Euro Area Inflation Differentials: Unit Roots, Structural Breaks and Non-Linear Adjustment

Andros Gregoriou *[a], Alexandros Kontonikas [b], Alberto Montagnoli [c]

[a] *Brunel Business School, Economics and Finance Section, Brunel University, Uxbridge, UB8 3PH, UK*

[b] *Department of Economics, University of Glasgow, Adam Smith Building, Glasgow, G12 8RT, UK*

[c] *Department of Economics, University of Stirling, Stirling, FK9 8BR, UK*

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Abstract

This paper examines the time series properties of inflation differentials in twelve EMU countries. We compute three alternative measures of inflation differentials using deviations from the policy reference value implied by the Maastricht Treaty, the ECB target, and deviations from the EMU average inflation. The evidence from standard linear unit root tests indicate that inflation differentials are highly persistent. However, when we account for endogenously determined structural breaks, we obtain greater support for stationarity. In addition, when we allow for the possibility that inflation differentials can be charterised by a non-linear mean reverting process we find evidence of stationarity. Our empirical results suggest that once we allow for structural breaks or non-linearities, inflation differentials do not consistently intensify real divergence in the euro area.

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[*] Corresponding author: Andros Gregoriou, e-mail:Andros.gregoriou@brunel.ac.uk, tel: +44 (0) 1895 816282.

1. Introduction

In June 1989 the European Council decided that the first stage towards European Monetary Union (EMU) would begin in July 1990[1]. The Treaty of Maastricht was agreed by the heads of state of the European Union (EU) in December 1991 setting out the framework for stages two and three of progress towards EMU. The Maastricht criteria were set in an effort to promote the convergence of the prospective eurozone economies in the lead-up to the euro, and the effectiveness of common monetary policy. Considering price stabilization, the Maastricht Treaty requires that inflation is not greater than 1.5% from the average of the three lowest inflation rates in the EU, in order for a country to qualify for the third stage[2]. According to the Treaty, during the third stage, the primary objective of the European Central Bank (ECB) is price stability, which the ECB has interpreted as an annual euro area inflation rate below, but close to, 2% in the medium run[3].

While post-euro, the eurozone countries' inflation rates are not explicitly bounded by the Treaty, and the ECB itself admits that "monetary policy can only influence the price level of the euro area as a whole and cannot affect inflation differentials across regions" (see *The Monetary Policy of the ECB*, 2004), national inflation rates should not, nevertheless, diverge considerably and persistently from the ECB target of 2%. Since the ECB sets the nominal interest rate

[1] In the first stage, the members of the European Monetary System (EMS) abolished all remaining capital controls. Also, there was an increase in the degree of co-operation among the EMS central banks, while exchange rate realignments remained possible. The second stage started on 1/1/1994. During that stage, the European Monetary Institute, the precursor of the European Central Bank, was created. In order to participate to the third stage, which started on 1/1/1999 (apart from Greece where it started on 1/1/2001) countries had to satisfy five convergence criteria.

[2] The convergence protocol states: "The criterion on price stability referred to in the first indent of Article 121(1) of this Treaty shall mean that a Member State has a price performance that is sustainable and an average rate of inflation, observed over a period of one year before the examination, that does not exceed by more than 1½ percentage points that of, at most, the three best performing Member States in terms of price stability. Inflation shall be measured by means of the consumer price index on a comparable basis, taking into account differences in national definitions".

[3] The Treaty states that the ECB should also be concerned with output and employment, albeit without prejudicing its main objective of price stability. The monetary policy framework adopted by the ECB to fulfill these tasks is based on two analytical perspectives or two *pillars*, namely economic analysis and monetary analysis. The ECB has repeatedly stated that achieving price stability is the most effective way to contribute to output and employment growth.

according to the eurozone inflation rate, persistence in inflation differentials would imply that 'one size does *not* fit all'. Diverging national inflation rates and common monetary policy imply that every member has to face a different real interest rate: countries with strong economic growth and high inflation[4] benefit from lower rates providing further stimulation to their economy; the reverse happens to low growth economies that experience low inflation rates[5]. It has been also argued that persistent divergence of national inflation rates hampers the efficient communication of monetary policy and complicates the design of an optimal policy response (see Benigno, 2003).

Within this context, the time series properties of eurozone inflation differentials target are vital. Discovering that inflation differentials are characterised by unit root behaviour can suggest that the idiosyncratic shocks impacting upon individual countries' inflation rates have persistent effects, which raises issues on whether EMU really constitutes an Optimal Currency Area that can be effectively managed by the ECB. In addition, it raises the question of whether the member countries have truly converged during the pre-euro period. On the other hand, finding that inflation differentials are only temporary, part of a rebalancing process between fast-growing and slow-growing regions, which would be characterised by a stationary process, would imply that the ECB can effectively implement and communicate its policies without exacerbating the differences that exist between EMU countries. Therefore, the degree of persistence of inflation differentials is of primary importance in order to establish whether the economic area exhibits

[4] There is sufficient empirical evidence indicating that inflation and demand pressures, as measured by the output gap, are positively related in the euro area countries (see e.g. ECB, 2003).

[5] This statement should be treated with caution. As Busetti *et al.* (2006) argue, if inflation differentials are due to differences in administered prices, or due to different import prices and/or wage growth that don't affect profit margins, then the resulting differences in real interest rates may affect private consumption, but should not impact upon investment. In fact, the elasticity of investment expenditure with respect to the real interest rate will depend on the degree of market integration within the EMU. Another argument against the procyclicality of inflation differentials works through the real exchange rate channel. According to this view, given that the nominal exchange rate is fixed, inflation differentials are part of a countercyclical adjustment mechanism: the competitiveness of countries with high inflation declines, therefore reducing economic activity. Busetti *et al*. (2006) point out that the answer to whether inflation differentials are procyclical or countercyclical will largely depend on the magnitude and persistence of inflation differentials.

imbalances which require structural interventions, or whether the asymmetries are just temporary phenomena which in the long run eliminate themselves.

Ample empirical evidence indicates that while in the run-up to the single currency the dispersion of inflation rates across the prospective eurozone members has decreased steadily, reaching the lowest point during 1999, it increased in 2000 and remained fairly stable since 2001[6]. Honohan and Lane (2003) suggest that the differential impact of the euro depreciation during the first years of the single currency may have caused higher inflation differentials. Contrary to inflation differentials within the United States, and among regions of individual euro area countries, inflation differentials across euro area countries are more persistent, with most countries' inflation rates persistently below (e.g. Germany, Austria) or above (e.g. Greece, Ireland) the euro area average since 1999 (see e.g. ECB, 2003).

Various explanations have been suggested for the persistence in euro area inflation differentials. In the context of the Balassa (1964) and Samuelson (1964) effect, persistent national inflation differentials within a monetary union may be associated with the process of real convergence: higher productivity growth in the tradable sector of the low income countries results into higher real wages in both their tradable and non-tradable sector implying higher overall inflation. Recent empirical evidence however, indicates that the Balassa-Samuelson effect alone cannot fully account for the observed persistence in inflation differentials (see e.g. Rogers, 2002)[7]. Another set of explanations focuses on the interaction between nominal and real rigidities, structural differences, price and wage setting, and common or idiosyncratic shocks[8].

[6] See among others, Duarte (2003), ECB (2003), and Weber (2004).

[7] MacDonald and Wojcik (2006) also point out the Balassa-Samuelson hypothesis cannot explain the recent dynamics of euro area inflation differentials. They propose an alternative explanation based on the neoclassical synthesis framework according to which divergent eurozone inflation rates are not an equilibrium phenomenon but may in fact be the result of a centralized monetary policy.

[8] For example, differences in the economic structure can result in diverse propagation of the various shocks: an industry-focused economy with low availability of raw materials will face higher inflation as a consequence of higher oil prices. Contrary to that, a country whose economy is mainly based on services may have a small impact from the same price hike.

Angeloni and Ehrmann (2004) suggest that the level of inflation persistence in each member country largely determines the persistence of inflation differentials in the euro area[9].

