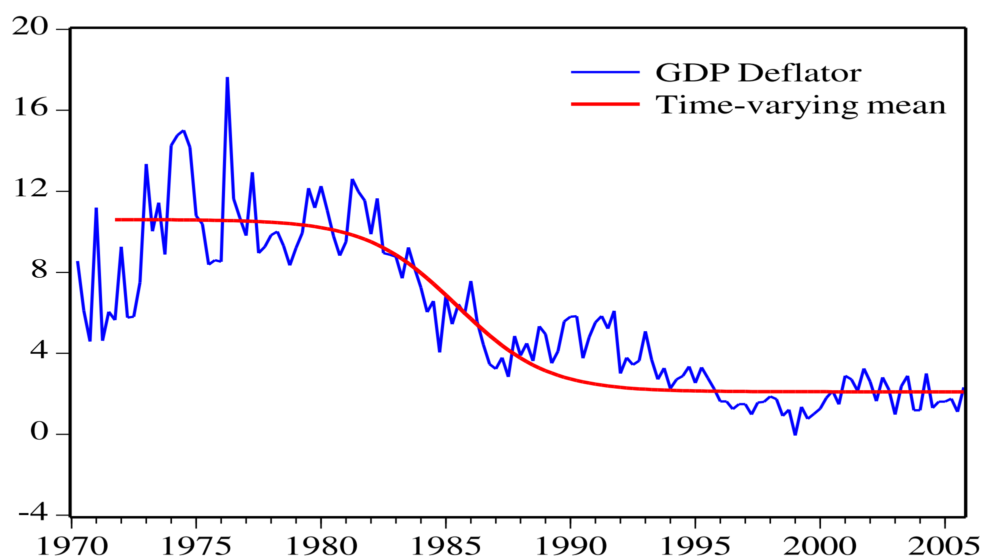
Figure 4: Price shocks: euro nominal effective exchange rate and oil price



(a) Euro nominal effective exchange rate (b) Oil price

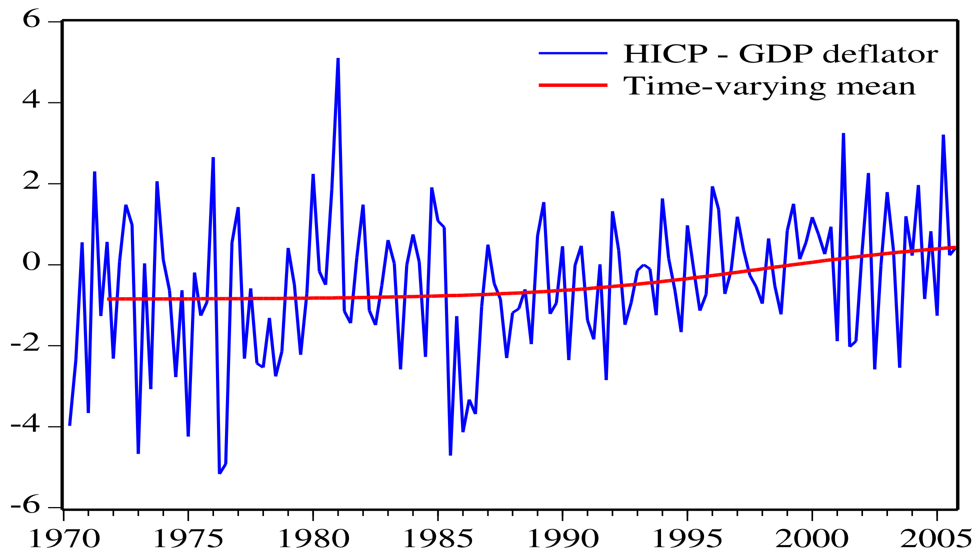
Note: The graphs show the quarterly euro nominal effective exchange rate and oil price for the period 1970:1-2005:4.

Figure 5: GDP deflator and time-varying mean



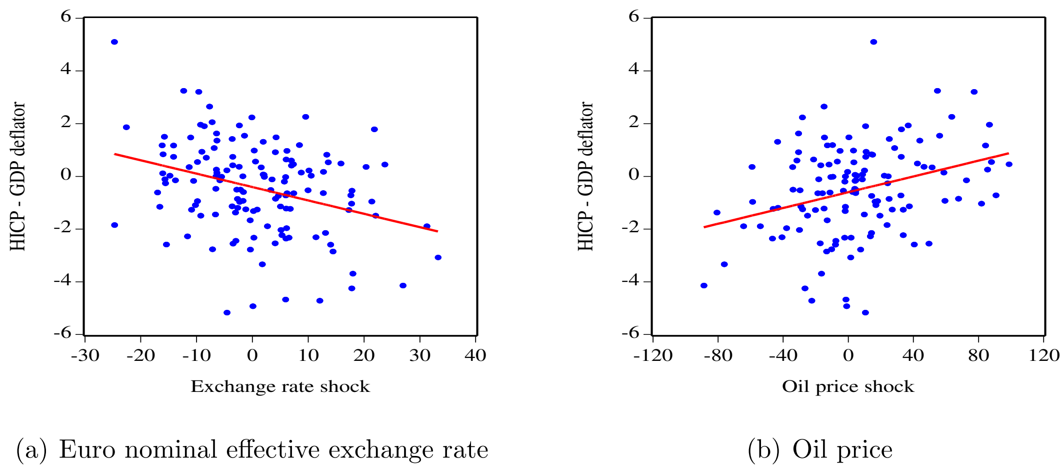
Note: The graph shows annualised quarter on quarter inflation rates for the euro area GDP deflator and the time-varying mean in the Phillips curve specification (7).

Figure 6: Difference between HICP and GDP deflator inflation



Note: The graph shows the difference between the annualised quarter on quarter inflation rates for the euro area HICP and GDP deflator for the period 1970:2-2005:4. The red line is the time-varying mean in the specification (14).

Figure 7: Price shocks: euro nominal effective exchange rate and oil price



(a) Euro nominal effective exchange rate

(b) Oil price

Note: The graphs show scatterplots of the quarterly change in the euro nominal effective exchange rate and oil price against the difference between the annualised quarter on quarter inflation rates for the euro area HICP and GDP deflator for the period 1970:2-2005:4. The solid red line shows the least squares fit of the inflation differential on a constant and the price shock.

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