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Testing similarities of short-run inflation dynamics among EU-25 countries after the Euro

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Abstract In this paper, we introduce two new definitions of pair-wise and multi-wise similarity between short-run dynamics of inflation rates in terms of equality of forecast functions and show that in the context of invertible ARIMA processes the autoregressive metric introduced by Piccolo (1990) is a useful measure to evaluate such similarity. Then, we study the similarity of short-run inflation dynamics across European Union (EU)-25 Member States during the Euro period. Consistent with studies on inflation differentials and inflation persistence, our findings suggest that after seven years from the launch of the Euro the degree of similarity of short-run inflation dynamics across Euro area countries is still weak. By contrast, we find that EU countries not adopting the common currency, whether old EU or new accession Members, display a higher degree of inflation dynamics similarity both among each other and with Euro area countries.

Keywords Autoregressive metric · Inflation dynamics · Euro

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1 Introduction

When optimum currency area conditions are not met, countries belonging to a monetary union must achieve an adequate degree of structural similarity in real and nominal economic quantities in order to wake the union politically and economically stable (Fratianni and von Hagen 1992; Feldstein 1997). It was this widely accepted principle which lay behind the convergence criteria fixed by the Maastricht treaty in February 1992 with the aim of forcing less disciplined countries towards the best practices of the more virtuous ones. In particular, to place the European Central Bank (ECB) in the position of effectively implementing a non-inflationary monetary policy, the treaty provided that, in order to enter the monetary union, the inflation rates of member countries should converge to a lower and steady common level.[1]

After the creation of the European Monetary System in March 1979, European Union (EU) countries experienced a steady convergence of their inflation rates both in terms of levels and dispersion.[2] This pattern continued throughout the 1990s, but has slightly reversed since the beginning of Stage Three of the Economic and Monetary Union (EMU) and the introduction of the Euro when inflation differentials among EMU countries area somewhat increased (see Fig. 1a). This trend was particularly marked for Ireland, the Netherlands and Portugal but also affected countries like Greece and Spain (ECB 2003; Honohan and Lane 2003).

An even stronger process of inflation convergence was experienced by the ten new accession countries from the date of their application to the EU.[3] In the second half of the 1990s, the inflation differentials with Germany drastically reduced (Fig. 1b), especially in Baltic countries whose average annual inflation rates were around 1,000% in 1992. After the end of admission negotiations in December 2002, accession countries, with the notable exceptions of Hungary, Poland and Slovenia, halted their nominal convergence. Although the average level of inflation rates usually stayed close to the Maastricht criterion, standard deviation of inflation rates increased and in some countries, like Latvia, the inflation differential with Germany arrived at 5% in 2006.

Descriptive evidence apart, a large number of inferential studies have analyzed inflation convergence within the EU. Obviously, the results reached in these studies vary with the notion of convergence, statistical methods, inflation measures, time

[1] To be precise, the Maastricht Treaty provided that for an accession country to be eligible to enter the third stage of Economic and Monetary Union (EMU) and adopt the Euro, its inflation rate during the three years preceding the accession cannot be more than 1.5% points higher than the average inflation rate of the three less inflationary Euro countries.

[2] In 1979, the EU Member States were Belgium, Denmark, Germany, France, Ireland, Italy, Luxembourg, the Netherlands and the United Kingdom. In 1981, Greece becomes the tenth member of the EU, while Portugal and Spain join the EU in 1986. Nine years later, in 1995, Austria, Finland and Sweden become the last three members of what is presently known as EU-15. In 2002, the EU enlargement goes on with the accession of eight central and eastern Europe countries—the Czech Republic, Estonia, Latvia, Lithuania, Hungary, Poland, Slovenia and Slovakia, plus Cyprus and Malta. Finally, in January 2007 the accession of Bulgaria and Romania completes the present boundaries of EU. Differently from the EU countries that signed the Treaty in 1992, all the new Member States assumed the obligation to adopt the Euro as soon as the compliance with the Maastricht criteria is realized.

[3] Cyprus and Malta submitted their formal application in July 1990. Bulgaria and Romania are excluded from our analysis.

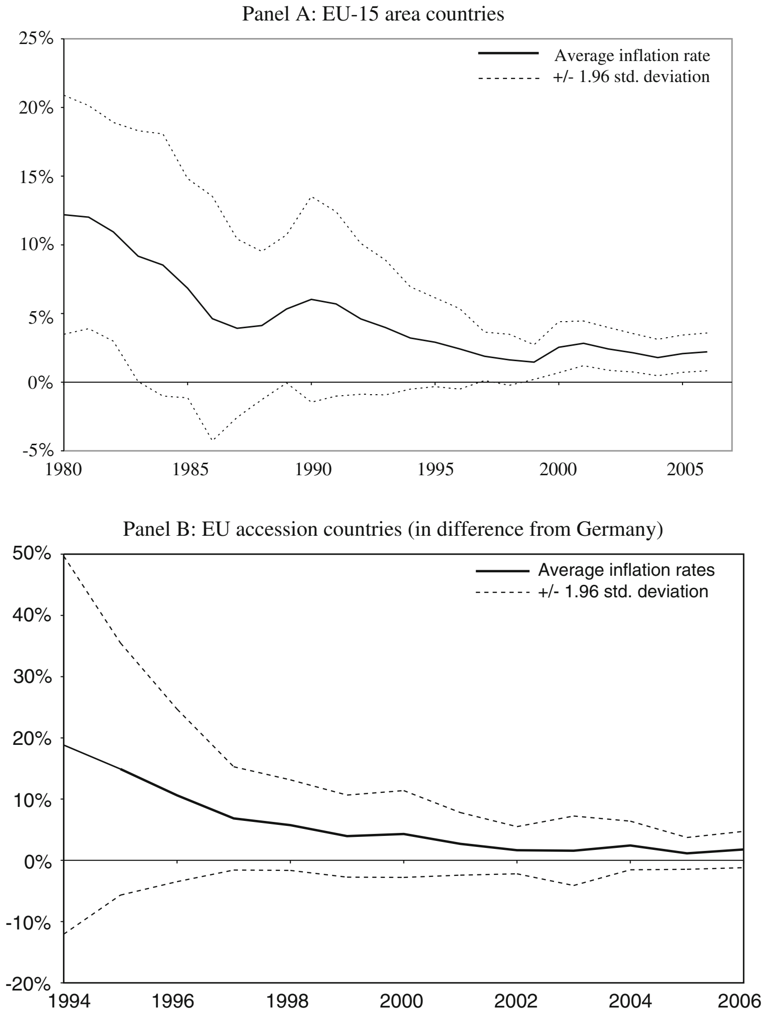

Fig. 1 Yearly average inflation rates. *Note*: Inflation rates are calculated by using the yearly seasonally unadjusted all-item consumer price index (Sources: OECD for panel A, IMF for panel B). CPI data for Estonia and Lithuania are available from 1993 onwards

periods and countries (or regions) considered in the analysis.[4] All in all, however, econometric findings have confirmed the presence of inflation convergence among EU countries towards German and area average levels.

[4] Different approaches for measuring convergence have been followed in the literature: cross-section tests for β- and σ-convergence (Weber and Beck 2003; Ball and Sheridan 2003; Hyvonen 2004); unit-root and stationarity tests (Kočenda and Papell 1997; Holmes 2002; Busetti et al. 2007); Johansen tests for the number of cointegrating vectors and common stochastic trends (Amian and Zumaquero 2002; Siklos and Wohar 1997; Westbrook 1998; Mentz and Sebastian 2003); time-varying parameter models (Hall and Wickens 1997; Holmes 1998).

For the oldest EU Members, this convergence was more intense during the “hard” Exchange Rate Mechanism period (1987–1992). The tight peg of exchange rates allowed high-inflation countries to import low inflation from Germany by creating a (more) credible commitment to follow the anti-inflationary Bundesbank’s monetary policy (Giavazzi and Giovannini 1989). Consistent with this argument, in the ERM period EU countries which continuously participated in the narrow fluctuation bands and never deviated from the mechanism (Belgium, Denmark, France, Germany, Ireland, Luxembourg and the Netherlands) displayed the strongest inflation convergence with a significant increase in the speed of catching-up with respect to the previous non-ERM period (Kočenda and Papell 1997).[5] Nominal convergence continued, albeit at a slower pace, after the exchange rate crises in 1992 and 1993 and essentially stopped after the birth of the Euro in 1999, when inflation differentials showed a diverging behaviour and persisting heterogeneity at country and regional level (Mentz and Sebastian 2003; Beck et al. 2006; Busetti et al. 2007).[6]

With regard to the new EU accession countries, econometric evidence clearly supports both the existence of nominal convergence towards the levels of lowest inflationary countries in the Euro area during the period 1995–2000 and the end of this catch-up process afterwards (Kočenda 2001; Brada et al. 2005; Drine and Rault 2005; Kutan and Yigit 2005; Kočenda et al. 2006).

Typically, current research steers attention towards the differential of inflation levels across EU countries and to the asymptotic properties of their inflation series. However, the convergence of inflation rates towards lower and common levels is not sufficient to allow the ECB to take on a common monetary policy, avoiding nationalistic tensions and asymmetric regional effects. In fact, so long as national short-run inflation dynamics remain reciprocally dissimilar, the appropriate stance of monetary policy can differ across Member States of the European System of Central Banks (Aksoy et al. 2002; Benigno 2004; Benigno and López-Salido 2006).

On this point the evidence available is not encouraging. First, while similarity in the sign of the price responses to monetary policy impulses clearly emerges (Mojon and Peersman 2001; Angeloni and Ehrmann 2007; Benigno and López-Salido 2006), the magnitude and variability of responses varies considerably across EU countries, especially across the new Member States (Mojon and Peersman 2001; Angeloni and Ehrmann 2007; Benigno and López-Salido 2006; Eickmeier and Breitung 2006). Second, the inflation persistence (i.e., the speed of convergence of inflation rates towards some reference level after a shock) appears to be significantly different across the EU countries, although it is moderately low on average and declining over time (Gadzinski and Orlandi 2004; Levin and Moessner 2005; Angeloni et al. 2006; Franta et al. 2007).

[5] These findings could be instructive in the light of the recent debate on the accession strategies—hard peg to the euro versus inflation targeting—of the new Member States (Backé et al. 2003; De Grauwe and Schnabl 2005).

[6] In particular, convergence in price levels, differences in productivity growth between tradable and non-tradable good sectors, different degree of openness towards non-EMU countries, asymmetries in business cycles across economies not yet perfectly integrated have been indicated as major factors responsible for the diverging dynamics of EMU country inflation rates after the introduction of the Euro. See ECB (2003) and Hofman and Remsperger (2005) for overviews of causes and consequences of inflation differentials in the Euro area.

In this paper we focus on the short-run inflation dynamics of EU countries after the introduction of the Euro by analysing the degree of dissimilarities of their data generating processes (DGPs). Specifically, in the context of univariate time series analysis we estimate ARIMA models for inflation rates of EU-25 area countries in the period 1999–2006. Therefore, for each pair of countries, we evaluate the dissimilarity between their inflation rate DGPs by using the autoregressive (AR) metric introduced by Piccolo (1989, 1990), and test the hypothesis that dissimilarity between AR representations is statistically equal to zero. Then we cluster inflation series on the basis of the dissimilarity tests and estimated distances.

The rest of this paper proceeds as follows. In Sect. 2, we discuss why it matters to have similar short-run inflation dynamics in a currency area. In Sect. 3, first we provide a definition of similarity of short-run inflation dynamics in terms of equality of forecast functions and then present the notion of AR distance between two time series as a useful measure for such similarity. In Sect. 4, we outline the statistical test we use to assess the similarity of inflation dynamics. In Sect. 5, we present results on short-run inflation dynamics in EU-25 countries. Section 6 concludes.