A number of papers have applied various unit root and cointegration tests to analyze the persistence of inflation differentials in the euro area. An early contribution to the literature is Siklos and Wohar (1997) who find evidence of a single stochastic trend (i.e. evidence of convergence) for the time period 1974-95. Kocenda and Papell (1997) also report evidence of inflation convergence during the pre-euro period using panel Augmented Dickey Fuller (ADF; Dickey and Fuller, 1979) unit root tests[10]. Busetti *et al.* (2006) apply univariate and multivariate unit root tests on bilateral inflation differentials and agree that the pre-euro (1980-1997) period is characterised by convergence (stationary differentials). They also provide evidence of diverging behaviour following the introduction of the euro[11]. Rodriguez-Fuentes *et al.* (2004) use the ADF, ADF with GLS detrending (Elliot *et al.*, 1996), the Elliot, Rothemberg and Stock optimal point (Elliot *et al.*, 1996), Phillips-Perron (Phillips and Perron, 1988) and KPSS (Kwiatkowski *et al.*, 1992) tests to investigate whether inflation differentials exhibit a unit root over the period 1980-1998. In contrast to previous studies that suggest convergence over the pre-euro period, Rodriguez-Fuentes *et al.'s* (2004) results indicate that national inflation deviations from the euro area inflation are non-stationary in eight out of eleven EMU countries.

This paper contributes to the existing literature in three important aspects. First, for robustness, we employ three alternative measures of inflation differentials. Our first measure is the difference between each country's inflation rate and the policy reference value implied by the Maastricht convergence criterion and the ECB target. This measure is based on the fact that

[9] A number of empirical papers document that euro area inflation is inertial and responds sluggishly to changes in monetary policy. See for example, Angeloni *et al.* (2005) who document that inflation persistence in the euro area did not decline after the introduction of the euro.

[10] They compute the inflation differential as the difference between an individual country's inflation rate and the average for all the countries.

[11] Their results suggest the existence of two clusters within the EMU: one of high inflation countries and another of low inflation countries. There is stationarity amongst the countries belonging to each cluster, but divergence between the two clusters.

during the pre-euro period, national inflation rates were explicitly bounded by the Treaty, and in the post-euro period, the inflation rate of each EMU country should not diverge considerably from the ECB target of 2%. For the other two measures we follow previous studies by using the EMU average inflation, instead of the policy reference value, in the calculation of inflation differentials. Both short-run (monthly) and long-run (annual) differentials are considered. Second, we examine whether persistence in inflation differentials is an artefact due to the presence of structural breaks. We investigate the possibility of a structural break around the introduction of the euro and common monetary policy in January 1999 by applying the recently published two-break unit root test of Lee and Strazicich (2003). Third, we present new empirical evidence, which explicitly allows for the possibility that inflation differentials can be characterized by a non-linear mean-reverting process, captured by the non-linear unit root test of Kapetanios *et al*.(2003). This process may exhibit near unit root behaviour in a specific range, so inflation differentials may appear non-stationary from the perspective of test procedures, which specify a linear non-stationary process as the null hypothesis. Following Gregoriou and Kontonikas (2006), we consider the hypothesis that the greater the inflation differential, the higher the speed of adjustment towards the policy reference value (or EMU average)[12].

The rest of the paper is structured as follows. Section 2 describes the dataset. Section 3 presents the linear unit root testing framework and provides the results of standard tests. Section 4 explains the econometric methodology and presents the results of unit root tests for inflation differentials allowing for the possibility of two endogenously determined structural breaks. Section 5 examines the time series properties of inflation differentials allowing for non linear mean reversion. Section 6 concludes with a summary of our main findings.

[12] Gregoriou and Kontonikas (2006) apply non-linear unit root tests to inflation deviations from the target in a sample of seven inflation targeting countries. The motivation of their study stems from a new class of monetary policy models that relax the assumptions of the conventional linear-quadratic preferences framework in an effort to introduce non-linearities in the response of monetary policy to inflation (see Orphanides and Wieland, 2000).

2. Data

Data was collected from Datastream for twelve EMU countries that adopted the euro and common monetary policy: Austria, Belgium, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, Netherlands, Portugal and Spain. The sample period is January 1996 - December 2005 effectively covering (part of) the second and the third stage of the process towards monetary union. Given that both the inflation convergence criterion and the ECB reference value monitor the evolution of annual inflation, our first inflation measure, π_t, is the twelfth difference of the natural log of the monthly Harmonised Consumer Price Index (HCPI): $\pi_t = 100 * (\ln HCPI_t - \ln HCPI_{t-12})$ [13]. Our sample consists of 120 observations for each country.

[INSERT TABLE 1 HERE]

Table 1 reveals some interesting patterns for the inflation rates of the EMU member countries. Greece has the highest inflation, which was nevertheless declining in the effort to join the EMU, until 1998. Thereafter, during four of the remaining seven sample years, Ireland had the highest inflation rate, a sign of overheating in the Irish economy. Greece and the other three club-Med countries (Italy, Portugal and Spain) typically feature in the list of high-inflation countries. Over time, the list of best performers usually includes two of the core EMU countries, France and Germany, as well as Austria, Finland, UK and Sweden. Luxembourg, which was one of the best performers in 1996, turns out to be the worst performer in 2004 and 2005. We also witness an increase in the inflation rate of both high and low inflation countries between 1999 and 2001. This is a reflection that, during the early years of the new monetary regime the euro area was affected by a variety of price shocks such as the 300% rise of oil prices between early

[13] Both the Maastricht Treaty inflation criterion and the ECB target are calculated by using annual HCPI inflation. The HCPI is a statistical indicator whose objective is to reflect the focus of the general public on the consumer goods prices, and to provide a common measurement of inflation which facilitates carrying out international comparisons. The HCPI series starts at January 1995 thereby providing the first observation of annual inflation at January 1996. In this paper, we also experimented using the conventional Consumer Price Index inflation that allows us to perform our empirical analysis from the start of the second stage towards the EMU (January 1994) thereby adding 24 observations to our sample for each country. The results (not reported and available upon request), remain the same.

1999 and mid-2000, the depreciation of the common currency over this period, and, in 2001, significant increases in food prices, due to a series of livestock epidemics.

In line with the policy objectives, during the period January 1996 to December 1998 the reference value for inflation, π_t^*, is calculated (year-per-year) as 1.5% plus the average inflation of the best three performing EU countries in terms of inflation control[14]. From January 1999 until the end of the sample, we set π_t^* equal to the ECB target of 2%. We acknowledge that the ECB target of 2% concerns the euro area as a whole[15], but nevertheless individual member countries inflation rates should converge around this reference value. In particular, national economic policies (fiscal, structural, wage-setting) in eurozone should be employed to deal with persistent inflation differentials (Weber, 2004). Otherwise, changes in the euro-wide nominal interest rate may be translated into diverse real interest rate changes thereby hampering the efficiency of ECB policies in stimulating euro area economic growth.

The degree of misalignment between inflation and the policy reference value is given by:

$$e_t = \pi_t - \pi_t * \qquad (1)$$

For robustness, we calculate two alternative measures of inflation differentials. First, we follow existing literature by using annual EMU average inflation rate as a proxy for π_t^* in equation (1). Second, we examine whether the horizon over which inflation is measured affects the persistence properties of inflation differentials by utilizing short-term (monthly) in addition to longer-term (annual) differentials. Short-term differentials are constructed as the deviation of

[14] For example, as we observe in Table 1, the three best performers during 1996 were Sweden (0.78%), Finland (1.06%) and Luxembourg (1.16%). Thus, the policy reference value for 1996 is $\frac{1}{3}(0.78+1.06+1.16)\%+1.5\%=2.5\%$. In a similar fashion we calculate the policy reference value for 1997 and 1998 as 2.7% and 2.19%, respectively. In the case of Greece, where stage two of the process towards EMU lasted until December 2000, we also calculate the policy reference value for 1999 and 2000 as 2.04% and 2.82%, respectively.

