

# **Nonlinearity and Inflation Rate Differential Persistence: Evidence from the Eurozone.**

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## **Abstract**

We employ a linear unit root test as well as a nonlinear two-regime Threshold Autoregressive (TAR) unit root test to determine whether inflation differentials in the Eurozone during the period 1970–2009 were persistent or transitory. The results imply that inflation rate differentials in the Eurozone are characterized by threshold nonlinearity. After modeling the nonlinear characteristics of the series with the appropriate unit root test, our test's results reveal that inflation rate differentials in the Eurozone are mainly persistent. Our findings imply that the higher the increase of the inflation rate differential, the more persistent the inflation rate differential is likely to be.

Keywords : EMU; Inflation Rate Differential; Unit Root; Nonlinearity; Threshold.

JEL Classification: C22, E31, F15, F36.

## 1. *Introduction*

It is widely accepted that a monetary union should be characterized, among other factors, by the symmetric response to shocks across country-members. The condition of symmetric response holds if a specific economic disturbance has the same effect on all members of the monetary union. Of course, this condition will be satisfied only if national fiscal policies are synchronized and consistent with the targets of the common monetary policy. In the case of the European Economic and Monetary Union (EMU), the main aim of the common monetary policy is the achievement and maintenance of price stability and the promotion of macroeconomic stability in general. This is reflected by the inflation rate Maastricht convergence criterion, which states that each member's inflation rate should not increase by more than 1.5% of the average inflation rate of the three members with the lowest inflation rate. This statement has a dual meaning. First, inflation rates in the Eurozone should be maintained at low levels and second, national inflation rates should not significantly diverge from each other. Indeed, inflation rate convergence increased in the 1990's, but since the creation of the EMU, inflation rate differentials have increased, thereby implying signs of asymmetries in the Eurozone.

In the absence of real convergence among EMU members, prices may be different across countries because of income inequality and different GDP growth rates. Egert (2007) argues that prices in poorer countries are lower and that fast-growing economies have higher inflation rates. Since these differences would be reflected by the real exchange rate, the competitiveness of high-inflationary countries would remain unaffected. However, in a monetary union such as the EMU, where countries share the same currency, such differences are reflected by inflation rate differentials. The presence of different inflation rates among EMU members leads to negative consequences for the common monetary policy and the EMU as a whole. Specifically, persistent inflation differentials induce internal and external asymmetries in the Eurozone.

Internal asymmetry represents different growth opportunities that EMU members face. While the common monetary policy sets the same nominal interest rate for all EMU members, the presence of different inflation rates entails different real interest rates for the countries of the monetary union. Hence, depending on the inflation rate benchmark, the economies of the countries with lower inflation rates than the EMU (benchmark) inflation rate are weakened by relatively higher real interest rates. In

contrast, the economies of the countries with higher inflation rates than the EMU inflation rate are strengthened by relatively lower real interest rates. Similarly, external asymmetry describes the situation in which different inflation rates across EMU members imply different competitive strengths of domestic economies in international trade. In a monetary union, countries with persistently higher inflation rates face a loss of competitiveness because movements in inflation differentials cannot be corrected by exchange rate adjustments.

In fact, the effect of an inflation rate differential on the Eurozone depends on the origin of the differential itself. In general, inflation rate differentials may originate from (a) supply-side factors such as the Ballassa–Samuelson effect (1964) (henceforth, BS effect);<sup>1</sup> (b) demand-side factors, that is, higher income elasticity of non-traded goods;<sup>2</sup> (c) external factors such as the oil price and exchange rate; and (d) structural factors, that is, price level convergence as a part of the inflation catching-up process. MacDonald & Wojcik (2008) argued that if inflation rate differentials arise from the BS effect, then these differentials can be considered as an equilibrium productivity-driven phenomenon. Moreover, Katsimi (2004) has argued that if inflation differential is due to the catching-up process (i.e., some countries experience rapid economic growth to fulfill real convergence in the monetary union), a higher inflation rate is reflected to higher productivity and therefore, competitiveness remains unaffected. As a consequence, inflation differentials disappear when real convergence is achieved and economic asymmetries in the Eurozone will gradually diminish as well.

The present study aims to determine whether or not inflation rate differentials in the Eurozone are persistent, or, in other words, whether or not inflation rate convergence exists among the 16 country-members. Previous studies have tested inflation rate convergence and inflation rate differential persistence by stationarity and cointegration techniques. The evidence of stationarity of inflation differentials implies that any differences between inflation rates are only transitory. Similarly, the presence of cointegration among inflation rates implies that they follow a common long-run

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<sup>1</sup> The BS effect states that low income countries that are in the catching-up process experience higher productivity growth in the traded goods sector compared to the non-traded goods sector. A positive productivity shock in the traded goods sector increases wages in both sectors. Given that wages increase more than productivity in the non-traded goods sector, a higher labor cost is reflected to higher prices. Hence, these developments imply higher inflation rate in poorer countries.

<sup>2</sup> To find more, see Egert (2007).

trend. Empirical studies apply time series analyses (see among others, Koedijk & Kool, 1992; Siklos & Wohar, 1997; Rodriguez-Fuentes et al., 2004; Buseti et al., 2007) and panel data techniques (see among others, Kocenda & Papell, 1997; Holmes, 2002; Beck & Weber, 2005). A majority of the above studies argue that inflation rate differentials were transitory during the pre-EMU period.<sup>3</sup> However, these studies have not taken into account the fact that inflation rate differentials may exhibit nonlinear instead of linear behavior. This gap in the literature has been filled by Arghyrou et al. (2005) and Gregoriou & Kontonikas (2006, 2009), who have demonstrated that inflation differentials follow a nonlinear mean reverting process. Employing the framework of Smooth Transition Autoregressive (STAR) models, these studies argue that the greater the inflation differential, the higher is the speed of adjustment toward the benchmark inflation rate.<sup>4</sup>

In the present study, we apply a nonlinear two-regime Threshold Autoregressive (TAR) unit root test, developed by Caner & Hansen (2001), to determine whether inflation differentials in the Eurozone during the period 1970–2009 were persistent or transitory. We model three types of inflation rate differentials according to the selected inflation rate benchmark. The first type is the difference between each member's inflation rate and the French inflation rate. Similarly, the second type is the difference between each member's inflation rate and the German inflation rate. Finally, the third type is the difference between each member's inflation rate and the euro area's inflation rate.<sup>5</sup>

Our paper contributes to the literature by providing evidence based on long-term data that includes the post-EMU period. While the empirical literature on inflation rate differentials is fairly rich, previous studies have mainly provided evidence for the pre-EMU period. To our knowledge, the present study is one of the few works that focus on EMU by using data for the post-EMU period. A salient feature of this study is that unlike other studies, it uses the most recent data, and therefore provides a clearer view of the stochastic properties of inflation differentials in the Eurozone. Another contribution stems from the applied econometric methodology, which differs

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<sup>3</sup> In contrast, Rodriguez-Fuentes et al. (2004) found that inflation rate differentials were persistent during the pre-EMU period.

<sup>4</sup> Arghyrou et al. (2005) estimate nonlinear models for the UK inflation rate, while Gregoriou & Kontonikas (2006, 2009) model nonlinearities in inflation deviations from the target in inflation-targeting countries.

<sup>5</sup> In the final case, the estimation is restricted to the period 1998–2009.

from other nonlinear models with regard to the type of the threshold variable. While in STAR models, the transition variable denotes the lagged inflation differential; in our study, it represents the dynamic behavior of the inflation differential, which is the change in the inflation differential during a specific period.

The structure of the paper is as follows. The next section describes our data set, while section 3 explains the econometric methodology. Section 4 presents our empirical findings and a final section summarizes and concludes.

## **2. Data Description**

The data were retrieved from the *International Financial Statistics* of the International Monetary Fund statistical database. The dataset includes monthly observations on national Consumer Price Indices (CPI) for the 16 EMU countries as well as the euro area. For a vast majority of the examined countries, the sample period is 1970:01–2009:08, namely, for Austria, Belgium, Cyprus, Finland, France, Greece, Italy, Luxembourg, Malta, the Netherlands, Portugal, and Spain. However, for others, the sample period is restricted depending on data availability, such as for Ireland and the euro area, only data during the period 1998:01–2009:08 were available. Similarly, the German CPI is available since 1992:01; the Slovenian, since 1992:12; and the Slovak, since 1994:01. Inflation rates ( $\pi$ ) correspond to annualized inflation rates, which have been calculated as the twelfth difference of the natural log of the CPI ( $p$ ), that is,

$$\pi_t = 100 * (\ln p_t - \ln p_{t-12}) \quad (1)$$

Table 1 presents some preliminary statistics that provide important information on the statistical properties of the examined inflation rates. The normality hypothesis has not been accepted for any series at the 5% significance level. Furthermore, it is found that all inflation rates contain a unit root at the 5% significance level, apart from the cases of Cyprus, Finland, Greece, and Slovenia. According to the estimated mean ( $\mu$ ), the lowest inflation rates are observed in Germany and in the Eurozone, while the highest inflation rates are those of Greece and Portugal. Similarly, standard deviation ( $\sigma$ ) estimates show that Germany's and the euro area's inflation rates have exhibited the lowest volatility. On the other hand, a less stable series are observed in Slovenia, Portugal, and Greece.

While the standard deviation is a measure of absolute dispersion, the coefficient of variation (CV) stands for a measure of relative dispersion of the series. High values imply that the standard deviation is larger than the magnitude of the mean. This implies that the higher the measure of CV, the higher the volatility of the series. According to CV measures, the lowest volatility has been observed in the cases of euro area, Germany, and Slovakia, while on the other hand, the most volatile inflation rates are those of Malta, Slovenia, Finland, and Portugal.

The above observations reveal that national inflation rates among the Eurozone countries do not follow a similar pattern. This finding enforces us to calculate and focus on the examination of inflation differentials in the Eurozone. We construct three types of inflation rate differentials according to the selected inflation rate benchmark. The first type is the difference between each member's inflation rate and the French inflation rate. Similarly, the second type is the difference between each member's inflation rate and the German inflation rate. Finally, the third type is the difference between each member's inflation rate and the euro area's inflation rate. Each type of inflation rate differential is constructed as

$$d_t = \pi_t - \bar{\pi}_t, \quad (2)$$

where  $\pi_t$  represents the national inflation rate; and  $\bar{\pi}_t$ , the inflation rate benchmark, that is, (i) the French inflation rate, (ii) the German inflation rate, or (iii) the euro area's inflation rate. Figures 1–3 plot the above computed inflation rate differentials. We show that most of the plotted inflation rate differentials exhibit cyclical behavior with changing slopes, which may imply the evidence of nonlinear behavior.

### ***3. Econometric Methodology***

The stochastic properties of the inflation differential series ( $d_t$ ) are tested by employing linear and nonlinear unit root tests. The evidence in favor of a unit root process of the inflation rate differential implies that the individual inflation rates differ persistently each other. In contrast, the evidence against nonstationarity of the inflation rate differential reveals that the difference between the individual inflation rates is only transitory. We begin by employing a standard unit root test, which assumes that all inflation rates follow a linear process. If linearity is the case, a simple

unit root test, based on Augmented Dickey Fuller (ADF) test, is described by:

$$\Delta d_t = \gamma + \delta \cdot t + (1 - \rho) \cdot d_{t-1} + \sum_{i=1}^k \beta_i \cdot \Delta d_{t-i} + e_t \quad (3)$$

The null hypothesis of non-stationarity ( $H_0 : \rho = 1$ ) is tested against the alternative that the real exchange rate is stationary ( $H_1 : \rho < 1$ ). However, if inflation rate differentials exhibit a nonlinear behavior, conventional linear unit root tests are biased against rejecting non-stationarity. This means that even if non-stationarity is rejected, the estimated half-lives imply slower mean reversion than the actual one.<sup>6,7</sup>

Next, we perform a nonlinear two-regime unit root test, originally presented by Caner & Hansen (2001), which is based on the following threshold autoregressive (TAR) model:

$$\Delta d_t = \theta'_1 x_{t-1} \ell(Z_{t-1} < \lambda) + \theta'_2 x_{t-1} \ell(Z_{t-1} \geq \lambda) + e_t \quad (4)$$

where  $t = 1, \dots, T$ ,  $x_{t-1} = (d_{t-1} r'_t \Delta d_{t-1} \dots \Delta d_{t-k})'$ ,  $\ell(\cdot)$  is the indicator function,  $e_t$  is an independent and identically distributed error term,  $r_t$  is a vector of deterministic components (intercept and linear time trend),  $Z_{t-1}$  is the threshold variable and  $\lambda$  is the threshold parameter. The latter is treated as unknown and it is assumed to take values in the interval  $\lambda \in \Lambda = [\lambda_1, \lambda_2]$  where  $P(Z_{t-1} \leq \lambda_1) > 0$  and  $P(Z_{t-1} \leq \lambda_2) < 1$ .

The threshold variable should be predetermined, strictly stationary, and ergodic with a continuous distribution function. Following Caner & Hansen (2001), the selection of the threshold variable of the form  $Z_{t-1} = d_{t-1} - d_{t-m-1}$ , for the delay parameter  $m \geq 1$ , provides theoretical as well as technical advantages. From a technical point of view, this type of the threshold variable ensures stationarity for itself under the assumption that the inflation rate differential follows a unit root or a random walk process. On a theoretical basis, this threshold variable allows us to split our sample to two regimes according to the dynamic behavior of the inflation rate differential. The first regime stands for  $Z_{t-1} < \lambda$ , which means that inflation rate

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<sup>6</sup> Half life is the necessary time for deviations to diminish by one half.

<sup>7</sup> For an empirical application on exchange rates, see among others, Taylor et al (2001), Sarno et al (2004), and Giannellis & Papadopoulos (forthcoming).

differential has fallen, remained constant, or has risen by less than  $\lambda$  during a certain period of time. Consequently, the second regime ( $Z_{t-1} > \lambda$ ) occurs when inflation rate differential has risen by more than  $\lambda$  during the same period.