2 Why study similarity of short-run inflation dynamics?

According to the Treaty on European Union and the Statute of the European System of Central Banks (ESCB), the primary objective of the ECB's monetary policy is to maintain price stability in the Euro area. With this aim, the ECB has established that price stability is guaranteed if the yearly area-wide aggregate inflation rate, in terms of the Harmonised Index of Consumer Prices (HICP), is below, but close to, 2% over the medium term. Although the ECB's monetary strategy explicitly ignores the short-run inflation dynamics of member countries, dissimilarities in the short-run dynamic properties of inflation series across Euro area countries might (i) make the aggregate Euro-wide price index worthless for short-run forecasting inflation rates of Euro area countries and (ii) give rise to a different dynamics of short-term real interest rates and differently affect the optimal monetary policy of each ESCB Member State.

In order that the aggregate Euro-wide price index summarizes the behaviour of its components and accurately informs monetary policy, members' inflation series have to share similar short- and long-run dynamic properties (Patell and Zeckauser 1990; Martín-Álvarez et al. 1999). Otherwise, the informative power of the aggregate index is weak and its use for policy decisions problematic. In particular, forecasts from Euro-wide models of inflation rates might become misleading and may be different and less accurate than forecasts built by pooling forecasts of country inflation rates (Marcellino et al. 2003).

Another reason why differentials of short-run inflation dynamics across Euro area countries matter is that they create potential conflicts within ECB in deciding the common monetary policy and affect the way in which it should be optimally conducted. In this spirit, Aksoy et al. (2002) analyze how decision procedures within the ECB's Governing Council influence the conduct of common monetary policy and members' welfare, where its propagation mechanisms on output and prices are dissimilar across State members. They show that when nationalistic perspectives prevail within the

Governing Council at least partly, differences between the interest rate desired by each State member and the interest rate jointly indicated by the Council can arise, generating high welfare losses, mostly for small countries. In the presence of differentials of short-run inflation dynamics, shared preferences about inflation stabilization among national central bankers are therefore not enough to prevent country-specific positions concerning monetary policy and strained terms within ECB.

Besides nationalistic tensions, asymmetries in the degree of price stickiness across Euro area countries might also have an impact on the optimal monetary policy at the aggregate level. This issue has been recently investigated by Benigno (2004) and Benigno and López-Salido (2006) in a two-region general equilibrium framework with monopolistic competition. In this framework, disparities in the degree of nominal rigidities and inflation dynamics between regions inefficiently affect the terms of trade and the allocation of resources following asymmetric shocks. To minimize distortions and deadweight losses, the optimal inflation targeting rule should provide for weighing more the inflation rate of the country where nominal rigidities are stronger. However, such an inflation targeting rule adjusted for country price rigidities might generate destabilizing incentive problems by lowering the urges of sticky countries to introduce reforms aimed at cutting down their nominal rigidities.

Finally, an additional reason to focus on the short-run dynamics of inflation rates is the EU's expansion to include Central and Eastern European countries. As we stated above, new EU members cannot rely on an opt-out clause to maintain their currency after nominal convergence criteria are fulfilled. However, compliance with the Maastricht criteria, to which new members are progressing rapidly (Kočenda et al. 2006), is not sufficient to guarantee the successful enlargement of EMU. It also necessitates a high degree of cyclical synchronization in output and price changes with early members, a challenging requirement for countries with persisting great differences in economic, market and regulatory structures with respect to Euro area members.[7] Therefore, studying short-run inflation dynamic dissimilarities between new and old EU countries can be informative to assess the preparedness for straightforward cost-free EMU enlargement.

3 Measuring similarities of inflation dynamics

Let us begin by introducing two new definitions of pair-wise and multi-wise similarity of short-run inflation dynamics.

Definition 1 (Pair-wise similarity of short-run inflation dynamics) Countries i and j have similar short-run inflation dynamics if they share the same forecast function, i.e., if inflation forecasts at a fixed time t and at step h, with $h = 1, 2, \dots, \infty$, are equal for the two countries:

$$E(X_{i,t+h} - X_{j,t+h} | \mathscr{I}_t) = 0 \quad \forall\, h \geq 1,$$

[7] However, there is a growing literature showing that the EU accession countries have achieved a satisfactorily level of real and nominal cycle correlation with Euro area, often even higher than for the peripheral Euro countries (Eickmeier and Breitung 2006; Fidrmuc and Korhonen 2006; Furceri and Karras 2006).

where $X_{z,t}$ is the inflation time series with $z = i, j$ and $\mathscr{I}_t$ is the information set at time t.

Definition 2 (Multi-wise similarity of short-run inflation dynamics) Countries belonging to a set $N = \{1, 2, \ldots, n\}$ have similar short-run inflation dynamics if all of them share the same forecast function, i.e., if inflation forecasts at a fixed time t and at step h, with $h = 1, 2, \ldots, \infty$, are equal for all countries:

$$E(X_{i,t+h} - X_{j,t+h} | \mathscr{I}_t) = 0 \quad \forall\, i, j \in N \quad \text{and} \quad \forall\, h \geq 1,$$

where $X_{z,t}$ is the inflation time series with $z = i, j$ and $\mathscr{I}_t$ is the information set at time t.

Definitions 1 and 2 extend to the short run the Bernard and Durlauf (1996) definitions of convergence in terms of equality of long-run forecasts at a fixed time. More exactly, when the series have identical initial values, our definition of similarity provide that the forecast functions of the two inflation series coincide in the short- as well as in the long-run.

Obviously, to make these notions of similarity operational, it is necessary to refer to a forecasting method and to a measure of similarity between statistical time series models. In this paper, we restrict our analysis to the class of invertible ARIMA models. As recent research suggests, traditional univariate linear models show a good short-run forecasting performance for macroeconomic series, which is hardly improvable by more complex multivariate or non-linear models (Meese and Geweke 1984; Canova 2002; Marcellino et al. 2003). Moreover, the statistical literature provides a number of criteria for measuring similarities of univariate linear time series models on the basis of their dynamic properties.[8] In particular, a useful measure for evidencing similarity of DGPs can be constructed from the AR metric proposed by Piccolo (1989, 1990).

3.1 The AR distance

Consider two mean-zero invertible ARIMA processes $X_{i,t}$ and $X_{j,t}$. In accordance with the classical Box and Jenkins (1976) notation,

$$X_{i,t} \sim \text{ARIMA}(p_i, d_i, q_i)(P_i, D_i, Q_i)$$

if

$$\phi_i(B)\Phi_i(B^s)\, \nabla^{d_i}\, \nabla_s^{D_i} X_{i,t} = \theta_i(B)\Theta_i(B^s)a_{i,t}, \tag{1}$$

where B indicates the backward operator, $\nabla = (1 - B)$, s represents the seasonality, $\nabla_s = (1 - B^s)$, $\phi_i(B)$ and $\theta_i(B)$ are polynomials in B of order p_i and q_i respectively,

[8] Statistical criteria to evaluate the similarity or dissimilarity between stochastic processes can be distinguished into two broad classes of (i) time–domain measures, which the AR metric belongs to (Thomson and De Souza 1985; Peña 1990; Piccolo 1990; Tong and Dabas 1990; Maharaj 2000, 1996), and (ii) frequency–domain measures (Shumway and Unger 1974; Alagon (1989); Kakizawa et al. 1998; Caiado et al. 2006). For a survey see Corduas (2003) and Liao (2005).

$\Phi_i(B^s)$ and $\Theta_i(B^s)$ are seasonal polynomials in B^s of order P_i and Q_i, and finally $a_{i,t}$ is a Gaussian white noise process (of course, an analogous representation holds for $X_{j,t}$).

The AR distance is defined as the Euclidean distance between the sequences of the autoregressive coefficients of the pure AR(∞) representations of $X_{i,t}$ and $X_{j,t}$, which is given by

$$\pi_i(B)X_{i,t} = a_{i,t} \tag{2}$$

for $X_{i,t}$ (and analogously for $X_{j,t}$), where

$$\begin{aligned} \pi_i(B) &= \phi_i(B)\Phi_i(B^s) \nabla^{d_i} \nabla_s^{D_i} \theta_i^{-1}(B)\Theta_i^{-1}(B^s) \\ &= 1 - \pi_{i,1}B - \pi_{i,2}B^2 - \cdots \end{aligned}$$

Therefore, in symbols, the AR distance is

$$d(X_{i,t}, X_{j,t}) = \sqrt{\sum_{k=1}^{\infty}(\pi_{i,k} - \pi_{j,k})^2}. \tag{3}$$

Since for invertible processes the coefficients of the AR(∞) representations converge, $d(X_{i,t}, X_{j,t})$ is always a finite number and assumes value zero if and only if $\pi_{i,k} = \pi_{j,k}$ for any k. Moreover, being defined upon the AR(∞) representation, the AR distance is robust to the quasi-cancellation of AR and MA operators and therefore it is not misled in the case of over-parametrization. Finally, contrary to other distances applied in time series analysis, such as the Mahalanobis distance used by Peña (1990), the AR distance does not take into account the white noise variances of the ARIMA processes, which represents a scale factor that does not affect the ARIMA structure of the model.

Except for initial values, the sequence of π-weights fully specifies the dynamic structure of an invertible ARIMA model and thereby the corresponding forecast function. For example, the optimal one step ahead forecast of X_i at time $t-1$ is given by the expectations of $X_{i,t}$ conditional upon its past history,

$$\hat{X}_{i,t} = \sum_{k=1}^{\infty} \pi_{i,k}X_{i,t-k}.$$

Therefore, for identical initial values, the AR distance between two processes is zero if and only if their forecast functions coincide (Piccolo 1990). Where the forecasting method employed in the analysis of inflation rates is based on linear autoregressive models, pair-wise similarity of short-run inflation dynamics requires that $d(X_{i,t}, X_{j,t}) = 0$, and multi-wise similarity of short-run inflation dynamics that $d(X_{i,t}, X_{j,t}) = 0$ for any $i, j \in N$.

On real data, an AR distance estimator can be obtained by considering finite versions truncated at lag L of the pure autoregressive representations of two estimated ARIMA processes:

$$\hat{d}(X_{i,t}, X_{j,t}) = \sqrt{\sum_{k=1}^{L} (\hat{\pi}_{i,k} - \hat{\pi}_{j,k})^2}. \tag{4}$$

4 Testing similarity of inflation DGPs

In this section we introduce two useful statistical tests to assess the pair-wise similarity of short-run inflation dynamics.

4.1 The similarity test

For inferential purposes, some results are available on the asymptotic properties of the squared AR distance estimator between independent stochastic processes. In particular, for ARMA and ARIMA models based on Maximum Likelihood (ML) estimates, Piccolo (1989) and Corduas (1996) show that the sample distribution of $\hat{d}^2(X_{i,t}, X_{j,t})$ is a linear combination of independent chi-squared random variables, whereas Sarno (2001) shows a similar result in case of Least Squares estimates.

The rationale behind such proofs may be briefly summarised as follows.[9] Consider two independent processes that can be modelled as ARMA, $X_{i,t}$ and $X_{j,t}$. Let $\hat{\theta}_z$ be the ML estimator of the ARMA parameters, for the property of invariance, $\hat{\pi}_z = f(\hat{\theta}_z)$ is the ML estimate of the AR(∞) representation coefficients vector, for $z = i, j$. Hence, as the length of the time series increases, the asymptotic distribution is $\hat{\pi}_z \sim MN(\pi_z, \hat{\Sigma}_z)$, where Σ_z indicates the covariance matrix. Since $f(\hat{\theta}_z)$ is continuous, the covariance matrix Σ_z can be analytically computed as $\hat{\Sigma}_z = J_z \hat{V}_z J_z'$, where $\hat{V}_z$ is the estimated covariance matrix of $\hat{\theta}_z$ and $J_z = \partial \hat{\pi}_z / \partial \hat{\theta}_z$ is the Jacobian matrix. Then, under the hypothesis $H_0 : \hat{\pi}_i = \hat{\pi}_j$, the two covariance matrices are $\Sigma_i = \Sigma_j = \Sigma$ and $(\hat{\pi}_i - \hat{\pi}_j) \sim MN(0, 2\hat{\Sigma})$, so that, defining $\hat{\eta} = (2\hat{\Sigma})^{1/2}(\hat{\pi}_i - \hat{\pi}_j)$, it follows that $\hat{\eta} \sim MN(0, I)$, where $\hat{\Sigma}$ can be estimated by $0.5(\hat{\Sigma}_i + \hat{\Sigma}_j)$. Therefore, the estimated squared AR distance is

$$\begin{aligned} \hat{d}^2(X_{i,t}, X_{j,t}) &= 2\hat{\eta}' \hat{\Sigma} \hat{\eta} \\ &= (\hat{\pi}_i - \hat{\pi}_j)'(\hat{\pi}_i - \hat{\pi}_j) \\ &= 2 \sum_{\ell=1}^{r} \lambda_\ell \chi_1^2, \end{aligned}$$

where λ_ℓ, with $\ell = 1, 2, \ldots, r$, are the positive eigenvalues of $\hat{\Sigma}$ and $r < p + q + P + Q$.

