EUROPEAN CENTRAL BANK

WORKING PAPER SERIES
NO. 388 / SEPTEMBER 2004

EURO AREA INFLATION DIFFERENTIALS

by Ignazio Angeloni
and Michael Ehrmann

EUROPEAN CENTRAL BANK

WORKING PAPER SERIES

NO. 388 / SEPTEMBER 2004

EURO AREA INFLATION DIFFERENTIALS [1]

by Ignazio Angeloni [2]
and Michael Ehrmann [3]

In 2004 all publications will carry a motif taken from the €100 banknote.

1 We are grateful to seminar participants at the ECB, IMF, OECD, the University of Vienna, New York University, European University Institute, the Konstanz Seminar, the CESifo-Delphi Conference, and especially to Pierpaolo Benigno, Günter Coenen, Fiorella De Fiore, George von Fürstenberg, Mark Gertler, Jürgen von Hagen, Boris Hofmann, Andrew Hughes Hallet, Gerard Roland, Frank Smets, Roland Straub and an anonymous referee for useful comments. We thank Ester Faia foruseful suggestions on the simulation techniques and Günter Coenen and Volker Wieland for providing the computer codes. Sandrine Corvoisier helped us with the calculations for Figures 3 and 4, and Susana Sommaggio provided excellent editorial assistance. All remaining errors are ours. The views expressed here are our own and do not involve the ECB.

2 European Central Bank, e-mail: ignazio.angeloni@ecb.int

3 European Central Bank, e-mail: michael.ehrmann@ecb.int

Address
Kaiserstrasse 29
60311 Frankfurt am Main, Germany

Postal address
Postfach 16 03 19
60066 Frankfurt am Main, Germany

Telephone
+49 69 1344 0

Internet
http://www.ecb.int

Fax
+49 69 1344 6000

Telex
411 144 ecb d

ISSN 1561-0810 (print)
ISSN 1725-2806 (online)

CONTENTS

Abstract

We build a stylised 12-country model of the euro area and use it to analyse why differences in national inflation and growth rates arise within the European monetary union. We find that inflation persistence is a key potential explanatory factor. Other more frequently mentioned reasons, like country-specific shocks or differences in the monetary transmission mechanism across countries, count less. We also look at how a monetary policy geared to area-wide average inflation affects these differentials. Our model suggests that area-wide inflation stability and low inflation differentials are complementary.

JEL classification: E31, E32, E52, F42

Keywords: currency union; inflation differentials; inflation persistence; euro area.

Non-technical summary

Five years after the launch of the euro, the inflation differences among euro area countries are still prominent in European economic debates. After converging sharply in the 1990s, national inflation rates started to diverge again around 1999. Although recently the differentials have closed somewhat, stylised facts show that inflation differentials are larger and more persistent than, for example, in the United States.

In this paper we build a stylised 12-country empirical model where determinants and monetary policy implications of such differences can be analysed. Each country is modelled with a pair of simple aggregate demand and aggregate supply equations. Each country is a small open economy where domestic prices and output are influenced by the country-specific effective exchange rate (nominal and real). The model is closed with a monetary policy rule. The model embodies three mechanisms that can be important for inflation differentials in a monetary union. First, since all countries share the same nominal interest rates, a high-inflation tends to have a lower real interest rate, assuming the relevant inflationary expectations are, at least partly, country-specific. Under these conditions the original inflation differentials would be amplified through the demand side (*dis-equilibrating* mechanism). Second, a high-inflation country tends to lose price competitiveness within the currency area, something that dampens demand and output at home (*re-equilibrating* mechanism). Third, stickiness in the dynamics of both inflation and output can propagate and amplify the differentials, both in time and across countries.

We simulate the model using panel estimates of the parameters obtained from quarterly 1998-2003 data. Under a variety of shocks, the model generates realistic inflation differentials that are relatively persistent but return to baseline within reasonable time spans. By varying the parameters within plausible ranges, we determine which factors affect more strongly the size and the duration of the inflation differences. Our results highlight the central role that inflation persistence can perform in amplifying and perpetuating inflation and other cyclical differentials. We also detect a significant (but less important) role for other factors, like for example asymmetries in the monetary policy transmission mechanism or different degrees of price flexibility and goods market integration across countries.

Finally, we consider the role of monetary policy by varying the parameters in the monetary policy rule. We find, first, that a highly forward-looking monetary rule tends to generate model indeterminacy, something already observed in other recent research. Second, we find that by stabilising the average area-wide inflation rate the central bank tends to reduce inflation differentials among countries as well.

1. Introduction

Five years after the launch of the euro, the inflation differences among euro area countries are still prominent in European economic debates. After converging sharply in the 1990s, national inflation rates started to diverge again around 1999. More recently the differentials have closed somewhat, but on average over the five years the standard deviation of annual changes of the harmonised CPI exceeded 1 percent[2]. Several questions arise in this context. The most obvious is what generates these rather sizeable inflation differences: monetary policy, the most popular explanation before 1999, can no longer be the reason now. A more general issue is how (and how quickly) these differences are reabsorbed in the absence of separate monetary policies; in other words, how well does the adjustment mechanism in the single currency area operate. The importance of these questions can hardly be overemphasised, given the frequently voiced concern that heterogeneity may eventually dent the solidity of the monetary union itself.

Differences in inflation and other cyclical variables are not unusual in large currency areas, as we will show. Yet there are reasons why those in the euro area deserve particular attention. First, goods and labour markets in Europe are still only partially integrated. The single market legislation has been in place for over a decade and the single currency will help integration further; but this takes time, and in the meantime the euro area countries will remain more prone to different price and output developments than, for example, US States and regions are. Second, most of the factors giving rise to such differences depend on policies largely under national control (budgetary and tax policies; competition policies in both the wholesale and the retail sectors; labour market regulations; and so on). There is no reason to expect that these policies will systematically be conducted so as to smooth price or output differentials. Thirdly, several important political economy considerations arise in the case of the euro area and not elsewhere. Inflation is unpopular, especially if it cannot be mitigated by a weaker exchange rate. Public opinion and politicians in high inflation countries may misinterpret its causes and blame the currency instead[3]. National differences may also make the interpretation of euro area indicators more challenging for the ECB Governing Council, which is mandated to set monetary policy for the area as a whole.

Some recent attempts to understand the origin of inflation differences have provided useful insights: see section 2 for a summary. But on the whole the available analyses on this important issue remain very limited. In this paper we try to make progress by building a simple but empirically realistic multi-country model of the euro area and using it to investigate the potential sources of differences in inflation and other cyclical variables. Our approach departs from the literature, where two directions have been pursued: 1) descriptive analyses, supported by correlation or regression results; 2) calibrated models with microeconomic foundation, used to illustrate certain theoretical properties of currency unions through stylised examples. Each of these lines of research alone is insufficient, we think. On the one hand descriptive analysis has probably reached a point of diminishing returns due to the scarcity of data. On the other, existing small micro-founded models, normally assuming two countries only, provide only partial answers. Inflation differentials are ultimately an empirical issue because they depend on the balance of countervailing forces, some generating or amplifying the differentials, others pushing towards re-equilibrium. The dimension of heterogeneity is also likely to depend on the number of countries (which are 12, not 2) and on their economic structures (on which there is information from previous empirical work, which

[2] A standard deviation of one percent may seem small, but actually it is not, particularly if the differences are persistent. Consider for example a union of twelve countries, six of which have an inflation rate close to the area average, while three and three deviate upward and downward, respectively, by the same amount, so that the overall standard deviation is one percent. If the differentials persist for five years (not an unusual pattern as we shall see), the three high inflation countries will eventually cumulate a competitiveness loss of some 13 percent relative to the rest of the area, and 20 percent relative to their low inflation partners.

[3] Honohan and Lane (2003) stress this point.

can be used). A full micro-founded model with empirical basis remains the ultimate goal; we see our model as a step in that direction.

This paper is located somewhere between these two lines of research. Specifically, our model includes 12 countries and is estimated in panel form with quarterly data over the most recent period (1998-2003). Each country consists of two simple equations, an aggregate demand and an aggregate supply. Given the scarcity of data, we check our estimation results against earlier results in the literature, all of which use data that predate EMU. We then close the model with a simple monetary policy rule and a random walk assumption for the euro exchange rate and analyse the sensitivity of our simulation results to changes in key model parameters within plausible ranges. The simulations are used to determine which parameters affect more strongly the size and the duration of the inflation differences[4].

Our results highlight the central role that inflation persistence can perform in amplifying and perpetuating inflation and other cyclical differentials following asymmetric shocks. A useful insight from our model is that the main factor behind the observed *differences* across countries may well be a feature that the countries have *in common*. We find that, for plausible parameter values, high inflation persistence – even if equal across countries – is likely to generate more inflation divergence than other more frequently mentioned factors, like for example asymmetries in the transmission mechanism (Cecchetti, 1999) or in demand or supply shocks (Bayoumi and Eichengreen, 1993). We also detect a role for price flexibility (as reflected in the slope of the Phillips curve) and goods market integration (reflected in the strength of international trade spillovers). Monetary policy obviously lacks degrees of freedom to control area-wide inflation and inflation differentials separately. However, we find that minimising the deviations of area-wide inflation from its long-run level and low differentials are complementary, each goal leading to the other as well.

The paper is organised as follows: we first review the relevant literature (section 2) and the main stylised facts (section 3). We then present our model, discussing the parameter estimates in light of the recent literature (section 4). Next, we present our sensitivity analyses keeping monetary policy fixed (section 5). Finally, we look at monetary policy (section 6) and we examine the results under alternative assumptions concerning the determination of the euro exchange rate (section 7)[5]. Section 8 concludes.

2. Related literature

The first analysis of post-EMU data specifically focused on cross-country inflation differentials is by Alberola (2000). His paper contains an informal overview of the data and attempts to disentangle two forces potentially at play: 1) a convergence from initially different price and productivity levels; 2) nation-specific cyclical factors, generating inflation differentials because of less-than-fully integrated product and labour markets. The evidence is sketchy, because of the very short data sample, but nonetheless suggests that both mechanisms are present. A subsequent paper by Ortega (2003) along similar lines, with more updated statistics, confirms this conclusion.

A more extensive review of data evidence is contained in ECB (2003). This paper surveys a variety of measures of price and cost developments at the national level in EU-12 during the 1999-2002 period and compares them with other macroeconomic indicators. Several useful

[4] Our approach emphasises the role of shocks and propagation mechanisms in generating inflation and output differences. Others (e.g. Sinn and Reutter, 2001) have focused instead on the convergence process from initially different price or productivity levels. The data evidence we survey supports the view that both elements are present. Our model can encompass also a convergence process, although we do not focus on it.

[5] Throughout the paper we retain the assumption that the euro area is a "small open" economy, which does not affect the rest of the world. Recent empirical research actually suggests that the transmission of financial shocks between the euro area and the US may have become more symmetric after the creation of the new European currency: see Ehrmann and Fratzscher (2004). However, our focus is on intra-euro-area differentials, for which the feedback from the rest of the world of domestic shocks is likely to be of second-order importance.

indications emerge. First, inflation differences among euro area countries are more persistent than similar differences among US regions. Second, both cyclical and "catch-up" elements are present, as found in the previous studies. Thirdly, inflation differentials are larger in the services sector but are also present, with broadly similar patterns, in the tradable goods sector and in labour costs. This suggests that national inflation differentials are not a sectoral phenomenon, but they spread across the whole domestic cost and price chains. Fourthly, changes in import prices (including raw materials) and in the euro exchange rate, which impact differently across countries, also play a significant role. Finally, national inflation differences are not explained by asymmetries in national consumption patterns; they do not, in other words, result from different inflation rates across sectors plus a "composition effect". This strengthens the impression that the explanation is country-specific, not sector-specific.

Honohan and Lane (2003) moved a step from description towards econometric analysis. They estimated a multivariate panel using annual 1999-2001 data where the spreads of national inflation rates from the area average are regressed on proxies of the catch-up effect and on three macroeconomic variables: nominal exchange rate changes; the fiscal balance, and the output gap. The conclusion is that "much of [inflation divergence] is attributable to the differential impact on different member states of the weakness of the euro or international currency markets in the early months of the union" (page 358). This conclusion however becomes, as we shall see, less clear-cut if one adds the more recent data to their estimate; see below section 3.

Two other papers have approached the same issue from a completely different perspective, building micro-founded 2-country models to study certain properties of currency unions among asymmetric countries. Both of them assume the euro area economy is closed, i.e. that feedback from the rest of the world or the exchange rate can be disregarded.

The one that is closest in spirit to ours is that by Andres, Ortega and Vallés (2003), who, building on work by Bergin (2003), build a 2-country model where each country produces differentiated goods traded in monopolistic competitive markets. Price discrimination occurs due to differentiated demand conditions and price adjustment costs: the key parameters in the model are the elasticity of demand and the slope of the Phillips curve, both of which are country-specific. There is no inflation persistence, only price-level stickiness. The model is calibrated so as to mimic the characteristics of the larger and less open euro area countries. The authors suggest that in their currency area inflation differences depend more on the characteristics of local demand than on price inertia. Though a rigorous comparison of results is difficult, due to the difference between the two models, we will refer to the conclusions of this paper again when presenting our own results (section 5).

Finally Benigno (2003) uses a model similar in certain respects to the previous one (two countries; monopolistic competition and price stickiness) to study alternative monetary policy rules. His focus is not on the causes of the differentials, but on the welfare implications of different monetary policy rules in presence of national asymmetries. His most important conclusion is that better welfare properties are obtainable with "inflation targeting" rules that assign a more-than-proportional weight to the country where prices are more sticky. This result is confirmed by Benigno and López-Salido (2002) in a model that includes also inflation persistence.[6]

3. Stylised facts

We describe only the main statistical facts in this section, among those directly relevant for our analysis. Readers interested in other details should refer to ECB (2003).

First, inflation differentials among the future euro area countries declined steadily in the 1990-99 period. Figure 1 shows a clear downward trend in the unweighted standard deviation

[6] The implications of alternative monetary policy rules under divergent inflation rates in the euro area are studied also by Monteforte and Siviero (2002).

of the annual growth rates of HICP. This standard deviation reached a historical minimum at about 1 percent in 1999, after which it inverted its trend and started to edge up again.

Could inflation differentials have reached some sort of "natural" lower bound exactly in 1999? This idea seems supported by the comparison with the inflation divergence among the 14 US "metropolitan areas", whose data are published by the Bureau of Labor Statistics. As shown in figure 1, the inflation divergence among US cities stayed remarkably constant at around 1 percent for many years. The analogy is probably misleading, however: US cities are much smaller than EU nations, and their price indices tend to be more volatile. An alternative and probably more appropriate comparison is that with the US Census regions. According to this measure, inflation discrepancy in the US is much lower, typically around 0.5 or less. The proper term of comparison for euro area countries should be something between US cities and US macro regions, probably closer to the latter. An alternative comparison is with the European regional data. Interestingly, as shown in figure 2, inflation divergence among European regions *within* individual states tends to be smaller than those observed *among* euro area nations, though regions are obviously smaller[7].

Another distinctive feature of euro area inflation differentials is their persistence. Table 1 shows annual deviations of national inflation rates from nation averages, for the euro area countries and for the four US macro-regions. Remarkably, out of 12 countries now constituting the euro area, 9 have remained on the same side relative to the area average in each single year since 1999. In 6 out of these 9 cases, these countries had also remained on the same side of the mean in all the preceding six years. No such striking regularity is observed in the case of the US regions, where each region has changed side within the last 5 years. Since countries have entered EMU with significantly different initial price levels, such a finding might not come unexpected, as this would suggest that countries with below average price levels may experience persistently higher than average inflation until convergence. In fact, for several countries there is a correspondence between the initial price gap (relative to the area average) and the inflation gap in the initial years of EMU, as we will show below. Note, however, that there are several cases where such a convergence process cannot explain the persistence of inflation differences: i) The Dutch price level in 1999 was close to the average price level, yet inflation in the Netherlands was above average for the last 7 years; ii) also Irish inflation remained above average since 1998, even though Irish prices had already been above average at the start of EMU; iii) Finland, which had the highest relative prices in 1999, experienced 4 years of above average inflation nonetheless. Hence, the persistent differentials of table 1 cannot be explained by convergence effects alone.[8]

Going more into details, there is a positive correlation across national inflation and growth rates over the period, as fig. 3 shows. This suggests that aggregate demand fluctuations are likely to be a factor. Demand is far from explaining all, however, as the large residual variance around the regression line of fig. 3 shows. Fig. 4 plots the residuals from that line against estimates of the deviations of consumer price levels from the Law of One Price, published by OECD (2003). There is a clear negative relation, as one would expect in the presence of a catch-up process. This confirms that the dynamics of inflation in the initial years of EMU was driven also by a convergence mechanism.