Focusing on the characteristics of the model, the vectors  $\theta_1$  and  $\theta_2$  are as follows

$$\theta_1 = \begin{pmatrix} \rho_1 \\ \beta_1 \\ \alpha_1 \end{pmatrix}, \quad \theta_2 = \begin{pmatrix} \rho_2 \\ \beta_2 \\ \alpha_2 \end{pmatrix},$$

where  $\rho_1$  and  $\rho_2$  are the slope coefficients on  $d_{t-1}$  in the two regimes,  $\beta_1$  and  $\beta_2$  are the slopes on the deterministic components in the two regimes, and  $\alpha_1, \alpha_2$  are the slope coefficients on  $(\Delta d_{t-1}, \dots, \Delta d_{t-k})$  in the two regimes as well. For  $\lambda \in \Lambda$ , the above TAR model is estimated by ordinary least squares (OLS).<sup>8</sup> For fixed  $\lambda$ , equation (4) is written as

$$\Delta d_t = \hat{\theta}_1(\lambda)' x_{t-1} \ell(Z_{t-1} < \lambda) + \hat{\theta}_2(\lambda)' x_{t-1} \ell(Z_{t-1} \geq \lambda) + \hat{e}_t(\lambda) \quad (5)$$

and the OLS estimate of the residual variance is given by  $\hat{\sigma}^2(\lambda) = T^{-1} \sum_{t=1}^T \hat{e}_t(\lambda)^2$ . The

OLS estimator of  $\lambda$  is this which minimizes the residual variance, i.e.  $\hat{\lambda} = \arg \min_{\lambda \in \Lambda} \hat{\sigma}^2(\lambda)$ . For a given value of  $\hat{\lambda}$ , the estimated TAR model is as follows

$$\Delta d_t = \hat{\theta}_1' x_{t-1} \ell(Z_{t-1} < \hat{\lambda}) + \hat{\theta}_2' x_{t-1} \ell(Z_{t-1} \geq \hat{\lambda}) + \hat{e}_t \quad (6)$$

with  $\hat{\theta}_1 = \hat{\theta}_1(\hat{\lambda})$ ,  $\hat{\theta}_2 = \hat{\theta}_2(\hat{\lambda})$  and residual variance  $\hat{\sigma}^2 = T^{-1} \sum_{t=1}^T \hat{e}_t^2$ .

A critical point of analysis in this model is whether the inflation rate differential exhibits a nonlinear behavior in the form of a threshold effect. The linearity hypothesis (i.e. no threshold effect) is described by the following null hypothesis,

$$H_0 : \theta_1 = \theta_2, \quad (7)$$

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<sup>8</sup> Hansen (1996, 1997) has shown that, under the assumption that the error term is normally and identically distributed with zero mean and variance  $\sigma^2$ , OLS is equivalent to maximum likelihood estimation (MLE).



which is tested against the alternative that the estimated parameters in  $\theta_1$  and  $\theta_2$  are different across regimes. The null hypothesis can be tested using a standard Wald statistic,

$$W_T = T \left( \frac{\hat{\sigma}_0^2}{\hat{\sigma}^2} - 1 \right), \quad (8)$$

where  $\hat{\sigma}_0^2$  is the OLS estimator of the residual variance of the linear model and  $\hat{\sigma}^2$  is the OLS estimator of the residual variance of the TAR model, as it is presented in equation (6). The Wald test, as described in (8), has a nonstandard asymptotic distribution due to the presence of nuisance parameters under the null (Davies, 1977).<sup>9</sup> In addition, Caner and Hansen (2001) argue that the distribution may be nonstandard due to the assumption of a unit root process.<sup>10</sup> For this reason, Caner and Hansen (2001) introduce two bootstrap approximations to the asymptotic distribution of  $W_T$ , one based on the unrestricted estimates (unrestricted bootstrap procedure) and the other based on the restriction of a unit root (restricted bootstrap procedure).<sup>11</sup> The former is appropriate only when the series is stationary. If the series contains a unit root, the correct asymptotic distribution and robust p-values are achieved by the restricted bootstrap procedure. Although, it seems that both bootstrap procedures have near identical size, Caner and Hansen (2001) suggest conducting both bootstrap procedures and selecting the larger p-value if the true order of integration of the series is unknown.

The null hypothesis of a unit root is described by the following expression

$$H_0 : \rho_1 = \rho_2 = 0, \quad (9)$$

which means that the inflation rate differential is integrated of order one, i.e.  $I(1)$ . On the other hand, the series is said to be stationary autoregressive if  $\rho_1 < 0, \rho_2 < 0$  and  $(1 + \rho_1)(1 + \rho_2) < 1$ . Thus, the alternative to the null hypothesis is as follows

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<sup>9</sup> The nuisance parameter is the threshold parameter  $\lambda$ , which is not identified under the null hypothesis of no threshold effect.

<sup>10</sup> In contrast to previous TAR models that have assumed that the data are stationary, ergodic and have no unit roots, Caner and Hansen (2001) introduce the TAR model with an autoregressive unit root.

<sup>11</sup> For a technical and detailed description of both bootstrap methods, see Caner and Hansen (2001, p. 1563-1565).

$$H_1 : \rho_1 < 0 \quad \text{and} \quad \rho_2 < 0, \quad (10)$$

While the null hypothesis states that the inflation rate differential has unit roots in both regimes, the alternative hypothesis states that it is stationary in both regimes. However, it is possible a series to behave like a unit root process in one regime and like a random walk process in the other regime. In other words, the inflation rate differential may have a unit root in one regime and may be stationary in the other regime. This partial nonstationarity is expressed by the alternative hypothesis  $H_2$ ,

$$H_2 : \begin{cases} \rho_1 < 0, & \text{and} & \rho_2 = 0 \\ & \text{or} & \\ \rho_1 = 0, & \text{and} & \rho_2 < 0 \end{cases} \quad (11)$$

Because both alternative hypotheses are one-sided, the null is tested against the alternative ( $\rho_1 < 0$  and  $\rho_2 < 0$ ) using the following one-sided Wald test statistic

$$R_{1T} = t_1^2 \ell \{ \hat{\rho}_1 < 0 \} + t_2^2 \ell \{ \hat{\rho}_2 < 0 \} \quad (12)$$

where  $t_1$  and  $t_2$  are the t-ratios for OLS estimates  $\hat{\rho}_1$  and  $\hat{\rho}_2$  from TAR model (6).<sup>12</sup> The authors suggest examining the individual t statistics ( $t_1$  and  $t_2$ ) to discriminate between the two alternative hypotheses, i.e. stationarity ( $H_1$ ) and partial nonstationarity ( $H_2$ ). If only one of the t-statistics is statistically significant, we should accept the alternative  $H_2$ . Finally, robust p-values are computed using a bootstrap distribution.<sup>13</sup>

## 4. Empirical Findings

### 4.1. Relative to France

We first report results from a linear unit root test on inflation rate differentials using the French inflation rate as a benchmark. The ADF test statistics, which are shown in Table 2, indicate that nonstationarity cannot be rejected in 13 out of the 15

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<sup>12</sup> The two-sided Wald test statistic for testing the null against the alternative ( $\rho_1 \neq 0$  and  $\rho_2 \neq 0$ ), which is given by  $R_{2T} = t_1^2 + t_2^2$ , is misleading and inappropriate. Moreover, Caner and Hansen (2001) have shown that the one-sided Wald test  $R_{1T}$  has more power than the two-sided Wald test  $R_{2T}$ .

<sup>13</sup> Caner and Hansen (2001) construct two bootstrap distributions, one that imposes an identified threshold effect (identified threshold bootstrap) and another that imposes an unidentified threshold effect (unidentified threshold bootstrap). Based on a Monte Carlo analysis they suggest calculating p-values using the unidentified threshold bootstrap. For a detailed description of both bootstrap procedures, see Caner and Hansen (2001, p. 1573).

cases. Further, there is evidence of stationarity inflation differentials only in the cases of Germany and Slovenia. These findings imply that a vast majority of the European countries' inflation rates deviate persistently from the French inflation rate. However, the ADF test has assumed that inflation rate differentials exhibit linear behavior. If the true process is nonlinear instead of the linear one, the above findings may be misleading and inappropriate. This is because conventional linear unit root tests are biased against rejecting nonstationarity when the true process is nonlinear. To avoid this inconsistency, we have to test the hypothesis that inflation rate differentials are characterized by linear adjustment. For this purpose, we employ a TAR model, as explained in section 2, and we test the hypothesis of no threshold effect. This test is undertaken by computing a Wald test statistic ( $W_T$ ) and the relevant bootstrap p-values for threshold variables of the form  $Z_{t-1} = d_{t-1} - d_{t-m-1}$ . Because the delay parameter ( $m$ ) is generally unknown, we let it be endogenously determined. The OLS estimate of the delay parameter ( $m$ ) is the value that minimizes the residual variance. As the  $W_T$  statistic is a monotonic function of the residual variance, equivalently, the selected value of  $m$  maximizes  $W_T$ .<sup>14</sup> The least squares estimates of  $m$  along with the estimates of the threshold parameter ( $\lambda$ ) are shown in the second column of Table 3, while the Wald test statistics and the corresponding p-values are shown in the third column of the same table. The results imply that the no threshold effect hypothesis is strictly rejected in all cases. The bootstrap p-values, apart from the cases of Germany, the Netherlands, and Slovakia, are close to 0.00, thus indicating strong evidence in favor of threshold nonlinearity.<sup>15</sup>

On the basis of the evidence of threshold nonlinearity, we estimate a TAR model for all inflation rate differentials and we conduct the threshold unit root test, developed by Caner and Hansen (2001), on these series. The results from the TAR model, presented in column 2 of Table 3, are based on the assumption of 15% minimum percentage of observations per regime (Andrews, 1993). Figure 4 presents the estimated division of each inflation rate differential series into two threshold regimes according to the estimated threshold parameter ( $\lambda$ ). In the case of Austria, for

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<sup>14</sup> The minimum delay parameter is equal to one, while the maximum delay order is set equal to 12. Bootstrap p-values are calculated on the basis of both the unrestricted and restricted bootstrap procedures and by conducting 10,000 replications.

<sup>15</sup> The null hypothesis of no threshold effect is tested at the 10% significance level. However, in most cases, the null is rejected at either the 5% or 1% level of significance.

$m = 2$  and  $\lambda = 0.457$ , about 84% of the data belong to the first regime, that is,  $Z_{t-1} = d_{t-1} - d_{t-3} < 0.457$ , and approximately 16% of the data belong to the second regime, that is,  $Z_{t-1} = d_{t-1} - d_{t-3} > 0.457$ . The first regime occurs when the inflation rate differential has fallen, remained constant, or has risen by less than 0.457 points over a two-month period; in contrast the second regime occurs when the inflation rate differential has risen by more than 0.457 points over a two-month period. Similarly, the remaining inflation rate differential series are split into two regimes.

Proceeding on to the main point of our investigation, which is the unit root hypothesis test, we calculate threshold unit root test statistics  $R_1$ ,  $t_1$ , and  $t_2$  for endogenously selected delay parameters ( $m$ ). The estimated test statistics are shown in Table 3 (columns 5–7). Test statistic  $R_1$  is utilized to test the null  $H_0$ , which states that the inflation rate differential has unit roots in both regimes, in comparison to the alternative  $H_1$ , which states that it is stationary in both regimes. To discriminate between pure nonstationarity and partial nonstationarity ( $H_2$ ), we employ test statistics  $t_1$  and  $t_2$ . According to the results, the examined inflation rate differentials can be decomposed into two subgroups. The first subgroup contains series that are nonstationary across both regimes (i.e., for Belgium, Cyprus, Finland, Ireland, the Netherlands, Portugal, and Slovakia), while the other subgroup encloses series that behave like a unit root in one regime and a stationary process in the other.

Specifically, the inflation rate differentials of Austria, Germany, Greece, Italy, Luxembourg, Malta, Slovenia, and Spain are found to be stationary in the first regime and nonstationary in the second regime. Illustrating the case of Greece as an example, for  $m = 12$  and  $\lambda = 1.91$ , stationarity has been observed when the inflation rate differential has fallen, remained constant, or has risen by less than 1.91 points over a twelve-month period. On the contrary, nonstationarity has been found when the inflation rate differential has risen by more than 1.91 points over the same period. A similar interpretation can be applied to the rest of the inflation rate differential series, apart from the cases of Germany and Slovenia, in which the threshold parameter is found to be negative. Hence, in the case of Germany, and for  $m = 5$  and  $\lambda = -0.216$ , the inflation rate differential follows a white noise process when it has decreased by more than  $|-0.216|$  points over a five-month period (regime 1, i.e.,  $Z_{t-1} = d_{t-1} - d_{t-6} < -0.216$ ) and a random walk process when it has reduced by less

than  $|-0.216|$ , remained constant, or has risen over a five-month period (regime 2, i.e.,  $Z_{t-1} = d_{t-1} - d_{t-6} > -0.216$ ). Similarly, for  $m = 11$  and  $\lambda = -2.67$ , in the case of Slovenia, regime 1 (stationarity) occurs when the inflation rate differential has declined by more than  $|-2.67|$  points over an eleven-month period and regime 2 (nonstationarity) occurs when the inflation rate differential has decreased by less than  $|-2.67|$ , remained constant, or has increased over the same period.

A direct implication that stems from this analysis is that when the inflation rate differential increases, it is found to be stationary when it increases by less than a certain rate (regime 1) and nonstationary when it increases by more than this rate (regime 2). However, when the inflation rate differential decreases, it follows a white noise process when it decreases by more than a certain rate (regime 1) and a random walk process when it decreases by less than the same rate (regime 2).

To sum up, we have found that some inflation rate differentials exhibit pure nonlinear nonstationarity (i.e., Belgium, Cyprus, Finland, Ireland, the Netherlands, Portugal, and Slovakia), while some others exhibit partial nonlinear stationarity (i.e., Austria, Germany, Greece, Italy, Luxembourg, Malta, Slovenia, and Spain). As shown in figure 4, the most recent period is characterized by stationarity (regime 1) in Austria, Greece, Italy, and Luxembourg, and by nonstationarity (regime 2) in Germany, Malta, Slovenia, and Spain.