[9] For details, see the references cited above.

The value identifying the critical region to reject H_0 at a level α can be obtained by implementing an exact procedure to elicit percentiles of a quadratic form in normal variables (Farebrother 1990). However, the analytical derivation of the matrix may be computationally cumbersome. To simplify the analysis, Corduas (1996) suggests that under H_0 the distribution of $\hat{d}^2(X_{i,t}, X_{j,t})$ can be approximated by a single chi-squared random variable with c degrees of freedom

$$\hat{d}^2(X_{i,t}, X_{j,t}) = a + b\chi_c^2, \tag{5}$$

where parameters a, b and c are evaluated via method of moments estimation. More exactly, recalling that $t_r = 2^r tr(\hat{\Sigma}^r)$, where $\hat{\Sigma}$ represents the estimated covariance matrix of the AR distance, we have $a = t_3/t_2$, $b = t_1 - t_2^2/t_3$ and $c = t_2^3/t_3^2$.

As Corduas (1996) shows, approximate and exact critical regions are quite similar and both satisfactory in terms of significance and power far from the non-invertibility region. In this paper we use a test procedure based on the Corduas approximation and implemented in Ox.[10]

4.2 The Diebold–Mariano test

The independence between DGPs involved by the similarity test can be a quite demanding assumption in the case of inflation rate series of countries belonging to a currency area. To relax this assumption, we follow the strategy suggested by Otranto and Triacca (2002). First, they show that a *necessary* (but not sufficient) condition for $d(X_{i,t}, X_{j,t}) = 0$ is the equal forecastability of processes $Y_{i,t} = (1-B)^{d_i} X_{i,t}$ and $Y_{j,t} = (1-B)^{d_j} X_{j,t}$ in the sense of Granger and Newbold (1976), i.e.

$$R_i^2 - R_j^2 = \frac{Var(a_{j,t})}{Var(Y_{j,t})} - \frac{Var(a_{i,t})}{Var(Y_{i,t})} = 0.$$

Then they propose a test procedure that compares the predictive accuracy of two different estimated models based on the Diebold and Mariano (1995) test statistic, which does not require the independence of the DGPs, by using as loss functions the quantities R_i^2 and R_j^2.

Formally, given two time series $Y_{i,t}$ and $Y_{j,t}$, the h-step ahead forecast errors conditional upon the information set $\mathscr{I}_t$ are given by $\{a_{i,T+h}|\mathscr{I}_t\}$ and $\{a_{j,T+h}|\mathscr{I}_t\}$ respectively. To determine whether the two models do not have a different forecasting accuracy, the null hypothesis to be tested is

$$H_0 : E(f_t) = E\left[\frac{a_{j,t}^2}{Var(Y_{j,t})} - \frac{a_{i,t}^2}{Var(Y_{i,t})}\right] = 0.$$

[10] The test procedure is available upon request from the authors. Corduas (2000) presents a similar test procedure in GAUSS.

Hence, the Diebold–Mariano test statistic is

$$S = \frac{\bar{f}}{\hat{V}(\bar{f})^{1/2}}. \tag{6}$$

A consistent estimator of the asymptotic variance of $\sqrt{T}\bar{f}$ is given by

$$\hat{V}(\bar{f}) = T^{-1}\left[\hat{\gamma}_0 + 2\sum_{k-1}^{g-1}\hat{\gamma}_k\right],$$

where $\bar{f}$ is the average value of f_t, $\hat{\gamma}_k = Cov(f_t, f_{t-k})$ and g is the Barlett lag window. Under the null, Diebold and Mariano (1995) show that $S \sim N(0, 1)$.

5 Similarities of short-run inflation dynamics among EU countries

5.1 Data and sample periods

Our dataset consists of the monthly seasonally unadjusted all-item consumer price index (CPI) from 1999:01 to 2006:12 for each EU-25 country and for the Euro-wide area.[11] The data sources are the IMF and OECD and they are drawn from Datastream. Inflation rates are computed as the monthly log-differences of CPIs, $p_t = 100[\ln(\mathrm{CPI}_t) - \ln(\mathrm{CPI}_{t-1})]$.

Although the ECB's objective of price stability is based on HICPs and not on CPIs, we decided to carry out the analysis in terms of national CPIs for both economical and technical reasons. First, in many EU countries CPI is a best measure of the cost of living of domestic resident households, and it is regularly used in contractual negotiations. The inclusion and treatment of some expenditures (e.g. owner-occupied housing, subsidised healthcare and education, lotteries, financial charges) are consistent with this purpose and they can substantially differ from HICP, whose purpose is to measure the final monetary consumption expenditures of resident and non-resident households. Second, the use of CPIs makes comparisons with studies on the pre-Euro period and non-Euro countries easier. Third, parameters of ARIMA models estimated from HCPIs are close to the non-invertibility region for most Euro area countries, making inference on distance weak since the similarity test looses power and informativeness in that region.[12]

[11] The exact list of countries is reported in the Appendix (Table 4).

[12] However, results of Diebold–Mariano tests on HCPIs are broadly supportive of our qualitative conclusions on CPIs, displaying a high degree of dissimilarity of inflation DGPs among Euro are countries (these results are available on request).

5.2 Modelling short-run inflation dynamics

The first step of our empirical analysis was to remove the seasonal component from the inflation rate series. In this context, we have chosen to treat seasonality as a deterministic component of the series, and therefore we regressed inflation rates against 11 monthly dummy variables. In this way we can model the (de-seasoned) inflation rates without reducing the number of sample observations.

The second step was to assess the degree of integration of our seasonally adjusted series. For this purpose, for robustness, we used three different unit root tests. The standard Augmented Dickey-Fuller test (hereafter ADF) was employed as a benchmark for evaluating the stationarity of inflation rates. Given that the available series are OLS residuals, the ADF was carried without the deterministic component.[13] Following Hall (1994), the number of lags was selected according to a general-to-specific approach.

The second test we used is the Elliott et al. (1996) efficient DFGLS test for an autoregressive unit root. This test is similar to the ADF test, but reveals best performance and higher power in small samples. Once again, Hall's generic-to-specific approach was used for the lag selection.

Finally, we applied the KPSS test (Kwiatkovski et al. 1992). This is a nonparametric test in which, contrary to ADF and DFGLS tests, the null hypothesis is the stationarity of the time series. The KPSS test statistic has a non-standard asymptotic distribution; it was computed without including a time trend in the estimated average inflation rates and by using 16 lags.[14]

In Table 1, we report the outcome of these tests and the critical values for the DFGLS and KPSS tests. On the whole, there is robust evidence in favour of the hypothesis of stationarity of inflation rate series. Specifically, the ADF test supports the hypothesis of stationarity for all countries at 1% level except for Finland and Poland for which P values are 0.0395 and 0.0866 respectively. The KPSS test statistic is generally lower than the critical value 0.347 not rejecting the hypothesis of stationarity at 10% level. For Denmark, Hungary and Poland stationarity is not rejected at 5% level, while for Latvia and Slovenia at 2.5%.

The results provided by the DFGLS are instead mixed. The null hypothesis of nonstationarity is rejected for five countries belonging to EU-15 (Austria, Belgium, Germany, Denmark and United Kingdom), for five new Member countries (Estonia, Latvia, Lithuania, Malta and Slovakia) and for the time series of the Euro-wide inflation rate. However, for the remaining countries the DFGLS test accepts the hypothesis of a unit root at a confidence level of 10%, even if the test statistics for Finland and Portugal are quite similar at the critical value of -1.6175.

Once the stationarity of seasonally adjusted inflation series had been ascertained, the third step of our analysis was to estimate ARMA models for EU-15 area countries jointly with the Euro-wide inflation rate (see Table 2, panel A) and for the new Member

[13] The mean of all these series is zero by definition, hence we excluded the ADF with the constant term to avoid misspecification. The specifications with the linear and quadratic trend were omitted because preliminary graphical inspection of series excluded the presence of significant patterns.

[14] The outcome of the KPSS test does not change when the number of lags is augmented to take autocorrelations of higher order into account.

Table 1 Unit roots tests

Series	Lags	ADF	p-value	Lags	DFGLS	KPSS
AT	2	−5.2019	2.80e−7	6	−1.9762	0.0900
BE	3	−6.4740	0.0000	4	−4.0464	0.0706
FI	7	−2.0416	0.0395	7	−1.5774	0.2720
FR	6	−6.3602	0.0000	7	−0.9347	0.2043
DE	3	−6.0413	3.71e−9	6	−2.4841	0.1079
GR	4	−7.9211	0.0000	7	−0.7797	0.1117
IE	0	−7.0847	0.0000	4	−1.7936	0.1782
IT	6	−4.2756	2.03e−5	7	−1.2450	0.2535
LU	7	−5.6544	2.86e−8	8	−1.1977	0.0820
NL	7	−3.5559	0.0004	8	−1.6616	0.2639
PT	5	−2.8661	0.0040	5	−1.5684	0.1712
ES	6	−4.2971	1.85e−5	7	−0.4018	0.0984
DK	0	−10.045	0.0000	1	−6.1056	0.3783
SE	7	−4.0668	4.91e−5	8	−1.0108	0.1131
UK	0	−9.5187	0.0000	1	−6.2968	0.1702
CY	5	−3.8346	0.0001	5	−1.0419	0.2040
CZ	6	−2.1558	0.0299	6	−1.0881	0.1545
EE	8	−2.2362	0.0244	8	−1.6594	0.1004
HU	0	−6.7175	4.9e−12	3	−0.9762	0.4044
LV	1	−4.7806	2.11e−6	2	−3.2591	0.5179
LT	4	−2.9604	0.0030	4	−1.7008	0.3234
MT	5	−3.3581	0.0008	5	−1.7554	0.0870
PL	7	−1.6877	0.0866	7	−0.1788	0.4411
SK	6	−3.4773	0.0005	6	−2.9819	0.3622
SI	2	−3.8369	0.0001	6	−0.5451	0.5536
EU	4	−6.1647	1.91e−9	1	−6.5110	0.1098

p-values for the ADF tests were computed by using the MacKinnon (1996) algorithm. KPSS test is carried out with a window size of 16. The critical values for the DFGLS test, provided by Elliott et al. (1996), are:

1%	5%	10%
−2.5873	−1.9434	−1.6175

The critical values for the KPSS test without trend, provided by Kwiatkovski et al. (1992), are:

10%	5%	2.5%	1%
0.347	0.463	0.574	0.739

States' inflation rate (see Table 2, panel B). By using adjusted inflation rates for seasonality, we avoid the risk of estimating overdifferentiated time series and we can also assume that inflation rates follow a stationary ARMA(p, q) model. Hence, equation (1) reduces to the form

$$\phi_i(B)X_{i,t} = \theta_i(B)a_{i,t}. \tag{7}$$

The lag selection was carried out by minimising the Hannan and Quinn (1979) information criterion: this method implies that only the statistical relevant coefficients in the ARMA(p, q) are estimated. Hence, in the final model specifications, parameters related to lags lower than p and q do not appear. This corresponds to a constrained model estimation with some parameters forced to be zero. The use of our seasonally adjusted series with zero mean permits model estimation without the constant, since it is not admitted in the AR(∞) representation (Piccolo 1990). For each country, Table 2 reports all the estimated ARMA models, the log-likelihood, the number of the estimated parameters and the values of the Bayesian Information Criterion (BIC) provided by Schwarz (1978) and the Hannan–Quinn Information Criterion (HQC). It may be worth noting that, in spite of the seasonal adjustment, the models selected for Belgium, Denmark, the Netherlands and Sweden require a high number of lags in the MA component. As regards the countries which joined the EU after 2004, this happens only for the Czech Republic and Slovakia.