[15] The euro area HCPI is computed by the Eurostat as the weighted average of the national HCPI's. The country weights are derived from national accounts data for 'household final monetary consumption expenditure' converted into purchasing power standards.

monthly national inflation, $\pi_t = 100 * (\ln HCPI_t - \ln HCPI_{t-1})$, from the monthly EMU average inflation rate.

[INSERT FIGURE 1 HERE]

Figure 1 plots annual inflation deviations from the policy reference value and EMU average inflation for our sample countries. Positive (negative) values indicate that national inflation is higher (lower) from the policy reference value, EMU average, respectively. Focusing on the policy reference value measure of differentials, we note that in May 1998, when the European council decided about EMU membership, only Greece exhibited a significant positive inflation misalignment (2.68%). However, by June 2000, Greek inflation had been sharply reduced (e_t = -0.64%) which, in conjunction with satisfaction of the other criteria, allowed Greece to join the EMU in January 2001. During 1996-1998, inflation differentials with respect to the policy reference value were constantly negative in Austria, Belgium, Finland, France, Germany and Luxembourg, while Ireland, Italy, Portugal and Spain exhibited both positive and negative differentials. During 1999-2005, relatively large positive deviations from the policy reference value are observed in Greece, Ireland, Netherlands, Luxembourg, Portugal and Spain.

Overall, inflation deviations from the policy reference value appear to be characterised by cyclical behaviour. The horizon of the cycles is relatively long since they seem to last for at least two years with a sharp correction, involving a large change in the underlying slope, occurring at the peak of each cycle. This pattern is consistent with our proposed hypothesis of higher speed of adjustment of inflation towards the policy reference value, the greater the deviation from this value. It also suggests the presence of structural breaks in the differentials series, due mainly to changing slopes. Regarding our alternative measure of inflation differentials, we notice that post-2000, inflation deviations from EMU average inflation are remarkably close to deviations from the policy reference value in the majority of the countries. Prior to 1999, the two measures still move in the same direction in most countries but they exhibit different magnitude due to the fact that EMU inflation over the period 1996-1998 was less then the policy reference value[16].

3. No-break linear unit root tests

3.1 ADF unit root test

The standard linear ADF test uses the following regression model to test the stationarity of inflation differentials:

$$\Delta e_t = \gamma_0 + \gamma e_{t-1} + \sum_{i=1}^{k} \gamma_i \Delta e_{t-i} + \varepsilon_t \qquad (2)$$

where the $\gamma's$ are constants and ε_t is a random disturbance term: $\{\varepsilon_t\} \sim iid(0, \sigma_\varepsilon^2)$. The terms in Δe_{t-i} are included to remove any serial correlation in ε_t. Rejecting the null of unit root requires the estimates of γ to be negative and significantly different from zero.

[INSERT TABLE 2.1 HERE]

The ADF results of inflation deviations from the policy reference value can be seen in Table 2.1. We observe that the null-unit root hypothesis is not rejected for all countries with the exception of Greece and Italy, in the presence of a constant only in the ADF specification. When, in addition to the constant we incorporate a linear trend in the ADF specification there is evidence of unit roots in all sample countries apart from Italy. Following Busetti *et al.* (2006) we also calculate the unit root test excluding both intercept and trend[17], because rejecting the null of unit root in regressions without intercept and trend would unambiguously imply that asymmetries are just temporary phenomena. The ADF results without intercept and trend are in line with those

[16] The average EMU annual inflation rate over the period 1996-1998 was 1.7%, while the average policy reference value was 2.5%.

[17] As Busetti *et al*. (2006, p. 15) point out "When the relevant hypothesis is that of absolute convergence, to enhance power unit root and stationarity tests should be run without allowing for an intercept term". *Absolute* convergence implies that $\lim_{k\to\infty} E[y_{t+k} | y_t] = a = 0$, where y_t denotes current and past observations. If $\alpha \neq 0$ then convergence is said to be *relative*.

that include a constant term in finding that the unit root hypothesis is rejected only in Greece and Italy. Overall, linear ADF tests provide strong evidence of unit root behavior in the deviations of EMU countries' inflation rates from the policy reference value.

[INSERT TABLES 2.2-2.3 HERE]

We further examine the robustness of our findings with respect to alternative measures of inflation differentials. Tables 2.2, 2.3 present results from the ADF unit root test applied on annual, monthly inflation deviations from the EMU average, respectively. Starting from Table 2.2, it appears that using the policy reference value or the EMU average to calculate inflation differentials from annual data does not affect the main result that differentials exhibit unit root behaviour in most sample countries.

As the results in table 2.3 indicate however, considerably different results are obtained using the monthly measure of inflation differentials. Unit root rejection rates increase, particularly in ADF regressions with constant and/or trend. For example, with constant and trend, unit root rejection rates increase from 2/12 to 11/12 when we switch from annual to monthly differentials. In regressions without constant or trend the increase in rejection rates is more modest: 4/12 with monthly differentials as opposed to 2/12 with annual differentials. Thus, overall, it appears that on the basis of ADF evidence short-term inflation differentials are less persistent than their longer-term counterparts, with the results depending upon the deterministic components' specification in the ADF regressions.

3.2 Ng Perron unit root test

The Ng and Perron (2001) MZ_{α} test modifies the Phillips (1987) and Phillips and Perron (1988) Z_{α} test in a number of ways in order to increase the test's size and power. This testing procedure ensures that non-rejections of the null-unit root are not due to a low probability of rejecting a false null hypothesis, while rejections are not related to size distortions. The test statistic is defined as[18]:

$$MZ_a = \left[T^{-1}e_T^{\ 2} - s_{AR}^2\right]\left[2T^{-2}\sum\nolimits_{t=1}^{T} e_{t-1}^{\ 2}\right]^{-1} \tag{3}$$

where t = 1…T , $s_{AR}^2 = \hat{\sigma}_k^2 / [1-\hat{\gamma}(1)]^2$ is an autoregressive estimate of the spectral density at frequency zero of $\upsilon_t = \theta(L)\varepsilon_t = \sum\nolimits_{j=0}^{\infty}\theta_j\varepsilon_{t-j}$ with $\sum\nolimits_{j=0}^{\infty} j\left|\theta_j\right| < \infty$; $\hat{\gamma}(1) = \sum\nolimits_{i=1}^{k}\hat{\gamma}_i$ and $\hat{\sigma}_k^2 = (T-k)^{-1}\sum\nolimits_{t=k+1}^{T}\hat{\varepsilon}_t^2$ are calculated using the OLS estimates from Eq. (2). Following Elliot *et al*. (1996), Ng and Perron (2001) employ the local-to-unity GLS detrending procedure in order to benefit from the increased power offered by GLS detrending[19]. They also suggest that the autoregressive truncation lag, *k*, should be chosen using the Modified Akaike Information Criterion (MAIC) in an effort to avoid size distortions while maintaining power. The MAIC is calculated as follows:

$$MAIC(k) = \ln(\hat{\sigma}_k^2) + \frac{2[\tau_T(k)+k]}{T-k_{\max}} \tag{4}$$

where $\tau_T(k) = \left(\hat{\sigma}_k^2\right)^{-1}\hat{\gamma}^2\sum\nolimits_{t=k_{\max}+1}^{T}\left(e_{t-1}^d\right)^2$, k_{max} is the maximum value of k considered[20], e_t^d is the GLS detrended e_t and $\hat{\sigma}_k^2$ is defined as before using $k = k_{max}$.

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[18] The test statistic corresponds to the case where the variable into consideration (e_t) contains no deterministic term. If we allow for a constant, or constant and trend, then e_{t-1} and e_T in Eq. (3) should be replaced by their detrended counterparts.