#### 4.2. *Relative to Germany*

Next, we perform the same analysis on inflation rate differentials using the German inflation rate as a benchmark. The linear ADF test (Table 2, column 3) shows that the unit root hypothesis can be rejected only in the cases of Belgium, Cyprus, Greece, Malta, and Slovenia. To avoid any inconsistency or arising from misleading results, we perform a linearity test on all inflation rate differential series. This test allows us to identify the true process of the above series. If the process is linear, we can rely on the results of the ADF test. However, if the process is nonlinear, we have first to estimate a TAR model and then conduct the threshold nonlinearity test, as in the previous section. The estimated Wald test statistics and the bootstrap p-values of accepting the null are shown in column 3 of table 4. The results show that, at the 10% level of significance, linearity can be accepted for Austria, Finland, Italy, Slovakia and Spain, while the remaining series have been found to follow a threshold nonlinear

process. This implies that we can accept the results from the ADF test for Austria, Finland, Italy, Slovakia, and Spain, which had been found to contain a unit root.

For the rest of the series, we estimate a TAR model and follow the Caner and Hansen (2001) methodology for testing the unit root hypothesis. The estimates of the critical parameters of the TAR model are shown in column 2 of Table 4. Similarly, we have assumed that the minimum percentage of observation per regime is 15%. Our data are divided into two regimes according to the estimated parameters  $m$  and  $\lambda$ . The division of the series into two regimes is shown in Figure 5. Having estimated the parameters of the TAR model, we calculate test statistics  $R_1$ ,  $t_1$ , and  $t_2$  and the corresponding bootstrap p-values to investigate the unit root hypothesis. Recall that the  $R_1$  statistic tests the null hypothesis of a unit root in both regimes against the alternative that the series is stationary across both regimes. If all test statistics are statistically different from zero at the 10% level, the examined series is said to be purely stationary. In our dataset, this is observed in the case of Cyprus. In contrast, if all test statistics are not statistically significant at the 10% level, it is implied that the series contains a unit root across both regimes (purely nonstationary). See Table 4 (columns 5–7) for Ireland and Portugal.

However, the results for the remaining series are inconclusive. As earlier, we focus on  $t_1$  and  $t_2$  test statistics to discriminate between pure nonstationarity and partial nonstationarity ( $H_2$ ). In the cases of Belgium, Greece, Luxembourg, Malta, the Netherlands, and Slovenia, inflation rate differentials against the German inflation rate follow a stationary process in regime 1, but a nonstationary process in regime 2. For example, for  $m = 9$  and  $\lambda = 0.915$ , deviations of the Belgium inflation rate from the German inflation rate are transitory when the inflation rate differential has fallen, remained constant, or has risen by less than 0.915 points over a nine-month period (regime 1, i.e.,  $Z_{t-1} = d_{t-1} - d_{t-10} < 0.915$ ). In contrast, these deviations are persistent when the inflation rate differential has risen by more than 0.915 points over the same period (regime 2, i.e.,  $Z_{t-1} = d_{t-1} - d_{t-10} > 0.915$ ). As in the previous subsection, negative estimates of the threshold parameter ( $\lambda$ ) need special interpretation. Similarly, in the case of Greece with  $d = 4$  and  $\lambda = -0.625$ , stationarity holds when the inflation rate differential has declined by more than  $|-0.625|$  points over a four-month period and nonstationarity occurs when the inflation rate differential has decreased by less than  $|-0.625|$ , remained constant, or has increased

over the same period. A similar explanation applies to the cases of Luxembourg, the Netherlands, and Slovenia.

Combining the results from the linear ADF test (wherever appropriate) with those from the nonlinear TAR test, we eventually argue that (linear or pure nonlinear) nonstationarity has been observed in the cases of Austria, Finland, Ireland, Italy, Portugal, Slovakia, and Spain. On the contrary, pure nonlinear stationarity has been observed in the Cyprus inflation rate differential. However, the most interesting finding is observed in the cases of Belgium, Greece, Luxembourg, Malta, the Netherlands, and Slovenia, where inflation rate differentials were found to follow a stationary process in regime 1 and a nonstationary process in regime 2. Figure 5, which illustrates the estimated division of the series into two regimes, shows that the most recent period is regarded as a stationarity period (regime 1) in Belgium and Malta. On the contrary, in the cases of Greece, the Netherlands, and Slovenia, nonstationarity (regime 2) characterizes the most recent period. Finally, the case of Luxembourg is inconclusive, since observations are almost equally distributed into the two regimes during the recent period.

#### *4.3. Relative to the Euro Area*

Our previous analysis has been focused on the examination of inflation rate differentials of the 16 EMU country-members against the inflation rate of two major economies of the Eurozone, that is, France and Germany. This selection is consistent with the dominant role of the countries in the Eurozone and specifically with their influence on the guidelines of the common monetary policy. In this section, we aim to investigate the stochastic properties of inflation rate differentials using the euro area's inflation rate as a benchmark inflation rate. In other words, we estimate inflation rate differentials of the EMU country members' inflation rates, including those of France and Germany, against the officially announced inflation rate of EMU.

Following the same estimation procedure, we conduct a linear ADF test on inflation rate differentials. Table 2 (column 4), shows that the unit root hypothesis can be rejected only in the cases of Austria, Greece, and Luxembourg. This implies that for a vast majority of the examined series, inflation rate differentials are persistent. However, on the basis of previous evidence, we have reasons to believe that some of the results may be misleading because of the presence of nonlinearities in the series. Hence, we should test the hypothesis that the process is characterized by a linear

autoregressive (AR) model instead of a TAR model. In other words, we should test the hypothesis that inflation rate differentials exhibit a linear behavior instead of a threshold nonlinear one. This test is conducted by computing a Wald test statistic ( $W_T$ ) and the relevant bootstrap p-values for threshold variables of the form  $Z_{t-1} = d_{t-1} - d_{t-m-1}$ . Once the critical parameters of the TAR model have been estimated, the Wald test statistic and the corresponding p-values are shown in the third column of table 5. The results imply that at the 10% level of significance, the no threshold effect hypothesis is accepted in 7 out of the 16 inflation rate differential series. The inflation rate differentials have been found to follow a linear process in the cases of Austria, France, Germany, Greece, Malta, Portugal, and Slovenia. This means that we can accept the implication derived from the linear ADF test for the above countries. Therefore, we have hitherto found that inflation rate differentials are stationary in the cases of Austria and Greece, while they are nonstationary in the cases of France, Germany, Malta, Portugal, and Slovenia. For the remaining series, we estimate TAR models and conduct the threshold unit root test on them.

As earlier, the estimation of TAR models is based on the assumption of 15% minimum percentage of observations per regime. Table 5 (column 2) presents estimates for the delay parameter ( $m$ ) and the threshold parameter ( $\lambda$ ). These estimates differ from country to country, reflecting the different behavior of each inflation rate differential series. Given these estimates, our data are divided into two regimes and this division is represented in figure 6. Taking the case of Luxembourg as an example, with  $m = 6$  and  $\lambda = 0.403$ , figure 6 illustrates that about 82% of the data belong to regime 1, that is, when the inflation rate differential has fallen, remained constant, or has risen by less than 0.403 points over a six-month period, and approximately 18% of the data belong to regime 2, that is, when the inflation rate differential has risen by more than 0.403 points during a six-month period.

We can now proceed to the threshold unit root test by constructing the  $R_1$ ,  $t_1$ , and  $t_2$  test statistics and the corresponding bootstrap p-values, which are shown in the last three columns of table 5. The results reveal that the null hypothesis  $H_0$  (pure nonstationarity) is accepted in the cases of Belgium, Finland, Ireland, Slovakia, and Spain as all test statistics are not statistically different from zero. For the rest of the series, we employ test statistics  $t_1$  and  $t_2$  to discriminate between the alternative hypothesis  $H_1$  (pure stationarity) and  $H_2$  (partial nonstationarity). It is shown that



inflation rate differentials in the cases of Cyprus, Italy, Luxembourg, and the Netherlands are found to be stationary in regime 1 and nonstationary in regime 2. This means that the above inflation rate differentials, apart from that of the Netherlands, are mean reverting when they increase by less than a specific rate, and are persistent when they are fast growing, that is, they increase by more than a specific rate. The Netherlands is an exceptional case because of the negative estimate of the threshold parameter ( $\lambda$ ). In this case, the inflation rate differential is mean reverting when it decreases more than  $|-0.362|$ , and persistent when it decreases less than this rate.

Summing up, the linear ADF and the nonlinear TAR unit root tests (each applied when appropriate) have shown that stationarity has been established in the cases of Austria and Greece, while (linear or nonlinear pure) nonstationarity could not be rejected in the cases of Belgium, Finland, France, Germany, Ireland, Malta, Portugal, Slovakia, Slovenia, and Spain. Furthermore, partial nonstationarity has been found for the remaining inflation rate differential series. That is, inflation rate differentials in the cases of Cyprus, Italy, Luxembourg, and the Netherlands have been found to follow a stationary process in regime 1 but, a nonstationary process in regime 2. As shown in figure 6, during the most recent period, regime 1 is present in the cases of Cyprus and Luxembourg, while regime 2 exists in the cases of Italy and the Netherlands.

## **5. Conclusion**

The present study was motivated by the indications of divergence of inflation rates among the EMU members after the creation of the EMU. Specifically, the aim of this study was to determine whether inflation rate differentials in the Eurozone are persistent or transitory. The answer to this research question is crucial, particularly for monetary unions such as the EMU. This is because differences in national inflation rates cannot be corrected by exchange rate adjustments. Hence, the evidence of persistent inflation rate differentials in the Eurozone implies significant internal and external asymmetries, such as different growth opportunities and different competitiveness power, across EMU members.

To provide an answer to the above research question, we employed a linear ADF unit root test as well a nonlinear two-regime TAR unit root test, originally presented by Caner & Hansen (2001), on inflation rate differentials of the 16 EMU members against three benchmark inflation rates (the French, German, and euro area's inflation

rates). The selection of benchmark inflation rates is in line with the leading role of France and Germany in the euro area's economy. Furthermore, the TAR unit root test is appropriate when the linearity hypothesis is rejected. The advantage of this methodology is that in the presence of nonlinear adjustment, the nonlinear unit root test allows us to discriminate between pure and partial nonstationarity. Pure nonstationarity (stationarity) exists when the series exhibits a random walk (white noise) process across both regimes, while partial nonstationarity exists when the series behaves like a unit root in one regime and like a stationary process in the other regime.

The results imply that inflation rate differentials in the Eurozone are characterized by threshold nonlinearity. When the French inflation rate is used as a benchmark, all series are found to follow a threshold nonlinear process. In addition, when the German inflation rate is utilized as a benchmark, linearity is rejected in 9 out of the 14 inflation rate differentials. Similarly, when the euro area's inflation rate is used, threshold nonlinearity is confirmed in 9 out of the 16 cases. After modeling the nonlinear characteristics of the series with the appropriate unit root test, our test's results reveal that inflation rate differentials in the Eurozone are mainly persistent. However, this statement should be examined more thoroughly. Pure stationarity has been observed in one case when the German inflation rate is used (i.e., the case of Cyprus) and in two cases when the euro area's inflation rate represents the benchmark inflation rate (i.e., the cases of Austria and Greece). In the remaining inflation rate differentials, the stationarity hypothesis has been rejected. Pure nonstationarity has been established in 7 out of the 15 series when the French inflation rate is employed, in 7 out of the 14 series when the German inflation rate is employed, and in 10 out of the 16 series when the euro area's inflation rate is used.

Nonetheless, the most interesting finding of this analysis is the evidence of partial nonstationarity in inflation rate differentials. In 8 out of the 15 inflation rate differentials against the French inflation rate, in 6 out of the 14 inflation rate differentials against the German inflation rate, and finally, in 4 out of the 16 inflation rate differentials against the euro area's inflation rate, we find evidence of stationarity in regime 1 and nonstationarity in regime 2. This finding implies that these inflation rate differentials are transitory in the first regime, but persistent in the second regime. An interesting interpretation of the above finding stems from the estimated sign of the threshold parameter. That is, if the threshold parameter is positive (i.e., the inflation

rate differential increases), the inflation rate differential is transitory when it increases by less than a certain rate (regime 1) and persistent when it increases by more than this rate (regime 2). However, if the inflation rate differential follows a decreasing trend ( $\lambda < 0$ ), it is found to be transitory when it decreases by more than a certain rate (regime 1) and persistent when decreased by less than the same rate (regime 2). It should be noted that these two statements are not contradictory and seem to be the two sides of the same coin. Specifically, the findings imply that the higher the increase of the inflation rate differential, the more persistent the inflation rate differential is likely to be. On the other hand, the higher the decrease of the inflation rate differential, the less persistent the inflation rate differential is likely to be.

Finally, the evidence for persistent inflation rate differentials implies the existence of a nefarious circle that reciprocally creates asymmetries in the Eurozone. This is because persistent inflation differentials arise from the existing asymmetries in the Eurozone such as the absence of real convergence across EMU members, while inflation differentials themselves increase the impact of these asymmetries on the euro zone. Thus, our empirical investigation indicates the existence of significant economic asymmetries in the Eurozone, which should be tackled by the economic authorities of the EMU.