Table 2 Estimated ARMA(p, q) models

Panel A: EU-15 area countries

	AT					**LU**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-1	−0.2278	0.0997	−2.2852	0.0246	AR-7	−0.2701	0.1112	−2.4292	0.0170
MA-3	0.2559	0.1114	2.2971	0.0238	AR-8	−0.4034	0.1124	−3.5891	0.0005
					MA-2	0.3863	0.1115	3.4646	0.0008
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	29.8295	2	−0.5264	−0.5582		−34.5932	3	0.8633	0.8156
	BE					**NL**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-4	−0.7432	0.1687	−4.4053	0.0000	MA-8	−0.3424	0.1068	−3.2056	0.0018
MA-4	0.6530	0.1783	3.6625	0.0004					
MA-11	0.1621	0.0743	2.1809	0.0317					
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	11.3498	3	−0.0938	−0.1416		−25.3418	1	0.5755	0.5596
	FI					**PT**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-2	0.8199	0.1520	5.3944	0.0000	MA-6	0.2363	0.1120	2.1100	0.0375
MA-2	−0.8560	0.1631	−5.2480	0.0000					
MA-8	0.2395	0.0677	3.5393	0.0006					
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	16.5904	3	−0.2030	−0.2507		12.8384	1	−0.2199	−0.2358

Table 2 continued

	FR					**ES**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-5	−0.2690	0.1037	−2.5940	0.0110	AR-3	−0.8828	0.0603	−14.6503	0.0000
MA-2	−0.3873	0.1026	−3.7744	0.0003	MA-1	0.2756	0.0881	3.1280	0.0023
MA-6	0.2071	0.1028	2.0145	0.0468	MA-3	0.3470	0.1061	3.2701	0.0015
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	35.2634	3	−0.5920	−0.6398		22.4600	3	−0.3253	−0.3730
	DE					**DK**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-7	0.1886	0.1007	1.8730	0.0642	MA-10	0.2134	0.0985	2.1676	0.0327
MA-1	−0.2191	0.0984	−2.2253	0.0285					
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	31.5649	2	−0.5625	−0.5943		39.6781	1	−0.7791	−0.7950
	GR					**SE**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-7	−0.2274	0.1133	−2.0073	0.0476	MA-8	−0.3162	0.1202	−2.6308	0.0100
MA-2	−0.1998	0.0995	−2.0075	0.0476					
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	−22.8061	2	0.5702	0.5384		−18.4635	1	0.4322	0.4163
	IE					**UK**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
MA-1	0.3364	0.0970	3.4664	0.0008	MA-6	0.1142	0.1056	1.0814	0.2823
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	5.8773	1	−0.0749	−0.0908		−74.1213	1	1.5917	1.5758
	IT					**EU**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-7	−0.2137	0.1261	−1.6944	0.0935	MA-3	−0.2548	0.1204	−2.1162	0.0370
MA-2	−0.3169	0.1030	−3.0768	0.0027					
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	48.3417	2	−0.9120	−0.9439		−0.2548	1	0.0529	0.0369
Panel B: EU accession countries									
	CY					**LT**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
MA-6	0.5630	0.1020	5.5196	0.2820	MA-6	0.1709	0.1083	1.5780	0.1180
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	−56.1777	1	1.2179	1.2020		−34.5932	3	1.1734	1.1257

Table 2 continued

	CZ					**MT**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-1	0.2392	0.0989	2.4186	0.017	AR-3	−0.1913	0.1041	−1.8377	0.069
MA-12	−0.4792	0.2090	−2.2928	0.024	MA-6	0.2578	0.1082	2.3826	0.019
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	−8.6018	2	0.2743	0.2425		−60.4585	2	1.3546	1.3228
	EE					**PL**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
MA-1	0.3540	0.1136	3.1162	0.002	AR-2	0.9032	0.0628	14.3821	0.0000
					MA-1	0.6163	0.1023	6.0244	0.0000
					MA-2	−0.6044	0.1170	−5.1658	0.0000
					MA-3	−0.4092	0.0989	−4.1375	0.0000
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	−35.2714	1	0.7824	0.7665		−11.7529	4	0.4350	0.3714
	HU					**SK**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-1	0.4167	0.0961	4.3361	0.0000	MA-1	0.1152	0.1094	1.0530	0.295
					MA-6	−0.1095	0.1015	−1.0788	0.284
					MA-7	0.4302	0.1133	3.7970	0.0000
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	−42.3413	1	0.9297	0.9137		−101.8663	3	2.2649	2.2171
	LT					**SI**			
	Coeff	SE	t-stat	p-value		Coeff	SE	t-stat	p-value
AR-1	0.9555	0.0617	15.4862	0.0000	AR-1	0.3113	0.0785	3.9656	0.0000
MA-1	−0.8472	0.1156	−7.3287	0.0000	AR-2	0.6620	0.0830	7.9760	0.0000
					MA-2	−0.8615	0.0600	−14.3583	0.0000
	loglik.	par.	BIC	HQC		loglik.	par.	BIC	HQC
	−30.4520	2	0.7295	0.6977		−43.9765	3	1.0588	1.0111

5.3 AR distances and pair-wise similarity of short-run inflation dynamics

For each estimated ARMA model, we derive the AR(L) representation, with $L = 200$, and compute the AR distance for each pair of series considered. In Table 3, we report the pair-wise distance matrix including the values of estimated AR distances, while Table 5 in the Appendix displays the results of the similarity test based on $\hat{d}^2(X_{i,t}, X_{j,t})$ and the Diebold–Mariano test.

Table 3 AR distances

Panel A: EU-15 area countries

	AT	BE	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	DK	SE	UK
BE	0.439	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FI	**0.540**	**0.448**	-	-	-	-	-	-	-	-	-	-	-	-	-
FR	0.686	0.564	**0.608**	-	-	-	-	-	-	-	-	-	-	-	-
DE	**0.353**	**0.373**	**0.481**	0.624	-	-	-	-	-	-	-	-	-	-	-
GR	0.468	**0.384**	**0.495**	**0.439**	0.501	-	-	-	-	-	-	-	-	-	-
IE	0.623	0.426	**0.534**	0.592	0.594	**0.421**	-	-	-	-	-	-	-	-	-
IT	0.540	0.457	**0.551**	0.404	0.549	**0.137**	0.465	-	-	-	-	-	-	-	-
LU	0.782	0.749	0.893	1.033	0.856	0.773	0.828	0.863	-	-	-	-	-	-	-
NL	0.508	0.486	**0.679**	0.729	0.499	0.477	0.510	0.537	0.559	-	-	-	-	-	-
PT	0.464	**0.334**	**0.506**	**0.548**	**0.383**	**0.398**	0.433	0.486	0.706	0.438	-	-	-	-	-
ES	0.961	0.678	0.728	0.767	0.779	0.654	0.598	0.700	0.947	0.732	0.609	-	-	-	-
DK	0.414	**0.321**	**0.360**	0.568	0.367	**0.379**	0.419	0.460	0.672	0.425	**0.327**	0.650	-	-	-
SE	0.487	0.459	**0.653**	0.710	0.474	0.453	0.488	0.517	0.560	**0.033**	**0.412**	0.716	**0.398**	-	-
UK	**0.392**	**0.262**	**0.436**	**0.539**	**0.318**	**0.332**	0.376	0.428	0.687	0.382	**0.130**	0.605	**0.392**	**0.353**	-
CY	0.813	0.708	0.867	0.783	0.743	0.754	0.770	0.813	0.912	0.767	**0.465**	0.821	0.715	0.754	0.583
CZ	**0.777**	**0.630**	**0.823**	**0.824**	**0.752**	**0.684**	**0.582**	**0.732**	**0.884**	**0.698**	**0.614**	**0.815**	**0.648**	**0.685**	**0.611**
EE	0.640	0.444	**0.547**	0.597	0.612	**0.433**	**0.023**	**0.472**	0.842	0.525	0.451	0.607	0.437	0.504	**0.396**
HU	0.699	0.480	**0.583**	0.696	0.666	0.519	**0.144**	0.580	0.804	0.553	0.482	0.579	0.470	0.534	0.432
LV	0.419	**0.319**	**0.432**	0.674	0.411	0.448	**0.335**	0.549	0.706	0.447	**0.283**	0.671	**0.282**	0.420	**0.211**
LT	0.422	**0.290**	**0.464**	**0.539**	**0.343**	**0.358**	0.398	0.451	0.693	0.403	**0.071**	0.603	**0.279**	**0.376**	**0.059**
MT	0.605	**0.400**	**0.559**	0.592	0.440	0.463	0.503	0.544	0.732	0.493	**0.200**	0.474	0.398	0.470	**0.251**

Table 3 continued

Panel A: EU-15 area countries

	AT	BE	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	DK	SE	UK
PL	0.981	0.806	0.782	0.798	0.975	0.754	**0.509**	0.807	1.084	0.894	0.723	0.690	0.752	0.877	0.724
SK	**0.715**	**0.641**	**0.775**	0.879	**0.556**	0.795	**0.618**	0.824	0.997	**0.627**	**0.667**	0.883	**0.615**	**0.614**	**0.611**
SI	**0.813**	**0.729**	0.903	0.939	0.820	**0.799**	**0.613**	**0.798**	1.060	**0.745**	**0.806**	1.069	**0.788**	**0.737**	**0.758**
EU	0.563	**0.354**	**0.483**	0.631	**0.390**	**0.403**	0.465	0.475	0.744	0.450	**0.398**	0.469	**0.342**	**0.425**	**0.312**

Panel B: EU accession countries

	CY	CZ	EE	HU	LV	LT	MT	PL	SK	SI
BE	-	-	-	-	-	-	-	-	-	-
FI	-	-	-	-	-	-	-	-	-	-
FR	-	-	-	-	-	-	-	-	-	-
DE	-	-	-	-	-	-	-	-	-	-
GR	-	-	-	-	-	-	-	-	-	-
IE	-	-	-	-	-	-	-	-	-	-
IT	-	-	-	-	-	-	-	-	-	-
LU	-	-	-	-	-	-	-	-	-	-
NL	-	-	-	-	-	-	-	-	-	-
PT	-	-	-	-	-	-	-	-	-	-
ES	-	-	-	-	-	-	-	-	-	-
DK	-	-	-	-	-	-	-	-	-	-

Table 3 continued

Panel B: EU accession countries										
SE	-	-	-	-	-	-	-	-	-	-
UK	-	-	-	-	-	-	-	-	-	-
CY	-	-	-	-	-	-	-	-	-	-
CZ	**0.6916**	-	-	-	-	-	-	-	-	-
EE	0.7809	**0.5885**	-	-	-	-	-	-	-	-
HU	0.7987	**0.5888**	**0.1479**	-	-	-	-	-	-	-
LV	0.6795	**0.6135**	**0.3548**	0.3534	-	-	-	-	-	-
LT	**0.5304**	**0.6116**	0.4172	0.4514	**0.2377**	-	-	-	-	-
MT	**0.4848**	**0.6458**	0.5212	0.5330	0.3961	**0.2198**	-	-	-	-
PL	0.9017	**0.8298**	**0.5025**	**0.4671**	0.6717	0.7200	0.7612	-	-	-
SK	0.9569	**0.7820**	**0.6264**	**0.6426**	**0.5794**	**0.6341**	**0.7075**	0.9878	-	-
SI	1.0570	**0.7776**	**0.6087**	**0.6667**	**0.7008**	**0.7785**	0.8913	1.0232	**0.6407**	-
EU	0.777	**0.662**	0.485	0.493	0.397	**0.348**	**0.342**	0.812	**0.626**	0.850

Values highlighted in bold correspond to pairs for which the similarity test returns p-values higher than 0.01 (see Table 5)

A. EU-15 area countries

On the whole, our results show the presence of a high degree of dissimilarity of inflation dynamics among EU countries. Assuming a critical region at level 0.05 (0.1), for only 20 (11) pairs of comparisons out of 120 the similarity test indicates that the structural dynamics of short-run inflation rates are not significantly dissimilar.