[19] For any series $\{e_t\}_{t=0}^{T}$ define $(e_0^{\bar{\alpha}}, e_t^{\bar{\alpha}}) = (e_0, (1-\bar{\alpha}L)e_t)$ for t = 1…T, and some chosen $\bar{\alpha} = 1 + \bar{c}/T$. The GLS detrended series is defined as: $e_t^d = e_t - \hat{\psi}' z_t$, where $\hat{\psi}$ minimizes $S(\bar{\alpha},\psi) = (e^{\bar{\alpha}} - \psi' z^{\bar{\alpha}})'(e^{\bar{\alpha}} - \psi' z^{\bar{\alpha}})$, and z_t denotes the set of deterministic components of e_t. Elliot *et al*. (1996) suggest to set the value of $\bar{c}$ at -7 in the case of constant only, and -13.5 in the case of constant and linear trend.

[20] The upper bound is calculated as $k_{\max} = \text{int}(12/(T/100)^{1/4})$, where int(x) denotes an integer part of x. See Hayashi (2000, p.594) for a discussion of the selection of this upper bound.

The Ng Perron unit root test results considering inflation deviations from the policy reference value can be seen in Table 3.1. The null-unit root is rejected only in Luxembourg (constant and trend). For all the other countries the results suggest that inflation deviations from the policy reference value are non-stationary. Employing the two other measures of inflation differentials provides further support for unit root behavior. For instance, in table 3.2 that considers deviations of annual inflation from the EMU average, unit root rejection rates range between 0/12 (constant) and 2/12 (constant and trend). Finally, there is a notable difference between the ADF and Ng-Perron monthly results. In particular, the results in table 3.3 indicate that deviations of monthly inflation from the EMU average follow a unit root process in most countries under investigation. Hence, contrary to the ADF test, results from the Ng-Perron unit root test indicate that both short-run and long-run inflation differentials are highly persistent.

[INSERT TABLES 3.1-3.3 HERE]

4. Two-break unit root test

A potential shortcoming of the ADF unit root test is that a stationary variable that is subject to structural breaks may appear non-stationary. Perron's (1989) initial approach was to allow for a single exogenously imposed structural break under both the null and alternative hypotheses. Subsequent literature has emphasized the need to determine the break endogenously from the data (see e.g. Perron, 1997). Given the graphical evidence in Figure 1 about multiple cycles and changing slopes in inflation differentials it is essential that we take into account the possibility of multiple structural breaks when testing for a unit root. Therefore, we use the endogenous two-break unit root test of Lee and Strazicich (2003). The two-break test counterbalances the potential loss of power of tests that ignore more than one break. The test includes breaks under both the null and the alternative hypotheses, with rejections of the null unambiguously implying trend stationarity[21]. Consider the following data generating process:

$$\pi_t = \delta' Z_t + \eta_t \ , \quad \eta_t = \lambda \eta_{t-1} + \vartheta_t \tag{5}$$

where Z_t is a vector of exogenous variables and $\vartheta_t \sim iid\ N(0, \sigma_\theta^2)$. Lee and Strazicich (2003) analyze two alternative models. Model A allows for two shifts in the level of inflation differentials: $Z_t = [1, t, D_{1t}, D_{2t}]'$, where D_{jt} = 1 for $t \geq T_{bj} + 1$ (j=1,2) and 0 otherwise. T_b indicates the time period when a break occurs. Model C allows for two shifts in the level and the trend: $Z_t = [1, t, D_{1t}, D_{2t}, DT_{1t}, DT_{2t}]'$, where $DT_{jt} = t - T_{bj}$ for $t \geq T_{bj} + 1$ (j=1,2) and 0 otherwise.

In Model A, the null and alternative hypotheses are given by equations (6) and (7), respectively:

$$\pi_t = \mu_0 + d_1 B_{1t} + d_2 B_{2t} + \pi_{t-1} + \upsilon_{1t} \tag{6}$$

$$\pi_t = \mu_1 + \gamma t + d_1 D_{1t} + d_2 D_{2t} + \upsilon_{2t} \tag{7}$$

where the error terms $(\upsilon_{1t}, \upsilon_{2t})$ are stationary processes; B_{jt} = 1 for $t = T_{bj} + 1$ (j=1,2) and 0 otherwise[22]. An LM score principle is used to estimate the Lee and Strazicich (2003) unit root test statistic based on the following regression model:

$$\Delta \pi_t = \delta' \Delta Z_t + \phi \widetilde{S}_{t-1} + u_t \tag{8}$$

where $\widetilde{S}_t = \pi_t - \widetilde{\psi}_x - Z_t \widetilde{\delta}$; t = 2,…,T; $\widetilde{\delta}$ are coefficients in the regression of $\Delta\pi_t$ on ΔZ_t; $\widetilde{\psi}_x = \pi_1 - Z_1 \widetilde{\delta}$, where π_1 and Z_1 denote the first observations of π_t and Z_t, respectively. We can

[21] The null hypothesis in the endogenous two-break unit root test of Lumsdaine and Papell (1997) assumes no structural breaks, while the alternative does not necessarily imply broken trend stationarity. Thus, rejecting the null may be interpreted as rejection of a unit root with no structural break, and not necessarily as rejection of a unit root per se.

[22] In Model C, we must add D_{jt} terms to (6) and DT_{jt} terms to (7), respectively.

consequently test the unit root null hypothesis by examining the t-statistic ($\tilde{\tau}$) associated with $\phi = 0$.

[INSERT TABLE 4.1 HERE]

Table 4.1 contains the results from Lee and Strazicich's two-break test for inflation deviations from the policy reference value. Model C that allows for two shifts in the intercept and the slope provides greater support for inflation differentials stationarity as opposed to Model A that considers only intercept changes. Unit root rejection rates increase from 1/12 to 7/12 when we switch from Model A to Model C. Compared with the no-break linear unit root test results, unit root rejection rates using Model C are higher indicating improvements in power when we endogenously account for structural breaks On the basis of the inflation differentials plots in Figure 1 it appears that model C is the most relevant since most series clearly exhibit changing slopes. Regarding the break dates in model C, in most countries at least one of them occurs around 1999-2000. Thus, it appears that, following the completion of the convergence process implied by the Maastricht criteria, the introduction of the euro and the adoption of common monetary policy were associated with changes in the structure of eurozone inflation differentials.

. **[INSERT TABLES 4.2-4.3 HERE]**

Tables 4.2 and 4.3 contain the results from Lee and Strazicich's two-break test for the two other measures of inflation differentials. Model C again provides stronger support for stationarity with unit root rejection rates increasing from 0/12 to 5/12 with annual inflation differentials, and 4/12 to 12/12 with monthly, when we switch from Model A to Model C. The results from Lee and Strazicich's two-break test assuming shifts in intercept and slope agree with the ADF results in that longer-term inflation differentials are more persistent than short-term ones. Finally, in line with the policy reference value results, in most countries the first of the two breaks in monthly or annual deviations from the EMU average occurs around 1999-2000, providing further support for the role of a shift towards common monetary policy in explaining eurozone inflation differentials.

5. Non-linear unit root test

Failure to reject non-stationarity using the ADF and the Ng-Perron tests may be the result of lack of power of linear unit root tests if the true data generating process of inflation differentials is Exponential Smooth Transition Autoregressive (ESTAR). Kapetanios et al (2003) developed a stationarity test where the null hypothesis of a unit root is tested against an alternative of nonlinear ESTAR process, which is globally mean reverting.[23] The ESTAR model assumes that the adjustment of inflation towards the policy reference value (or EMU average) is characterized by a symmetric non-linear process[24]:

$$e_t = \beta e_{t-1} + \delta e_{t-1}\left(1 - \exp[-\alpha e_{t-1}{}^2]\right) + u_t \tag{9}$$

where u_t is the error term and the other variables are as previously defined. Under the null-non stationarity, $\beta = 1$ and $a = 0$, inflation follows a random walk around π_t^*. In the case of stationarity ($a > 0$), inflation reverses to π_t^*. Computing a first-order Taylor series approximation to (9) under the null and allowing for serial correlation in u_t, we obtain the following auxiliary regression model (Kapetanios *et al*., 2003):

$$\Delta e_t = \gamma_0 + \gamma e_{t-1}{}^3 + \sum_{i=1}^{k} \gamma_i \Delta e_{t-i} + v_t \tag{10}$$

[23] In order to implement the Kapetanios et al (2003) unit root test on our dataset we used the nonlinearity testing procedure formulated by Terasvirta (1994) to determine whether inflation differentials followed a non-linear mean reverting process. Applying the Terasvirta (1994) nonlinearity tests we found that we could reject the null of linearity and that the ESTAR specification was preferred to the Logistic STAR (LSTAR) specification for all empirical models. The results are not reported but are available upon request.