---

[7] The volatility of relative price indices is strongly affected by borders and currency arrangements, as shown by Beck and Weber (2001).

[8] The stylised facts we show here focus exclusively on consumer prices (specifically, the Harmonised Index of Consumer Prices and its national components). Other price measures, like core inflation or producer prices, could be used without much change in the results. The close cross-country correlation between consumer prices and other inflation measures, including labour costs, is illustrated in ECB (2003).

A further potentially important factor is given by import prices. There are two dimensions to be considered here. First, since countries differ in their openness to international trade, any given change in import prices (expressed in domestic currency, hence including exchange rate changes) impacts differently on national inflation rates. Moreover, the composition of imports differs, potentially giving rise to further asymmetries. It turns out that, indeed, euro area inflation rates are correlated across countries with their degree of external openness and with the changes in import prices (see ECB, 2003). Honohan and Lane (2003) have stretched this interpretation further, arguing that the depreciation of the euro after 1999 may be the main explanation for the euro area inflation differentials. Fig. 5, replicated from Honohan and Lane's paper, provides strong *prima facie* confirmation to this idea for the first years of EMU.

To explore this hypothesis further, we have updated Honohan and Lane's panel estimates including another year of data (plus data revisions intervened in the meantime), and also checked the sensitivity of their results to the exclusion of Ireland (an outlier, with very high inflation and growth in the sample period). The results, in table 2, confirm that an exchange rate effect exists, but its statistical significance is rather weak, particularly if one extends the sample. Conversely, the significance of the output gap and of lagged prices (seen as a proxy for initial deviations from PPP) is strengthened if one adds more recent data.

4. The model

We model each national economy by means of an aggregate supply and an aggregate demand equation. Aggregate supply is specified as a so-called "hybrid" Phillips curve, where consumer price inflation depends on past and expected future inflation and on the domestic output gap.[9] The lagged inflation term measures the degree of inflation persistence[10]. This equation contains also a "pass-through" mechanism, i.e. a direct effect of changes in the nominal exchange rate on inflation. For each country, changes in the nominal effective exchange rate depend on changes of the euro exchange rates with non euro area currencies, weighted by the country-specific trade shares. Aggregate demand consists in an output gap equation, function of past and expected future domestic output gaps, and a short-term real interest rate. The lagged output gap term measures output persistence[11]. The output gap also depends on the real effective exchange rate, which measures the country's external price competitiveness. Real effective exchange rates are constructed from the relevant bilateral intra- and extra-area exchange rates, weighted by the appropriate trade shares. The presence of the real effective exchange rate term generates cross-country spillovers from domestic inflation in our model: excess inflation in a given country generates real appreciation, leading to deflationary tendencies that tend to eventually re-equilibrate the initial inflation differential.[12] This mechanism plays a key role in the international adjustment mechanism within the model, as we shall see.

---

[9] We disregard the possibility that these relations are sector-specific in order to keep the model tractable. For an analysis of sector-specific effects see, e.g., Altissimo et al. (2004), who show that the differentials exist in both the non-tradable and in the tradable sectors, though they tend to be larger in the former.

[10] In a single country framework this specification can be derived in an optimising model with Calvo pricing, if prices are not re-optimised each period and indexed to general, past, inflation. See e.g. Woodford (2003), chapter 3.3.2.

[11] In a single country framework this specification can be derived in an optimising model assuming adjustment costs in investment or "habit formation" in consumption. See e.g. Woodford (2003), chapter 5.1.

[12] We opted to model the output gap dependent on the real effective exchange rate as opposed to the effective terms of trade, for reasons of data availability. Since foreign goods are also contained in the consumption bundle of home consumers (and vice versa), the re-equilibrating effect in a model with real effective exchange rates could be somewhat smaller than with the effective terms of trade, unless the coefficient estimates change accordingly.

The model can be written in linear form as follows:

$$\pi_{t,j} = c_1 + \alpha_1 \pi_{t-1,j} + \alpha_2 E_t \pi_{t+1,j} + \beta gap_{t,j} + \gamma \Delta neer_{t,j} + \varepsilon_{1t,j} \qquad [1]$$

$$gap_{t,j} = c_2 + \alpha_3 gap_{t-1,j} + \alpha_4 E_t gap_{t+1,j} + \delta(r_t - E_t \pi_{t+1,j}) + \lambda reer_{t,j} + \varepsilon_{2t,j} \qquad [2]$$

The index j represents a generic country; neer and reer denote the nominal and the real effective exchange rat of each country; all other symbols are self-explanatory. The model is written here in generic form with unrestricted α parameters, no lags except for the persistence mechanisms, and constant terms. Some of these details will change following the estimation of the parameters, where some restrictions will be introduced and some lags will be allowed for based on goodness of fit (see table 3). Moreover, some parameters will be allowed to differ across countries, as described in the sequel, in order to evaluate the effect of such differentiation in generating inflation and output differences.

Note that, if all coefficients are equal across countries and if c_1 equals zero, the model admits a steady state where all inflation rates are equal, all real exchange rates are constant and all output gaps are zero. Re-normalising all real exchange rates to unity, the "natural" real interest rate consistent with this steady state is $\frac{c_2 - \lambda}{\delta}$. In general, neither the price level nor the inflation rate are determined by [1] and [2] in steady state; for that one needs an appropriate monetary policy rule, determining r_t .

Outside the steady state, the dynamics of inflation, output and the real exchange rate for each country is driven by a combination of factors, some of them producing and amplifying, and some others reducing inflation and other differentials among countries. For example, excess inflation in country j could reduce the domestic real interest rate under a common monetary policy if inflation expectations at the relevant horizon differ across countries. In the absence of fully integrated goods and capital markets (i.e., if the relevant real interest rate for agents is given by the domestic rate), it seems reasonable to assume a strong "home bias" in the mechanism driving inflationary expectations in the national economies. In this case, the resulting lower real interest rate would amplify the original inflation differentials.[13]. Over time, however, the real exchange rate appreciation that occurs in country j produces deflationary effects on the domestic economy, which eventually drive inflation differentials back to equilibrium. Note also that, if the system starts from an initial condition where the real exchange rates are not in steady state equilibrium, a convergence process takes place during which national inflation rates temporarily differ. Hence the model can be used to mimic the catch-up effect of the initial years of the euro area. We will return to this issue in more detail in Section 5.

We estimate the model on quarterly data from 1998:I to 2003:II[14], using panel instrumental variables without fixed effects and considering the 12 national inflation equations and the 12 output equations separately[15]. The scarcity of data severely limits the degree of parameter

[13] See also the discussion on this issue in ECB (2003).

[14] We assume that 1998 is sufficiently close to the post-EMU regime to be included in our sample.

[15] We use four lags as instruments. A drawback of estimating the two blocks separately is that we assume no covariance between domestic output and inflation; this means assuming that the domestic interactions between supply and demand are sufficiently well represented by the explicit terms in equations [1] and [2]. To keep the model tractable, we have furthermore decided not to include further variables, such as fiscal policy (see, e.g., Canova and Pappa 2003), or analyse separately country-specific and common euro area shocks. The introduction of direct inflation and output spillovers did not change the results in any noteworthy fashion, as these effects turned out to be of second order importance.

differentiation across countries we can allow for. Given this constraint, we initially assume full symmetry across countries except for the degree of external exposure: this is achieved by using appropriate trade weights for the construction of $reer_{t,j}$ in equation [2] and letting λ differ depending on external openness – in practice here we distinguish two groups, characterised by "low" and "high" openness, and estimate the respective λ coefficients: see details in table 3. This is what we call our "benchmark" model. Next, we explore another possible source of cross-country differences: the monetary policy transmission mechanism. This seems the logical next aspect to examine, due to the emphasis placed by the literature on transmission asymmetries[16]. Again, we allow for two different country groups respectively characterised by a "weak" and a "strong" interest rate channel of monetary transmission, based on evidence by Angeloni, Kashyap and Mojon (2003), and estimate the respective values of δ. Finally, we conduct sensitivity analyses around the "benchmark" model by changing a other parameters within their estimated confidence intervals and seeing how the simulation properties of the model are affected.

As we have seen in Figure 4, EMU has started with relatively sizeable differences in the purchasing power price levels across countries. This is likely to imply a convergence process, during which countries that start from below average price levels experience above average inflation rates and *vice versa*. To take account of this, we have estimated three model specifications, first by allowing for country-fixed effects, second by including the price level differences at the start of EMU and third by entering the time path of these deviations. Since all other parameter estimates remained virtually unchanged, we decided to use the model with homogeneous intercepts for the remainder of this paper.

The estimates are shown in table 3 (see Appendix 1 for a description of the data used). The table also indicates, in its right-hand side, the values of corresponding parameters obtained in some recent papers that consider models comparable to ours.

Both the backward and forward parameters in the inflation equation (α_1 and α_2) are significantly positive and can be restricted to sum to unity based on standard significance levels (at 5 percent level)[17]. The point estimate of α_1 (0.46) broadly matches other estimates in the literature: Smets and Wouters (2003) obtain 0.31 in their area-wide SDGE model estimated with 1980-1999 quarterly data with Bayesian techniques, whereas Smets (2003) obtains 0.48 in a simple 2-equation model estimated with annual 1980-1999 data using GMM[18]. Benigno and López-Salido (2002) report estimates of α_1 that differ across European countries; they rank Germany at the lower end with 0.04, and classify Italy as the most persistent country with an estimate of 0.55. However, note that their results are based on an older sample period (1970-1997), characterised by larger cross-country differences in inflation. Note that our point estimate (0.46) is surrounded by a rather large standard error (0.21): hence other values of α_1 located in the central region of the admissible [0, 1] range are also plausible on the basis of our results.

For the slope of the Phillips curve (parameter β) our value of 0.09 is about half of that obtained by Smets (2003); however he uses annual data, which naturally leads to larger estimates for this parameter. The passthrough coefficient in the inflation equation is equal to -0.08, which compares with coefficients of -0.04 and –0.07 in Angeloni, Kashyap, Mojon

[16] For example, in an influential paper Cecchetti (1999) suggested that the national transmission mechanisms differ among euro area countries due to a variety of institutional reasons. This could be a source of economic divergence under a single monetary policy.

[17] The restriction is consistent with optimising behaviour if the rate of time preference is unity; see for example Benigno and López-Salido (2002).

[18] Galí, Gertler and López-Salido (2001) obtain a lower level of persistence: between 0.04 and 0.27.

and Terlizzese (2003a; table 2) and a range between -0.1 and -0.3 obtained by Honohan and Lane (2003)[19].

The estimates of the backward and forward parameters in the output gap equation (α_3 and α_4) conform less well to the theoretical priors from optimising models. We found no evidence of forward-looking behaviour here. On the contrary, the backward-looking coefficient is very precisely estimated at 0.51. In the spirit of remaining close to the data, we use this purely backward looking formulation as our benchmark model, despite its lesser theoretical appeal. We have explored the sensitivity of the results in two alternative formulations: a pure forward-looking one and a hybrid one in which the backward- and forward-looking coefficients are restricted to sum to one (the results are reported in a footnote in section 5.5).

The estimates concerning monetary policy transmission seem to confirm the earlier evidence regarding the existence of two country groups. In fact, we cannot reject in our panel the hypothesis that in the "weak interest rate channel" group δ equals zero: a result somewhat more extreme than the one reported by Angeloni, Kashyap and Mojon (2003), who find that the transmission mechanism works with the expected sign in all countries. In the table we also report estimates obtained assuming a homogeneous interest rate coefficient in all countries; the order of magnitude is comparable to that in earlier papers. Concerning, finally, the elasticity to the real exchange rate across countries, we again assume two country groups, based on the degree of openness to international trade, and estimate the coefficients. Signs and relative size of the coefficient are broadly in accordance with earlier estimates reported in the table.

5. Sensitivity analyses

Figures 6 to 9 report the impulse responses to a variety of single-period unitary shocks in our benchmark model.[20] The figures show profiles of inflation and output following demand and cost-push shocks in one country (Germany in this example) or demand and cost-push shocks of equal size in all countries. We show results for each of the 12 countries and for aggregate area-wide inflation and output gap, as well as the cross-country dispersion of inflation and the output gaps, measured by the simple standard deviation. We assume in all cases that monetary policy follows a simple rule of the type $r_t = 1.5 E_t \pi_{t+1}$, i.e. the short-term interest rate reacts to expected inflation with a coefficient greater than unity in accordance with the "Taylor principle", and that the exchange rate is constant. We will analyse different monetary policy rules and exchange rate determination mechanisms in the next sections.

Several results are worth noting. First, the model generates economically significant inflation and output differentials. Focusing first on the idiosyncratic shocks (figures 6 and 7), we see that the disturbance in Germany (dotted line) is transmitted to the other countries in a heterogeneous fashion already in the initial quarters. Inflation dispersion tends to be larger and more long-lived than output dispersion in most cases. Area-wide average effects are generally rather short-lived. It is interesting to note that a cost-push shock in Germany produces *both* an increase in inflation (on impact) *and* an initial increase in output (developing gradually). This rather unusual result depends on the real interest rate, which declines on impact; the deflationary effect through lower German competitiveness develops

[19] Honohan and Lane (2003) calculate the passthrough after one year; this can explain why their estimates are somewhat larger.

[20] We decided to use a single-period shock, and not a persistent one, to better illustrate the properties of the model in the simplest possible case. Our estimates are consistent with the hypothesis that the residuals in all equations are white noise.

more slowly. In the short run, the country subject to a cost-push shock is able to export all the deflationary output effect to the rest of the area.

As one expects, common shocks affect the euro area average more than idiosyncratic shocks; the latter, in turn, tend to generate large differentials but move the mean relatively little. The impulse responses of the output gap to a common cost-push shock reveal that the adjustment process in the more open economies like Ireland (dotted line in the second panels) differs strongly from those in the other countries. Looking at area-wide average effects, common area-wide demand shocks move inflation and output in the same direction, as expected, whereas common cost-push shocks move them in the opposite direction[21].

In the remainder of this section we analyse the sensitivity of the results to changes in the model parameters, focusing on inflation differentials. For this purpose, we summarise the shape of its impulse response of inflation dispersion with two parameters: the "maximum dispersion" (peak of the impulse response) and the "half life" (number of quarters where the cumulated impulse response reaches one half of its final value). We still consider the same four shocks as above (two idiosyncratic, two common). We analyse the sensitivity to departures from our benchmark model, within equal confidence ranges (plus or minus two times the standard deviation for each parameter), in five directions:

1) Changes in the size of the shocks;
2) Changes in the monetary policy transmission mechanism;
3) Changes in the degree of inflation persistence;
4) Changes in the slope of the Phillips curve;
5) Changes in output persistence or the size of the external spillovers.

In tables 4 to 11 the second column reports the size of the largest characteristic root of the system, which needs to be lower than one for stability. The shaded area in the table highlights the "confidence region" comprised between plus or minus twice the standard error of our estimate; and darker shading denotes the benchmark value of the parameter. The other columns in the table show the maximum dispersion and the half-life of inflation dispersion for each of the four shocks.

5.1 – Size of shocks

Following Bayoumi and Eichengreen (1993), several authors have pointed at asymmetric country shocks as a main potential driver of heterogeneous cycles in the euro area. In our model, countries are subject to asymmetric demand and cost-push shocks with an estimated covariance matrix. Increasing the size of the shocks (table 4) increases inflation dispersion but does not change the time profile of this dispersion, as expected due to the fact that the shocks enter linearly in our model. Idiosyncratic shocks produce more inflation dispersion than common shocks, and cost-push shocks produce more dispersion than demand shocks, as was already apparent from the impulse responses. The most interesting indication from this table is that, within our estimated confidence range for the size of the shock, the variation in the size of inflation differentials is not very large. Under a common cost-push shock, (the one that potentially gives rise to the largest inflation differences), the standard deviation of inflation rates changes by about 0.2 relative to the benchmark. This can be judged against the fact that the standard deviation of inflation in the recent historical data is in the order of 1 percent.

[21] In another simulation exercise, not reported here, we mimicked the convergence process starting from the pre-EMU price levels. As shown in figure 4, such levels (as measured by OECD) diverged considerably from PPP. Our model suggests that convergence to equilibrium should have taken place quickly and with considerable oscillations around the steady state. On the contrary, the OECD data suggest that convergence is monotonic and slow. A possible explanation of this puzzle is that the initial one-off price convergence process may be more gradual than the dynamic adjustment following shocks around a steady state, since it presupposes a structural change in the degree of product market integration. We plan to explore this issue further in future work.