When we limit our attention to the twelve Euro area countries (Table 3, panel A), the number of cases in which the null hypothesis of a zero AR distance is accepted drastically reduces to 12 (5). The AR distance calculated between Greece and Italy is the lowest (0.14), while it assumes the largest values for the pairs France–Luxembourg (1.03), Austria–Spain (0.96) and Luxembourg–Spain (0.95). The DGP of the Euro-wide area inflation rate mimics the inflation dynamics of Finland with good statistical significance (the similarity test accepts the null at 10% confidence level). It is similar to Belgium, Germany, Greece and Portugal DGPs at the level 0.01, while it is largely dissimilar to the inflation dynamics prevailing in Austria, France, Ireland, Italy, Luxembourg and Spain.

Rather surprisingly, EU countries that have preserved their national currency (Denmark, Sweden and the United Kingdom) display a high degree of similarity of their own short-run inflation dynamics with Euro area countries. In particular, the AR distance between inflation series of Sweden and the Netherlands is almost zero, while it is very low between the pairs Belgium–Denmark, Belgium–United Kingdom, Germany–United Kingdom and Portugal–United Kingdom. Moreover, inflation dynamics of Denmark, Sweden and United Kingdom are not significantly different from that of the Euro-wide area at least at a significance level 0.01.

These results are fully corroborated by the Diebold–Mariano test which, as we stated above, does not call for the independence of the inflation time series. Since the equal forecastability of inflation rates is a necessary condition for similarities of inflation dynamics, if the Diebold–Mariano test is rejected we can reject the hypothesis $d(X_{i,t}, X_{j,t}) = 0$. However, if the Diebold–Mariano test is accepted we cannot say that the AR distance is zero. As shown in Table 5, in all cases in which the similarity test is accepted, the Diebold–Mariano test is consistently not rejected at least at the 5% level. Moreover, also according to the Diebold–Mariano test, the DGP of the Euro-wide inflation fails to reproduce the short-run dynamics of the inflation of all State members. In particular, the hypothesis of equal forecastability of the Euro-wide inflation rate is clearly rejected against France, Luxembourg and Spain.

B. EU accession countries

As in the case of three oldest EU countries not adopting the Euro, also in the new EU Member States the short-run inflation dynamics show a somewhat surprisingly high degree of pair-wise similarity both across each other and with Euro area countries.[15]

[15] This result is roughly consistent with previous findings on output and inflation correlations with the Euro area that show a high degree synchronization for many new accession and stronger homogeneity within these group of countries than within EMU Member States (Eickmeier and Breitung 2006; Fidrmuc and Korhonen 2006).

According to the similarity test, the inflation dynamics of accession countries are not dissimilar at significance level 0.05 (0.01) in 24 (53) cases out of 150 possible comparisons with EU-15 countries. The Czech Republic and Slovenia have the largest number of acceptances (15 and 7, respectively), although for these two countries the results of similarity test are not always corroborated by those of the Diebold–Mariano test.

Looking at the AR distances (Table 3, panel B), the highest inflation similarity is between Baltic and youngest Euro countries as Finland, Ireland and Portugal. For example, between Estonia and Ireland $\hat{d}$ is 0.02 and highly significant, while it is 0.07 and 0.19 for the pairs Latvia–Portugal and Lithuania–Portugal. Finland has a short-run inflation dynamics which is not significantly different from that prevailing in Estonia (at a 0.05 significance level), Latvia and Lithuania (at a 0.1 significance level), even if the value of AR distances are not particularly low. Other countries that share a similar inflation dynamics are Hungary and Ireland and Latvia and UK, where the AR distances are, respectively, 0.14 and 0.06.

All in all, Baltic countries are those where short-run inflation dynamics is more in line with those of future Euro partners, while for Slovenia, which adopted the common currency in January 2007, and Poland the AR distance is, on average, the highest. The DGP of inflation rates of the Czech Republic, Malta, Lithuania and Slovakia mimic the Euro-wide inflation DGP, even if in the case of the Czech Republic the Diebold–Mariano test rejects the hypothesis of equal forecastability and DGP similarity.

Although it is difficult to relate our results to the literature because of differences in methodology and inflation dynamics measures employed, they seem to be only partly supported by previous findings. Eickmeier and Breitung (2006) find that the inflation rates in the Czech Republic and Lithuania are highly correlated with price changes in Euro area and that the share of variance of inflation changes in Lithuania explained by common euro-area factors is 36%. By contrast, Backé et al. (2003) show that deviations in the inflation rates of the Czech Republic, Lithuania and Slovakia from their own long-run trends (computed by the Hodrick-Prescott filter) are feebly correlated with deviations from EU long-run inflation and largely determined by country-specific factors. Finally, both Eickmeier and Breitung (2006) and Backé et al. (2003) find that inflation in Hungary, Poland and Slovenia follows a strictly Euro-wide inflation pattern, whereas similarity and Diebold–Mariano tests consistently show that inflation DGPs of these countries differ from Euro-wide inflation DGP.

When we consider the similarity of inflation dynamics of the ten accession countries, the null of zero AR distance is accepted in 16 (22) comparisons with a significance of 5% (1%) and in five comparisons with a significance higher than 10%. The AR distance is lower than 0.4 between the pairs Estonia–Hungary, Estonia–Latvia, Hungary–Latvia, Latvia–Lithuania, Lithuania–Malta, while it is higher than one for Cyprus–Slovenia and Poland–Slovenia.

5.4 Multi-wise similarity of short-run inflation dynamics

In this section, we extend the analysis to the notion of multi-wise similarity of short-run inflation dynamics described in Definition 2 and apply it to the Euro, EU-15, new EU accession and EU-25 country sets.

In order to elicit homogeneous groups of inflation DGPs we use, alternatively, graph and cluster analysis. Clustering algorithms classify objects into group structures such that the within-group dissimilarity is minimized and the between-group dissimilarity is maximized. Initially developed for static data, nowadays there is extensive literature on clustering univariate and multivariate time series with effective applications to many disciplines and domains as discovering similar patterns from DGPs and data mining.[16] In this sense, the AR distance is one of the first model-based criteria used for grouping time series by standard cluster algorithms (Piccolo 1990).

However, the strategy of clustering time series from the estimated AR distances has two major weaknesses. First, in this way we waste the valuable information arising from the inferential analysis on the squared AR distance. Second, the sample distribution of $\hat{d}^2(X_{i,t}, X_{j,t})$ depends on the parameter space, showing an increasing mean and variance as one gets closer to non-invertibility regions. Therefore, making comparisons between estimated distances, corresponding to different points of the parameter space, can be misleading (Sarno and Zazzaro 2002).

A natural way to overcome the commensurability problem is to discount each estimated squared distances by their standard error $\mathrm{SE}(\hat{d}^2)$, which is an inverse measure of the estimates' precision, and then to execute a traditional agglomerative hierarchical cluster analysis upon these quantities.

In addition, in order to rescue the inferential side of the AR distance for multi-wise comparisons, we propose to group countries on the basis of the density properties of a graph built on the statistical significance of the pairwise similarity tests.

5.4.1 Graph analysis

Consistent with Definition 2, we can group short-run inflation dynamics of EU countries on the basis of the similarity test on $\hat{d}^2(X_{i,t}, X_{j,t})$. However, given the assumption of DGPs independence required by the similarity test, we condition the acceptance of the null $d(X_{i,t}, X_{j,t}) = 0$ to the non rejection of the hypothesis of equal forecastability made by the Diebold–Mariano test.

Following graph theory, from a pairwise distance matrix Δ we can build up an adjacency matrix $A = \{a_{ij}\}$ where

$$a_{ij} = \begin{cases} 1 & \text{if } p\text{-value of similarity test} \geq \text{significance level } \alpha \\ & \text{and } p\text{-value of DM test} \geq \text{significance level } \alpha' \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

[16] Liao (2005) provides a wide review of methodological and applied contributions on clustering time series that he distinguishes in raw-data-based, feature-based and model-based time series clustering algorithms depending upon whether they work directly with raw data or with features and models extracted from these data.

Therefore, from A we can derive the graph $\mathscr{G}$, where each node represents a country and connecting lines (edges) between nodes designate short-run inflation dynamics that are not significantly dissimilar.[17]

When the number of comparisons is large, a graph is a powerful tool to investigate and visualize a number of interesting properties that either unite or separate inflation rate DGPs (Cappelli and Sarno 2003). In particular, we can immediately elicit: (i) the number of countries with which a country i shares the same DGP, that is, in graph theory terminology, the degree of a vertex,[18] (ii) the number, size and composition of country subsets for which every pair of countries shares the same inflation DGP, that is the size and composition of cliques,[19] (iii) size and composition of the country subset for which each element has a different inflation DGP, that is, the size and composition of the independent set.[20]

Obviously, both cliques and the independent set depend on the choice of the significance level for the similarity test and Diebold–Mariano tests. For the similarity test we assume, alternatively, a significance level of 0.05 and 0.01, while for the test of Diebold and Mariano we set the significance level at 0.01.

A. EU-15 area countries

In Fig. 2, we report four graphs regarding the Euro countries (panel A), EU-15 countries (panel B), new Member States (panel C) and EU-25 (panel D).[21]

As displayed in panel A, during the first seven years of life of the Euro, two groups of countries with the same inflation dynamics emerge. On one side, there are France, Greece, Finland and Italy that form the largest clique. On the other side, there are Austria, Finland and Germany whose inflation dynamics are reciprocally similar according to both the similarity and Diebold–Mariano tests. Finland is at the centre of these two groups, showing the highest degree of similarity with other Euro partners. Astonishingly, for eight of the twelve Euro area countries (namely, Austria, Belgium, France, Ireland, Luxembourg the Netherlands, Portugal and Spain) the short-run inflation dynamics is statistically dissimilar. Among these countries, Luxembourg and Spain display idiosyncratic inflation dynamics without any linkages with other Euro area countries, while inflation dynamics in the Netherlands is statistically

[17] This grouping procedure was introduced by Sarno (2005). In a similar vein, Maharaj (1996, 2000) and Corduas and Piccolo (2008) suggest to use a standard clustering procedure based on the p-values associated with a test on the equality of the autoregressive parameters. The advantage of following the Maharaj's procedure is that one can get a perfect partition of the EU countries' inflation dynamics. Once again, however, in this way we would lose valuable information, failing to highlight all the inflation dynamics that are reciprocally statistically non-dissimilar, albeit with a slightly lower p-value.

[18] According to graph theory, the degree of a vertex is the number of edges which it is incident with.

[19] According to graph theory, a clique of a graph $\mathscr{G}$ is a sub-graph of $\mathscr{G}$ whose vertices are pair-wise adjacent, that is, incident to a common edge.

[20] According to graph theory, an independent set of graph $\mathscr{G}$ is a subset of vertices such that no two vertices in the subset are adjacent.

[21] Graphs and their metrics are elicited by Graph Interface (GRIN), a software by V. Pechenkin freely available on the Web at http://www.geocities.com/pechv_ru/.