[24] See, among others, Granger and Terasvirta (1993) for other applications of the ESTAR model.

where v_t is the error term and the other variables are defined as previously. The null hypothesis in equation (10) is that $\gamma = 0$. Equation (10) does not provide a direct method to test the statistical significance of γ. This is because the cubic term embedded in γ is a non-linear function of the underlying parameter estimate resulting in the distribution of γ being unknown. Therefore, we use a bootstrap technique to obtain an asymptotic *t* statistic to test the significance of γ .The model that represents the null is

$$\Delta e_t = \gamma_0 + \sum_{i=1}^{k} \gamma_i \Delta e_{t-i} + v_t \tag{10a}$$

Model (10a) is a fully specified parametric model, which means that each set of parameter values for γ_0 and γ_1 defines just one data generating process (dgp). The first step in constructing a bootstrap dgp is to estimate (10a) by OLS, yielding the restricted estimates $\overline{\gamma}_0$, $\overline{\gamma}_1$. Then the boostrap dgp is given by

$$\Delta e_t{*} = \gamma_0{*} + \sum_{i=1}^{k} \gamma_i \Delta e^{*}{}_{t-i} + v_t{*} \tag{11}$$

which is just the element of the model (10a) characterized by the parametric estimates under the null, with stars to indicate that the data are simulated. By computing 10000 bootstrapped resamples of $v_t{*}$ for each of our sample countries we obtain 95% confidence intervals to test the null hypothesis of $\gamma = 0$ in equation (10). The idea in 10000 replications is to determine the appropriate critical values for the t test under the null hypothesis of $\gamma = 0$. In our empirical estimates we report the p-values obtained through the simulation exercise for the estimated *t* values.[25]

[INSERT TABLE 5.1 HERE]

The non-linear unit root test results considering inflation deviations from the policy reference value are presented in Table 5.1. The Jarque-Bera normality test indicates that the residuals are normally distributed in all cases. Thus, non-linearities in inflation differentials are not the outcome of any outliers in the data. The non-linear ADF tests show that inflation deviations follow a stationary process at all levels of significance. Comparing the linear and non-linear ADF results it appears that the decisive rejection of the null-unit root is the result of the significant increase in the magnitude of the estimated ADF coefficient, γ . This finding is unaffected by either the inclusion of a linear trend in the regressions or the exclusion of all deterministic components. Hence, non-stationarity in long-run inflation differentials (implied the linear unit root tests) disappears when we allow for non-linear adjustment. Evidence in Table 5.2 indicates that the aforementioned result is robust the employment of an alternative measure of long-run differentials, deviations from annual EMU average. Finally, non-linear unit root test results in Table 5.3 verify that short-run differentials are stationary in all cases.

[INSERT TABLES 5.2-5.3 HERE]

6. Conclusions

This paper investigates the time series properties of eurozone inflation differentials. We compute a unique measure of inflation differentials based upon the deviation of national annual inflation from the policy reference value implied by the Maastricht Treaty and the ECB target. We also calculate monthly and annual inflation differentials with respect to EMU average

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[25] The Kapetanios et al (2003) study reports asymptotic critical values under the null hypothesis for their non-linear mean reverting unit root test. However, these critical values are only valid for large samples, and given that we only have a maximum of 120 observations per country the bootstrap simulation gives more accurate critical values.

inflation. The results from standard linear unit root tests show that longer-run inflation differentials are fully persistent in the majority of the eurozone members with the alarming implication that common monetary policy leads to permanently diverging real interest rates. Unit root evidence appears to be robust to the use of alternative measures for long-run differentials, and alternative specifications of the linear unit root tests. Regarding short-run inflation differentials, linear tests generally disagree with the ADF test generating more evidence for differentials' stationarity.

Results from a unit root test that endogenously determines structural breaks provide greater support for stationarity of both short-run and long-run inflation differentials. The estimated break dates indicate that the end of the period of formal convergence implied by the Maastricht Treaty and the adoption of the euro and common monetary policy were associated with changes in the underlying structure of eurozone inflation differentials. Finally, we show that the existence of non-linearities in inflation differentials seriously affects the inference results from unit root tests. Upon application of the ESTAR unit root test, we discover that both short-run and long-run inflation differentials follow a stationary non-linearly mean reverting process. Our empirical findings indicate that once we allow for structural breaks or non-linearities, persistence in inflation differentials is drastically lower, suggesting that they do not consistently exacerbate real divergence. Given the importance of identifying the time-series structure of eurozone inflation differentials and the low power of the standard linear unit root tests, the empirical findings in this paper should not be ignored.

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Table 1: Average annual inflation rate (%) of three best and worst performing EU countries.

Year	Three Best Performers			Three Worst Performers		
1996	Sweden 0.78	Finland 1.06	Luxembourg 1.16	Greece 7.57	Italy 3.9	Spain 3.5
1997	Austria 1.15	Finland 1.21	Ireland 1.23	Greece 5.4	Italy 1.88	Portugal 1.87
1998	Germany 0.59	France 0.66	Austria 0.82	Greece 4.42	Portugal 2.18	Ireland 2.12
1999	Austria 0.51	Sweden 0.54	France 0.56	Ireland 2.42	Spain 2.21	Portugal 2.14
2000	UK 0.78	Germany 1.38	France 1.81	Ireland 5.13	Luxembourg 3.7	Spain 3.41
2001	UK 1.23	France 1.76	Germany 1.88	Netherlands 4.98	Portugal 4.31	Ireland 3.9
2002	UK 1.24	Germany 1.34	Belgium 1.54	Ireland 4.61	Greece 3.84	Netherlands 3.79
2003	Germany 1.03	Austria 1.28	Finland 1.29	Ireland 3.92	Greece 3.38	Portugal 3.21
2004	Finland 0.14	Denmark 0.88	Sweden 1.01	Luxembourg 3.17	Spain 3	Greece 2.98
2005	Finland 0.76	Sweden 0.81	Denmark 1.68	Luxembourg 3.68	Greece 3.42	Spain 3.32

Note: The inflation rate was calculated as the twelfth difference of the monthly HCPI.

Table 2.1: Linear Unit root test results, ADF, deviations from policy reference value, annual inflation, 1996-2005.

Country	Linear ADF t-test statistic		
	Constant	Constant and Trend	None
Austria	-1.53 [12]	-2.25 [1]	-1.43 [12]
Belgium	-0.98 [5]	-1.55 [5]	-1.18 [5]
Finland	-1.96[12]	-1.91 [12]	-1.78 [12]
France	-1.27 [12]	-2.43 [12]	-1.37 [12]
Germany	-1.03 [12]	-2.29 [4]	-1.13 [12]
Greece	-3.13 [3] *	-2.57 [3]	-2.84 [3]**
Italy	-4.2 [0]**	-4.5 [0]**	-4.41 [0]**
Ireland	-1.38 [12]	-0.6 [12]	-0.94 [12]
Luxembourg	-1.41 [12]	-2.53 [12]	-1.39 [12]
Netherlands	-1.65 [3]	-1.43 [0]	-1.60 [3]
Portugal	-1.26 [12]	-1.12 [12]	-0.76 [12]
Spain	-1.2 [12]	-2.66 [0]	-0.52 [12]

Note: The number in the bracket shows the number of lagged difference terms in the ADF unit root test. It was chosen by the Modified Akaike Criterion. The reported *t*-statistic tests the null hypothesis that inflation differentials contain a unit root using equation (2). **, * indicate rejection of the null-unit root hypothesis at the 1, 5% level of significance.

Table 2.2: Linear Unit root test results, ADF, deviations from EMU average, annual inflation, 1996-2005.