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Table 1. Preliminary Statistics: National Inflation Rates

	$\mu$	$\sigma$	CV	Sk	Ks	JB	ADF
Austria	3.61	2.26	0.63	0.86	3.06	58.90 (0.00)	-3.12 (0.10)
Belgium	4.12	3.14	0.76	1.38	5.03	233.52 (0.00)	-2.93 (0.15)
Cyprus	4.86	3.41	0.70	1.51	5.59	314.28 (0.00)	-4.12 (0.01)
Finland	5.46	4.73	0.87	1.03	3.24	84.58 (0.00)	-3.61 (0.03)
France	5.02	4.14	0.82	0.87	2.47	65.90 (0.00)	-2.37 (0.39)
Germany	1.96	1.24	0.63	1.43	5.17	113.59 (0.00)	-2.81 (0.19)
Greece	11.15	8.94	0.80	-0.21	3.45	7.45 (0.02)	-4.25 (0.00)
Ireland	3.23	2.25	0.69	-1.90	8.08	234.92 (0.00)	-1.40 (0.15)
Italy	7.62	6.16	0.81	1.05	2.88	86.99 (0.00)	-2.77 (0.21)
Luxembourg	3.98	2.87	0.72	0.86	3.03	58.10 (0.00)	-2.89 (0.17)
Malta	3.69	3.67	0.99	1.41	5.32	265.00 (0.00)	-1.89 (0.06)
Netherlands	3.65	2.72	0.75	0.91	2.96	65.38 (0.00)	-1.50 (0.13)
Portugal	10.95	9.00	0.82	0.82	2.53	58.01 (0.00)	-3.19 (0.09)
Slovakia	6.86	3.65	0.53	0.85	3.15	22.78 (0.00)	-2.48 (0.12)
Slovenia	8.96	8.74	0.98	3.57	21.63	3317.3 (0.00)	-4.19 (0.01)
Spain	8.03	5.89	0.73	1.05	3.43	90.44 (0.00)	-2.71 (0.23)
Euro Area	2.01	0.78	0.39	-0.36	4.25	12.13 (0.00)	-2.02 (0.28)

Notes:

1.  $\mu$  and  $\sigma$  stand for the mean and the standard deviation of each series, respectively.
2. CV stands for the coefficient of variation, calculated as the standard deviation divided by the mean.
3. Sk and Ks are the skewness and kurtosis statistics, respectively.
4. JB and ADF are the Jargue-Bera and Augmented Dickey-Fuller test statistics, respectively.
5. P-values of accepting the null hypothesis are shown in parentheses.

Table 2. Linear Unit Root Test: Inflation Rate Differentials

	<i>Relative to FRANCE</i>			<i>Relative to GERMANY</i>			<i>Relative to EURO AREA</i>		
	Exogenous term	$\rho$	ADF stat.	Exogenous term	$\rho$	ADF stat.	Exogenous term	$\rho$	ADF stat.
<i>Austria</i>	none	-0.011	-1.76*	constant	0.038	-2.76*	none	-0.191	-2.81
<i>Belgium</i>	none	-0.016	-2.14**	none	-0.090	-3.47	none	-0.136	-2.36**
<i>Cyprus</i>	none	-0.049	-2.23**	constant	-0.356	-4.20	constant	-0.301	-3.23**
<i>Finland</i>	none	0.029	-2.07**	none	-0.044	-2.09**	none	-0.039	-1.43*
<i>France</i>	----- none available -----			----- none available -----			constant	-0.122	-2.03**
<i>Germany</i>	none	-0.002	-2.99	----- none available -----			constant	-0.122	-2.03*
<i>Greece</i>	constant & trend	-0.030	-2.83*	none	-0.031	-2.98	constant	-0.307	-4.73
<i>Ireland</i>	constant & trend	-0.036	-1.32*	constant & trend	-0.040	-1.19*	constant & trend	-0.032	1.14*
<i>Italy</i>	constant & trend	-0.040	-3.40*	constant & trend	-0.086	-3.23*	constant & trend	-0.220	-2.66*
<i>Luxembourg</i>	constant & trend	-0.031	-2.61*	constant	-0.087	-2.21*	constant & trend	-0.364	-4.49
<i>Malta</i>	constant & trend	-0.052	-3.15*	constant	-0.192	-4.00	none	-0.179	-2.47**
<i>Netherlands</i>	constant	-0.009	-1.49*	none	-0.056	-2.38**	constant	-0.049	-1.62*
<i>Portugal</i>	constant & trend	-0.042	-3.18*	none	-0.037	-1.91*	constant & trend	-0.128	-2.06*
<i>Slovakia</i>	constant & trend	-0.080	-2.53*	constant & trend	-0.074	-2.39*	constant & trend	-0.134	-2.63*
<i>Slovenia</i>	constant & trend	-0.065	-4.31	constant & trend	-0.078	-4.03	none	-0.015	-0.918*
<i>Spain</i>	constant & trend	-0.033	-2.61*	constant	-0.081	-2.39*	constant & trend	-0.162	-2.03*

Notes: (1)  $\rho$  is the estimated autoregressive parameter of the linear ADF model. (2) \* means that the null hypothesis (unit root) is accepted at 5% significance level. (3) \*\* means that the null hypothesis (unit root) is accepted at 1% significance level. (4) Critical values: (i) with no exogenous term:  $cv_{n,1\%} = -2.598$ ,  $cv_{n,5\%} = -1.945$ ,  $cv_{n,10\%} = -1.613$ , (ii) with constant term:  $cv_{c,1\%} = -3.459$ ,  $cv_{c,5\%} = -2.874$ ,  $cv_{c,10\%} = -2.573$ , (iii) with constant & trend:  $cv_{t,1\%} = -3.990$ ,  $cv_{t,5\%} = -3.430$ ,  $cv_{t,10\%} = -3.139$ .

Table 3. Nonlinear (TAR) Unit Root Test: Inflation Differentials relative to France

	TAR specification			Linearity test		$\rho$ coefficient		$R_1$ test		$t_1$ test		$t_2$ test	
	Exog. Term	m	$\lambda$	Wald stat.	Boot. P-value	Reg. 1	Reg. 2	Wald stat.	Boot. P-value	t stat.	Boot. P-value	t stat.	Boot. P-value
Austria	c	2	0.457	43.90	0.01	-0.055	0.005	10.80	0.06	0.02	0.02	-0.69*	0.92
Belgium	c	3	-0.424	55.00	0.00	-0.024	-0.005	3.25*	0.55	1.70*	0.28	0.59*	0.73
Cyprus	c	12	-0.024	46.70	0.00	-0.062	-0.050	6.89*	0.20	2.09*	0.17	0.32*	0.32
Finland	c	9	-0.459	49.80	0.00	-0.043	-0.023	4.91*	0.38	0.31*	0.31	0.36*	0.36
Germany	c	5	-0.216	33.10	0.06	-0.070	-0.060	10.30	0.07	2.79	0.06	1.58*	0.31
Greece	t	12	1.91	107.00	0.00	-0.051	-0.073	17.30	0.04	3.72	0.03	1.84*	0.41
Ireland	t	6	-1.13	55.10	0.00	0.298	-0.079	3.88*	0.56	-0.70*	0.99	1.97*	0.27
Italy	t	4	0.688	84.40	0.00	-0.045	-0.040	12.80	0.08	3.29	0.04	1.41*	0.55
Luxembourg	t	6	0.355	45.90	0.00	-0.080	-0.008	14.60	0.05	3.78	0.01	0.56*	0.81
Malta	t	8	2.94	48.40	0.00	-0.063	-0.096	17.70	0.02	3.50	0.03	2.34*	0.23
Netherlands	c	4	0.508	35.80	0.04	-0.011	0.006	2.50*	0.67	1.58*	0.33	-0.38*	0.88
Portugal	c	9	3.37	81.70	0.00	-0.029	-0.053	8.81*	0.13	2.30*	0.14	1.87*	0.22
Slovakia	t	1	0.368	65.80	0.03	-0.050	0.080	2.30*	0.84	1.52*	0.49	-0.85*	0.96
Slovenia	t	11	-2.67	61.60	0.00	-0.054	-0.067	19.80	0.05	2.16	0.04	3.89*	0.16
Spain	t	12	1.03	90.80	0.00	-0.089	0.076	22.60	0.01	4.76	0.00	-3.16*	0.99

Notes: (1) c stands for the inclusion of a constant term, (2) t stands for the inclusion of both constant and trend terms, (3) m is the delay parameter, (4)  $\lambda$  is the threshold variable, (5) Wald stat. stands for the Wald test statistic, (6) Boot. P-value stand for the p-value based on the Bootstrap distribution, (7)  $\rho$  is the estimated autoregressive parameter of the nonlinear TAR model, (8)  $R_1$  stands for the one-sided unit root test in both regimes, (9)  $t_1$  stand for the unit root test in regime 1, (10)  $t_2$  stand for the unit root test in regime 2. (11) \* means that the null hypothesis is accepted at 10% significance level.



Table 4. Nonlinear (TAR) Unit Root Test: Inflation Differentials relative to Germany

TAR Specification				Linearity test		$\rho$ coefficient		$R_1$ test		$t_1$ test		$t_2$ test	
	Exog. Term	m	$\lambda$	Wald stat.	Boot. P-value	Reg. 1	Reg. 2	Wald stat.	Boot. P-value	t stat.	Boot. P-value	t stat.	Boot. P-value
Austria	c	11	0.357	31.20*	0.11	-0.20	-0.04	-----linear-----					
Belgium	c	9	0.915	40.80	0.01	-0.13	-0.05	18.40	0.00	18.40	0.00	4.12*	0.48
Cyprus	c	1	0.571	33.70	0.06	0.09	-0.45	25.10	0.00	4.61	0.00	1.97	0.01
Finland	c	10	-0.85	24.20*	0.43	-0.04	-0.03	-----linear-----					
Greece	c	4	-0.625	46.30	0.00	-0.04	-0.02	11.00	0.05	3.13	0.03	1.06*	0.48
Ireland	t	9	-1.61	39.30	0.08	-0.26	-0.08	6.97*	0.55	1.60*	0.53	2.10*	0.41
Italy	t	10	0.611	31.20*	0.15	-0.16	0.02	-----linear-----					
Luxembourg	c	5	-0.162	38.80	0.03	-0.20	-0.05	11.40	0.06	3.14	0.03	1.21*	0.44
Malta	c	9	1.86	38.00	0.02	-0.31	-0.04	19.20	0.01	4.35	0.00	0.55*	0.67
Netherlands	c	1	-0.269	54.40	0.00	-0.07	-0.04	10.20	0.07	3.13	0.03	0.62*	0.62
Portugal	t	8	0.627	36.20	0.05	-0.05	-0.27	8.41*	0.32	1.11*	0.64	2.68*	0.16
Slovakia	t	12	0.522	33.80*	0.25	-0.09	0.03	-----linear-----					
Slovenia	t	10	-2.91	57.40	0.00	-0.07	-0.04	13.30*	0.18	3.59	0.05	0.68*	0.82
Spain	c	3	-0.594	27.40*	0.26	-0.03	-0.09	-----linear-----					

Notes: (1) c stands for the inclusion of a constant term, (2) t stands for the inclusion of both constant and trend terms, (3) m is the delay parameter, (4)  $\lambda$  is the threshold variable, (5) Wald stat. stands for the Wald test statistic, (6) Boot. P-value stand for the p-value based on the Bootstrap distribution, (7)  $\rho$  is the estimated autoregressive parameter of the nonlinear TAR model, (8)  $R_1$  stands for the one-sided unit root test in both regimes, (9)  $t_1$  stand for the unit root test in regime 1, (10)  $t_2$  stand for the unit root test in regime 2. (11) \* means that the null hypothesis is accepted at 10% significance level.

Table 5. Nonlinear (TAR) Unit Root Test: Inflation Differentials relative to Euro Area

TAR Specification				Linearity test		$\rho$ coefficient		$R_1$ test		$t_1$ test		$t_2$ test	
	Exog. Term	m	$\lambda$	Wald stat.	Boot. P-value	Reg. 1	Reg. 2	Wald stat.	Boot. P-value	t stat.	Boot. P-value	t stat.	Boot. P-value
Austria	c	7	-0.017	32.10*	0.10	-0.134	-0.253	-----linear-----					
Belgium	c	6	0.231	33.20	0.09	-0.178	-0.219	9.94*	0.31	2.47*	0.17	1.96*	0.51
Cyprus	c	9	1.370	34.20	0.05	-0.390	-0.704	16.70	0.04	3.59	0.02	1.95*	0.33
Finland	c	12	-0.780	56.50	0.00	0.114	-0.045	2.87*	0.59	-1.90*	0.98	1.70*	0.31
France	c	5	0.184	34.20*	0.11	-0.150	0.337	-----linear-----					
Germany	c	2	0.067	32.20*	0.10	-0.128	0.047	-----linear-----					
Greece	c	3	0.041	28.70*	0.27	-0.247	-0.451	-----linear-----					
Ireland	c	1	-0.317	65.10	0.00	0.476	-0.057	4.18*	0.44	-4.33*	0.99	2.04*	0.20
Italy	t	9	0.172	38.40	0.05	-0.395	0.213	13.80	0.07	3.72	0.02	-1.26*	0.72
Luxembourg	t	6	0.403	51.30	0.01	-0.353	-0.367	20.80	0.04	4.47	0.01	0.92*	0.69
Malta	c	1	0.199	29.10*	0.19	-0.190	-0.149	-----linear-----					
Netherlands	c	2	-0.362	45.50	0.06	-0.598	-0.068	14.20	0.04	2.97	0.05	2.31*	0.15
Portugal	t	7	0.317	32.20*	0.19	-0.145	-0.187	-----linear-----					
Slovakia	t	1	0.353	71.60	0.04	-0.041	0.429	0.75*	0.93	0.87*	0.68	-1.58*	0.99
Slovenia	c	5	-1.150	27.50*	0.25	0.100	-0.015	-----linear-----					
Spain	t	5	-0.613	40.40	0.06	0.185	-0.237	8.09*	0.38	-0.62*	0.93	2.84*	0.14

Notes: (1) c stands for the inclusion of a constant term, (2) t stands for the inclusion of both constant and trend terms, (3) m is the delay parameter, (4)  $\lambda$  is the threshold variable, (5) Wald stat. stands for the Wald test statistic, (6) Boot. P-value stand for the p-value based on the Bootstrap distribution, (7)  $\rho$  is the estimated autoregressive parameter of the nonlinear TAR model, (8)  $R_1$  stands for the one-sided unit root test in both regimes, (9)  $t_1$  stand for the unit root test in regime 1, (10)  $t_2$  stand for the unit root test in regime 2. (11) \* means that the null hypothesis is accepted at 10% significance level.