5.2 – Monetary transmission parameters

Our experiments here consist in changing the parameters of the transmission mechanism while leaving all the other parameters in the model at their benchmark values. First, we vary the strength of the transmission mechanism (expressed by δ) homogeneously in all countries. Second, we differentiate the transmission parameters; we do this by progressively increasing, from zero, the differentiation between the "weak" and the "strong" transmission countries, following the country classification explained in section 4.

The main message coming from these results is that, within our confidence ranges, the increase in inflation differentials following a *homogeneous increase* in the strength of monetary transmission is greater than that resulting from *more differentiation* across countries. A stronger monetary transmission even if equally distributed across countries tends to generate greater inflation differentials, because with a common nominal interest rate countries with high inflation receive a further inflationary stimulus (and vice versa), which amplifies the initial gap. This pro-cyclical effect remains limited until one approaches the upper part of the confidence region for the monetary transmission parameters. As δ grows further out of this region, the model tends to become dynamically unstable[22]. On the other hand, cross-country differences in the strength of the interest rate channel within the plausible range have a more limited effect.

5.3 – Inflation persistence

We perform three experiments here. In the first (top panel) the value of the persistence parameter is kept equal in all countries and varies within its confidence range. In the second (middle panel), persistence is differentiated in two country groups, "high persistence" and "low persistence"[23]. In the third (lower panel) only one country is classified as having "high persistence". Through these three examples we try to measure, respectively, the implications of different levels of inflation persistence generalised across all countries of the monetary union, as opposed to the effects of high persistence concentrated in a group of countries or even only in one of them.

The results of the first experiment are remarkable because they indicate that even a small increase in persistence from the benchmark value, well within the confidence range, can increase inflation divergence sharply and make the system dynamically unstable. The threshold value of α_1 where unstable solutions arise is just below 0.5, against a benchmark value of 0.46. This happens both when all α_1 are equal, and when they are differentiated in two groups (second experiment). Even when only one country is classified as persistent (third experiment), instability arises when its persistence parameter rises just above 0.5. This suggests that there is a critical range of values for this parameter, at which the size of inflation differentials in the union tends to grow very sharply; this range depends on whether the relatively high persistence occurs in one country or in several of them. We will examine this critical region in more detail in section 6.

[22] Dynamic instability is a situation in which the number of roots outside the unit circle is higher than that of non-predetermined variables, so that the model solution is explosive. Indeterminacy is the situation when it is lower, so that the model has multiple solution paths.

[23] Specifically, we included France, Greece, Ireland, Italy and Portugal in the "high persistence" group, following Nicoletti, Scarpetta and Boyland (2000) who identify these countries as those with stricter product market regulation. Admittedly, this classification is very tentative and should be refined when clearer evidence on the relative extent of inflation persistence in euro area countries becomes available.

5.4 – The slope of the Phillips curve

We explore here both changes in the value of β, keeping its value equal in all countries, and a differentiation of β in two groups, following the same country classification used in the previous subsection.

The results show, interestingly, that an increase in the slope of the Phillips curve, which can be interpreted as a measure of price flexibility, tends to increase the size and the duration of inflation differentials. Under asymmetric demand shocks this is rather intuitive: a higher β translates these shocks directly into higher inflation differentials. Less intuitive is the fact that this carries over to other shocks as well. The useful indication to be drawn from this result is that more price level flexibility (higher β) tends to produce higher inflation differentials, unless, of course, this is accompanied by lower inflation persistence (lower α_1).

An interesting limiting case arises if $\beta = 0$; in this case, output gaps cease to have an impact on inflation and differences in real effective exchange rates can no longer be corrected through different inflation rates. Accordingly, price levels do not return to equilibrium, as reflected by the fact that the maximum root equals unity. On the contrary, inflation rates do return to baseline eventually. For high common values of β, just outside its confidence region, the system tends to become unstable. This does not happen when β is differentiated in two country groups. Note that the extreme case where the lower is equal to zero and the higher one is 0.18 gives rise to indeterminacy in the model.

All in all, these examples show that cross-country differentiation of the slope of the Phillips curve in our model tends to have a sizeable impact on inflation differentials within the confidence range, something that echoes the result of Andres, Ortega and Vallés (2003). However, such impact is much lower than that exercised by inflation persistence[24].

5.5 – Output persistence and international spillovers

Changing the output persistence parameter also produces larger inflation differences, but only if the relevant parameter reaches the upper edge of its confidence range[25].

We examine the sensitivity with respect to the real exchange rate elasticity of output by both changing the value of λ, keeping it equal across countries, and differentiating λ in two country groups (one of which more open to international trade[26]). Note, first, that when $\lambda = 0$, price level differentials cease to feed back on output; as in the case noted earlier, price levels cannot return to equilibrium after a shock (as reflected by a maximum root exactly on

[24] As we noted in section 2, Andres, Ortega and Vallés (2003) conclude that the differences in the slope of the Phillips curve are the major factor behind euro area inflation differentials.

[25] The results are somewhat sensitive to the way in which the output gap equation is specified. We have experimented with two alternative formulations for the output gap equation, in addition to our benchmark one. The first assumes a purely forward-looking output gap equation; with this formulation the results of the benchmark model are broadly confirmed but somewhat weakened. Inflation persistence continues to be the most important driver of inflation differentials, though it no longer generates explosive oscillations. A forward-looking behaviour of output tends to stabilise the model. The second formulation for the output gap equation is a mixed backward- and forward-looking specification, with parameters restricted to sum to unity. Here, inflation differentials become very sensitive to the degree of output persistence within the confidence range.

[26] Following Andres, Ortega and Vallés (2003), we classified all countries with a ratio of consumption of domestically produced goods to domestic output below 0.5 as most open to trade. As they document, this is the case for Belgium, Ireland and the Netherlands; furthermore, however, it holds also for Luxembourg.

the unit circle). The real exchange rates do not return to the steady state value, while inflation rates do. As the value of λ rises (equally for all) above zero, inflation differentials and their duration tends to fall; this is clearly intuitive, since cross-country spillovers via changes in real exchange rates tend to re-equilibrate inflation differences. Country-by-country differentiation of λ does not seem to matter much until in some countries $\lambda = 0$, in which case again price levels cannot converge.

5.6 – Summary

In sum: within our confidence ranges for the parameters, small changes in inflation persistence are capable of producing very sharp (in the limit, even unbounded) increases in inflation differentials. Other factors (monetary transmission and its differentiation; the slope of the Phillips curve and its differentiation; output persistence) play a significant, but less important role.

6. The role of monetary policy

So far we have assumed the simplest possible form of monetary policy rule: $r_t = 1.5 E_t \pi_{t+1}$. We now extend our analysis in two directions. First, we check whether our earlier results are sensitive to changes in the monetary policy rule. Second, we analyse how a monetary policy geared to area-wide price stability affects inflation differentials. In looking at both questions we are naturally interested in whether monetary policy can alter the tendency towards large inflation differentials that arise in our model in certain regions of the parameter space.

We consider extensions of the policy rule of the form:

$$r_t = \rho r_{t-1} + (1-\rho)[\varphi_\pi E_t \pi_{t+k} + \varphi_y gap_t],$$

where ρ measures the inertia of the nominal short-term interest rate, φ_y measures the interest rate response to the area-wide output gap, and k measures the extent to which the policy rule is forward-looking on inflation. The rule considered earlier is a special case, with $\rho = 0$, $\varphi_\pi =$ 1.5, $k = 1$ and $\varphi_y = 0$.

Table 9 shows the results of changing ρ and φ_y while leaving $k = 1$ and φ_π constant at 1.5. Our earlier results remain essentially unchanged for alternative values of ρ and φ_y over a wide range. Inflation differentials (size and duration) increase slightly only for very large values of ρ and remain identical for all values of φ_y.

More interesting are the results in table 10, where the policy horizon is extended up to three years into the future (the two panels in this table should be compared with the benchmark case, reported on top of table 11). Our analysis here is related to that of Batini, Levine and Pearlman (2004), who study the performance of forward-looking rules in open economies with floating exchange rates; they find that such rules generate indeterminacy when the forecast horizon lengthens beyond a certain threshold. We are interested in seeing if this result carries over to our model of the euro area. In the table we see that the benchmark results remain essentially unchanged if k rises from 1 to 6 quarters, but change significantly if we move up to 12 quarters. Highly forward-looking rules tend to generate indeterminacy, the more the higher is the value of φ_π [27].

Our next question focuses on the interaction between an aggregate area-wide inflation goal for monetary policy and inflation differentials, when inflation persistence is present. To approach this question we return to our simple rule $r_t = \varphi_\pi E_t \pi_{t+1}$ and examine the combination of alternative degrees of persistence and policy "activism" (values of φ_π ranging from zero to large positive numbers), seeing what they imply for inflation differentials as well as for aggregate inflation[28].

In table 11 we show three examples. In the first, inflation persistence (parameter α_1) is set to our benchmark value of 0.46 in all countries. In the second, α_1 is set to zero for all countries but one, which is set to 0.5. In the third we replicate the latter experiment but assume that monetary policy assigns a larger weight to the country where inflation is more persistent[29]. This assumption follows in spirit the idea of Benigno (2003), recalled already in section 2, according to which highly persistent countries should receive a higher weight in the central bank's decision making function.

In the first case (top panel; α_1 equal for all) a high degree of monetary activism does reduce inflation dispersion (both its size and its half-life) under common shocks, while it is not influential under idiosyncratic shocks. This suggests that there may be complementarity between aggregate inflation and inflation differences under common shocks, more policy activism (in the sense defined earlier) helping on both fronts. This is the case also when persistence is differentiated across countries (middle panel), though, as one would expect, given the high asymmetry introduced in the model in this way the level of inflation divergence rises dramatically. Note that when the inflation persistence parameter in one country is set to 0.5, the system is unstable if monetary policy does not react strongly enough to inflation (i.e., φ_π at 0 or 0.5). In this case, a higher φ_π both stabilises the model and reduces inflation differentials under common shocks. Finally, if we let the country with high persistence receive a larger weight in the policy rule (lower panel), we get again similar results, but the range of parameters leading to instability seems to shrink: for example, a value of φ_π equal to 0.5 is sufficient for stability.

Figure 10 explores this issue further, showing in the (α_1; φ_π) parameter space the regions where instability occurs, in the different models generated by alternative assumptions about α_1. When all α_1 are equal (long dashed line) the parameter space is nearly equally divided into the stability and instability region; for α_1 close to a threshold value around 0.5, the model

[27] It would be interesting to examine in the context of our model questions concerning the "optimal horizon" of monetary policy, of the type studied by Batini and Nelson (2001) and Smets (2003) with very similar single-country models. We leave this extension to future work.

[28] Angeloni, Coenen and Smets (2003) study the performance of alternative monetary policy rules in an aggregate area-wide model when the central bank is uncertain about the true value of inflation persistence. They find that under uncertainty the central bank is better off assuming a high degree of inflation persistence. In principle one could use our model to extend their analysis to a multi-country framework, considering also the implications for inflation dispersion. We leave this to future work.

[29] In our simulations, the persistent country receives a weight of 0.8; the remaining 0.2 are distributed among the other countries according to their size.

has stable solutions for all values of φ_π, whereas for α_1 higher than that threshold, the model is unstable for all φ_π. If one country is persistent (short dashed line), the instability region shrinks and the boundary between the two regions becomes positively sloped: the important implication is that, in this case, a high value of φ_π can restore stability. The area that is delimited by the long and short dashed lines contains the intermediate cases, where all other countries are set to (equal or different) values of α_1 below the threshold. If the persistent country receives a higher weight (continuous gray line) the instability region shrinks markedly. It is interesting to note that the instability region in this case is very similar to the one arising in the case of a single country, with the same degree of inflation persistence. The latter is shown in the figure for comparison (continuous black line). Intuitively, if only one country in the area has persistent inflation, the stability properties of the model tend to coincide with those of that country taken in isolation[30].

Figure 11 shows combinations of stability of area-wide inflation and inflation differentials that can be obtained with different values of φ_π, in our benchmark model under common demand and cost-push shocks. Aggregate inflation stability is measured by the integral of the absolute deviation of the impulse response of euro area inflation from steady state; inflation differentials are measured by the integral of the impulse response of inflation dispersion from steady state. The value of φ_π is allowed to range between 0 and 10; the values of 1 and 1.5 are denoted in the figure respectively by a small cross and a small circle. All lines are positively sloped, illustrating the complementarity relation: as φ_π increases, economic outcomes move towards the origin, with less deviations of inflation from its long-run level and lower inflation differentials.[31] If all countries' inflation is equally persistent (long dashed and continuous line) the set of attainable combinations is closer to the Y-axis than in the case where persistence exists in one country only, as one would expect.

7. Alternative exchange rate models

So far we have assumed that the expected exchange rate remains constant. In this section we briefly examine the implications of two alternative exchange rate determination models, more commonly used in theoretical work: pure Uncovered Interest Parity (UIP), and UIP augmented by a risk premium.

Pure UIP can be written as follows:

$$r_t = r_t^* + [E(neer_{t+1}) - neer_t]$$

[30] A policy rule with weights determined according to the degree of inflation persistence is an interesting concept, but probably not an advisable or even realistic option. First and most basically, price stickiness and inflation persistence are hard to measure, as the controversy surrounding this issue demonstrates. Estimates that can easily be challenged hardly constitute a good basis for practical policymaking. Second, it has been argued that price inertia is affected by expectations and hence is probably endogenous to policy. If so, it would seem unwise to crystallise in a policy rule national features that are endogenous to the rule itself. Such rule could even discourage national reforms of the price formation mechanism that could eventually enhance welfare for the whole area (Benigno and López-Salido, 2002, make this point). To better understand all these aspects one would need a model where the price inertia mechanisms are endogenous.

[31] This complementary relation is invariant to the level of the steady state inflation in our model. We are grateful to Jürgen von Hagen for pointing this out to us.

Where as before $neer_t$ is the nominal effective exchange rate (an increase means appreciation), and r_t^* is a representative foreign short-term interest rate (constant in our case). A more general version of UIP includes a time-varying risk premium:

$$r_t = r_t^* + [E(neer_{t+1}) - neer_t] + \psi_t$$

Small open economy models such as ours under rational expectations and pure UIP tend to generate indeterminate solutions; a way to restore uniqueness of equilibria is to postulate that UIP is augmented by a debt-dependent risk premium (see Schmitt-Grohé and Uribe, 2003). In our model, the "augmented UIP" rule needs to pin down the exchange rate level in steady state. In the spirit of Lane and Milesi-Ferretti (2001) we assume that the risk premium ψ_t depends on the value of the euro area residents' net foreign asset position; the latter in turn depends on the exchange rate. Based on information on euro area net foreign assets and their currency denomination, we approximate ψ_t linearly as $\psi(neer_t)$, where $\psi = 0.1$.[32] This means that a unitary increase in the euro effective exchange rate implies, other things equal (specifically, for given exchange rate expectations), an increase in the interest rate differential of 10 basis points.

To compare the properties of our model under the two alternative exchange rate rules we first identify the regions of the parameter space where indeterminate or explosive solutions occur; this is done in fig. 12. For comparison we also show two limiting cases: the "closed economy" (which assumes that no trade between the euro area and the rest of the world takes place), and the "single economy", where the euro area is treated as a single entity. The charts in the first column are obtained letting the coefficient of inflation persistence vary identically in all countries from zero to one. The next two columns show the cases where only one country is persistent, and the policy rule is, respectively, size-weighted and re-weighted so as to assign a higher weight (80 percent) to the persistent country. Finally, the last column shows the single country case.

The figure provides several interesting insights. First of all, pure UIP indeed greatly increases the area of indeterminacy, especially when the model is strongly forward-looking (low persistence). When persistence is high, uniqueness of solutions can be restored by an active monetary policy (high φ_π). The properties of the model when only one country is persistent tend to approach those of the single country case, as intuition suggests. In this model, as expected, "augmenting" the UIP condition with a risk premium increases the areas of the parameter space where unique and stable solutions occur. Again there is considerable similarity between the case where only one country is persistent and that of the single country.

Under "augmented UIP", the "benchmark" model examined in the previous sections (marked in the charts by the black diamond) is located close to the intersection between the determinacy and the indeterminacy region, slightly within the latter. In this case, a slightly lower persistence, or a slightly weight on inflation in the policy rule, are sufficient to restore uniqueness.