Country	Linear ADF t-test statistic		
	Constant	Constant and Trend	None
Austria	-3.64 [1]**	-3.58 [1]*	-1.36 [12]
Belgium	-2.33 [7]	-2.34 [7]	-2.38 [7]*
Finland	-1.98 [0]	-2.63 [12]	-1.11 [12]
France	-2.14 [2]	-2.28 [2]	-1.27 [2]
Germany	-2.08 [1]	-2.7 [1]	-1.78 [1]
Greece	-2.2 [1]	-1.71 [2]	-2.44 [1] *
Italy	-2.49 [12]	-3.6 [4]*	-1.84 [12]
Ireland	-1.14 [12]	-0.56 [12]	-0.67 [12]
Luxembourg	-2.06 [12]	-2.43 [2]	-1.49 [12]
Netherlands	-1.94 [0]	-2.03 [0]	-1.69 [0]
Portugal	-1.68 [12]	-1.64 [12]	-0.87 [12]
Spain	-2.81 [0]	-2.94 [0]	-0.21 [12]

Note: See Table 2.1 notes.

Table 2.3: Linear Unit root test results, ADF, deviations from EMU average, monthly inflation, 1996-2005.

Country	Linear ADF t-test statistic		
	Constant	Constant and Trend	None
Austria	-7.81 [1]**	-7.78 [1]**	-7.64 [1]**
Belgium	-17.2 [0]**	-17.14 [0]**	-17.28 [0]**
Finland	-1.25 [12]	-10.47 [0]**	-1.17 [12]
France	-12.4 [0]**	-12.38 [0]**	-1.07 [12]
Germany	-9.6 [0]**	-9.56 [0]**	-1.14 [12]
Greece	-10.6 [0]**	-10.62 [0]**	-2.13 [11]*
Italy	-11.01 [0]**	-10.99 [0]**	-10.9 [0]**
Ireland	-1.48 [11]	-1.48 [11]	-1.22 [11]
Luxembourg	-15.87 [0]**	-15.93 [0]**	-1.88 [12]
Netherlands	-1.34 [11]	-9.15 [0]**	-1.26 [11]
Portugal	-9.83 [0]**	-9.8 [0]**	-1.48 [12]
Spain	-10.39 [0]**	-10.38 [0]**	-0.93 [12]

Note: See Table 2.1 notes.

Table 3.1: Linear Unit root test results, Ng-Perron, deviations from policy reference value, annual inflation, 1996-2005.

Country	**Ng Perron MZ_α test statistic**	
	Constant	Constant and Trend
Austria	-6 [12]	-13.73 [12]
Belgium	-1.13[5]	-4.76 [5]
Finland	-3.01 [12]	-6.95 [12]
France	-4.86 [12]	-8.71 [12]
Germany	-2.55 [12]	-11.7 [4]
Greece	-0.78 [3]	-3.79 [3]
Italy	-0.19 [12]	-2.02 [0]
Ireland	-2.19 [12]	-2.97 [12]
Luxembourg	-1.69 [12]	-144 [12]**
Netherlands	-4.34 [12]	-5.21 [3]
Portugal	-2.17 [12]	-3.61 [12]
Spain	-4.41 [12]	-6.2 [12]

Note: The number in the bracket shows the number of lagged difference terms in the Ng-Perron unit root tests. It was chosen by the Modified Akaike Criterion. The reported MZ_α statistic tests the null hypothesis that inflation differentials contain a unit root using equation (3). **, * indicate rejection of the null-unit root hypothesis at the 1, 5% level of significance.

Table 3.2: Linear Unit root test results, Ng-Perron, deviations from EMU average, annual inflation, 1996-2005.

Country	Ng Perron MZ_{α} test statistic	
	Constant	Constant and Trend
Austria	-6.87 [12]	-19.77 [1] *
Belgium	-2.00 [12]	-6.92 [12]
Finland	-1.64 [12]	-2.87 [12]
France	-7.31 [2]	-9.2 [2]
Germany	-1.44 [1]	-4.7 [1]
Greece	-0.08 [3]	-2.25 [2]
Italy	0.43 [12]	-2.77 [12]
Ireland	-1.49 [12]	-1.51 [12]
Luxembourg	-1.33 [12]	-30.1 [12] **
Netherlands	-3.79 [12]	-3.7 [0]
Portugal	-3.09 [12]	-5.36 [12]
Spain	-4.84 [12]	-9.12 [12]

Note: See Table 3.1 notes.

Table 3.3: Linear Unit root test results, Ng-Perron, deviations from EMU average, monthly inflation, 1996-2005.

Country	Ng Perron MZ_{α} test statistic	
	Constant	Constant and Trend
Austria	0.24 [12]	0.14 [12]
Belgium	0.15 [12]	-0.07 [12]
Finland	0.64 [11]	-0.41 [11]
France	-0.07 [12]	0.03 [12]
Germany	-58.95 [0] **	1.6 [12]
Greece	0.07 [11]	-0.05 [11]
Italy	-0.16 [11]	0.13 [12]
Ireland	1.27 [12]	0.9 [11]
Luxembourg	0.42 [12]	0.44 [12]
Netherlands	0.79 [11]	0.49 [11]
Portugal	-0.04 [12]	-58 [0] **
Spain	0.36 [11]	-0.3 [11]

Note: See Table 3.1 notes.

Table 4.1: Two-break unit root test results, deviations from policy reference value, annual inflation, 1996-2005.

Country	Model A			Model C		
	$\tilde{\tau}$ **-stat**	**Breaks**		$\tilde{\tau}$ **-stat**	**Breaks**	
Austria	-2.28 [12]	2001m03	2003m04	-3.69 [12]	2000m07	2003m05
Belgium	-4.01 [11]*	2000m08	2002m03	-7.12 [11]**	1999m12	2002m04
Finland	-2.23 [12]	1997m07	1997m12	-4.76 [11]	2002m01	2004m02
France	-1.94 [12]	2001m03	2001m12	-6.01 [11]**	1998m11	2000m12
Germany	-3.48 [11]	2000m03	2004m12	-5.14 [11]	2000m07	2003m04
Greece	-2.58 [8]	2001m11	2003m01	-6.26 [11]**	2000m05	2001m06
Italy	-1.39 [12]	2000m11	1998m10	-6.41 [11]**	1997m08	2001m03
Ireland	-1.78 [12]	1998m07	2002m12	-4.27 [11]	1999m06	2000m11
Luxembourg	-3.54 [12]	1999m01	2004m03	-4.44 [12]	2000m02	2002m05
Netherlands	-2.32 [12]	1998m12	2001m12	-5.29 [12]*	2000m11	2003m02
Portugal	-1.67 [12]	1998m01	2001m12	-5.93 [12]**	2000m11	2004m05
Spain	-1.95 [12]	1997m03	2002m03	-7.66 [11]**	1998m12	2001m05

Note: The number in the bracket shows the number of lagged difference terms in the Lee-Strazicich unit root test. It was chosen by the 't-sig' approach suggested by Perron (1997). We set an upper bound of twelve for the lag length and test down until a significant (at the 10% level) lag is found. The reported $\tilde{\tau}$ statistic tests the null hypothesis that inflation differentials contain a unit root using equation (8). **, * indicate rejection of the null-unit root hypothesis at the 1, 5% level of significance.

Table 4.2: Two-break unit root test results, deviations from EMU average, annual inflation, 1996-2005.