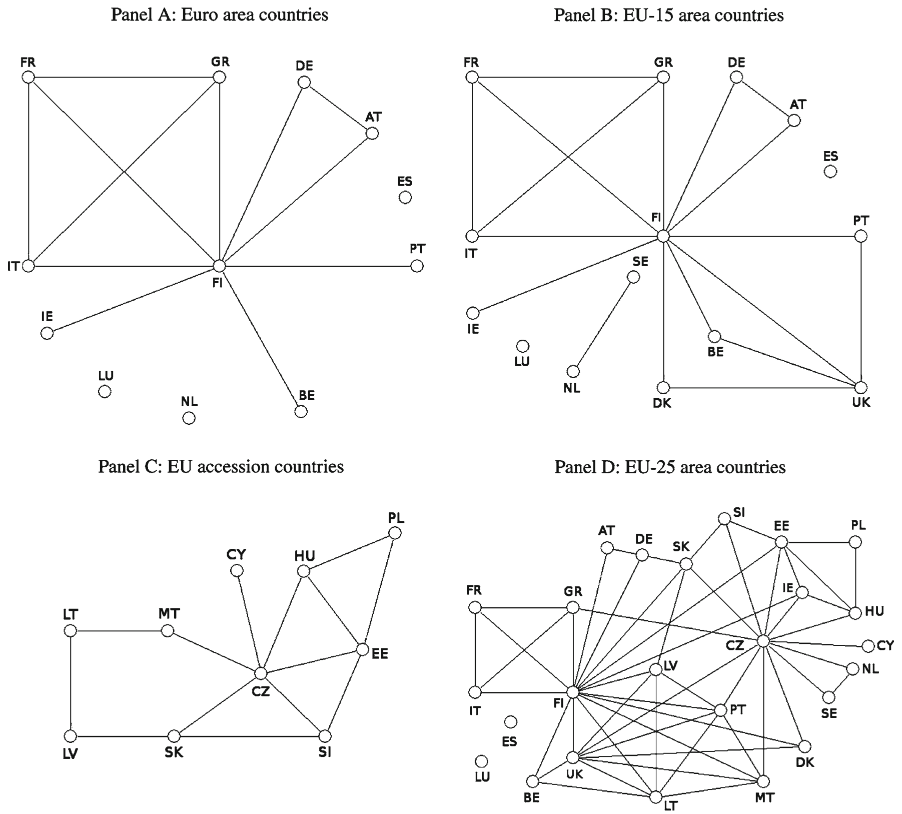

Fig. 2 Multi-wise similarity of short-run inflation dynamics: graph analysis. *Note*: According to equation (8), the p-value for the similarity test is set to $\alpha = 0.05$, while the p-value for the DM test is set to $\alpha' = 0.01$

similar only to that of Finland at 1% level. For France and Germany, both similarity and Diebold–Mariano tests reject the hypothesis of equal forecastability of inflation rates.

When we reduce the critical region for the dissimilarity test to the 0.01 level, one more four-country (Belgium–Finland–Greece–Portugal) and four more three-country cliques (Belgium–Finland–Germany; Belgium–Portugal–Germany; Greece–Finland–Ireland; Greece–France–Portugal) emerge.[22] Even so, the number of countries in the independent set remains very large, with only Portugal less with respect to panel A. Bearing in mind the strict relationship between the AR distance and the forecast functions, the strong dissimilarity of inflation dynamics after the introduction of the Euro may help to explain the findings of Marcellino et al. (2003) that inflation forecasts constructed by aggregating the country-specific models are more accurate than forecasts built on aggregate Euro-wide data.

[22] To save space, graphs considering a 0.01 significance level for the similarity test, are not reported, but are available upon request from the authors.

In panel B, we also take into account the inflation dynamics of Denmark, Sweden and the United Kingdom. At the 0.05 significance level, three cliques pivoted on the UK, and including Belgium, Denmark, Finland and Portugal add to the number of cliques elicited in panel A. The similarity of short-run inflation dynamics among these countries is still greater if we consider a significance level of 0.01. In this case, the largest clique is formed by Belgium, Denmark, Finland, Greece, Portugal and the UK. Finally, neither Denmark, Sweden nor the UK belongs to the independent set.

B. EU accession countries

Looking at panel C in Fig. 2, new EU accession members can be easily split into (i) countries that share the same inflation DGP, (ii) countries with an idyosincratic inflation DGP and (iii) Lithuania that has strong similarity with countries in both groups.

Making up the first group of countries is the Czech Republic, Estonia, Hungary, Slovakia and Slovenia. When we set the critical region of the similarity test at 0.05, these countries form three different three-country cliques, with the Czech Republic at the centre of these linkages. With a critical region at 0.01, the Czech Republic, Estonia, Hungary and Slovakia form the largest clique, while Slovenia is excluded from this group due to the rejection of the Diebold–Mariano test of equal forecastability with respect only to Hungary. Cyprus, Latvia, Malta, Poland and Slovenia belong to the second group; they form the independent set of countries in panel C, whose inflation rates follow a short-run dynamics dissimilar to each other.[23]

Finally, the inflation dynamics in Lithuania is very similar to that prevailing in Latvia and Malta, it is similar at 0.01 to that of Slovakia and it is only slightly dissimilar to that of Estonia (in this case, the Diebold–Mariano test largely accepts the null of equal forecastability but the *p*-value of the similarity test is only 0.0084).

These results are broadly in accordance with previous studies on inflation patterns in EU accession countries. For example, Backé et al. (2003) show that short-run inflation dynamics of the Czech Republic and Estonia are highly correlated. Boreiko (2003), by analysing the degree of compliance with Optimal Currency Area criteria,[24] finds that the Czech Republic, Estonia, Hungary, and Slovenia form the cluster of most virtuous countries in the period 1999–2001, while Latvia and Lithuania belong to another cluster. With respect to Maastricht criteria, instead, the Czech Republic, Hungary and Slovakia are in the same cluster with Lithuania and Poland, while Estonia, Latvia and Slovenia are in a different cluster. Finally from the meta-analysis of Fidrmuc and Korhonen (2006) the Czech Republic, Hungary, Slovakia and Slovenia have a similar degree of business cycle (including inflation) correlation with Euro area countries.

[23] With a critical region at 0.01, however, Cyprus and Malta have a similar short-run inflation dynamics.

[24] In optimal currency area criteria, Boreiko (2003) includes correlation in business cycle with Germany, standard deviation of log difference in bilateral real exchange rate against Deutsche Mark, the ratio of import and export to the EU over total imports and exports, the differential between the CPI and the EU-15 average inflation.

In panel D, we consider all the linkages across the EU-25 area countries, setting the critical region at a level of 0.05. The largest clique is formed by Finland, Latvia, Lithuania, Portugal and the UK. Estonia, Hungary, Ireland and Poland form two different three-country cliques separated only by the dissimilarity between inflation DGPs of Ireland and Poland. Inflation dynamics of Luxembourg and Spain confirm their peculiarities, while those prevailing in Austria, France and Italy seem to be dissimilar to those of all accession countries.[25]

5.4.2 Cluster analysis

As the similarity test does not satisfy transitivity, the approach based on graph theory does not allow us to get a partition of the short run-inflation dynamics. For this purpose, we also run a traditional cluster analysis using the agglomerative hierarchical complete linkage method. However, in order to make AR distances commensurable, we implement the cluster method on the estimated squared distances discounted by their standard error.

A. EU-15 area countries

From the dendrogram for the Euro area countries (Fig. 3, panel A) two clusters of countries clearly emerge. The first cluster is formed by Austria, Belgium, Germany, Portugal, and Finland, the second by France, Greece and Italy. The inflation rates of Luxembourg and the Netherlands gravitate towards the first cluster and that of Ireland gravitates towards the second, while Spain shows very idiosyncratic inflation dynamics.

Interestingly, our findings are only partly consistent with results on convergence clubs of long-run inflation rates in Euro area countries recently obtained by Busetti et al. (2007) in the context of stationarity tests on pair-wise inflation differentials. According to them, we find strong similarity of short-run dynamics of inflation rates among Austria, Belgium, Finland and Germany. However, while long-run inflation in France and Germany seem to have converged, their short-run behaviour are still quite different. Moreover, although its inflation rate fluctuates around higher levels, Greece displays quite a similar short-run inflation dynamics to that of France and Italy. While our analysis is purely statistical, a possible explanation for this unexpected result could be found in the similar high degree of stickiness of the labour market and low competition in non-tradable sectors.

The dendrogram reported in panel B confirms the findings of graph analysis and show that inflation dynamics of Denmark and the UK belong to the cluster of low inflation countries, while inflation dynamics of Sweden is very similar to that prevailing in the Netherlands.

25 At a 0.01 significance level, France–Czech Republic, France–Slovenia, Italy–Czech Republic and Italy–Estonia can be said to share a similar DGP.

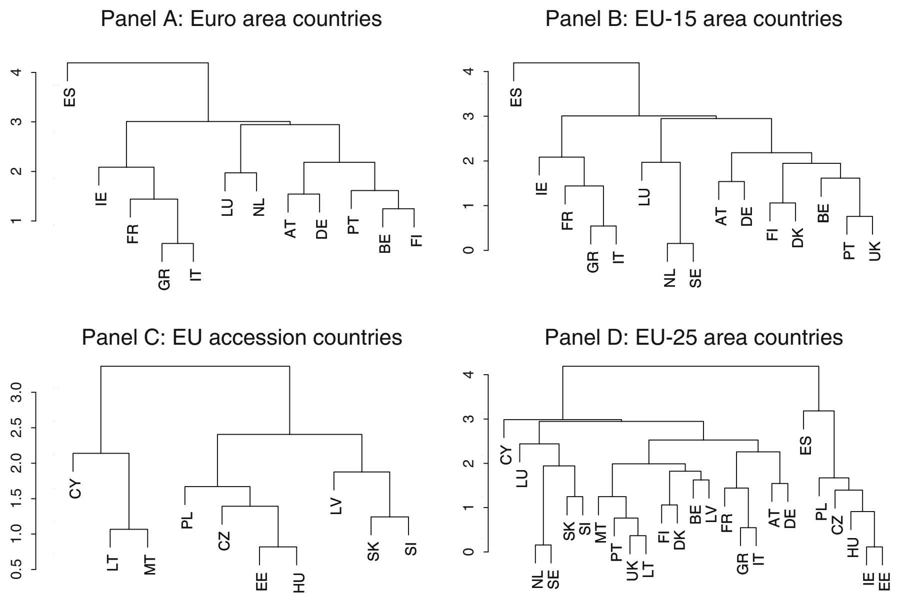

Fig. 3 Multi-wise similarity of short-run inflation dynamics: cluster analysis

B. EU accession countries

With regard to new EU Member States, cluster analysis confirms the high degree of similarity that characterizes the short-run inflation dynamics of these countries. Sectioning the dendrogram reported in panel C at height 2.3, we obtain a large cluster formed by the Czech Republic, Estonia, Hungary, Latvia, Poland, Slovakia and Slovenia and a second cluster formed by Cyprus, Lithuania and Malta. The former cluster breaks into two more homogeneous clusters at height 1.8, with Latvia, Slovakia and Slovenia on one side, and the Czech Republic, Estonia, Hungary, and Poland on the other.

Finally, if we look at the dendrogram of EU-25 area countries, the first countries to cluster below the threshold level 1 (that is, the most homogeneous groups) are the Netherlands and Sweden; Lithuania, Portugal and the United Kingdom; Greece and Italy; Estonia, Ireland and Hungary. If we section the dendrogram around 2, we obtain four large clusters that largely corroborate graph analysis: (i) the Netherlands, Slovakia, Slovenia and Sweden; (ii) Belgium, Denmark, Finland, Latvia, Lithuania, Malta, Portugal and the United Kingdom; (iii) Austria, Germany, France, Italy and Greece; (iv) the Czech Republic, Estonia, Hungary, Ireland and Poland.

6 Conclusions

The purpose of this paper was to assess the degree of similarity of short-run dynamic properties of inflation rates among EU-25 area countries after the introduction of the

Euro in 1999. This is of prime importance for designing a common monetary policy in a currency area. For example, similarity of short-run inflation dynamics is required to forecast the impact of European Central Bank (ECB) monetary policy at country level starting from the aggregate Euro-wide price index. Moreover, it reduces potential nationalist tensions within ECB concerning optimal monetary policy.

In this paper, we introduced two definitions of pair-wise and multi-wise similarity of inflation rates in terms of forecast functions. We then used AR distance (Piccolo 1990) to measure the pair-wise similarity of short-run inflation dynamics. Finally, on the basis of inferential analysis conducted on the estimated AR distances, we appraised the multi-wise similarity of inflation DGPs among EU countries by means of graph and cluster methods.

On the whole, we can draw three main conclusions from our analysis. First, consistent with studies on inflation differentials and inflation persistence, we find that after seven years from the launch of the Euro the degree of similarity in short-run inflation dynamics among Euro Area countries is still weak. Within this picture, however, we were able to elicit two groups of countries (namely, France–Greece–Italy and Austria–Belgium–Finland–Germany–Portugal) whose own inflation DGPs showed a statistically similar behaviour.