[32] Gross foreign financial assets held by euro area residents amounted to some 7.300 bn. euro at end-2002 (see ECB Monthly Bulletin, April 2004, table 7.4), more or less counterbalanced by equivalent gross liabilities. We assume that all liabilities are denominated in euro and conjecture, based on partial information, that about 80 percent of foreign assets are denominated in foreign exchange. This leads to an estimated currency mismatch in the aggregate euro area residents' financial portfolio of about 6.000 euro, or about 5 times the annual value of euro area exports (goods and services). Lane and Milesi-Ferretti (2001, table 8) estimate that in the average of OECD countries a unitary increase in the ratio of NFA to exports lowers the risk premium on domestic interest rates by 100 basis points. In our case this means that a one percent euro appreciation reduces the NFA/export ratio by 5 percent and rises the risk premium by 5 basis points. We adjusted this estimate upward to 10 basis points to take into account other components of wealth not included in net foreign assets.

To check the robustness of the sensitivity exercises we have also replicated the calculations reported in tables 4-11 using our "augmented UIP" assumption. The results (not reported here for brevity) suggest the following few qualifications. In general, exchange rate floating tends to generate larger inflation differentials particularly following common shocks. It is still true that inflation persistence amplifies inflation differentials, and generates explosive solutions within our plausible parameter range, as was the case under constant exchange rate. However, as one would intuitively expect, the results become much more sensitive to the monetary policy rule. Specifically, interest rate inertia reduces inflation differentials, whereas assigning a positive weight to the output gap tends to reduce their magnitude somewhat, while increasing their persistence. In some cases, a more active monetary policy rule (large φ_π) actually *increases* inflation differentials and *destabilises* area-wide inflation, as a result of larger exchange rate oscillations under UIP. A more extensive analysis of monetary policy rules and exchange rate mechanisms in our model is warranted, but we see it as beyond the scope of this paper and we leave it to future work.

8. Conclusions

Inflation and growth divergences among euro area countries are likely to remain prominent in European political and popular debates for a long time, and for good reasons. In the euro area regional economic divergences are more likely to occur than in other currency areas, a phenomenon that can only increase once the area is enlarged to new entrants.

In this paper we build a stylised empirical model of EU-12 where the determinants and the monetary policy implications of inflation and other cyclical differences among member countries can be analysed. Our skeleton model includes two equations for each national economy (an aggregate demand and an aggregate supply), linked by trade, which differ across countries only for a few well-identified factors: national economic disturbances; monetary transmission mechanisms; degree of openness to international trade and response to external shocks. Our main findings are twofold. First, inflation persistence, in one or more countries, is under plausible parameter values the factor that can propagate inflation differences most. Other explanations that have received more attention in the literature in recent years, like country-specific shocks or differences in the monetary transmission mechanism, seem to count less. Second, a monetary policy that is geared to minimising the deviations of average area-wide prices from their long-run values is likely to lead also to low cross-country inflation differentials. It is important to stress that our results are positive, not normative; our model does not permit formal welfare analyses. The point we make is, simply, that in our model of the euro area these two conclusions hold.

The fundamental question we leave open – is inflation persistence indeed an intrinsic phenomenon in euro area countries? – is an empirical one. The sketchy estimates we provided in table 3 obviously cannot do justice to this very complex and important question, on which views are divided. Some have argued that inflation persistence is the by-product of monetary policy regimes that are unable to anchor long-term inflationary expectations[33]. If so, we should see in the coming years dramatic drops in inflation persistence in all euro area countries from the current levels, which as we have shown are quite consistent with the existence of a powerful mechanism of propagation of inflation differentials. Others[34] see persistence as a more structural and long-lasting phenomenon. A variety of empirical projects now ongoing will hopefully provide part of the answers[35].

[33] See e.g. Levin and Piger (2004).

[34] See e.g. Galí, Gertler and López-Salido (2001).

[35] One is the "Inflation Persistence Network", a team set up by the Eurosystem central banks to measure patterns and determinants of inflation persistence in the euro area using micro, macro and survey data; see ECB website for some more details. The group will deliver its results in 2005.

Meanwhile our own analysis could be improved and extended in several directions. First, the model could be made more realistic. A more detailed multi-country model, such as the one that the central banks of the Eurosystem are trying to build jointly in an ongoing project[36] could provide a better representation of the euro area internal adjustment mechanism. Also, as more data become available, it will be possible to include further variables and to relax some of the cross-country homogeneity restrictions that we have applied to our model. Second, our model could be re-specified to include explicit micro-foundations. This would permit to analyse, in a realistic setting, normative questions concerning monetary policy. Finally, a model like ours could be used to analyse problems of inflation and cyclical divergence in an enlarged euro area. All these extensions are useful directions for future work.

[36] See www.ecb.int for more information.

Appendix 1: Data Description

- National Harmonised Index of Consumer Prices (figures 1, 2, 3, 5, tables 1, 2, 3): Data source Eurostat
- US Metropolitan Statistical Area (MSA) and Census Region Consumer Price Indices (figure 1, table 1): Data source Bureau of Labor Statistics. MSAs are: Atlanta, Boston, Chicago, Cleveland, Dallas, Detroit, Houston, Los Angeles, Miami, New York, Philadelphia, San Francisco, Seattle, Washington. Census Regions are: Midwest, West, South and Northeast
- Italian City and German Länder Consumer Price Indices (figure 2): Data source Datastream. Italian cities are: Ancona, Aosta, Bari, Bologna, Cagliari, Campobasso, Firenze, Genova, L'Aquila, Milano, Napoli, Venezia. German Länder are: Baden-Württemberg, Bayern, Berlin, Brandenburg, Hessen, Mecklenburg-Vorpommern, Niedersachsen, Nordrhein-Westfalen, Saarland, Sachsen, Sachsen-Anhalt, Thüringen
- Spanish Autonomous Communities Consumer Price Indices (figure 2): Data source Instituto Nacional de Estadística. Autonomous Communities are: Andalucía, Aragón, Asturias, Baleares, Canarias, Cantabria, Castilla y León, Castilla-La Mancha, Cataluña, Valencia, Extremadura, Galicia, Madrid, Murcia, Navarra, País Vasco, Lo Rioja, Ceuta y Melilla
- PPP level of consumer prices (figure 4, table 2): Data source OECD Main Economic Indicators
- GDP growth, euro area countries (figure 3): Data source Eurostat ESA95 database
- US$/euro exchange rate (figure 5): Data source Datastream
- Nominal effective exchange rate (tables 2, 3): Data source IMF, IFS database
- Output gap, annual (table 2): Data source OECD Economic Outlook
- Fiscal stance: Primary Government Balance, Cyclically Adjusted, in % of potential GDP (table 2): Data source OECD Economic Outlook
- Output gap, quarterly (table 3): Constructed using the HP-filter (λ=1600) from GDP data, Data source Eurostat ESA 95 database, seasonally and working day adjusted
- Interest rates (table 3): 3 month money market rates, Data source Reuters
- Real effective exchange rate, quarterly (table 3): Real national competitiveness indicator, CPI deflated, against the currencies of United States, Japan, Switzerland, United Kingdom, Sweden, Denmark, Greece (excluded as from 1 January 2001), Norway, Canada, Australia, Hong Kong, South Korea, Singapore, Algeria, Argentina, Brazil, China, Croatia, Cyprus, the Czech Republic, Estonia, Hungary, India, Indonesia, Israel, Malaysia, Mexico, Morocco, New Zealand, the Philippines, Poland, Romania, Russia, Slovakia, Slovenia, South Africa, Taiwan, Thailand and Turkey. Data source: ECB

  For the simulations of the model, the real effective exchange rate of each country was modelled as $reer = e + p - p^*$, where p^* is defined as a weighted average of foreign price levels, where the weights are given through a set of trade linkages. For example, for a country A, the weight of country B's price level in p^* is given by the share of trade (exports plus imports) of country A with country B in country A's total trade (exports plus imports) in 2002. The resulting trade matrix is shown below (trade shares in %). Data source: OECD Monthly Statistics of International Trade.

%	AT	BE	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	RoW
AT trade with…		1.8	0.8	4.2	36.2	0.4	0.8	7.8	0.2	2.8	0.5	2.2	42.3
BE trade with…	0.8		0.5	14.4	18.0	0.4	3.9	4.7	1.2	13.6	0.7	2.8	39.0
FI trade with…	1.1	2.6		4.4	13.0	0.6	0.9	3.5	0.1	4.2	0.5	2.1	67.0
FR trade with…	1.0	6.9	0.7		15.9	0.5	1.4	9.1	0.5	4.4	1.3	8.5	49.8
DE trade with…	4.7	5.0	1.0	10.2		0.6	1.5	6.9	0.4	7.1	1.0	3.9	57.7
GR trade with…	0.8	3.5	0.8	5.2	11.7		0.6	10.8	0.1	4.8	0.3	3.5	57.9
IE trade with…	0.4	9.7	0.7	4.7	7.0	0.3		3.2	0.1	3.5	0.4	1.9	68.1
IT trade with…	2.5	3.7	0.6	11.7	15.7	1.3	0.9		0.2	4.2	0.9	5.5	52.8
LU trade with…	1.1	24.6	0.4	17.5	25.8	0.2	0.4	3.6		4.9	0.4	2.5	18.6
NL trade with…	1.1	11.4	1.0	8.0	22.0	0.5	1.4	4.7	0.3		0.7	2.9	46.0
PT trade with…	0.7	3.6	0.4	11.0	16.4	0.3	0.7	5.7	0.2	4.3		24.8	31.9
ES trade with…	1.0	2.9	0.6	17.6	14.4	0.7	1.1	9.1	0.1	3.6	6.0		42.9

References

Alberola, E. (2000), Interpreting inflation differentials in the euro area, *Banco de España Economic Bulletin*, April: 61-70.

Altissimo, F., Benigno, P. and D. Rodriguez Palenzuela (2004). Optimal response to inflation differentials in a currency area. Paper presented at the conference "Designing a macroeconomic policy framework for Europe", CEPR and CREI, May 2004.

Andres, J., E. Ortega and J. Vallés (2003), Market Structure and inflation differentials in the European Monetary Union, *Banco de España Documento de Trabajo* No. 0301.

Angeloni, I., G. Coenen and F. Smets (2003), Persistence, the transmission mechanism and robust monetary policy, *Scottish Journal of Political Economy* 50(5), 1071-1101.

Angeloni, I., A. Kashyap, and B. Mojon eds. (2003), Monetary policy transmission in the Euro area, Cambridge University Press.

Angeloni, I., A. Kashyap, B. Mojon and D. Terlizzese (2003a), Monetary transmission in the Euro area: Does the interest rate channel explain all? *NBER Working Paper* No. 9984.

Angeloni, I., A. Kashyap, B. Mojon and D. Terlizzese (2003b), The Output composition puzzle: a difference in the monetary transmission mechanism in the Euro area and U.S., *ECB Working Paper* No. 268, *NBER Working Paper* No. 9985. Forthcoming in the *Journal of Money, Credit and Banking.*

Batini, N. and E. Nelson (2001), Optimal horizons for inflation targeting, *Journal of Economic Dynamics and Control*, 25(6-7): 891-910.

Batini, N., P. Levine and J. Pearlman (2004), Indeterminacy with inflation-forecast-based rules in a two-bloc model, *ECB Working Paper 340.*

Bayoumi, T. and B. Eichengreen (1993), Shocking aspects of European Monetary Integration, in *The Transition to Economic and Monetary Union in Europe*, eds. F. Torres and F. Giavazzi, Cambridge University Press: 193-229.

Beck, G. W. and A. A. Weber (2001), How wide are European borders? On the integration effects of monetary unions, *CFS Working Paper* No. 2001/07.

Benigno, P. (2003), Optimal monetary policy in a currency area, *Journal of International Economics*, forthcoming.

Benigno, P. and D. López-Salido (2002), Inflation persistence and optimal monetary policy in the euro area, *ECB Working Paper* No. 178.

Bergin, P. (2003), A Model of Relative National Price Levels under Pricing to Market, *European Economic Review* 47(3): 569-586.

Canova, F. and E. Pappa (2003). Price Differentials in Monetary Unions: The Role of Fiscal Shocks. Mimeo, Universitat Pompeu Fabra

Cecchetti, S. (1999), Legal structure, financial structure and the monetary policy transmission mechanism in *The monetary transmission process. Recent developments and lessons for Europe*, ed. Deutsche Bundesbank, Palgrave: 170-194.

European Central Bank (2003), Inflation differentials in the euro area: potential causes and policy implications.

Ehrmann, M. and M. Fratzscher (2004), Equal size, equal role? Interdependence between the euro area and the United States. Forthcoming, *Economic Journal.*

Galí, J., M. Gertler and D. López-Salido (2001), European inflation dynamics, *European Economic Review,* 45(7): 1237-1270.

Honohan, P. and P. Lane (2003), Divergent inflation rates in EMU, *Economic Policy,* 18(37): 358-394.

Lane, P. and G. M. Milesi-Ferretti (2001), Long-Term Capital Movements, *NBER Working Paper* No. 8366.

Levin, A. and J. Piger (2004), Is inflation persistence intrinsic in industrial economies?, *ECB Working Paper* No. 334.

Monteforte, L. and S. Siviero (2002), The economic consequences of euro are modelling shortcuts, *Banca d'Italia, Temi di Discussione* No. 458.

Nicoletti, G., S. Scarpetta and O. Boyland (1999) Summary indicators of product market regulation with an extension to employment protection legislation, *OECD Economics Department Working Papers* No. 226.

OECD (2003), Main Economic Indicators, December.

Ortega, E. (2003), Persistent inflation differentials in Europe, *Banco de España Documento de Trabajo* No. 0305.

Schmitt-Grohé, S. and M. Uribe (2003), Closing small open economy models, *Journal of International Economics*, 61: 163-185.

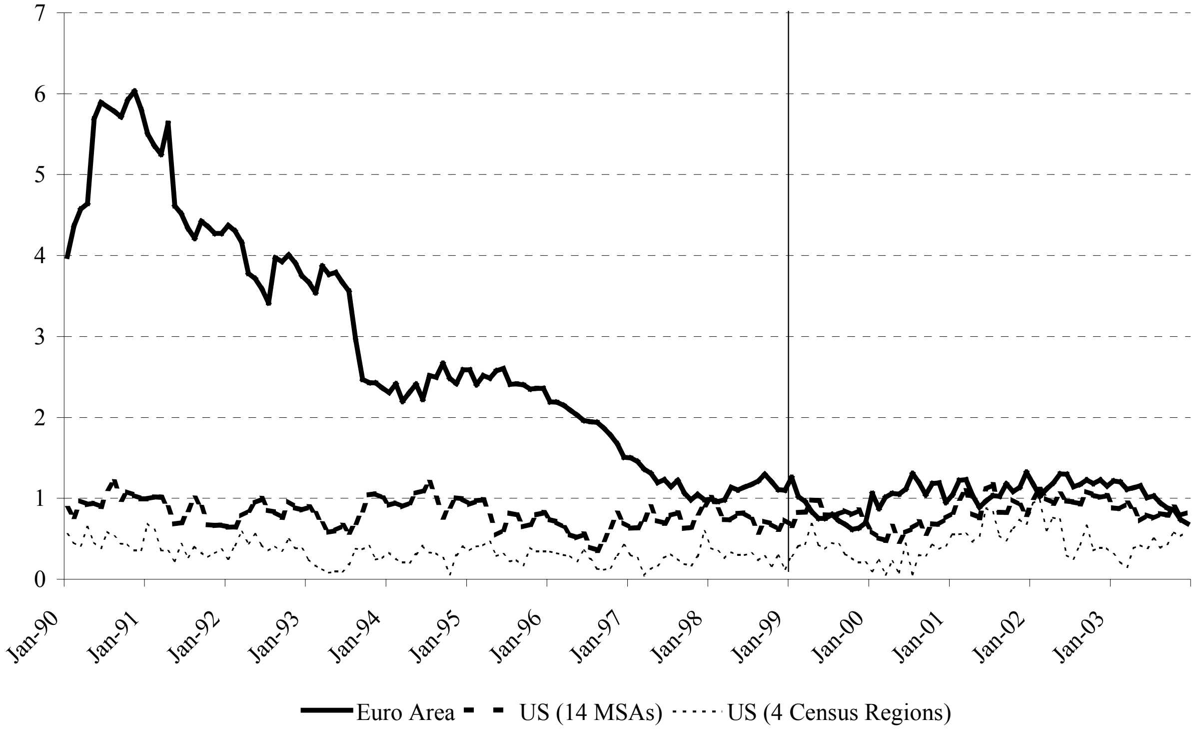
Sinn, H.-W. and M. Reutter (2001), The minimum inflation rate for Euroland, *NBER Working Paper* No. 8085.