Country	Model A			Model C		
	$\tilde{\tau}$ -stat	Breaks		$\tilde{\tau}$ -stat	Breaks	
Austria	-3.29 [12]	2001m12	2003m08	-4.95 [12]	2002m07	2004m08
Belgium	-2.74 [6]	1999m12	2002m03	-6.53 [11]**	1999m12	2002m04
Finland	-1.23 [10]	1997m07	2004m02	-4.17 [12]	1999m04	2003m11
France	-3.69 [11]	2001m06	2003m01	-5.09 [11]	2001m06	2003m07
Germany	-2.24 [5]	1998m04	2001m02	-5.18 [11]	1998m08	2002m10
Greece	-1.95 [12]	2001m12	2002m02	-6.38 [11]**	1999m03	2001m12
Italy	-1.66 [12]	1997m07	2003m04	-5.09 [11]	1999m01	2003m01
Ireland	-1.81 [12]	1997m07	2001m03	-3.91 [12]	1999m10	2004m01
Luxembourg	-3.5 [12]	2000m07	2002m02	-6.38 [11]**	2000m05	2003m10
Netherlands	-2.35 [12]	1998m12	2001m12	-5.56 [11]*	1999m05	2001m01
Portugal	-3.03 [12]	2003m05	2003m10	-7.84 [11]**	2002m06	2004m05
Spain	-3.06 [12]	1999m01	2001m08	-4.63 [12]	1998m11	2000m11

Note: See Table 4.1 notes.

Table 4.3: Two-break unit root test results, deviations from EMU average, monthly inflation, 1996-2005.

Country	Model A			Model C		
	$\tilde{\tau}$ -stat	Breaks		$\tilde{\tau}$ -stat	Breaks	
Austria	-6.02 [0]**	2000m01	2002m12	-9.31 [0]**	1998m10	2000m02
Belgium	-2.77 [10]	2000m05	2001m03	-9.11 [12]**	1999m12	2004m01
Finland	-4.91 [12]**	1997m04	1998m12	-7.59 [12]**	2000m02	2004m02
France	-3.61 [11]	2002m10	2004m08	-7.78 [11]**	2000m02	2004m02
Germany	-2.95 [11]	1997m04	1998m04	-9.8 [11]**	2000m02	2001m01
Greece	-3.98 [12]*	1997m05	1997m11	-11.11 [11]**	1997m07	2004m12
Italy	-2.81 [11]	1997m04	1997m10	-8.8 [12]**	2001m01	2002m07
Ireland	-3.86 [12]*	1998m04	1998m07	-7.51 [11]**	1998m08	1999m12
Luxembourg	-3.83 [9]	2003m10	2004m11	-9.87 [11]**	2000m05	2004m02
Netherlands	-3.7 [12]	1997m03	2002m03	-10.36 [11]**	2000m11	2004m12
Portugal	-3.38 [9]	2003m12	2004m11	-6.64 [11]**	2001m10	2002m11
Spain	-3.19 [12]	1997m04	1997m09	-7.71 [11]**	1998m01	2004m07

Note: See Table 4.1 notes.

Table 5.1: Non-Linear Unit root test results, deviations from policy reference value, annual inflation, 1996-2005.

Country	Non-Linear ADF t-test statistic					
	Constant	Constant and Trend	None	NORM (2) Constant	NORM (2) Constant and Trend	NORM (2) None
Austria	-4.76** [0] (0.005)	-4.99**[0] (0.005)	-4.70** [0] (0.007)	0.144	0.149	0.132
Belgium	-4.34** [12] (0.004)	-4.39** [12] (0.004)	-4.28** [12] (0.005)	0.147	0.153	0.140
Finland	-4.22** [12] (0.005)	-4.25** [12] (0.005)	-4.20** [12] (0.006)	0.141	0.142	0.135
France	-4.33** [12] (0.005)	-4.34** [12] (0.005)	-4.27** [12] (0.006)	0.143	0.146	0.138
Germany	-4.62** [12] (0.005)	-4.65** [1] (0.005)	-4.59** [12] (0.006)	0.146	0.148	0.140
Italy	-4.65** [12] (0.005)	-4.69** [12] (0.005)	-4.60** [12] (0.006)	0.148	0.150	0.141
Ireland	-4.24** [13] (0.004)	-4.27** [13] (0.004)	-4.17** [13] (0.005)	0.149	0.151	0.145
Netherlands	-4.27** [13] (0.004)	-4.28** [13] (0.004)	-4.20** [13] (0.006)	0.151	0.154	0.141
Portugal	-4.30** [12] (0.004)	-4.32** [12] (0.004)	-4.27** [12] (0.005)	0.152	0.155	0.149
Spain	-4.24** [12] (0.004)	-4.26** [12] (0.005)	-4.20** [12] (0.004)	0.147	0.150	0.140

Note: The non-linear unit root tests were not applied to the cases of Greece and Luxembourg since using the Terasvirta (1994) nonlinearity tests we cannot reject the null of linearity at the 5% level of significance. The number in the bracket shows the number of lagged difference terms in the regressions. It was chosen by the Modified Akaike Criterion. The reported *t*-statistics test the null hypothesis that inflation contains a unit root using equation (10). **, * indicate rejection of the null-unit root hypothesis at 1, 5% level of significance. NORM(2) is the P-value of the Normality test. Figures in the round brackets represent the p-value of the t statistic obtained through bootstrap simulation.

Table 5.2: Non-Linear Unit root test results, deviations from EMU average, annual inflation, 1996-2005.

Country	Non-Linear ADF t-test statistic					
	Constant	Constant and Trend	None	NORM (2) Constant	NORM (2) Constant and Trend	NORM (2) None
Austria	-4.70** [0] (0.007)	-4.64**[0] (0.006)	-4.68** [0] (0.007)	0.145	0.146	0.130
Belgium	-4.28** [12] (0.005)	-4.22** [12] (0.007)	-4.27** [12] (0.005)	0.149	0.150	0.141
Finland	-4.14** [12] (0.004)	-4.08** [12] (0.006)	-4.17** [12] (0.006)	0.138	0.140	0.133
France	-4.22** [12] (0.007)	-4.19** [12] (0.006)	-4.20** [12] (0.006)	0.141	0.144	0.137
Germany	-4.52** [12] (0.006)	-4.48** [1] (0.004)	-4.48** [12] (0.006)	0.148	0.147	0.142
Italy	-4.59** [12] (0.006)	-4.52** [12] (0.006)	-4.58** [12] (0.006)	0.151	0.148	0.139
Ireland	-4.18** [13] (0.005)	-4.10** [13] (0.007)	-4.17** [13] (0.005)	0.140	0.150	0.142
Netherlands	-4.20** [13] (0.006)	-4.17** [13] (0.005)	-4.23** [13] (0.006)	0.152	0.152	0.140
Portugal	-4.25** [12] (0.005)	-4.22** [12] (0.005)	-4.21** [12] (0.005)	0.150	0.150	0.146
Spain	-4.19** [12] (0.005)	-4.14** [12] (0.006)	-4.27** [12] (0.004)	0.145	0.147	0.139