Second, and somewhat surprisingly, short-run inflation dynamics seem to be more homogeneous across old and new non-Euro Member States. In particular, new accession countries can be divided into two groups. The former is formed by the Czech Republic, Estonia, Hungary, Slovakia and Slovenia. To these countries we should add Poland whose inflation DGP proves statistically similar to the inflation DGP of Estonia, Hungary and, according to the similarity test, the Czech Republic. The latter group is formed by Cyprus, Latvia, Lithuania and Malta which, despite showing some strong pair-wise inflation similarity, do not share all the same inflation DGP.

Third, the linkage between the Euro area and accession countries are primarily Finland, Ireland and Portugal, while inflation DGPs of the oldest EU countries seem to be still largely dissimilar to that of new Member States.

These findings are not always straightforward to interpret and explain. However, what actually drives the similarity of short-run inflation dynamics across EU countries is a key issue which lies beyond the aim of this paper and is left to future research.

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Appendix

Table 4 Country codes

EU-15 area countries		EU accession countries	
Code	Country	Code	Country
Euro countries			
AT	Austria	CY	Cyprus
BE	Belgium	CZ	Czech Republic
FI	Finland	EE	Estonia
FR	France	HU	Hungary
DE	Germany	LV	Latvia
GR	Greece	LT	Lithuania
IE	Ireland	MT	Malta
IT	Italy	PL	Poland
LU	Luxembourg	SK	Slovakia
NL	The Netherlands	SI	Slovenia
PT	Portugal		
ES	Spain		
EU	Euro-wide area		
Non Euro countries			
DK	Denmark		
SE	Sweden		
UK	United Kingdom		

Table 5 Test statistics for pairwise similarity

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
AT-BE	12.937	3.304	0.006**	−0.411	0.682
AT-FI	4.671	1.636	0.068	0.247	0.805
AT-FR	18.060	3.021	0.000**	1.325	0.188
AT-DE	6.427	2.484	0.062	−0.327	0.744
AT-GR	13.353	3.094	0.004**	−0.199	0.843
AT-IE	18.356	1.932	0.000**	0.014	0.989
AT-IT	16.406	3.323	0.001**	0.149	0.882
AT-LU	24.538	3.010	0.000**	1.594	0.114
AT-NL	14.977	2.597	0.001**	0.020	0.984
AT-PT	10.959	2.007	0.004**	−0.409	0.683
AT-ES	47.741	2.375	0.000**	1.629	0.107
AT-DK	11.330	2.484	0.006**	−0.458	0.648
AT-EE	15.494	1.736	0.000**	0.081	0.936

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
AT-HU	25.709	1.907	0.000**	0.163	0.871
AT-LV	10.086	2.108	0.007**	−0.754	0.453
AT-LT	9.399	1.959	0.009**	−0.684	0.496
AT-MT	16.701	2.276	0.000**	−0.076	0.940
AT-PL	27.455	2.511	0.000**	5.296	0.000**
AT-SK	8.410	1.919	0.014*	1.059	0.292
AT-SI	7.108	1.226	0.011*	2.691	0.008**
AT-EU	12.217	1.540	0.001**	−0.639	0.524
BE-FI	2.952	1.536	0.157	1.040	0.301
BE-FR	12.100	2.887	0.006**	2.589	0.011*
BE-DE	12.205	4.143	0.018*	0.247	0.805
BE-GR	9.816	3.149	0.023*	0.230	0.819
BE-IE	14.054	2.974	0.003**	0.624	0.534
BE-IT	11.904	3.101	0.009**	0.277	0.783
BE-LU	21.658	2.696	0.000**	1.544	0.126
BE-NL	12.490	2.038	0.002**	0.197	0.844
BE-PT	8.130	2.871	0.039*	0.011	0.991
BE-ES	37.380	3.529	0.000**	4.478	0.000**
BE-DK	9.308	3.283	0.032*	−0.081	0.936
BE-SE	9.465	1.835	0.007**	0.176	0.861
BE-UK	6.111	3.280	0.128	−0.034	0.973
BE-CY	12.294	1.361	0.001**	3.619	0.001**
BE-CZ	2.988	1.075	0.093	3.788	0.000**
BE-EE	10.586	2.261	0.007**	0.577	0.566
BE-HU	22.618	3.311	0.000**	0.400	0.690
BE-LV	9.448	3.291	0.030*	−0.128	0.898
BE-LT	7.030	3.157	0.079	−0.208	0.836
BE-MT	11.419	3.555	0.016*	0.378	0.706
BE-PL	19.588	2.458	0.000**	4.206	0.000**
BE-SK	6.548	1.786	0.030*	1.567	0.120
BE-SI	5.551	1.150	0.023*	3.833	0.000**
BE-EU	7.812	2.576	0.035*	0.103	0.918
FI-FR	5.708	2.067	0.061	1.887	0.062
FI-DE	3.552	1.536	0.113	−0.542	0.589
FI-GR	3.869	1.653	0.106	−0.396	0.693
FI-IE	4.558	1.506	0.063	−0.303	0.762
FI-IT	4.957	1.805	0.070	−0.010	0.992
FI-LU	14.296	2.183	0.001**	1.090	0.278
FI-NL	7.715	1.586	0.013*	−0.080	0.936
FI-PT	4.067	1.524	0.084	−0.477	0.634

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
FI-ES	8.687	1.519	0.007**	3.310	0.001**
AT-SE	12.274	2.458	0.004**	−0.044	0.965
AT-UK	8.229	1.915	0.015*	−0.016	0.987
AT-CY	16.557	1.511	0.000**	2.757	0.007**
AT-CZ	4.795	1.137	0.035*	2.034	0.045*
FI-DK	1.848	1.434	0.269	−0.701	0.485
FI-SE	7.188	1.666	0.019*	−0.164	0.870
FI-UK	2.890	1.446	0.149	−0.006	0.995
FI-CY	13.244	2.164	0.002**	2.752	0.007**
FI-CZ	5.776	1.706	0.041*	1.852	0.067
FI-EE	4.912	1.656	0.061	−0.117	0.907
FI-HU	5.423	1.394	0.035*	0.028	0.978
FI-LV	2.782	1.413	0.153	−0.984	0.328
FI-LT	3.333	1.473	0.119	−1.380	0.171
FI-MT	5.017	1.635	0.057	−0.536	0.593
FI-PL	10.056	2.335	0.009**	3.392	0.001**
FI-SK	9.360	2.851	0.022*	1.212	0.228
FI-SI	9.494	2.076	0.009**	2.718	0.008**
FI-EU	3.707	1.578	0.108	−0.702	0.485
FR-DE	14.502	2.743	0.002**	−2.935	0.004**
FR-GR	5.181	2.107	0.083	−1.763	0.081
FR-IE	12.443	2.431	0.003**	−1.447	0.151
FR-IT	4.270	2.322	0.152	−0.282	0.779
FR-LU	34.002	3.264	0.000**	0.474	0.636
FR-NL	19.867	2.714	0.000**	−0.448	0.655
FR-PT	8.366	1.854	0.013*	−1.194	0.235
FR-ES	22.721	2.797	0.000**	0.915	0.362
FR-DK	12.210	2.501	0.004**	−1.597	0.114
FR-SE	18.155	2.740	0.000**	−0.515	0.608
FR-UK	8.695	1.916	0.012*	−0.086	0.932
FR-CY	12.957	1.828	0.001**	1.392	0.167
FR-CZ	5.411	1.281	0.030*	0.620	0.537
FR-EE	11.726	2.456	0.005**	−0.778	0.439
FR-HU	18.731	2.405	0.000**	−0.674	0.502
FR-LV	16.431	2.307	0.000**	−2.236	0.028*
FR-LT	8.443	1.887	0.013*	−2.344	0.021*
FR-MT	10.025	2.118	0.008**	−1.832	0.070
FR-PL	13.785	2.569	0.002**	2.148	0.034*
FR-SK	13.518	2.509	0.002**	0.159	0.874
FR-SI	9.741	1.488	0.004**	1.880	0.063

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
FR-EU	14.054	2.529	0.002**	−2.603	0.011*
DE-GR	10.841	1.881	0.004**	0.055	0.956
DE-IE	19.247	1.812	0.000**	0.408	0.684
DE-IT	12.372	2.120	0.002**	0.255	0.799
DE-LU	27.851	2.755	0.000**	1.397	0.166
DE-NL	15.082	2.342	0.001**	0.127	0.899
DE-PT	10.697	2.737	0.011*	−0.148	0.882
DE-ES	40.234	2.658	0.000**	2.781	0.006**
DE-DK	11.516	2.922	0.009**	−0.272	0.786
DE-SE	11.591	2.096	0.003**	0.062	0.950
DE-UK	8.617	2.925	0.033*	−0.002	0.998
DE-CY	13.794	1.379	0.000**	4.260	0.000**
DE-CZ	4.463	1.108	0.041*	3.275	0.002**
DE-EE	15.793	1.603	0.000**	0.299	0.765
DE-HU	24.115	1.575	0.000**	0.543	0.589
DE-LV	9.129	1.660	0.007**	−0.459	0.647
DE-LT	9.572	2.893	0.021*	−0.530	0.598
DE-MT	13.615	3.372	0.005**	0.143	0.886
DE-PL	28.302	2.447	0.000**	5.512	0.000**
DE-SK	4.740	1.800	0.078	1.538	0.128
DE-SI	7.220	1.170	0.009**	4.385	0.000**
DE-EU	9.296	2.414	0.015*	−0.319	0.750
GR-IE	8.791	1.847	0.010*	0.184	0.855
GR-IT	0.605	1.972	0.733	0.196	0.845
GR-LU	20.431	2.562	0.000**	1.325	0.188
GR-NL	13.038	2.445	0.003**	0.110	0.913
GR-PT	9.700	2.448	0.013*	−0.232	0.817
GR-ES	25.259	2.493	0.000**	1.783	0.078
GR-DK	9.425	2.335	0.013*	−0.215	0.830
GR-SE	10.518	2.317	0.007**	0.062	0.951
GR-UK	7.142	2.311	0.038*	−0.009	0.993
GR-CY	14.488	1.511	0.000**	1.908	0.059
GR-CZ	3.620	1.099	0.066	1.827	0.071
GR-EE	7.434	1.694	0.017*	0.192	0.848
GR-HU	17.919	2.134	0.000**	0.433	0.666
GR-LV	11.890	1.985	0.003**	−0.348	0.728
GR-LT	8.207	2.389	0.025*	−0.409	0.683
GR-MT	13.215	3.091	0.005**	0.099	0.921
GR-PL	13.935	2.076	0.001**	3.011	0.003**
GR-SK	10.262	1.827	0.005**	1.104	0.272