Smets, F. and R. Wouters (2003), An estimated dynamic stochastic general equilibrium model of the euro area, *Journal of the European Economic Association*, 1(5): 1123-1175.

Smets, F. (2003), Maintaining price stability: how long is the medium term?, *Journal of Monetary Economics,* 50(6): 1293-1309.

Woodford, M. (2003) Interest and prices. Foundations of a theory of monetary policy, Princeton University Press.

Figure 1: Inflation dispersion in the euro area and the US, 1990-2003



Note: The chart shows the unweighted standard deviation of national inflation rates in the euro area, of inflation rates in 14 metropolitan statistical areas and of 4 census regions in the US.

Figure 2: Inflation dispersion in the euro area and within three euro area countries, 1990-2003

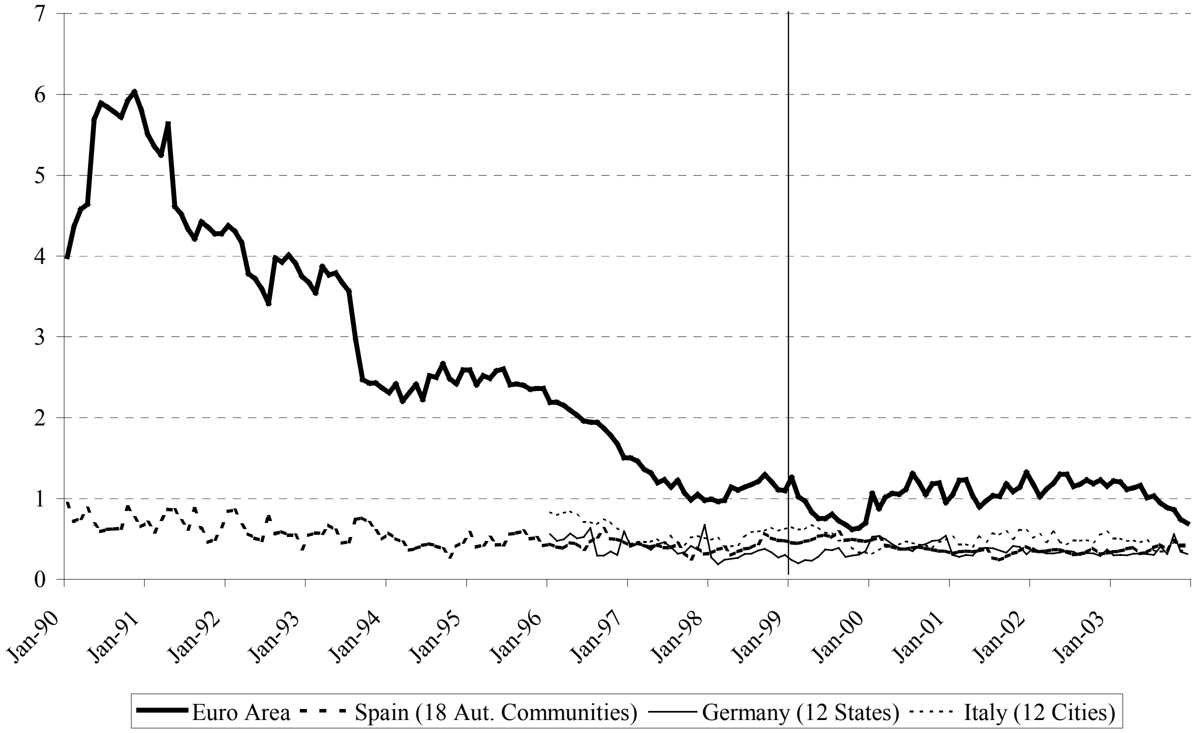
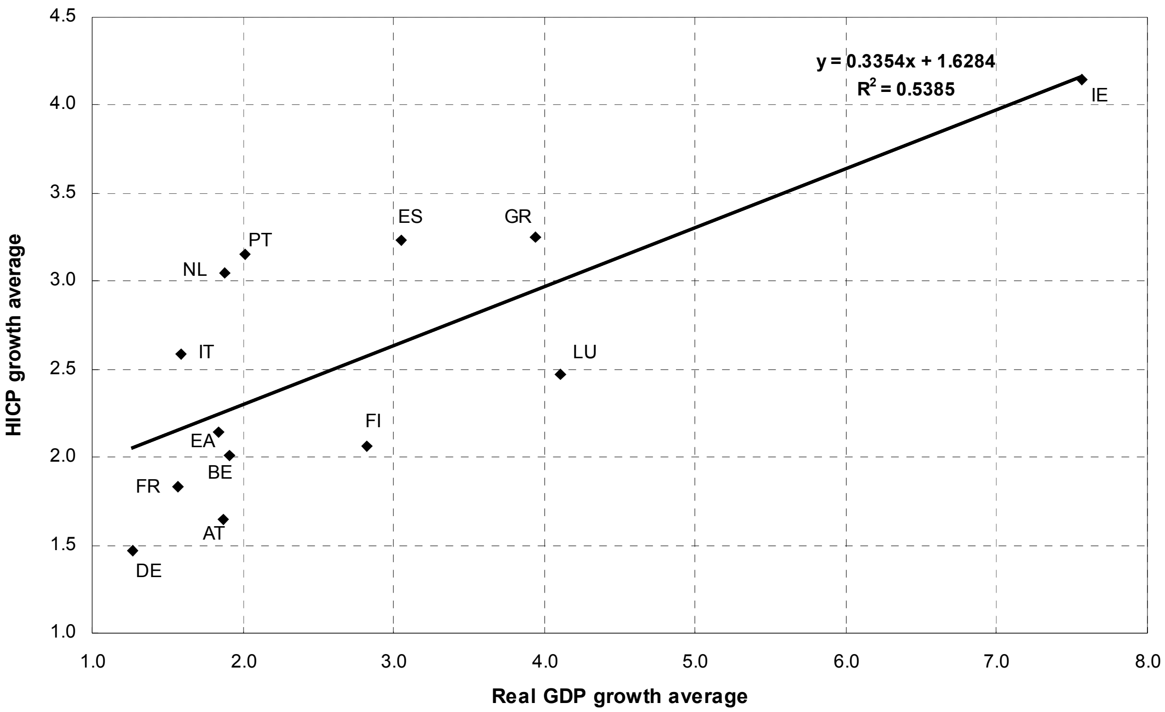
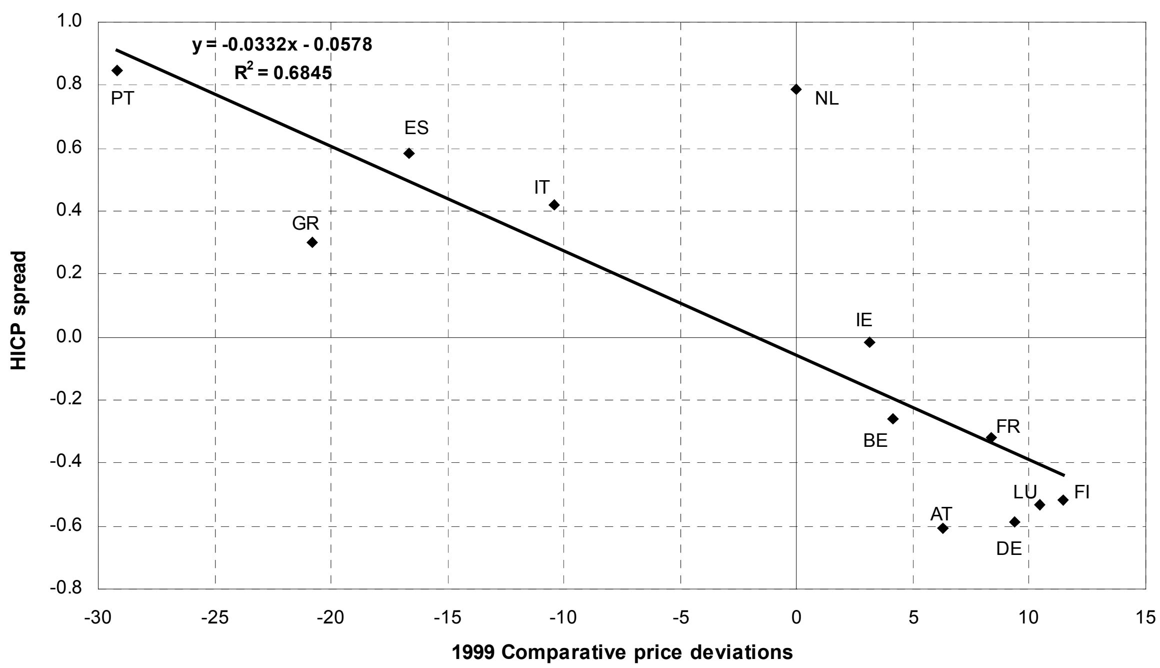


Figure 3: GDP growth and inflation, 1999-2003



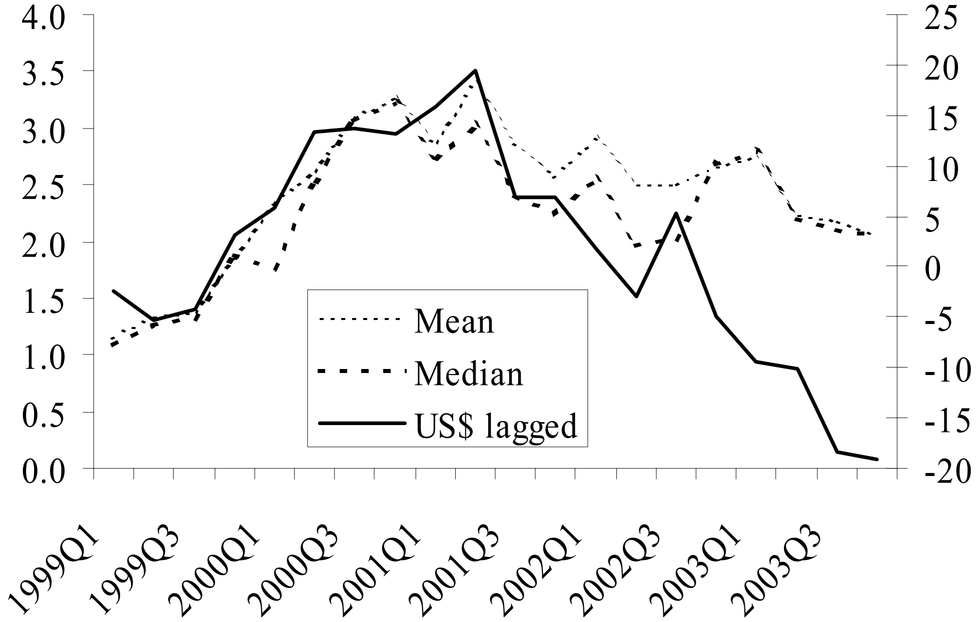
Note: The chart shows average GDP growth and average HICP inflation over the five-year period

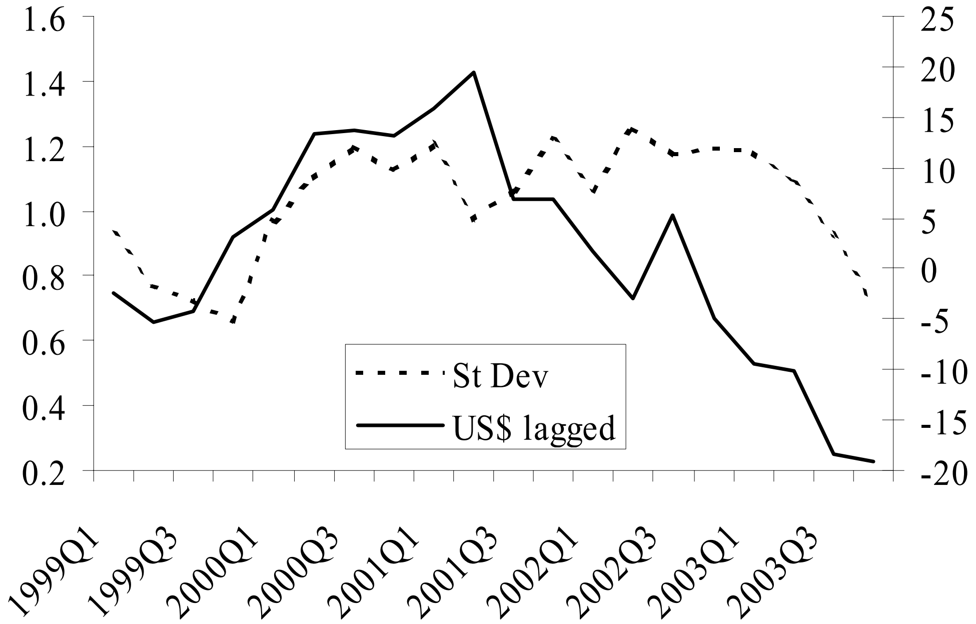
Figure 4: Deviations from law of one price in 1999 and inflation in the euro area countries



Note: The chart plots the unexplained part of average inflation in figure 3 against the deviations of consumer price levels from the law of one price in 1999. Source: See Appendix.

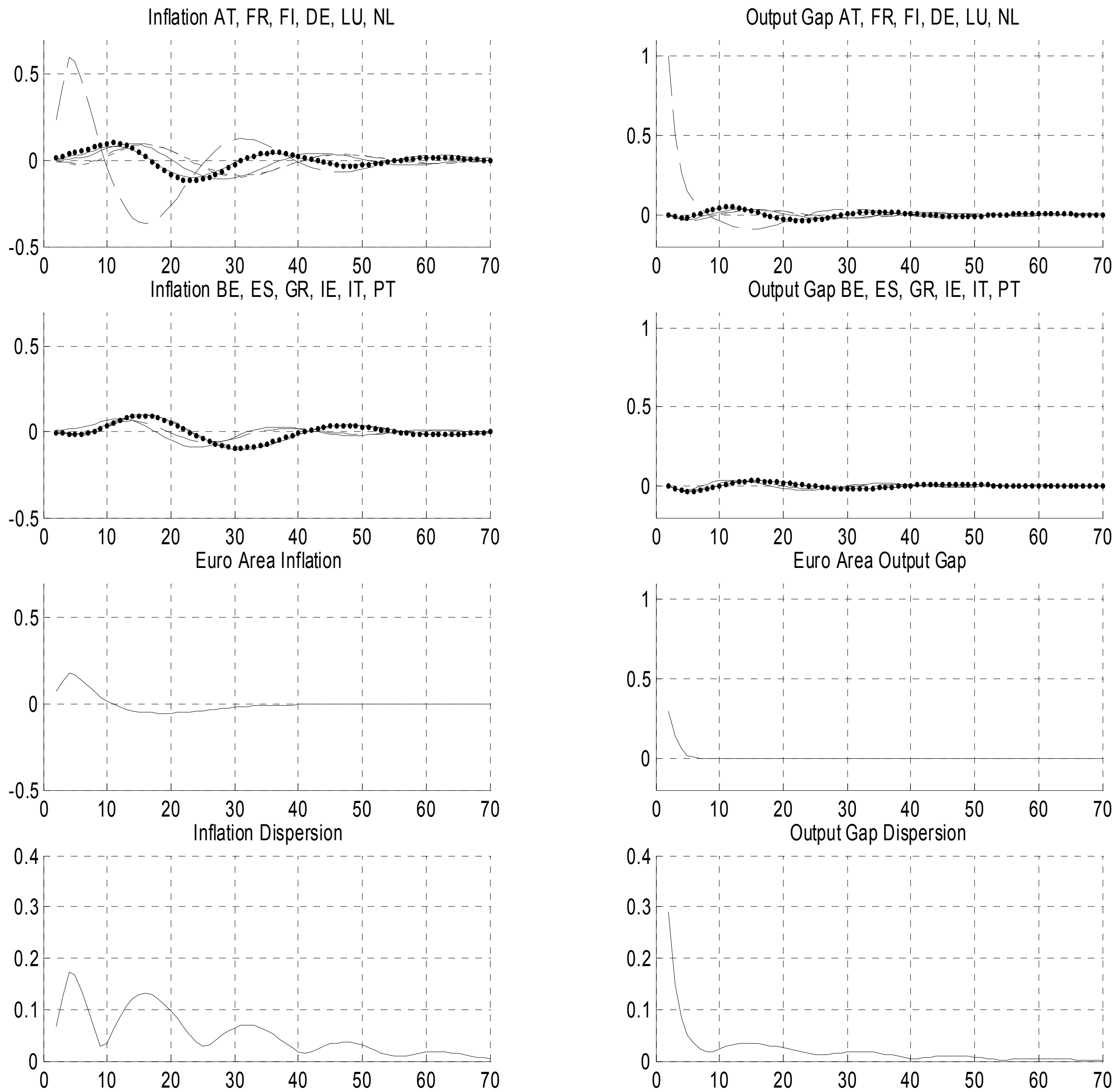
Figure 5: Exchange rate developments and inflation in the euro area, 1999-2003