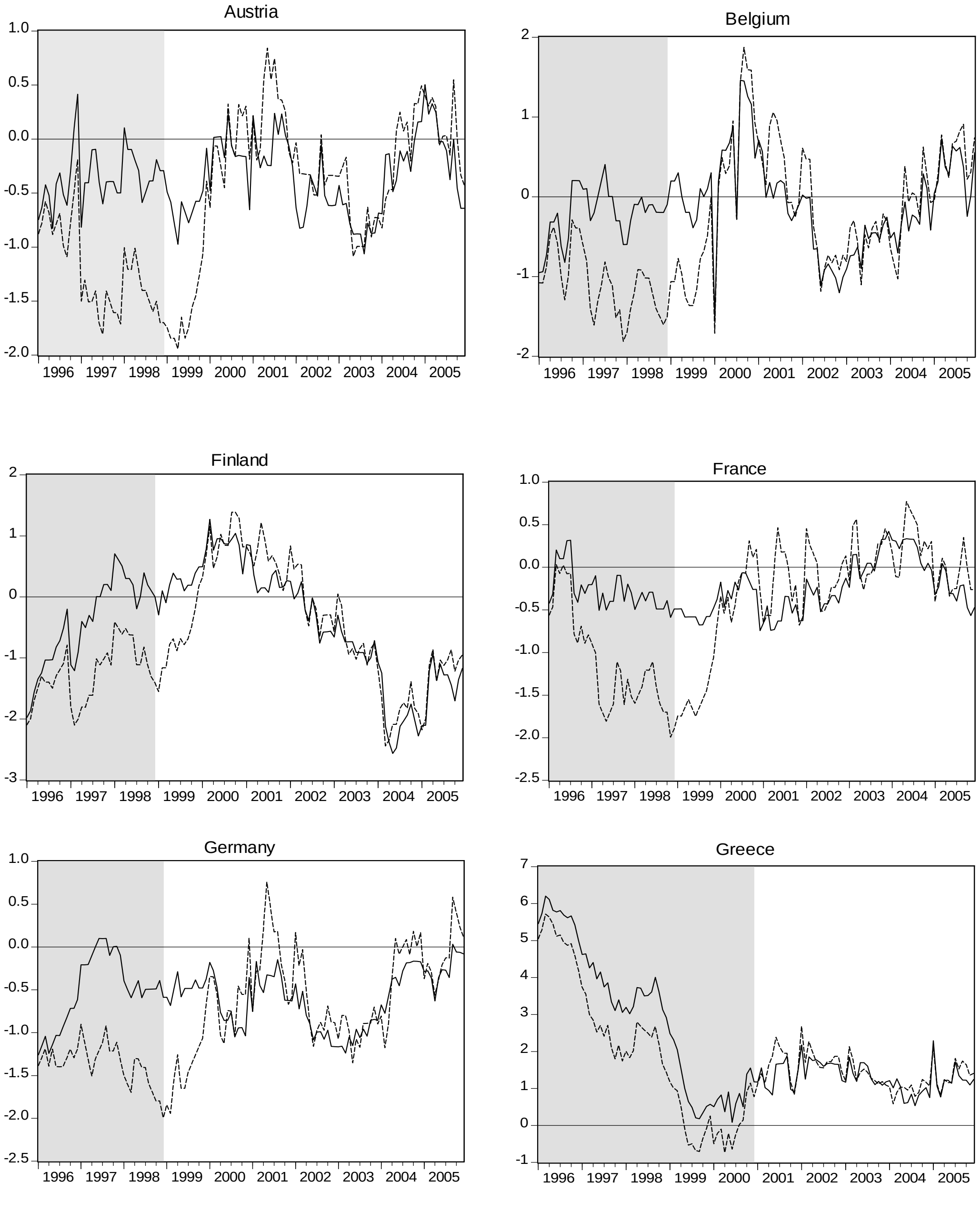
Note: See Table 5.1 notes.

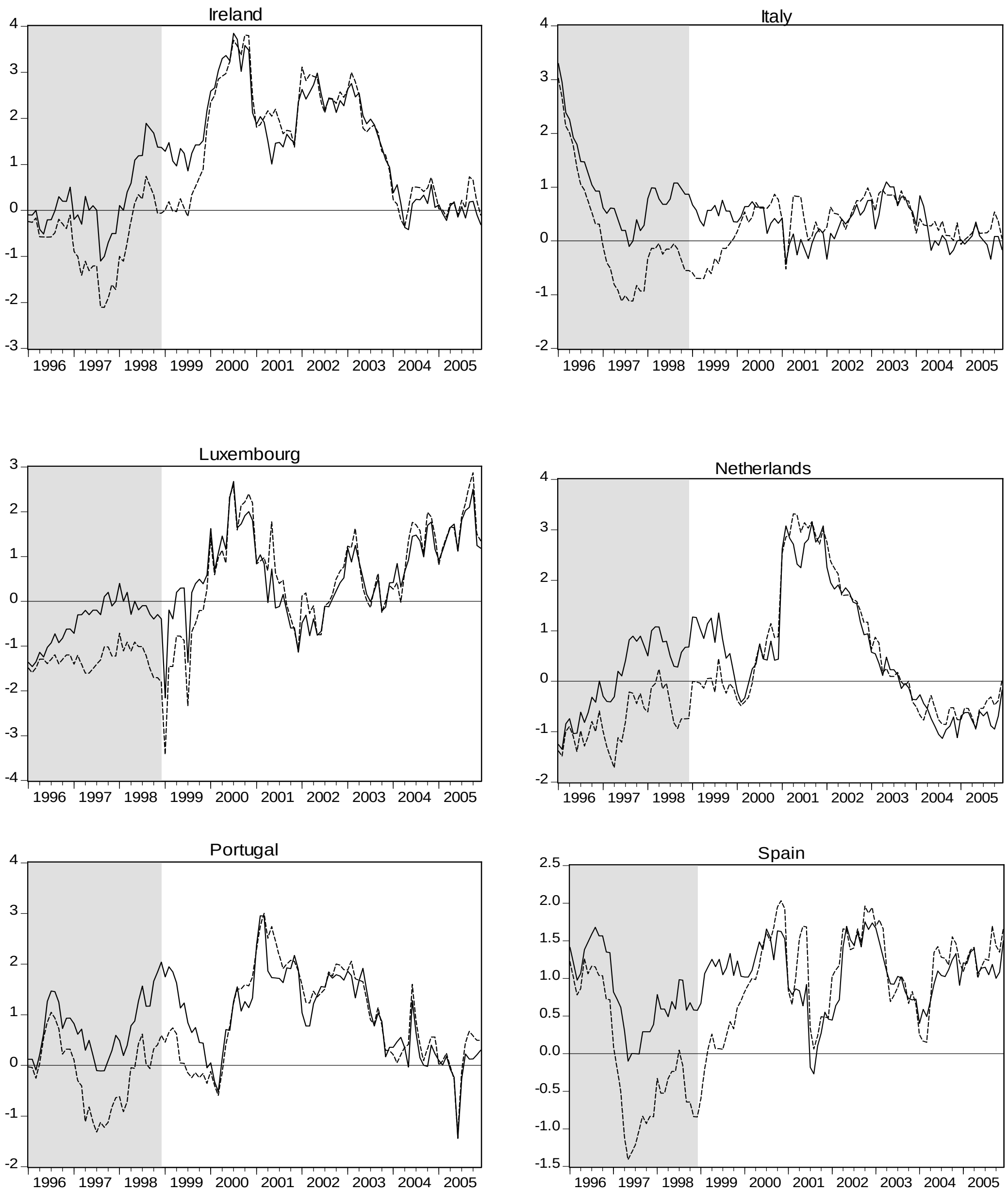
Table 5.3: Non-Linear Unit root test results, deviations from EMU average, monthly inflation, 1996-2005.

Country	Non-Linear ADF t-test statistic					
	Constant	Constant and Trend	None	NORM (2) Constant	NORM (2) Constant and Trend	NORM (2) None
Austria	-4.62** [2] (0.004)	-4.60**[2] (0.005)	-4.63** [2] (0.005)	0.140	0.141	0.132
Belgium	-4.25** [1] (0.006)	-4.23** [1] (0.006)	-4.21** [1] (0.006)	0.141	0.142	0.143
Finland	-4.12** [1] (0.006)	-4.10** [1] (0.006)	-4.13** [1] (0.006)	0.130	0.132	0.130
France	-4.20** [1] (0.007)	-4.18** [1] (0.007)	-4.17** [1] (0.007)	0.146	0.148	0.139
Germany	-4.45** [1] (0.007)	-4.42** [1] (0.007)	-4.40** [1] (0.007)	0.149	0.147	0.140
Italy	-4.50** [1] (0.008)	-4.51** [1] (0.008)	-4.48** [1] (0.008)	0.154	0.151	0.138
Ireland	-4.16** [1] (0.007)	-4.17** [1] (0.007)	-4.15** [1] (0.007)	0.146	0.143	0.139
Netherlands	-4.14** [1] (0.008)	-4.15** [1] (0.008)	-4.12** [1] (0.008)	0.155	0.154	0.144
Portugal	-4.20** [1] (0.007)	-4.19** [1] (0.007)	-4.19** [11] (0.007)	0.157	0.156	0.147
Spain	-4.18** [1] (0.006)	-4.19** [1] (0.006)	-4.17** [1] (0.006)	0.140	0.142	0.135

Note: See Table 5.1 notes.

Figure 1: Annual inflation deviations from the policy reference value and EMU average, 1996-2005.





Note: Straight, dotted lines represent deviations of national inflation from EMU average inflation, policy reference value, respectively.