Figure 1. Inflation Differentials Relative to France

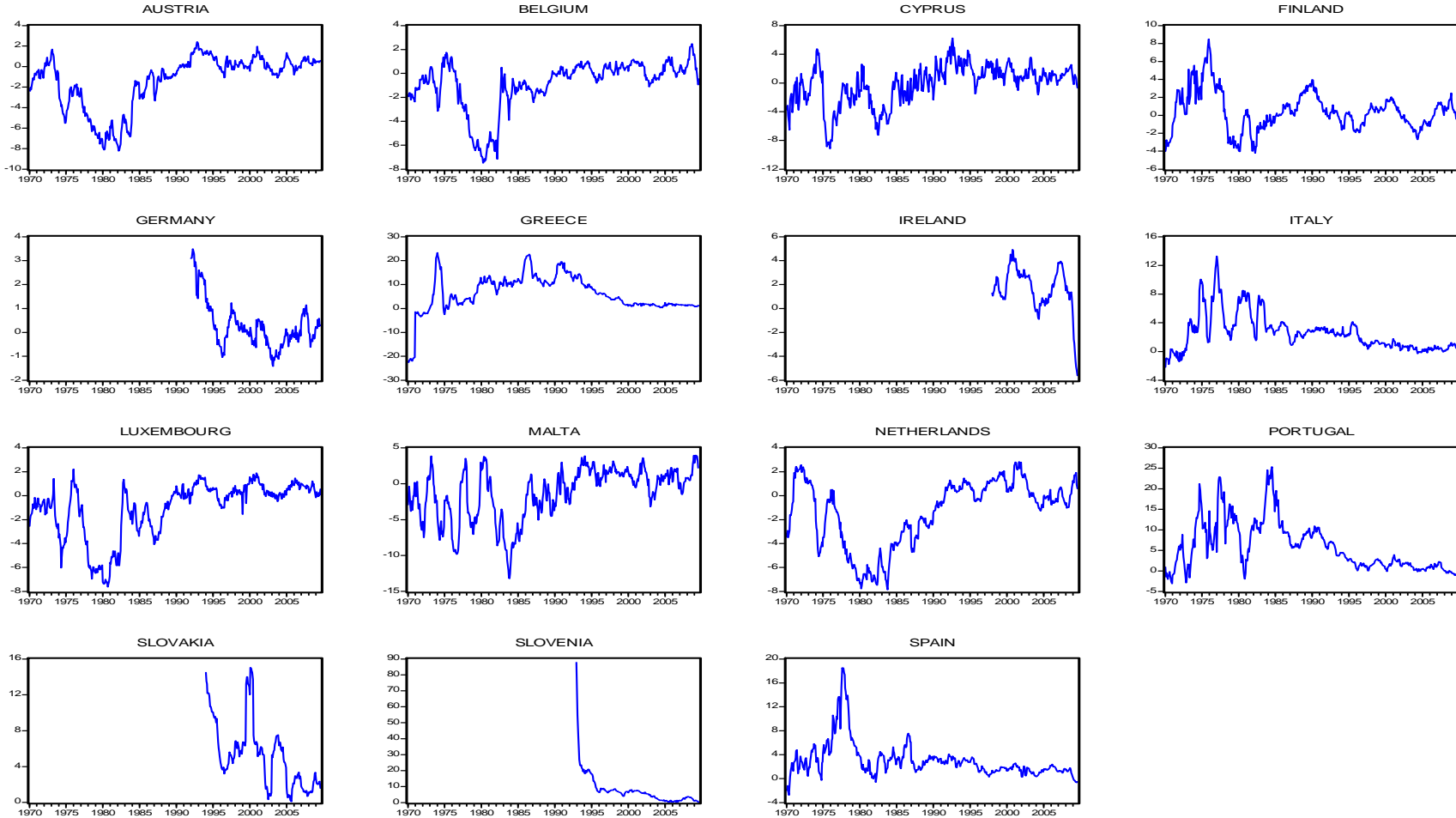


Figure 2. Inflation Differentials Relative to Germany

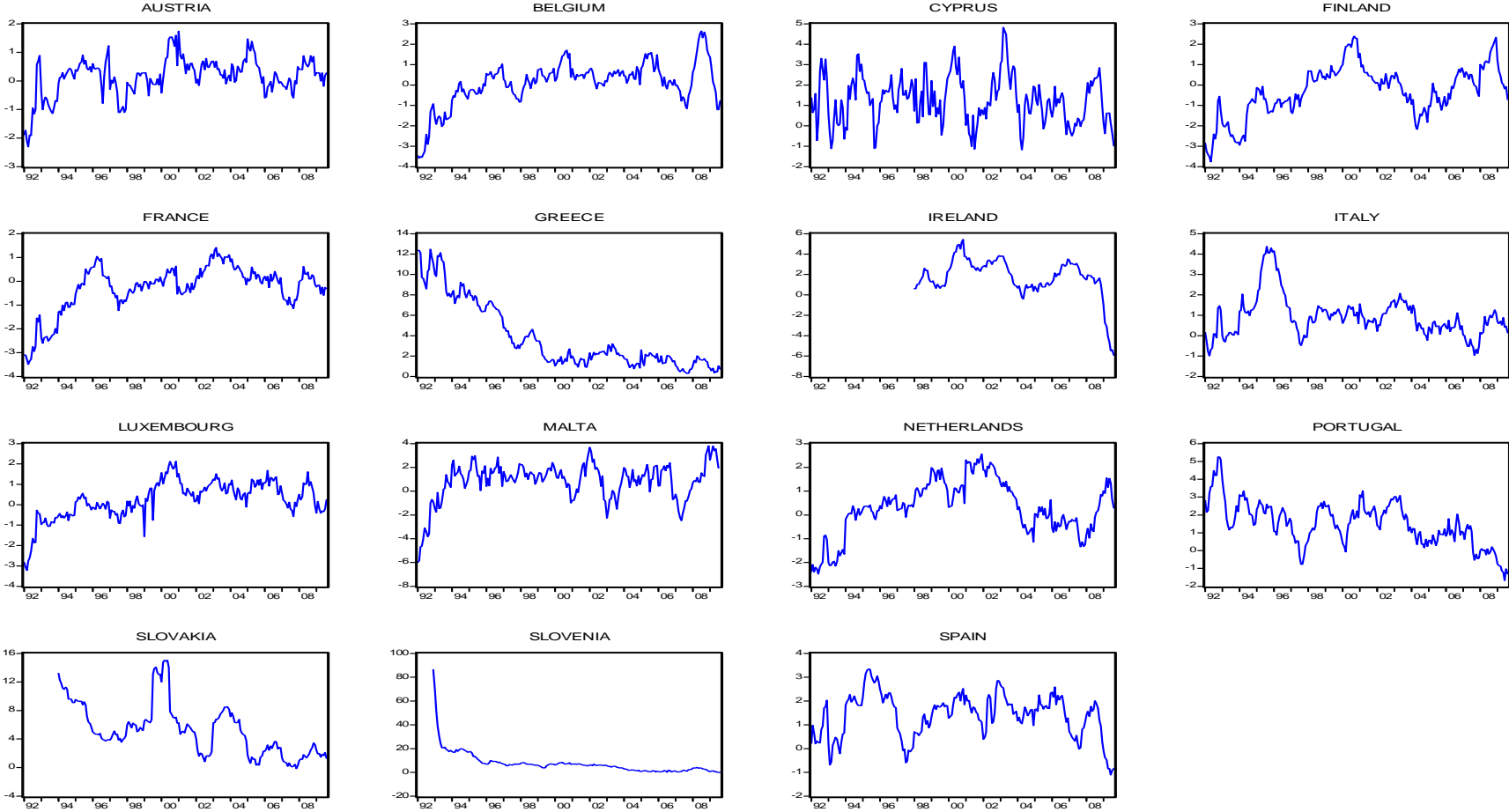


Figure 3. Inflation Differentials Relative to Euro Area

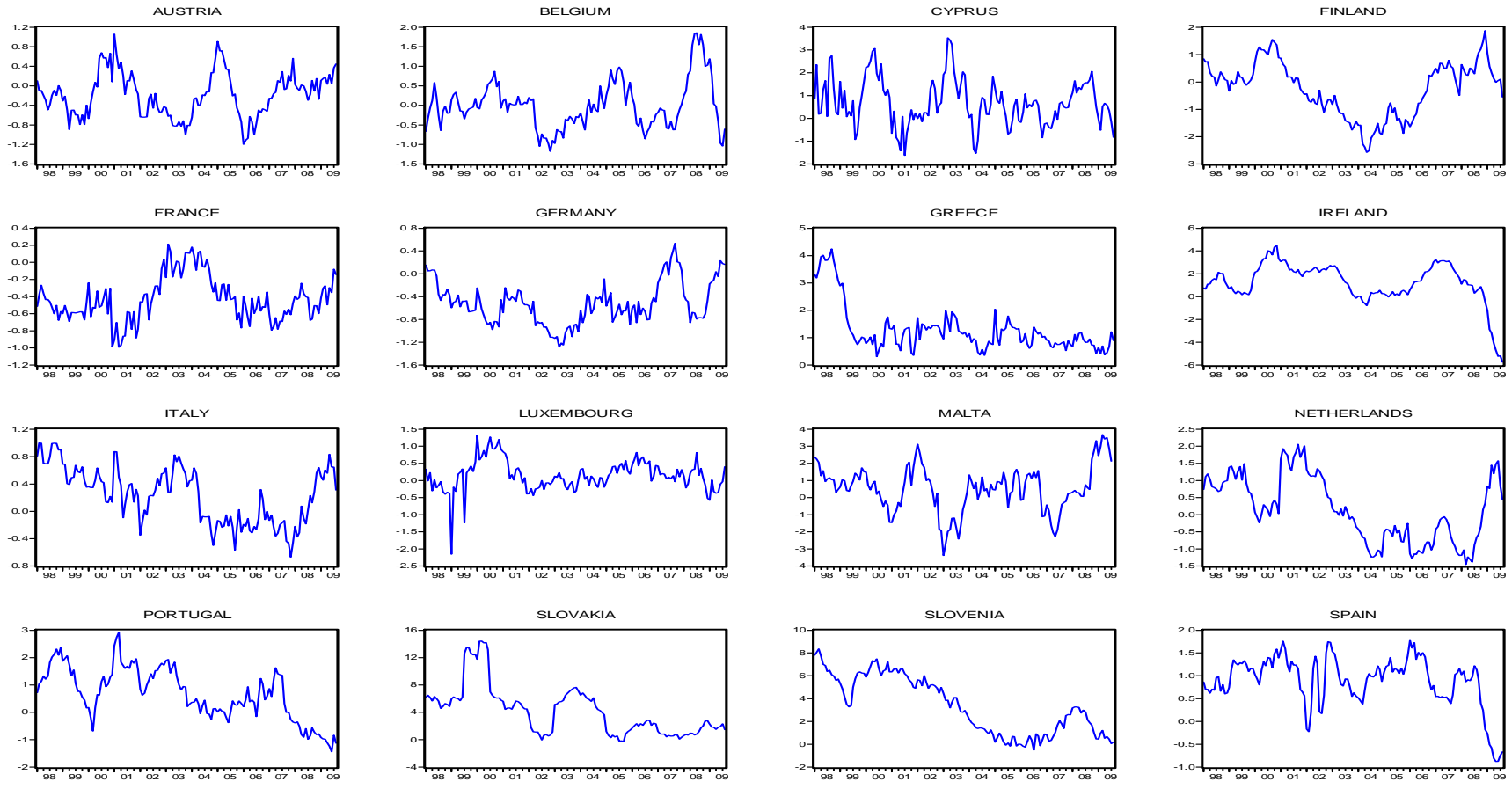
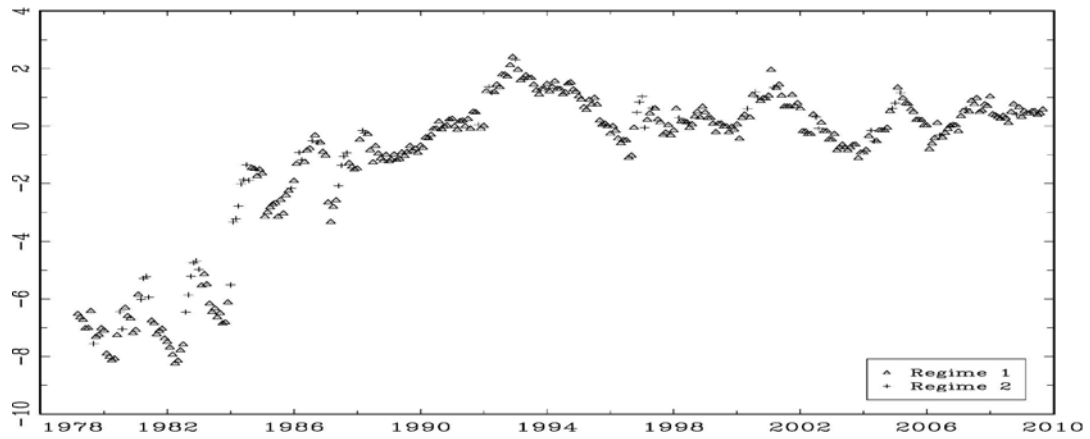
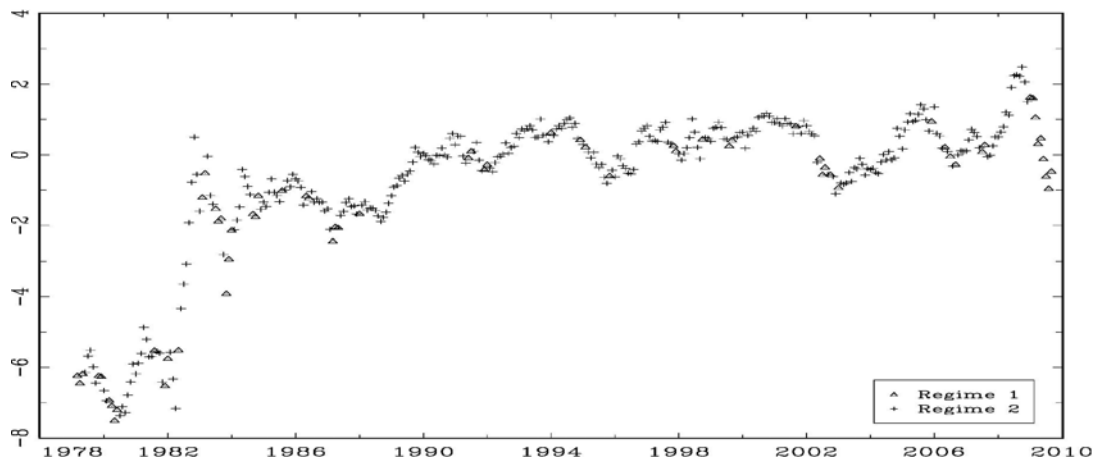