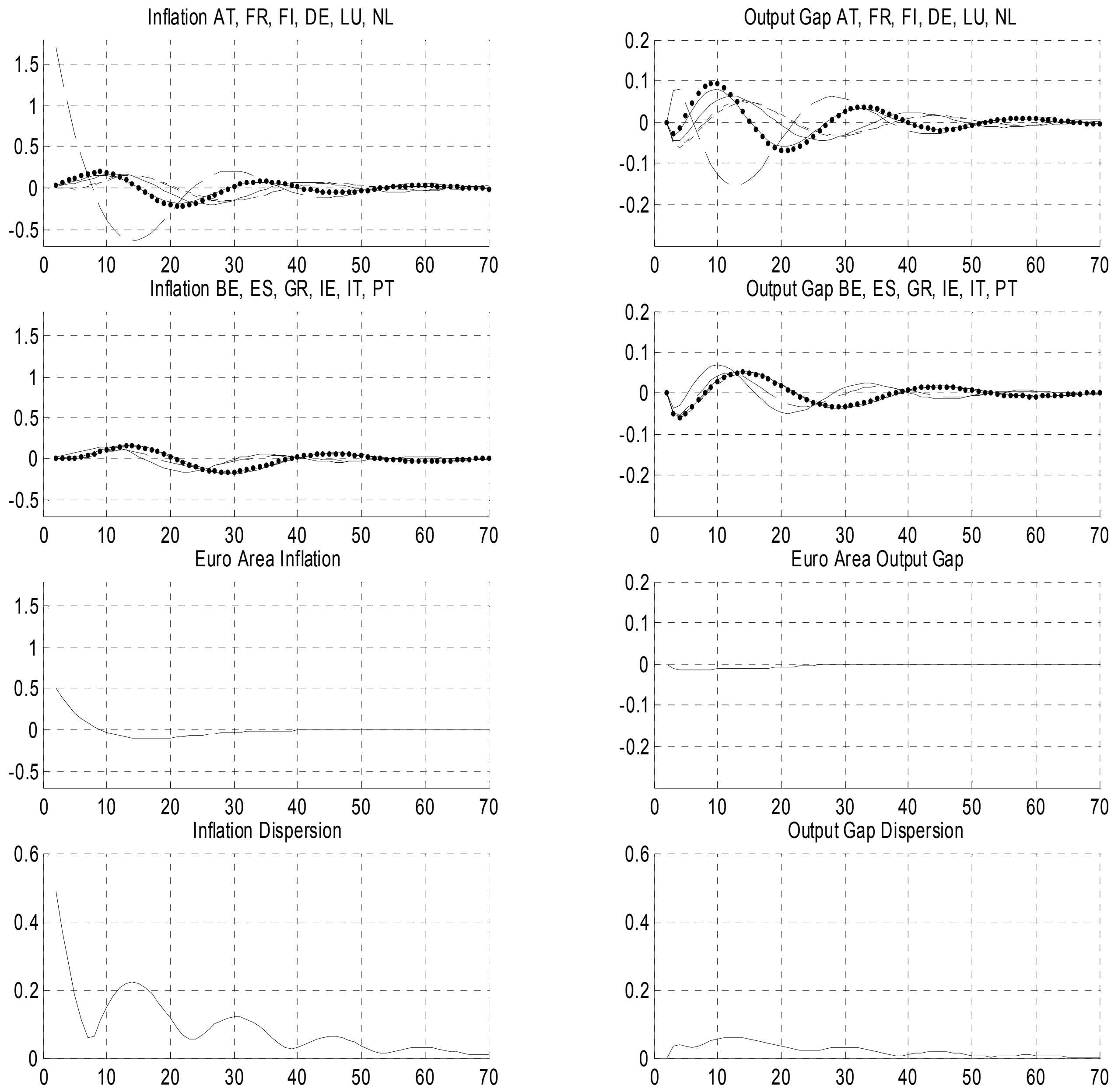
Note: The chart shows the mean, median and standard deviation of national HICP inflation rates (left axis) and the annual rate of the exchange rate change of the euro (DM before 1999) against the US dollar lagged 2 quarters (right axis). The chart updates comparable charts in Honohan and Lane (2003).

Figure 6: Impulse responses to a demand shock in one country (Germany)



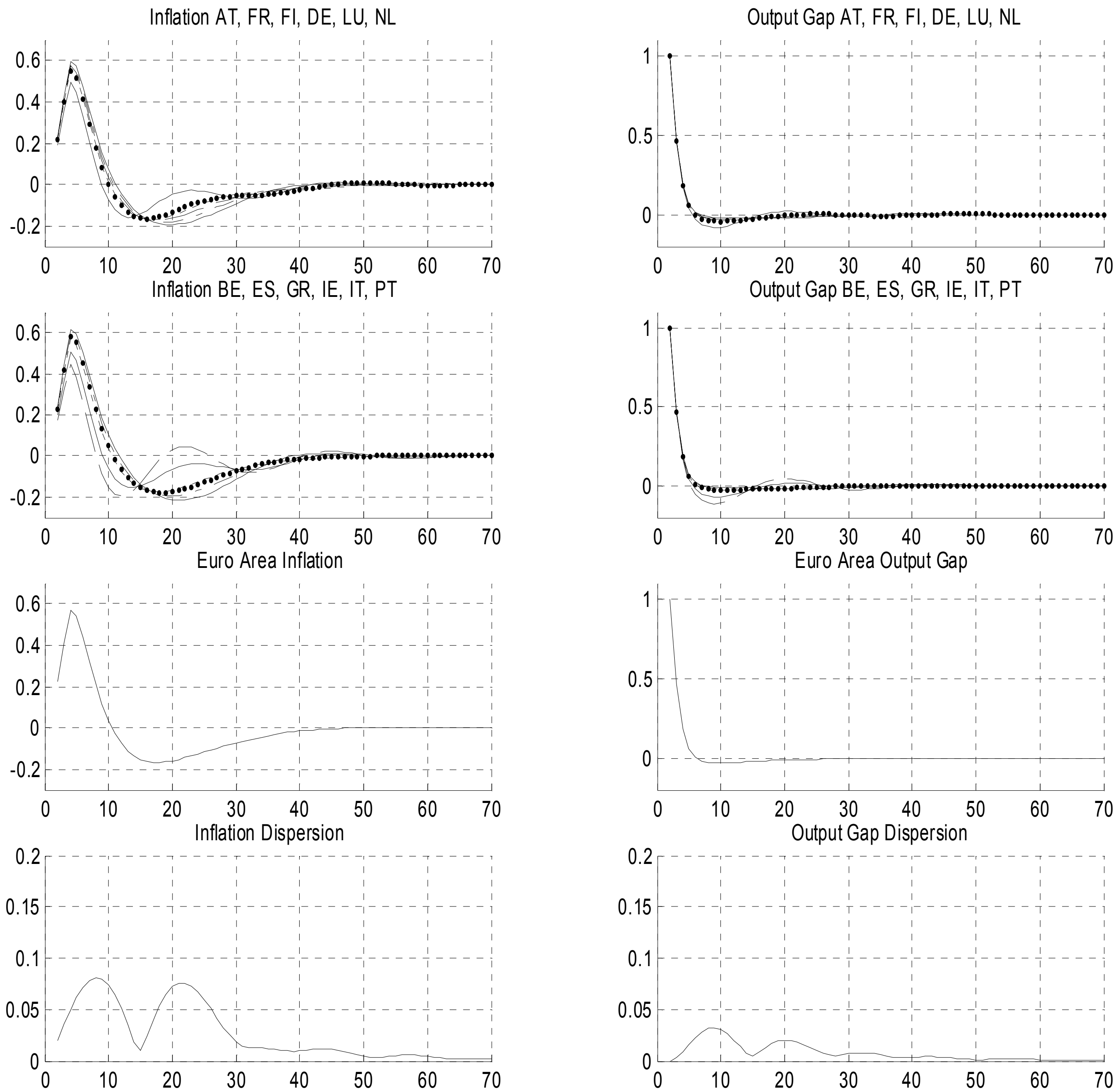
Note: X-axis: quarters; Y-axis: percent deviations from steady state.

Figure 7: Impulse responses to a cost-push shock in one country (Germany)



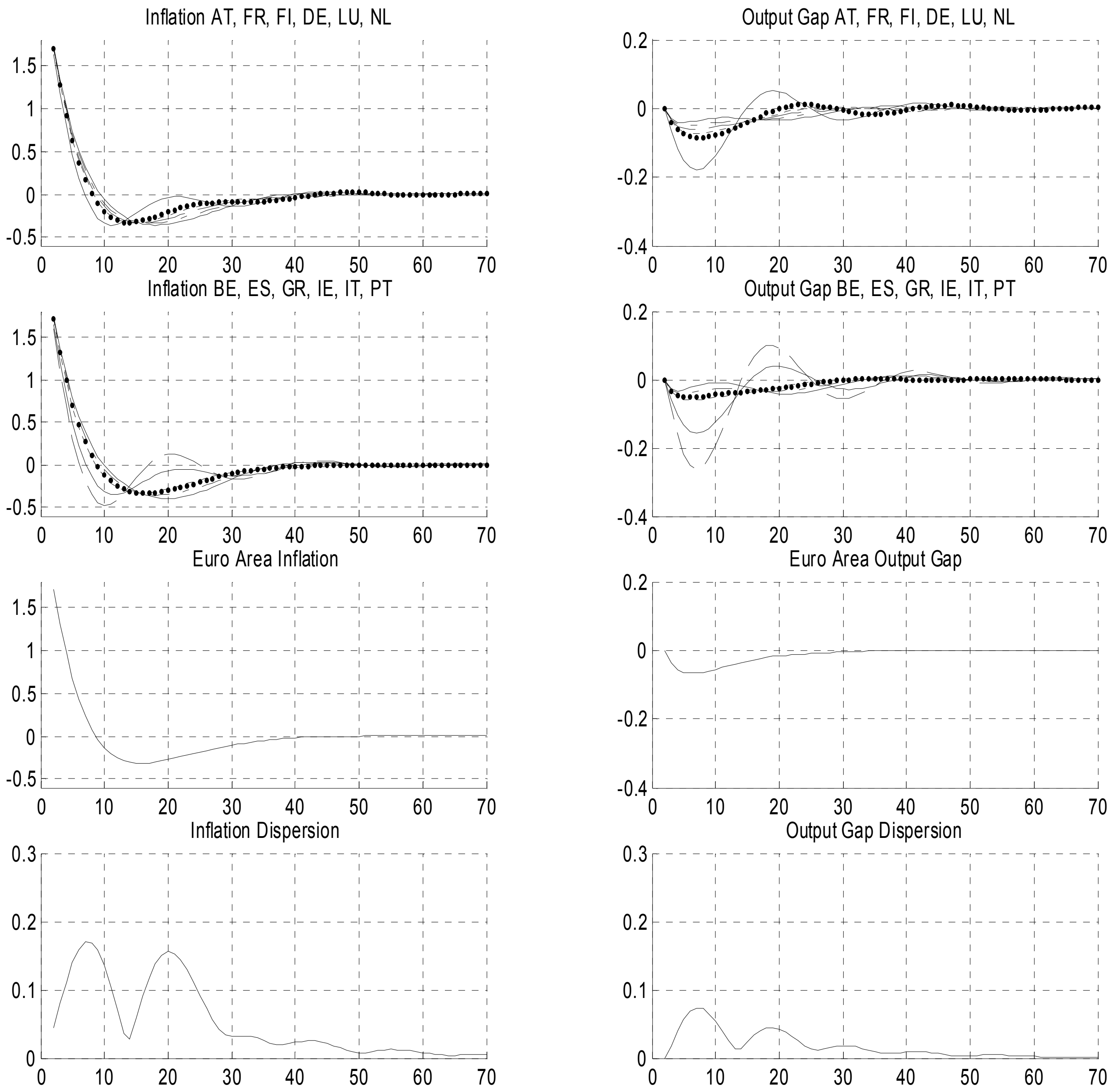
Note: X-axis: quarters; Y-axis: percent deviations from steady state.

Figure 8: Impulse responses to a demand shock in all countries



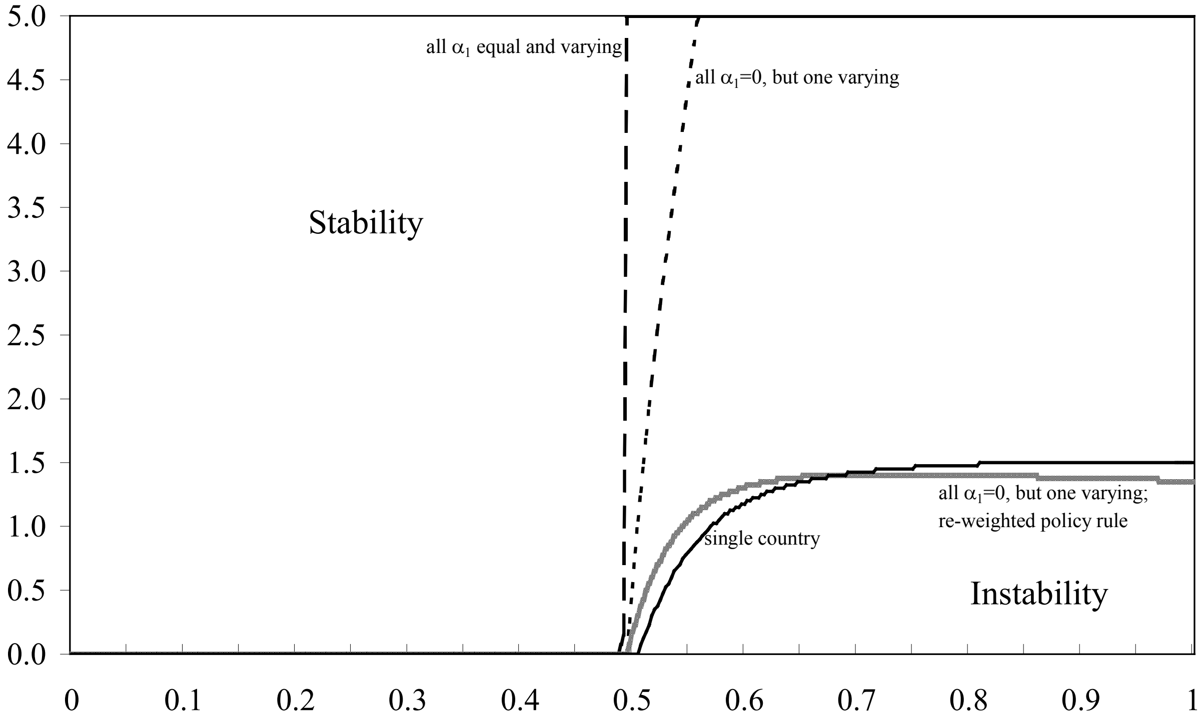
Note: X-axis: quarters; Y-axis: percent deviations from steady state.