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
GR-SI	6.814	1.197	0.012*	3.825	0.000**
GR-EU	9.049	2.390	0.016*	−0.276	0.783
IE-IT	9.916	2.079	0.008**	0.108	0.914
IE-LU	25.869	2.387	0.000**	1.573	0.119
IE-NL	15.160	1.937	0.001**	0.015	0.988
IE-PT	12.166	1.995	0.002**	−0.418	0.677
IE-ES	15.907	1.488	0.000**	2.550	0.012*
IE-DK	12.711	1.910	0.002**	−0.656	0.513
IE-SE	12.113	1.822	0.002**	−0.056	0.955
IE-UK	10.203	1.913	0.005**	−0.072	0.943
IE-CY	14.677	1.299	0.000**	4.988	0.000**
IE-CZ	2.641	1.098	0.118	2.349	0.021*
IE-EE	0.013	1.000	0.907	0.092	0.927
IE-HU	0.877	1.033	0.360	0.231	0.818
IE-LV	6.898	1.458	0.017*	−1.029	0.306
IE-LT	11.098	1.973	0.004**	−0.785	0.434
IE-MT	15.640	2.492	0.001**	−0.109	0.914
IE-PL	6.123	1.908	0.043*	4.331	0.000**
IE-SK	6.082	1.759	0.037*	1.486	0.141
IE-SI	3.937	1.175	0.060	4.699	0.000**
IE-EU	11.304	1.697	0.002**	−0.549	0.584
IT-LU	24.594	2.679	0.000**	1.188	0.238
IT-NL	15.598	2.784	0.001**	−0.107	0.915
IT-PT	12.847	2.601	0.003**	−0.697	0.488
IT-ES	27.803	2.945	0.000**	0.586	0.559
IT-DK	12.372	2.559	0.004**	−0.383	0.703
IT-SE	13.328	2.711	0.003**	−0.143	0.886
IT-UK	10.208	2.426	0.010*	−0.296	0.768
IT-CY	17.417	1.766	0.000**	0.674	0.502
IT-CZ	4.180	1.137	0.050	0.601	0.549
IT-EE	8.468	1.917	0.013*	−0.046	0.963
IT-HU	19.616	2.362	0.000**	0.065	0.949
IT-LV	15.644	2.151	0.001**	−0.487	0.627
IT-LT	11.300	2.506	0.006**	−0.411	0.682
IT-MT	16.462	3.228	0.001**	−0.190	0.850
IT-PL	16.631	2.395	0.000**	0.918	0.361
IT-SK	10.852	1.881	0.004**	0.466	0.642
IT-SI	6.535	1.215	0.015*	1.388	0.168
IT-EU	11.933	2.733	0.006**	−0.363	0.717
LU-NL	10.780	2.441	0.007**	−2.208	0.030*

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
LU-PT	17.883	2.279	0.000**	−4.495	0.000**
LU-ES	32.481	2.372	0.000**	−0.231	0.818
LU-DK	16.824	2.253	0.000**	−1.300	0.197
LU-SE	10.163	2.392	0.010*	−4.861	0.000**
LU-UK	17.571	2.233	0.000**	−0.871	0.386
LU-CY	20.191	2.080	0.000**	−0.034	0.973
LU-CZ	6.259	1.253	0.018*	−0.317	0.752
LU-EE	25.294	2.493	0.000**	−0.983	0.328
LU-HU	25.839	2.313	0.000**	−0.909	0.365
LU-LV	19.401	2.305	0.000**	−1.964	0.052
LU-LT	17.635	2.249	0.000**	−1.536	0.128
LU-MT	19.499	2.611	0.000**	−1.348	0.181
LU-PL	32.149	3.035	0.000**	0.258	0.797
LU-SK	16.863	2.329	0.000**	−0.423	0.673
LU-SI	12.723	1.460	0.001**	0.250	0.803
LU-EU	21.805	2.731	0.000**	−2.009	0.047*
NL-PT	11.025	1.960	0.004**	−0.324	0.747
NL-ES	33.154	2.316	0.000**	0.509	0.612
NL-DK	10.805	1.743	0.003**	−0.175	0.862
NL-SE	0.026	1.000	0.873	−0.131	0.896
NL-UK	8.723	1.750	0.009**	−0.242	0.809
NL-CY	14.728	1.411	0.000**	0.952	0.344
NL-CZ	3.798	1.086	0.058	0.714	0.477
NL-EE	13.540	1.964	0.001**	0.023	0.982
NL-HU	18.242	1.541	0.000**	0.116	0.908
NL-LV	11.368	1.541	0.002**	−0.240	0.811
NL-LT	9.678	1.848	0.007**	−0.259	0.796
NL-MT	14.358	2.617	0.002**	−0.054	0.957
NL-PL	23.947	2.449	0.000**	0.978	0.331
NL-SK	6.161	1.763	0.036*	0.461	0.646
NL-SI	5.806	1.147	0.020*	1.307	0.194
NL-EU	10.807	2.000	0.004**	−0.245	0.807
PT-ES	25.105	2.402	0.000**	1.339	0.184
PT-DK	7.443	1.879	0.021*	−0.052	0.958
PT-SE	8.581	1.858	0.012*	0.514	0.609
PT-UK	0.610	1.001	0.435	−0.018	0.986
PT-CY	3.999	1.028	0.047*	2.131	0.036*
PT-CZ	2.875	1.065	0.098	2.059	0.042*
PT-EE	10.304	1.859	0.005**	0.346	0.730

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
PT-HU	16.461	1.683	0.000**	0.764	0.447
PT-LV	5.525	1.771	0.050	−0.131	0.896
PT-LT	0.171	1.000	0.679	−0.141	0.888
PT-MT	1.191	1.297	0.362	0.259	0.796
PT-PL	14.468	2.155	0.001**	3.401	0.001**
PT-SK	7.251	1.785	0.021*	1.040	0.301
PT-SI	6.977	1.144	0.010*	3.916	0.000**
PT-EU	7.160	1.452	0.015*	0.070	0.944
ES-DK	34.826	2.662	0.000**	−2.643	0.010*
ES-SE	27.158	2.084	0.000**	−0.859	0.393
ES-UK	28.445	2.499	0.000**	−0.227	0.821
ES-CY	16.712	1.349	0.000**	0.823	0.413
ES-CZ	5.250	1.097	0.025*	−0.187	0.852
ES-EE	12.814	1.353	0.001**	−1.413	0.161
ES-HU	18.848	1.549	0.000**	−0.890	0.376
ES-LV	34.545	2.299	0.000**	−3.659	0.000**
ES-LT	27.071	2.493	0.000**	−3.423	0.001**
ES-MT	12.002	2.425	0.004**	−2.544	0.013*
ES-PL	11.978	2.123	0.003**	1.578	0.118
ES-SK	12.974	1.821	0.001**	−0.487	0.627
ES-SI	12.521	1.188	0.001**	1.464	0.146
ES-EU	9.282	1.521	0.005**	−2.749	0.007**
DK-SE	8.020	1.601	0.011*	0.147	0.884
DK-UK	5.207	2.000	0.074	−0.002	0.999
DK-CY	12.332	1.188	0.001**	3.896	0.000**
DK-CZ	3.267	1.054	0.076	2.536	0.013*
DK-EE	9.716	1.605	0.005**	1.032	0.305
DK-HU	20.609	1.924	0.000**	0.546	0.586
DK-LV	7.093	1.988	0.029*	−0.065	0.949
DK-LT	6.206	1.977	0.044*	−0.121	0.904
DK-MT	10.904	2.580	0.008**	0.305	0.761
DK-PL	16.762	2.203	0.000**	4.378	0.000**
DK-SK	6.052	1.683	0.035*	1.642	0.104
DK-SI	6.615	1.110	0.012*	3.880	0.000**
DK-EU	6.858	1.727	0.024*	0.148	0.883
SE-UK	6.256	1.607	0.029*	−0.198	0.843
SE-CY	14.435	1.534	0.000**	0.810	0.420
SE-CZ	3.664	1.108	0.065	0.667	0.506
SE-EE	11.695	2.000	0.003**	0.096	0.923

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
SE-HU	14.186	1.418	0.000**	0.230	0.818
SE-LV	8.414	1.425	0.007**	−0.247	0.805
SE-LT	7.160	1.710	0.020*	−0.215	0.830
SE-MT	11.599	2.450	0.005**	−0.002	0.998
SE-PL	22.839	2.541	0.000**	1.045	0.299
SE-SK	5.870	1.806	0.044*	0.675	0.502
SE-SI	5.681	1.174	0.022*	1.333	0.186
SE-EU	8.780	1.970	0.012*	−0.153	0.878
UK-CY	7.030	1.048	0.009**	0.148	0.882
UK-CZ	2.877	1.053	0.096	0.038	0.969
UK-EE	7.960	1.609	0.012*	0.056	0.956
UK-HU	17.288	1.919	0.000**	0.155	0.877
UK-LV	3.942	2.021	0.142	0.001	0.999
UK-LT	0.137	1.000	0.711	0.004	0.997
UK-MT	2.344	1.383	0.192	0.021	0.984
UK-PL	14.607	2.064	0.001**	0.400	0.690
UK-SK	5.988	1.724	0.038*	0.325	0.746
UK-SI	6.101	1.110	0.016*	0.345	0.731
UK-EU	4.508	1.314	0.052	0.013	0.989
CY-CZ	3.206	1.091	0.083	−0.883	0.379
CY-EE	15.616	1.549	0.000**	−1.897	0.061
CY-HU	15.209	1.123	0.000**	−1.322	0.189
CY-LV	10.971	1.141	0.001**	−5.578	0.000**
CY-LT	5.566	1.039	0.019*	−5.439	0.000**
CY-MT	4.327	1.144	0.046*	−1.904	0.060
CY-PL	19.535	2.530	0.000**	1.121	0.265
CY-SK	15.893	2.380	0.001**	−1.041	0.300
CY-SI	13.104	1.553	0.001**	0.556	0.580
CY-EU	14.752	1.380	0.000**	3.139	0.002**
CZ-EE	2.717	1.149	0.120	−1.261	0.210
CZ-HU	2.716	1.074	0.109	−0.894	0.373
CZ-LV	2.913	1.057	0.095	−3.620	0.001**
CZ-LT	2.875	1.057	0.097	−3.069	0.003**
CZ-MT	3.147	1.090	0.086	−2.058	0.042*
CZ-PL	5.671	1.437	0.032*	1.731	0.087
CZ-SK	5.088	1.808	0.066	−0.214	0.831
CZ-SI	4.441	1.642	0.078	1.990	0.049*
CZ-EU	3.415	1.092	0.073	4.485	0.000**
EE-HU	0.704	1.030	0.412	0.144	0.886

Table 5 continued

Countries	Similarity test			DM test	
	d^2	df	p-value	z-stat	p-value
EE-LV	5.561	1.309	0.029*	−0.681	0.497
EE-LT	8.882	1.712	0.008**	−0.636	0.526
EE-MT	13.339	2.239	0.002**	−0.135	0.893
EE-PL	5.357	1.836	0.059	2.485	0.015*
EE-SK	6.264	1.867	0.038*	0.846	0.399
EE-SI	3.867	1.238	0.068	2.425	0.017*
EE-EU	10.264	1.698	0.004**	0.387	0.700
HU-LV	7.967	1.151	0.006**	−0.765	0.446
HU-LT	17.069	1.835	0.000**	−0.664	0.508
HU-MT	19.846	2.384	0.000**	−0.253	0.801
HU-PL	5.926	2.044	0.054	1.361	0.177
HU-SK	6.615	1.678	0.026*	0.608	0.545
HU-SI	4.713	1.115	0.036*	3.003	0.003**
HU-EU	14.160	1.526	0.000**	0.785	0.434
LV-LT	4.572	1.933	0.096	−0.113	0.910
LV-MT	10.138	2.296	0.009**	0.430	0.668
LV-PL	13.361	2.216	0.002**	9.357	0.000**
LV-SK	5.285	1.670	0.051	2.028	0.045*
LV-SI	5.199	1.111	0.027*	6.462	0.000**
LV-EU	8.502	1.478	0.007**	−0.327	0.744
LT-MT	1.641	1.345	0.283	0.435	0.665
LT-PL	14.407	2.095	0.001**	6.562	0.000**
LT-SK	6.492	1.744	0.030*	2.123	0.036*
LT-SI	6.458	1.122	0.013*	3.581	0.001**
LT-EU	5.602	1.370	0.030*	−0.316	0.752
MT-PL	16.205	2.410	0.001**	2.923	0.004**
MT-SK	8.236	1.892	0.014*	1.113	0.269
MT-SI	8.631	1.204	0.005**	3.609	0.001**
MT-EU	3.725	1.351	0.084	0.310	0.757
PL-SK	17.283	2.776	0.001**	−1.442	0.153
PL-SI	12.084	1.752	0.002**	−0.326	0.745
PL-EU	18.810	2.321	0.000**	6.237	0.000**
SK-SI	2.687	1.253	0.137	1.185	0.239
SK-EU	6.414	1.839	0.034*	1.373	0.173
SI-EU	7.883	1.190	0.007**	5.671	0.000**

According to Eq. (8), country pairs highlighted in bold correspond to those for which the p-value for the similarity is higher than $\alpha = 0.05$, and the p-value for the DM test is higher than $\alpha' = 0.01$
*, ** Statistical significance at the 5 and 1% level, respectively

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