Figure 4. Division of Inflation Rate Differentials vis-a-vis the French Inflation Rate into Regimes

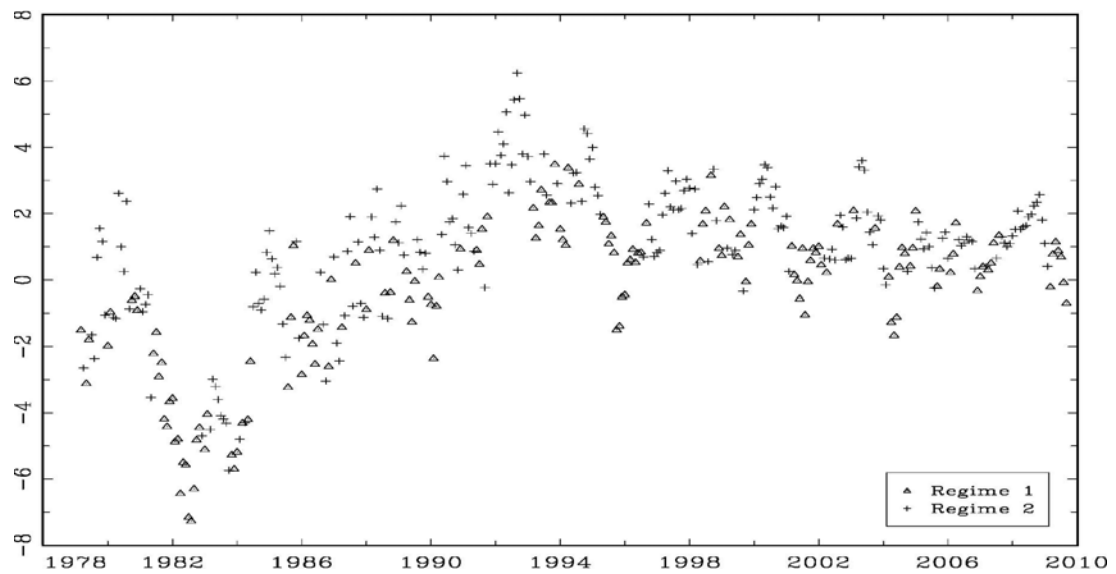
Part 1: Austria



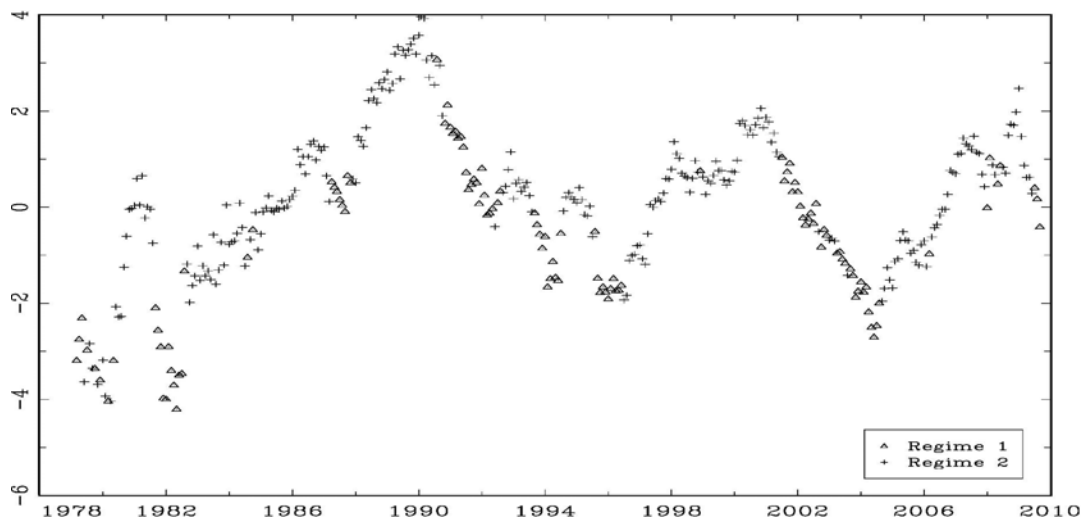
Part 2: Belgium



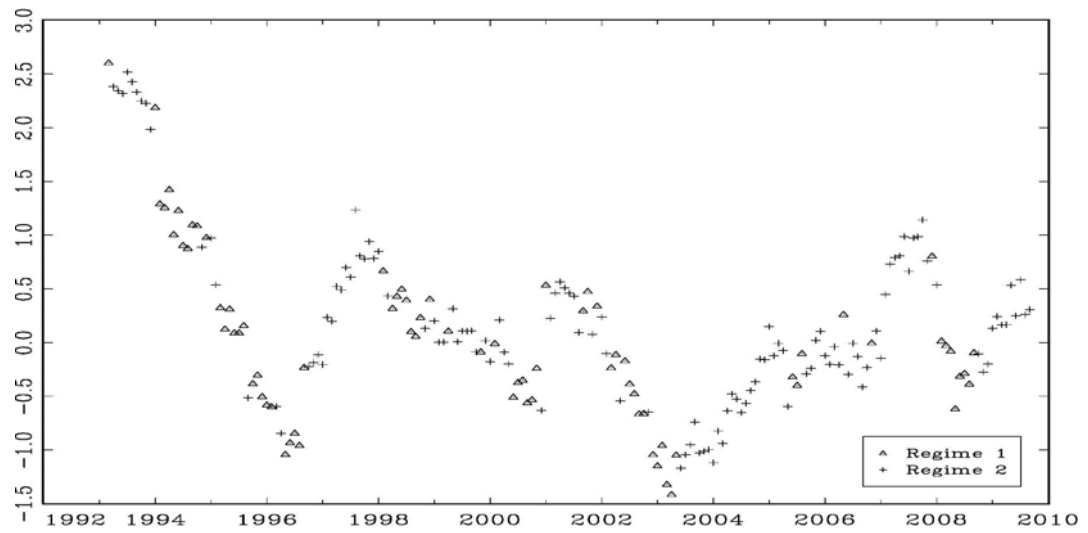
Part 3: Cyprus



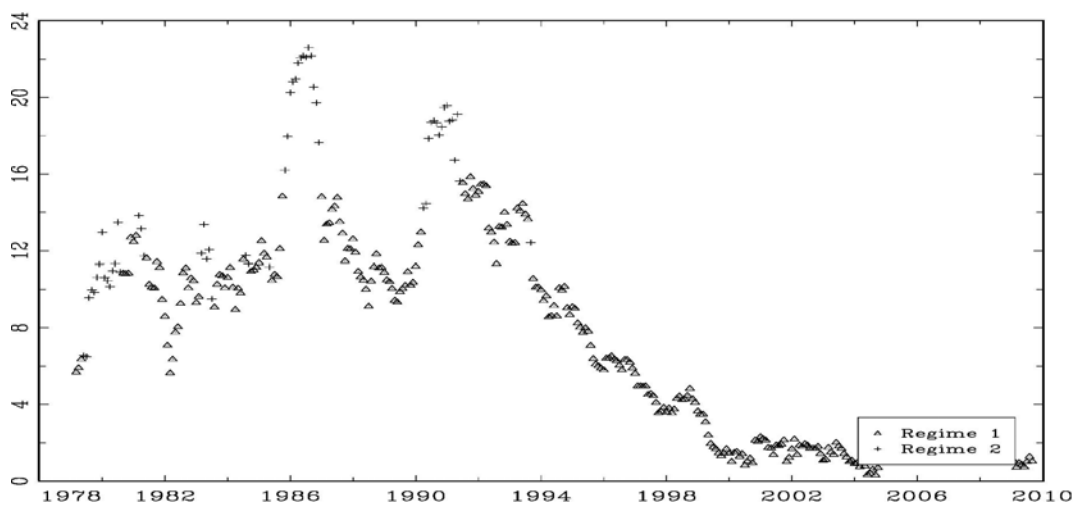
#### Part 4: Finland



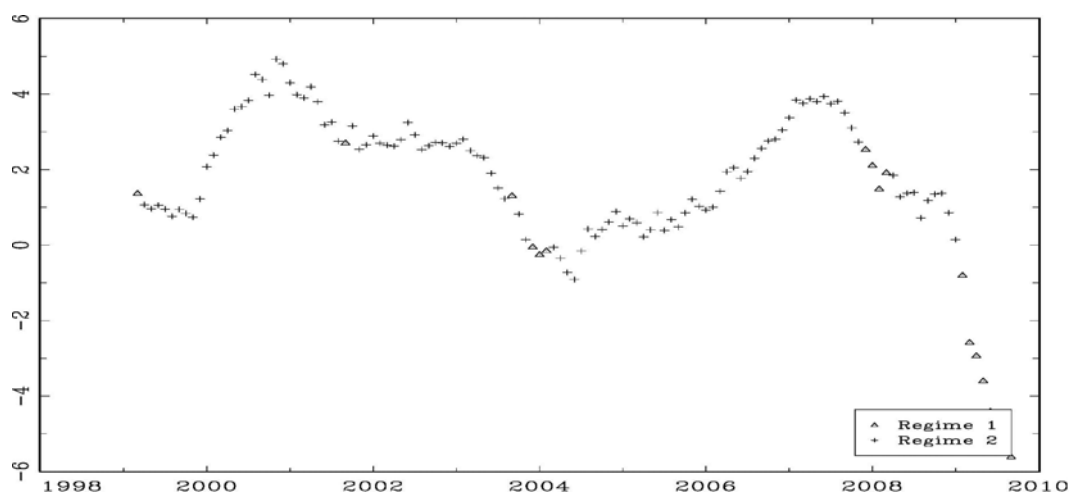
#### Part 5: Germany



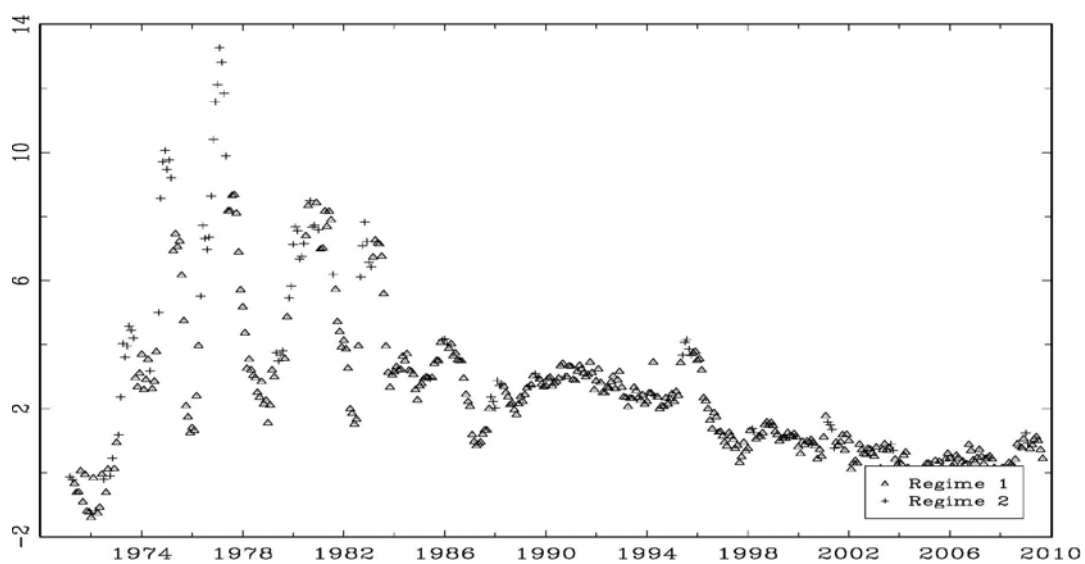
#### Part 6: Greece



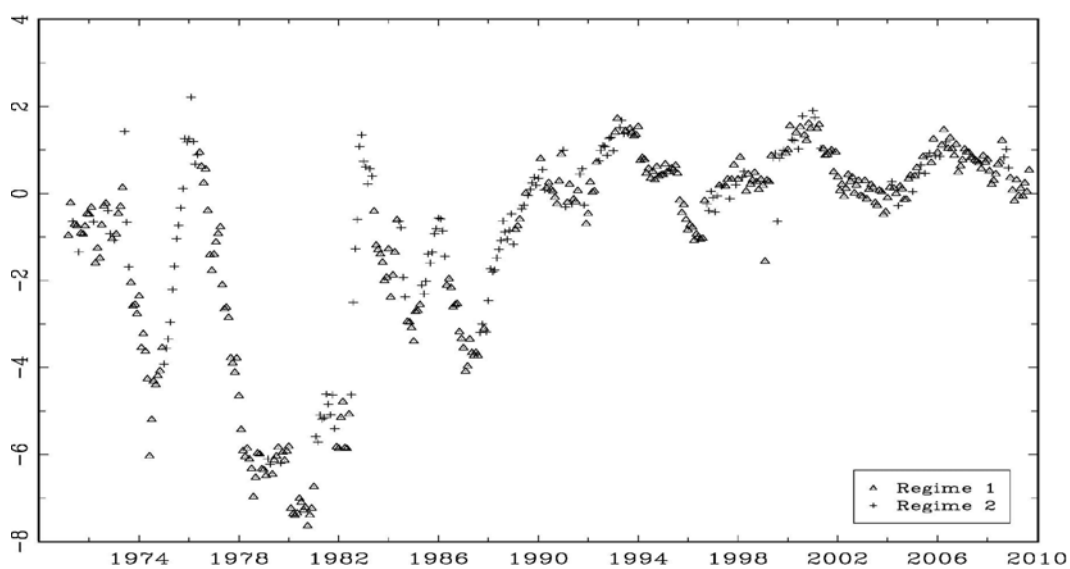