Figure 9: Impulse responses to a cost-push shock in all countries



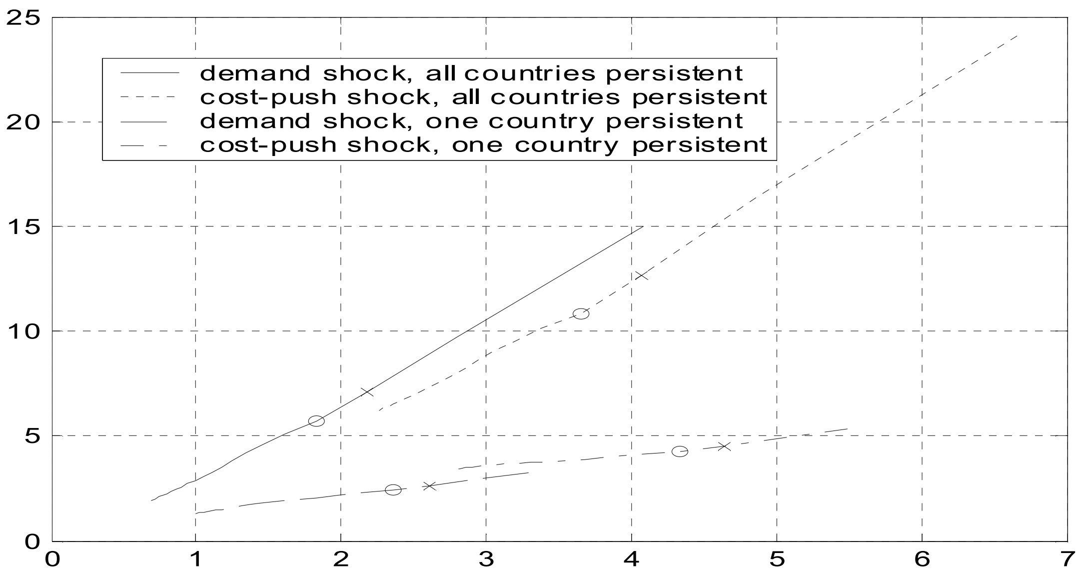
Note: X-axis: quarters; Y-axis: percent deviations from steady state.

Figure 10: Stability and instability regions



Note: The X-axis shows alternative values of the inflation persistence parameters (α_1); the Y-axis alternative values of the coefficient φ_π in the monetary policy rule $r_t = \varphi_\pi E_t \pi_{t+1}$

Figure 11: Complementarity between aggregate inflation and inflation differentials

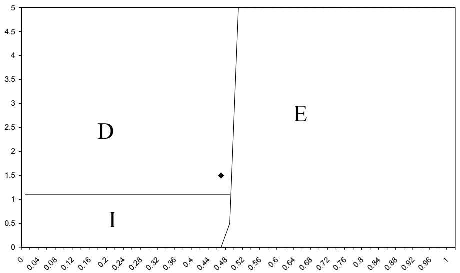


Note: X-axis: integral of the impulse response of inflation dispersion; Y-axis: integral of the absolute values of the impulse response of euro area inflation. φ_π varies between 0 and 10; a cross indicates $\varphi_\pi = 1$, a circle $\varphi_\pi = 1.5$. Inflation persistence parameter: $\alpha_1 = 0.46$.

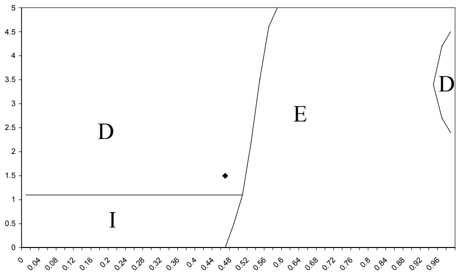
Figure 12: Regions of determinacy, indeterminacy and instability

Closed economy

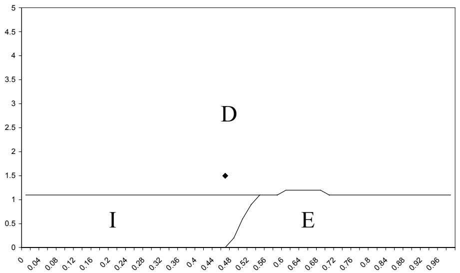
Monetary union, all countries persistent



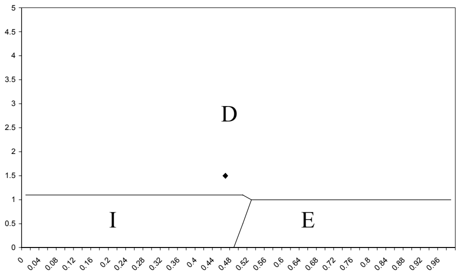
Monetary union, one country persistent



Monetary union, one country persistent and reweighted

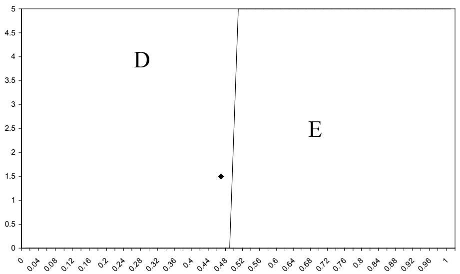


Single country

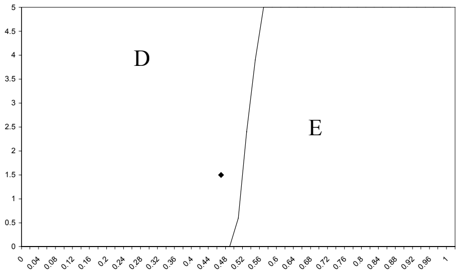


Fixed exchange rates

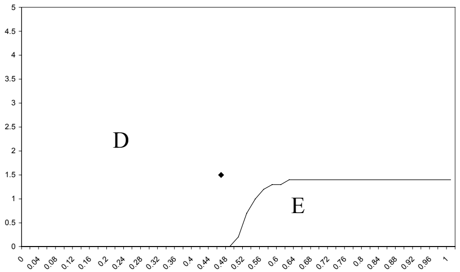
Monetary union, all countries persistent



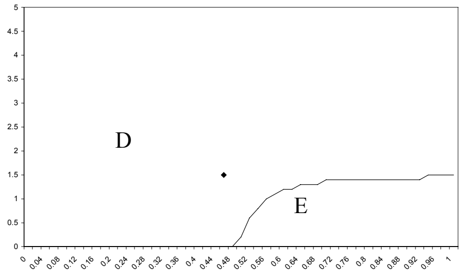
Monetary union, one country persistent



Monetary union, one country persistent and reweighted

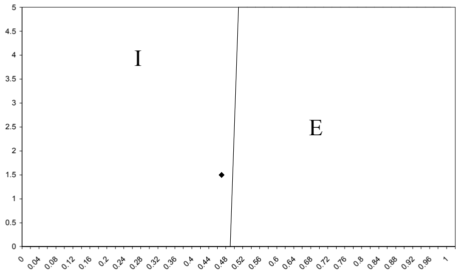


Single country

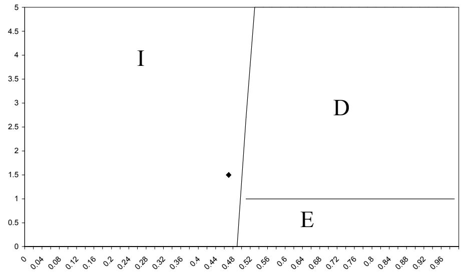


UIP

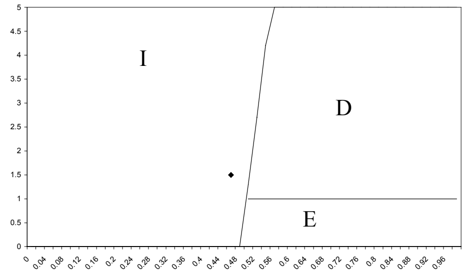
Monetary union, all countries persistent



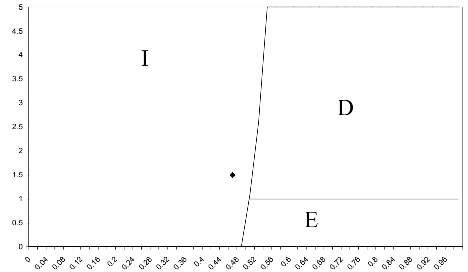
Monetary union, one country persistent



Monetary union, one country persistent and reweighted

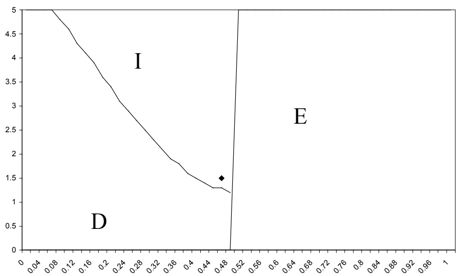


Single country

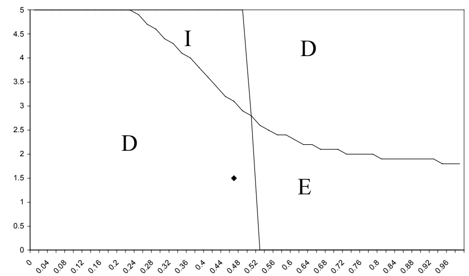


UIP + risk premium

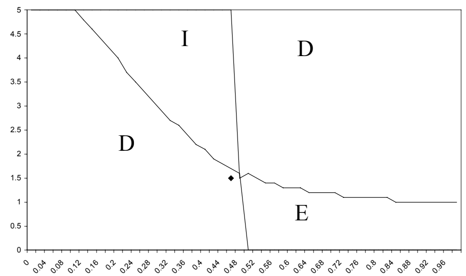
Monetary union, all countries persistent



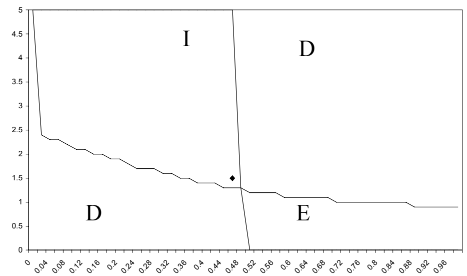
Monetary union, one country persistent



Monetary union, one country persistent and reweighted



Single country



Note: D = region of determinacy; E = region of instability; I = region of indeterminacy; benchmark parameters (α_1=0.46, φ_π=1.5) are denoted by the little diamond.

Table 1: Inflation differentials with respect to the euro area/US average

		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Euro area	Austria	-0.2	-0.1	-0.9	-0.5	-0.5	-0.3	-0.6	-0.2	-0.1	-0.6	-0.8
	Belgium	-0.9	-0.4	-1.3	-0.5	-0.2	-0.3	0.0	0.6	0.1	-0.7	-0.6
	Finland	-0.1	-1.2	-2.1	-1.2	-0.4	0.2	0.2	0.8	0.3	-0.3	-0.8
	France	-1.2	-1.1	-0.8	-0.2	-0.4	-0.5	-0.6	-0.3	-0.6	-0.3	0.1
	Germany	-0.2	-0.6	-1.3	-1.1	-0.1	-0.6	-0.5	-0.7	-0.5	-0.9	-1.0
	Greece	10.0	7.4	6.4	5.6	3.8	3.4	1.0	0.8	1.3	1.6	1.4
	Ireland	-1.6	0.1	0.3	-0.1	-0.4	1.0	1.3	3.1	1.6	2.5	1.9
	Italy	1.1	1.4	2.8	1.7	0.2	0.8	0.5	0.5	0.0	0.3	0.7
	Luxembourg	-3.4	-2.8	-2.6	-1.1	-0.3	-0.2	-0.1	1.7	0.0	-0.2	0.5
	Netherlands	-1.8	-0.7	-1.2	-0.9	0.2	0.6	0.9	0.2	2.8	1.6	0.2
	Portugal	2.5	2.1	1.4	0.6	0.2	1.1	1.0	0.7	2.0	1.4	1.2
	Spain	1.5	1.8	2.0	1.3	0.2	0.6	1.1	1.4	0.5	1.3	1.0
USA	North East	-0.2	-0.2	-0.2	-0.2	0.1	-0.2	-0.1	0.0	0.0	0.5	0.5
	Mid West	-0.1	0.3	0.3	0.1	0.1	0.1	-0.1	0.0	-0.1	-0.4	-0.4
	South	0.2	0.2	0.2	0.1	-0.2	-0.3	-0.2	-0.2	-0.5	-0.3	0.0
	West	0.0	-0.3	-0.2	-0.3	0.1	0.3	0.5	0.1	0.9	0.3	-0.2

Table 2: Replicating Honohan and Lane (2003)

	Honohan/Lane	Replacing inflation	Replacing output gap	Dropping Ireland	Extending to 2002
Lagged change in	-0.28 **	-0.17	-0.18	-0.38	-0.02
effective exchange rate	*-2.71*	*-1.68*	*-1.43*	*-1.54*	*-0.31*
Output gap	0.22 **	0.27 ***	0.26 ***	0.19	0.41 ***
	2.65	*3.19*	*3.06*	*1.18*	*5.95*
Fiscal stance	0.02	0.05	0.06	0.01	0.11
	0.32	*0.59*	*0.91*	*0.06*	*1.68*
Lagged price level	-0.03 **	-0.04 ***	-0.03 ***	-0.03 ***	-0.04 ***
	-2.88	*-3.36*	*-3.06*	*-2.84*	*-4.03*

Table 3: Estimation results

	Parameter	1998:I-2003:II Estimate	*Std Error*	*Sign.*	Parameter estimates in the literature: Estimate	Source	Remarks
Inflation equation	c_1	0.000	*0.000*		--	--	
	α_1	0.461 **	*0.210*		0.31	Smets & Wouters 2003	
					0.04-0.55	Benigno & Lopez-Salido (2002)	Strong cross-country heterogeneity: lowest for Germany, highest for Italy
					0.48	Smets 2003	
					0.04; 0.27	Gali et al. 2001	
	$(1-\alpha_1)$	0.539 **	--	*0.026*			
	β	0.087 *	*0.043*		0.18	Smets 2003	
	γ	-0.075 **	*0.028*		-0.04; -0.07	Angeloni et al. 2003a	Average effect within one year
Output gap equation	c_2	0.083 **	*0.034*		--	--	
	α_3	0.515 ***	*0.135*		0.44	Smets 2003	The estimated equation contains a forward-looking component
	δ	-0.085 *	*0.047*		-0.22; -0.27	Angeloni et al. 2003b	Effect on output after one year
					-0.3	Smets & Wouters 2003	4-quarter rate increase on consumption
					-0.12; -0.19	Angeloni et al. 2003b	Effect on consumption after one year
					-0.34; -0.72	Angeloni et al. 2003b	Effect on investment after one year
					-0.06	Smets 2003	4-quarter rate increase on consumption
	δ_l	-0.007	*0.019*				
	δ_h	-0.147 **	*0.063*	*0.045*			
	λ	-0.082 **	*0.034*		-0.04	Smets & Wouters 2002	Effect on output after 1 year
					-0.05; -0.09	Angeloni et al. 2003a	Average effect of a shock to nom. eff. ex. rates on output within 1 year
					-0.0029	Batini & Nelson 2001	Effect of a change in nominal exchange rates in the UK
	λ_l	-0.052 **	*0.023*				
	λ_h	-0.209 **	*0.090*	*0.077*			

Notes: The inflation equation is estimated as $\pi_{t,j} = c_1 + \alpha_1 \pi_{t-1,j} + (1-\alpha_1) E_t \pi_{t+1,j} + \beta gap_{t-2,j} + \gamma \Delta neer_{t,j} + \varepsilon_{1t,j}$

The output gap equation is estimated as $gap_{t,j} = c_2 + \alpha_3 gap_{t-1,j} + \delta_j (r_{t-1} - \pi_{t-1,j}) + \lambda_j reer_{t-1,j} + \varepsilon_{2t,j}$

*/**/*** denotes significance at the 10, 5 and 1% level respectively. The test whether $\alpha_1+\alpha_2=1$ cannot be rejected at the 5% level with a p-value of 0.067. ***Sign.*** denotes the p-value of the tests for significance of $(1-\alpha_1)$ or for cross-country differences. The estimates for c_2 and α_3 are obtained in a model with undifferentiated coefficients. They remain roughly unchanged in the differentiated model. Country differentiation w.r.t. δ: weak transmission in Belgium, Finland, France, Germany, the Netherlands and Portugal (Angeloni, Kashyap and Mojon 2003). Country differentiation w.r.t. λ: Belgium, Ireland, the Netherlands and Luxembourg most open to trade (Andrés et al. 2003).

Table 4: Model simulations: changing the size of the shock

rescaled shock size	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.10	0.955	0.02	18	0.01	19	0.05	16	0.02	18
0.30	0.955	0.05	18	0.02	19	0.15	16	0.05	18
0.60	0.955	0.10	18	0.05	19	0.29	16	0.10	18
0.80	0.955	0.14	18	0.06	19	0.39	16	0.14	18
1.00	0.955	0.17	18	0.08	19	0.49	16	0.17	18
1.10	0.955	0.19	18	0.09	19	0.54	16	0.19	18
1.30	0.955	0.23	18	0.11	19	0.63	16	0.22	18
1.60	0.955	0.28	18	0.13	19	0.78	16	0.27	18

Note: "inf" denotes explosive solutions, "ind" indeterminate ones. "max dispersion" refers to the peak response of the unweighted standard deviation of national inflation rates following the specified shock. "half-life" refers to the quarter in which the cumulated response of the unweighted standard deviation of national inflation rates reaches 50% of the total accumulated response.