### Part 7: Ireland



### Part 8: Italy

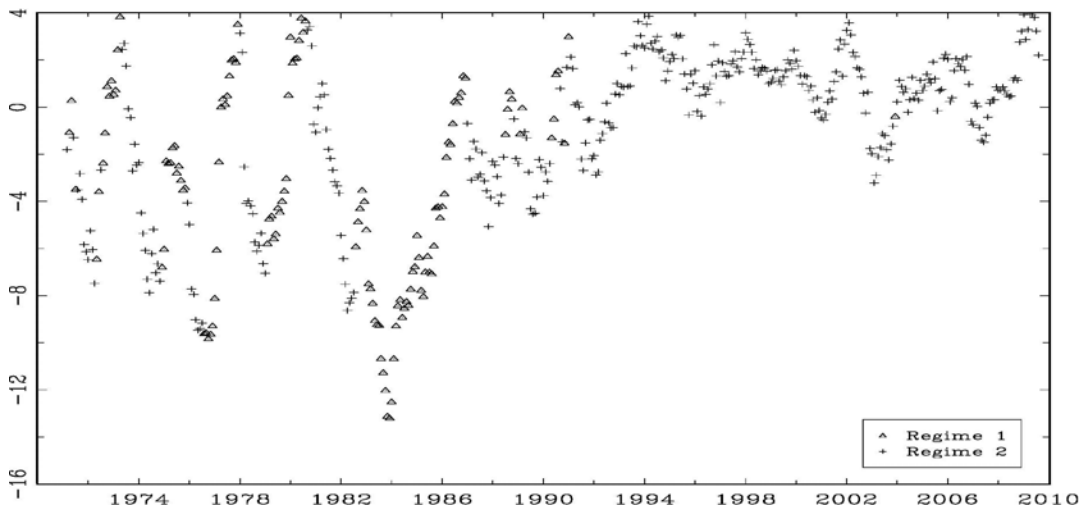


### Part 9: Luxembourg

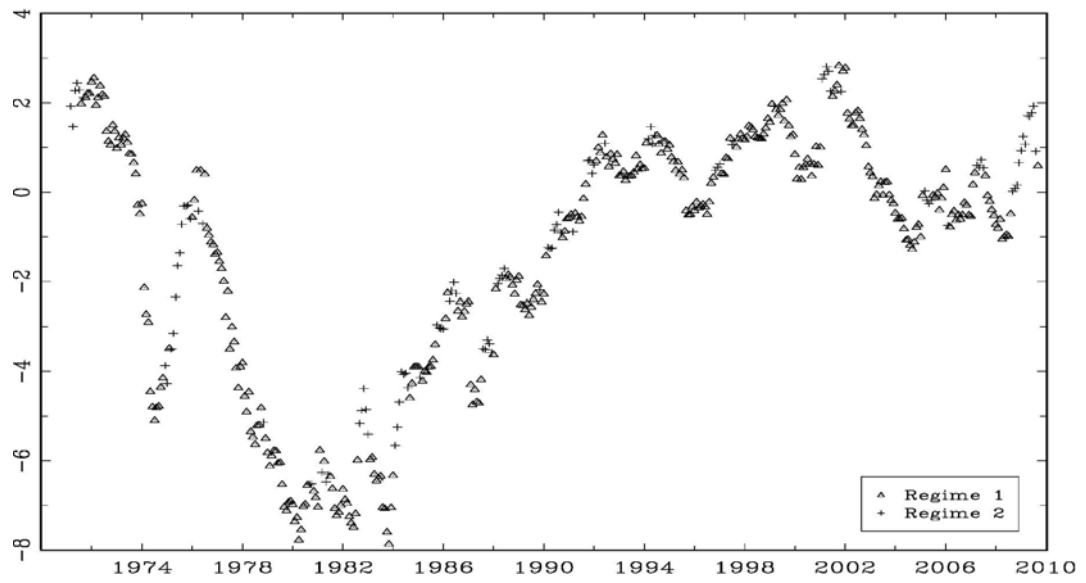




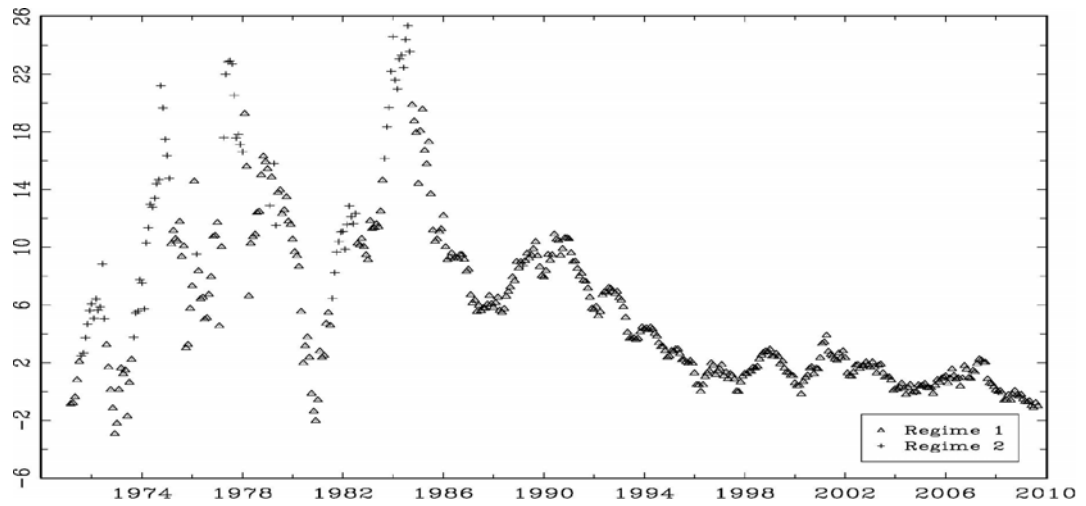
Part 10: Malta



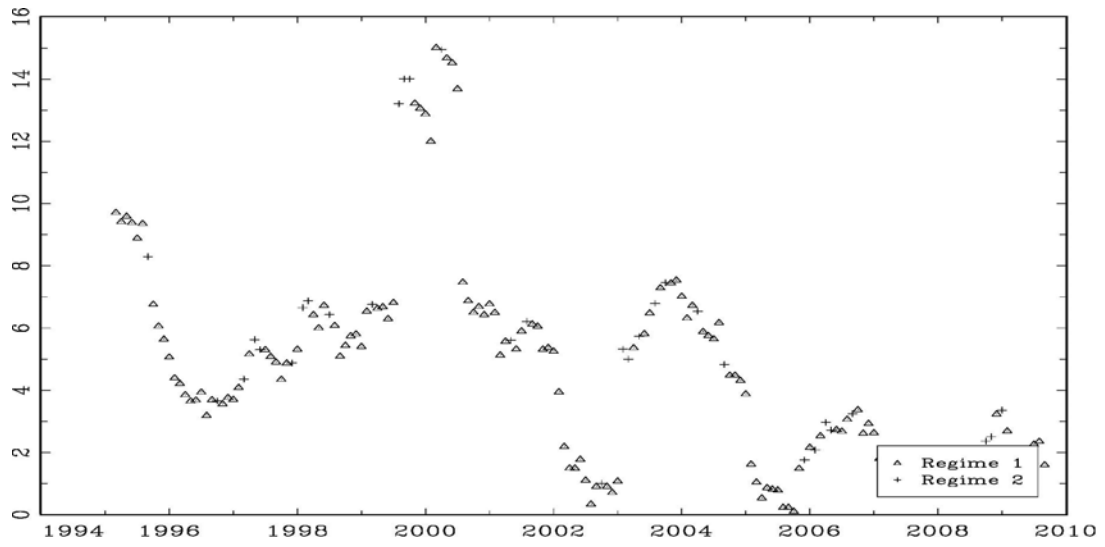
Part 11: Netherlands



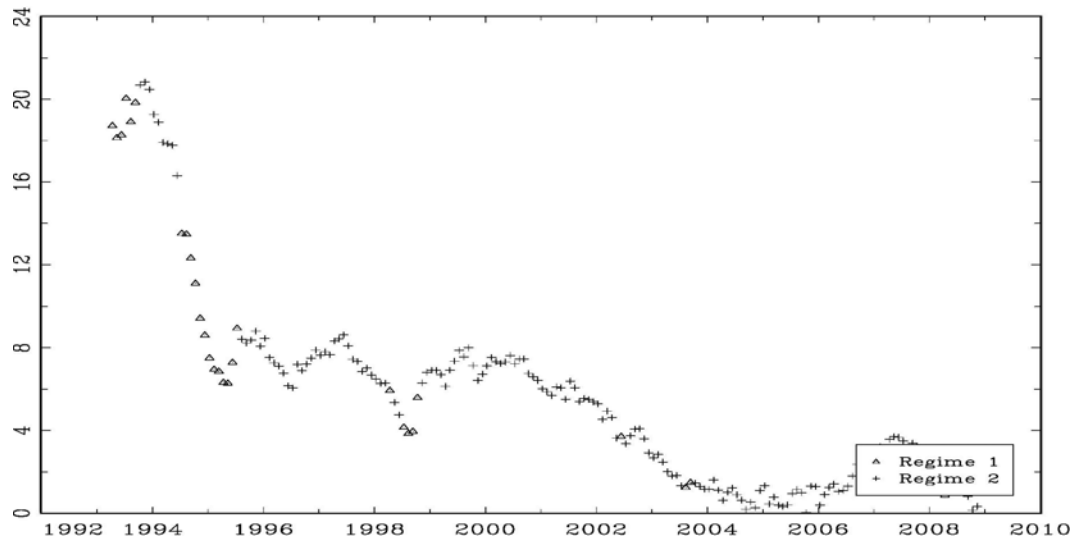
Part 12: Portugal



### Part 13: Slovakia



### Part 14: Slovenia



### Part 15: Spain

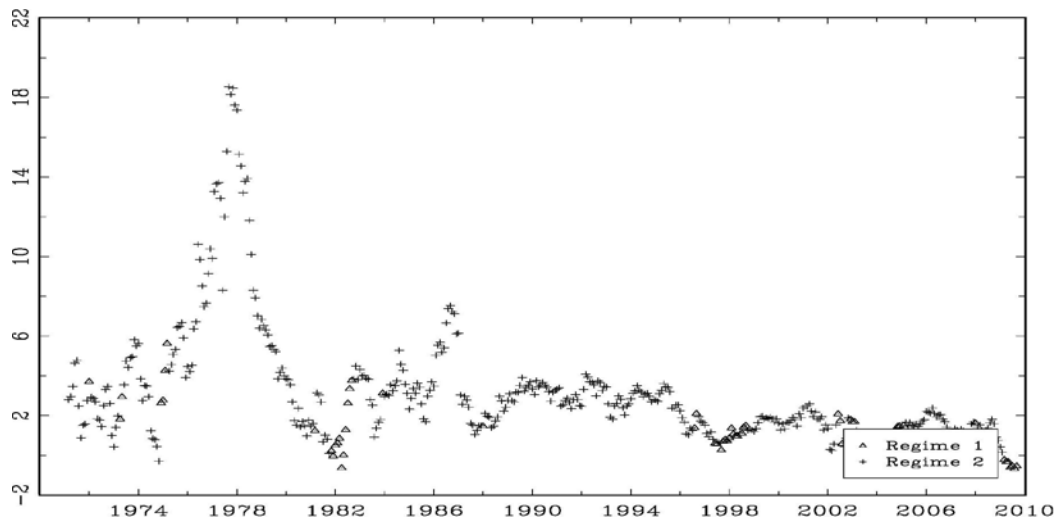
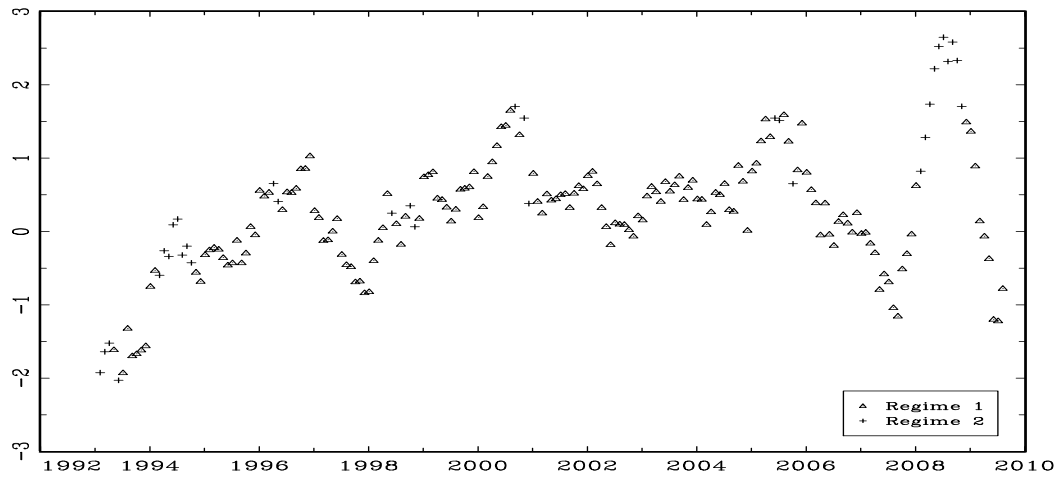
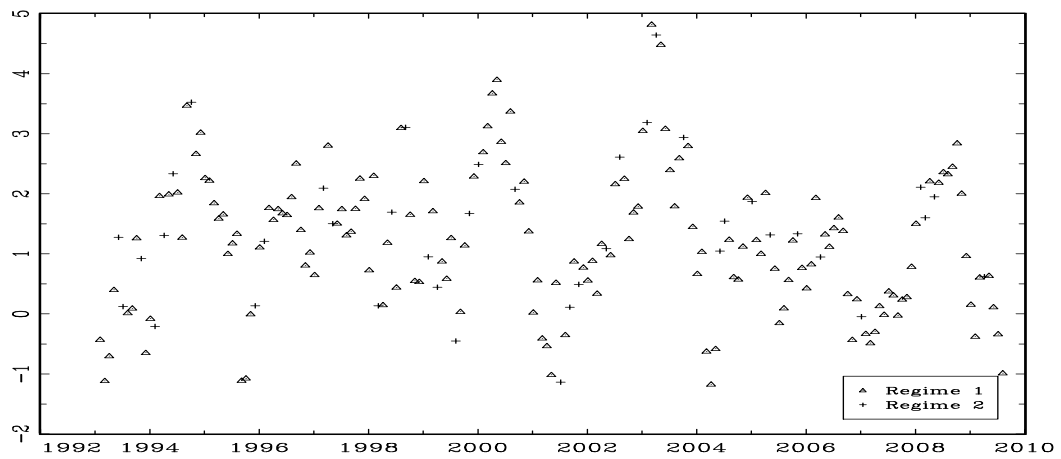