Table 5: Model simulations: changing the monetary transmission parameters

δ	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
-0.00	0.899	0.16	12	0.07	18	0.48	10	0.13	16
-0.03	0.915	0.16	13	0.07	18	0.48	11	0.14	16
-0.06	0.936	0.17	15	0.08	18	0.48	13	0.15	17
-0.09	0.955	0.17	18	0.08	19	0.49	16	0.17	18
-0.15	0.986	0.18	51	0.10	29	0.50	49	0.21	29
-0.17	0.995	0.21	125	0.10	80	0.50	123	0.23	78
-0.18	1.000	0.23	237	0.11	200	0.50	235	0.25	197
-0.19	1.004	inf	inf	inf	inf	inf	inf	inf	inf

Note: see table 4.

δ_h, δ_l	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
-0.09, -0.09	0.955	0.17	18	0.08	19	0.49	16	0.17	18
-0.10, -0.08	0.959	0.17	18	0.08	19	0.49	16	0.17	18
-0.12, -0.06	0.970	0.17	19	0.08	19	0.48	17	0.18	18
-0.14, -0.04	0.980	0.17	21	0.08	22	0.48	19	0.19	20
-0.15, -0.03	0.985	0.17	25	0.09	23	0.48	23	0.19	21
-0.16, -0.02	0.989	0.17	29	0.09	26	0.48	27	0.20	24
-0.17, -0.01	0.994	0.17	35	0.10	32	0.48	34	0.21	29
-0.18, -0.00	0.998	0.17	73	0.11	65	0.48	78	0.22	58

Note: see table 4. Belgium, Finland, France, Germany, the Netherlands and Portugal have weak transmission

Table 6: Model simulations: changing inflation persistence

α_l	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	0.966	0.04	7	0.01	18	0.28	2	0.01	17
0.20	0.956	0.07	7	0.01	15	0.34	4	0.03	14
0.25	0.952	0.08	7	0.02	15	0.36	4	0.03	13
0.35	0.937	0.11	8	0.03	14	0.42	6	0.06	12
0.45	0.942	0.17	16	0.07	17	0.48	14	0.15	16
0.46	0.955	0.17	18	0.08	19	0.49	16	0.17	18
0.47	0.968	0.18	26	0.09	21	0.49	24	0.19	20
0.50	1.008	inf	inf	inf	inf	inf	inf	inf	inf

Note: see table 4.

α_h, α_l	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.35, 0.35	0.937	0.11	8	0.03	14	0.42	6	0.06	12
0.38, 0.32	0.938	0.10	8	0.06	12	0.40	5	0.14	10
0.40, 0.30	0.939	0.09	8	0.09	12	0.39	5	0.22	10
0.42, 0.28	0.941	0.09	8	0.13	12	0.38	5	0.30	10
0.44, 0.26	0.942	0.08	8	0.16	13	0.37	5	0.39	11
0.46, 0.24	0.954	0.08	9	0.20	15	0.36	6	0.48	13
0.48, 0.22	0.980	0.07	12	0.24	19	0.35	8	0.57	18
0.50, 0.20	1.019	inf	inf	inf	inf	inf	inf	inf	inf

Note: see table 4. France, Greece, Ireland, Italy and Portugal are more persistent

α_h, α_l	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.35, 0.35	0.937	0.11	8	0.03	14	0.42	6	0.06	12
0.38, 0.32	0.941	0.10	8	0.04	12	0.40	5	0.09	10
0.40, 0.30	0.943	0.09	8	0.06	12	0.39	5	0.13	10
0.42, 0.28	0.945	0.09	8	0.08	13	0.38	5	0.18	11
0.44, 0.26	0.947	0.08	8	0.10	14	0.37	5	0.23	12
0.46, 0.24	0.949	0.08	8	0.12	16	0.36	5	0.28	14
0.48, 0.22	0.963	0.07	11	0.15	21	0.35	7	0.34	19
0.51, 0.19	1.000	0.07	227	0.24	242	0.34	222	0.46	241

Note: see table 4. France is more persistent

Table 7: Model simulations: changing the slope of the Phillips curve

β	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	1.000	ind	ind	ind	ind	ind	ind	ind	ind
0.02	0.927	0.04	15	0.01	21	0.50	13	0.11	20
0.04	0.931	0.08	15	0.03	19	0.50	13	0.14	18
0.09	0.955	0.17	18	0.08	19	0.49	16	0.17	18
0.14	0.974	0.26	30	0.14	20	0.48	28	0.21	20
0.18	0.987	0.34	55	0.20	34	0.48	53	0.24	33
0.22	0.999	0.50	223	0.27	179	0.48	220	0.28	175
0.24	1.005	inf	inf	inf	inf	inf	inf	inf	inf

Note: see table 4.

β_h, β_l	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.09, 0.09	0.955	0.17	18	0.08	19	0.49	16	0.17	18
0.10, 0.08	0.958	0.19	20	0.08	19	0.49	18	0.17	18
0.12, 0.06	0.965	0.22	26	0.17	19	0.48	24	0.18	19
0.14, 0.04	0.973	0.26	30	0.28	18	0.48	28	0.20	20
0.15, 0.03	0.976	0.27	33	0.33	18	0.48	31	0.22	21
0.16, 0.02	0.979	0.29	38	0.40	19	0.48	36	0.25	22
0.17, 0.01	0.983	0.30	41	0.46	19	0.48	39	0.30	23
0.18, 0.00	1.000	ind	ind	ind	ind	ind	ind	ind	ind

Note: see table 4. France, Greece, Ireland, Italy and Portugal have a smaller coefficient

Table 8: Model simulations: changing output persistence and external spillovers

α_3	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	0.922	0.10	13	0.03	16	0.50	12	0.14	16
0.10	0.925	0.11	14	0.04	16	0.49	12	0.14	16
0.20	0.930	0.12	14	0.04	16	0.49	13	0.15	16
0.40	0.944	0.15	16	0.06	17	0.49	14	0.16	17
0.50	0.955	0.17	18	0.08	19	0.49	16	0.17	18
0.60	0.969	0.21	28	0.11	21	0.49	26	0.19	20
0.70	0.988	0.29	62	0.18	39	0.48	58	0.24	39
0.80	1.011	inf	inf	inf	inf	inf	inf	inf	inf

Note: see table 4.

λ	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
-0.00	1.000	ind	ind	ind	ind	ind	ind	ind	ind
-0.05	0.955	0.18	17	0.04	22	0.49	15	0.08	22
-0.08	0.948	0.16	16	0.04	21	0.48	14	0.08	20
-0.15	0.941	0.14	14	0.04	20	0.46	12	0.09	19
-0.20	0.940	0.13	14	0.05	19	0.45	12	0.10	18
-0.25	0.939	0.12	14	0.05	19	0.45	12	0.10	18
-0.30	0.940	0.12	14	0.05	19	0.44	12	0.11	17
-0.45	0.945	0.11	17	0.05	19	0.43	15	0.12	18

Note: see table 4.

λ_h, λ_l	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
-0.200, -0.050	0.955	0.17	18	0.08	19	0.49	16	0.17	18
-0.210, -0.040	0.958	0.18	19	0.09	18	0.49	17	0.19	17
-0.220, -0.030	0.962	0.19	20	0.11	18	0.50	19	0.22	17
-0.225, -0.025	0.964	0.19	21	0.12	18	0.50	19	0.24	17
-0.230, -0.020	0.967	0.20	22	0.13	18	0.51	20	0.26	17
-0.235, -0.015	0.970	0.21	24	0.14	18	0.51	22	0.28	17
-0.240, -0.010	0.974	0.22	27	0.15	18	0.52	25	0.30	17
-0.250, -0.000	1.000	ind	ind	ind	ind	ind	ind	ind	ind

Note: see table 4. Belgium, Ireland, Luxembourg and the Netherlands are more open to trade

Table 9: Model simulations: sensitivity to the monetary policy rule (I): changing the inertia of interest rates and the response to the output gap

ρ	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	0.955	0.17	18	0.08	19	0.49	16	0.17	18
0.30	0.955	0.17	18	0.07	18	0.49	16	0.16	17
0.40	0.955	0.17	18	0.07	18	0.49	16	0.16	17
0.60	0.973	0.17	18	0.06	18	0.49	16	0.15	17
0.70	0.981	0.17	18	0.05	18	0.49	17	0.14	17
0.80	0.988	0.17	18	0.04	18	0.49	17	0.13	17
0.90	0.995	0.17	19	0.03	18	0.49	17	0.11	17
0.95	0.997	0.17	19	0.03	18	0.49	17	0.11	17

Note: see table 4.

ϕ_y	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	0.955	0.17	18	0.08	19	0.49	16	0.17	18
0.50	0.955	0.17	18	0.08	18	0.49	16	0.17	18
1.00	0.955	0.17	18	0.08	18	0.49	16	0.18	18
1.50	0.955	0.17	18	0.08	18	0.49	16	0.18	17
2.00	0.955	0.17	18	0.08	18	0.49	16	0.18	17
2.50	0.955	0.17	18	0.08	18	0.49	16	0.18	17
3.00	0.955	0.17	18	0.07	18	0.49	16	0.19	17
4.00	0.955	0.17	18	0.07	18	0.49	16	0.19	17

Note: see table 4.

Table 10: Model simulations: sensitivity to the monetary policy rule (II): changing the forward-lookingness of the monetary policy rule

$\phi_{\pi(t+6)}$	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	0.962	0.17	18	0.14	28	0.49	16	0.23	27
0.50	0.964	0.17	19	0.15	24	0.49	17	0.26	23
1.00	0.959	0.17	19	0.15	22	0.49	17	0.26	21
1.50	0.955	0.17	19	0.14	20	0.49	17	0.27	19
2.00	0.955	0.17	18	0.14	19	0.49	17	0.27	18
3.00	0.955	0.17	18	0.13	18	0.49	16	0.27	17
5.00	0.977	0.17	18	0.11	18	0.49	17	0.25	17
10.00	0.990	0.17	19	0.09	19	0.49	17	0.23	19

Note: see table 4.

$\phi_{\pi(t+12)}$	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	0.962	0.17	18	0.14	28	0.49	16	0.23	27
0.50	0.987	0.17	37	0.20	58	0.49	31	0.30	55
1.00	1.018	inf	inf	inf	inf	inf	inf	inf	inf
1.50	0.992	0.18	64	0.28	82	0.49	53	0.46	79
2.00	0.979	0.18	25	0.25	33	0.49	22	0.43	30
3.00	0.962	0.18	19	0.22	22	0.49	17	0.40	20
5.00	0.968	ind	ind	ind	ind	ind	ind	ind	ind
10.00	0.954	ind	ind	ind	ind	ind	ind	ind	ind

Note: see table 4.

Table 11: Model simulations: sensitivity to the monetary policy rule (III): changing the response to the expected inflation

$\phi_{\pi(t+1)}$	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	0.962	0.17	18	0.14	28	0.49	16	0.23	27
0.50	0.955	0.17	18	0.12	21	0.49	16	0.21	20
1.00	0.955	0.17	18	0.09	20	0.49	16	0.18	18
1.50	0.955	0.17	18	0.08	19	0.49	16	0.17	18
2.00	0.955	0.17	18	0.08	18	0.49	16	0.17	17
3.00	0.961	0.17	18	0.07	18	0.49	16	0.16	17
5.00	0.980	0.17	18	0.05	18	0.49	17	0.14	17
10.00	0.991	0.17	19	0.03	18	0.49	17	0.11	18

Note: see table 4.

$\phi_{\pi(t+1)}$, proportional weights	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	1.006	inf	inf	inf	inf	inf	inf	inf	inf
0.50	1.001	inf	inf	inf	inf	inf	inf	inf	inf
1.00	0.995	0.04	76	0.23	119	0.28	66	0.47	118
1.50	0.989	0.04	33	0.20	65	0.28	25	0.47	63
2.00	0.983	0.04	22	0.19	42	0.28	13	0.47	40
3.00	0.974	0.04	16	0.17	27	0.28	8	0.46	25
5.00	0.983	0.04	14	0.15	19	0.28	6	0.45	17
10.00	0.991	0.05	12	0.12	15	0.28	5	0.43	13

Note: see table 4. In all countries but France α_1=0.0; for France, α_1=0.5; the Taylor rule weighs each country according to its size

$\phi_{\pi(t+1)}$, disproportional weights	largest root of companion matrix	idiosyncratic demand shock: DE		common demand shock		idiosyncratic cost-push shock: DE		common cost-push shock	
		max dispersion	half-life	max dispersion	half-life	max dispersion	half-life	max dispersion	half-life
0.00	1.006	inf	inf	inf	inf	inf	inf	inf	inf
0.50	0.985	0.04	14	0.20	50	0.28	9	0.47	48
1.00	0.962	0.04	8	0.18	21	0.28	3	0.46	19
1.50	0.959	0.04	7	0.17	17	0.28	2	0.44	15
2.00	0.964	0.04	7	0.15	15	0.28	2	0.43	13
3.00	0.972	0.04	7	0.14	13	0.28	2	0.42	11
5.00	0.983	0.04	7	0.11	11	0.28	2	0.40	9
10.00	0.992	0.04	7	0.08	10	0.28	2	0.37	8

Note: see table 4. In all countries but France α_1=0.0; for France, α_1=0.5; the Taylor rule weighs France at 80%, the other countries at 20%, each according to its size

European Central Bank working paper series

For a complete list of Working Papers published by the ECB, please visit the ECB's website (http://www.ecb.int)

366 "The informational content of over-the-counter currency options" by P. Christoffersen and S. Mazzotta, June 2004.

367 "Factor substitution and factor augmenting technical: progress in the US: a normalized supply-side system approach" by R. Klump, P. McAdam and A. Willman, June 2004.

368 "Capital quality improvement and the sources of growth in the euro area" by P. Sakellaris and F. W. Vijselaar, June 2004.

369 "Sovereign risk premia in the European government bond market" by K. Bernoth, J. von Hagen and L. Schuknecht, June 2004.

370 "Inflation persistence during periods of structural change: an assessment using Greek data" by G. Hondroyiannis and S. Lazaretou, June 2004.

371 "Inflation persistence: facts or artefacts?" by C. R. Marques, June 2004.

372 "The operational target of monetary policy and the rise and fall of reserve position doctrine" by U. Bindseil, June 2004.

373 "Technology shocks and robust sign restrictions in a euro area SVAR" by G. Peersman and R. Straub, July 2004.

374 "To aggregate or not to aggregate? Euro area inflation forecasting" by N. Benalal, J. L. Diaz del Hoyo, B. Landau, M. Roma and F. Skudelny, July 2004.

375 "Guess what: it's the settlements!" by T. V. Koeppl and C. Monnet, July 2004.

376 "Raising rival's costs in the securities settlement industry" by C. Holthausen and J. Tapking, July 2004.

377 "Optimal monetary policy under commitment with a zero bound on nominal interest rates" by K. Adam and R. M. Billi, July 2004.

378 "Liquidity, information, and the overnight rate" by C. Ewerhart, N. Cassola, S. Ejerskov and N. Valla, July 2004.

379 "Do financial market variables show (symmetric) indicator properties relative to exchange rate returns?" by O. Castrén, July 2004.

380 "Optimal monetary policy under discretion with a zero bound on nominal interest rates" by K. Adam and R. M. Billi, August 2004.

381 "Fiscal rules and sustainability of public finances in an endogenous growth model" by B. Annicchiarico and N. Giammarioli, August 2004.

382 “Longer-term effects of monetary growth on real and nominal variables, major industrial countries, 1880-2001” by A. A. Haug and W. G. Dewald, August 2004.

383 “Explicit inflation objectives and macroeconomic outcomes” by A. T. Levin, F. M. Natalucci and J. M. Piger, August 2004.

384 “Price rigidity. Evidence from the French CPI micro-data” by L. Baudry, H. Le Bihan, P. Sevestre and S. Tarrieu, August 2004.

385 “Euro area sovereign yield dynamics: the role of order imbalance” by A. J. Menkveld, Y. C. Cheung and F. de Jong, August 2004.

386 “Intergenerational altruism and neoclassical growth models” by P. Michel, E. Thibault and J.-P. Vidal, August 2004.

387 “Horizontal and vertical integration in securities trading and settlement” by J. Tapking and J. Yang, August 2004.

388 “Euro area inflation differentials” by I. Angeloni and M. Ehrmann, September 2004.