Figure 5. Division of Inflation Rate Differentials vis-a-vis the German Inflation Rate into Regimes

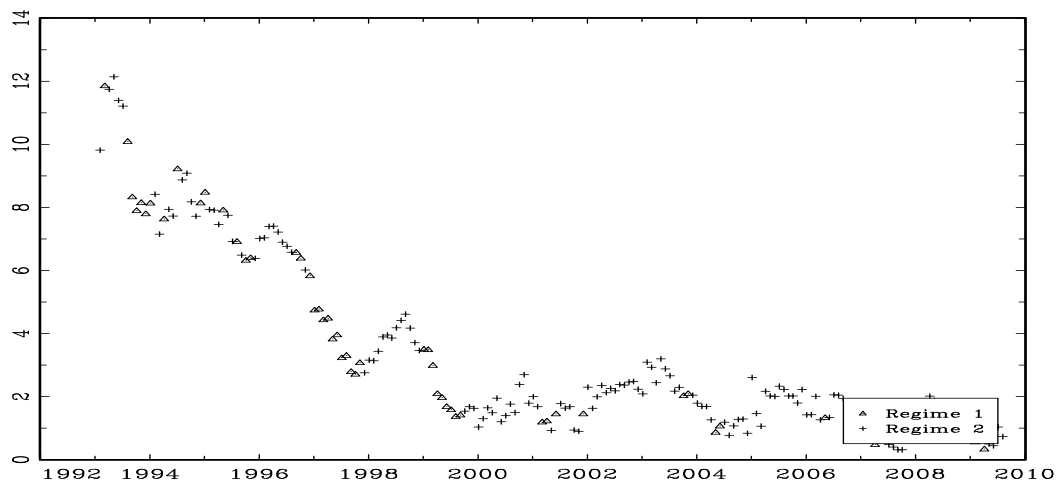
Part 1: Belgium



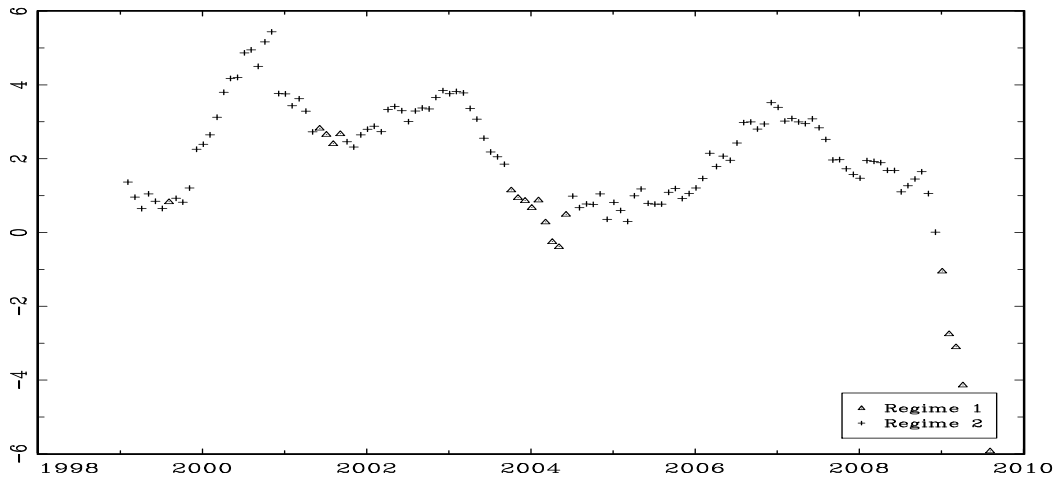
Part 2: Cyprus



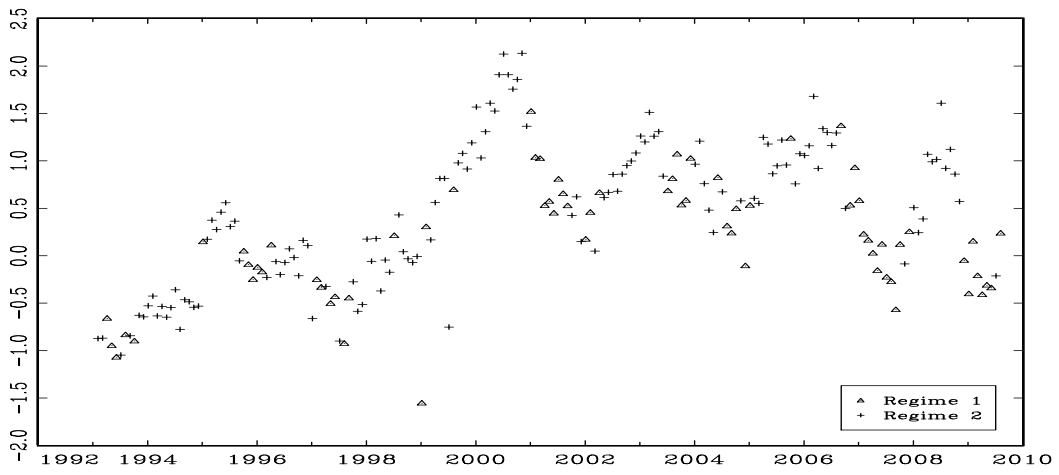
Part 3: Greece



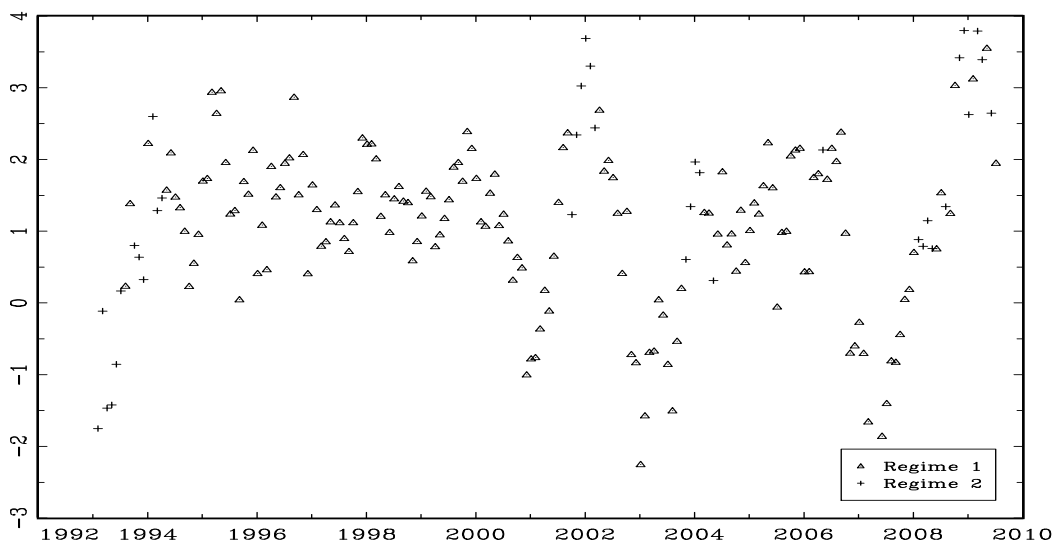
### Part 4: Ireland



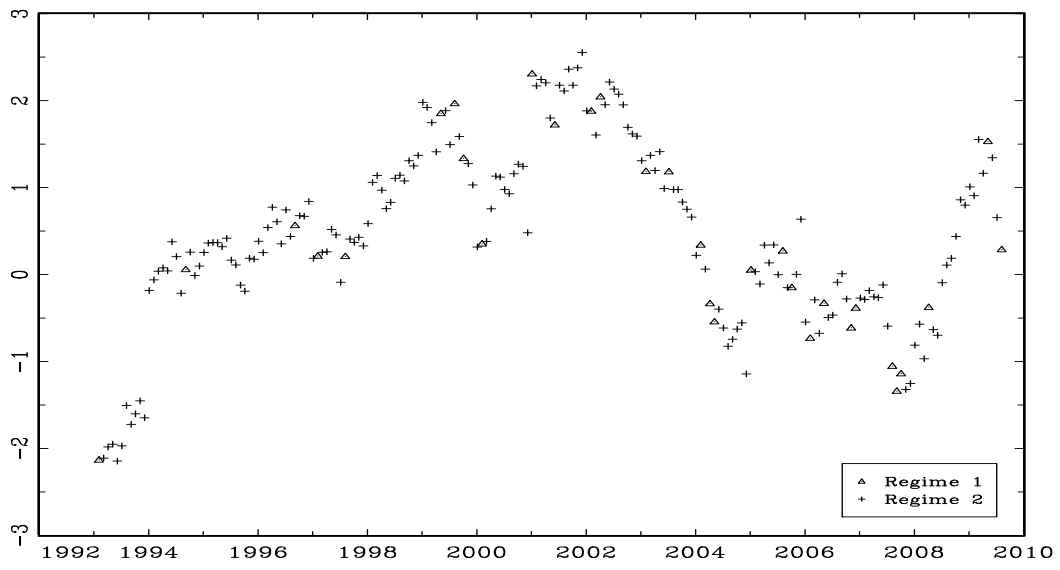
### Part 5: Luxembourg



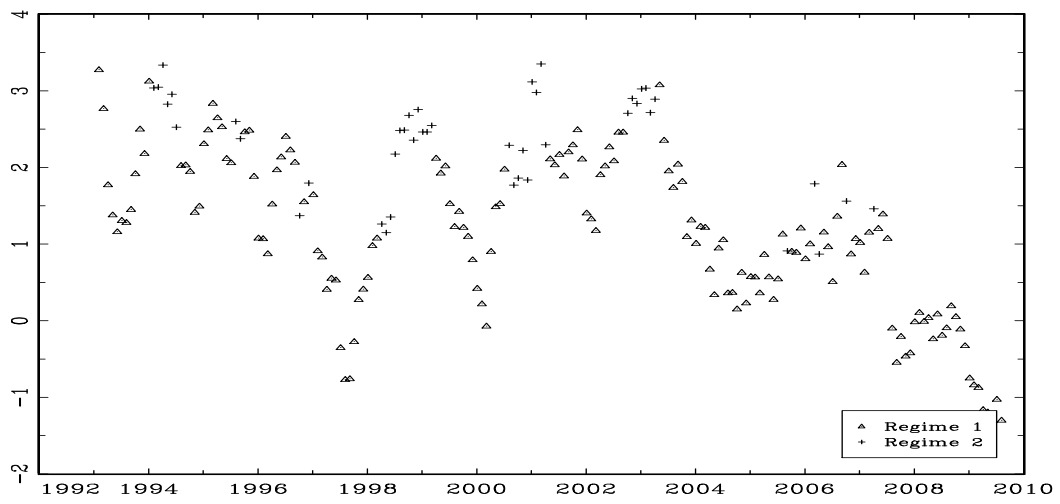
### Part 6: Malta



### Part 7: Netherlands



### Part 8: Portugal



### Part 9: Slovenia

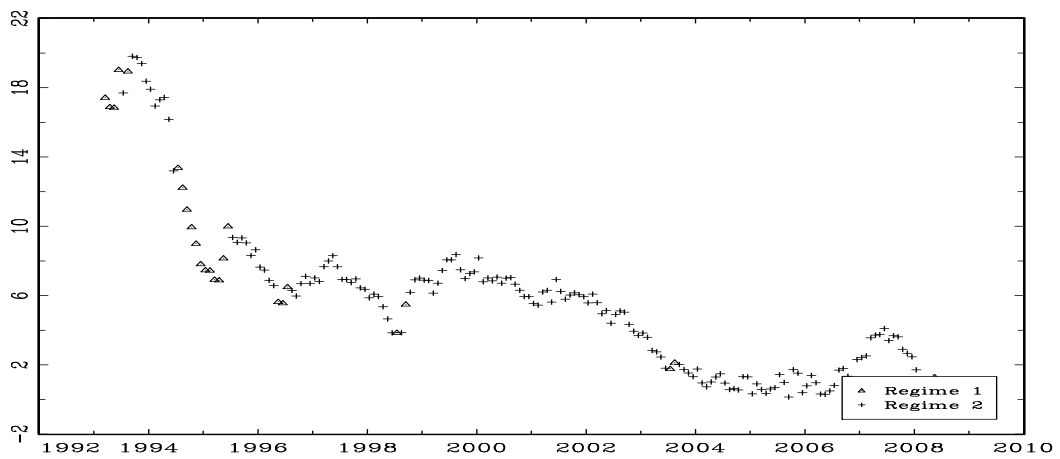
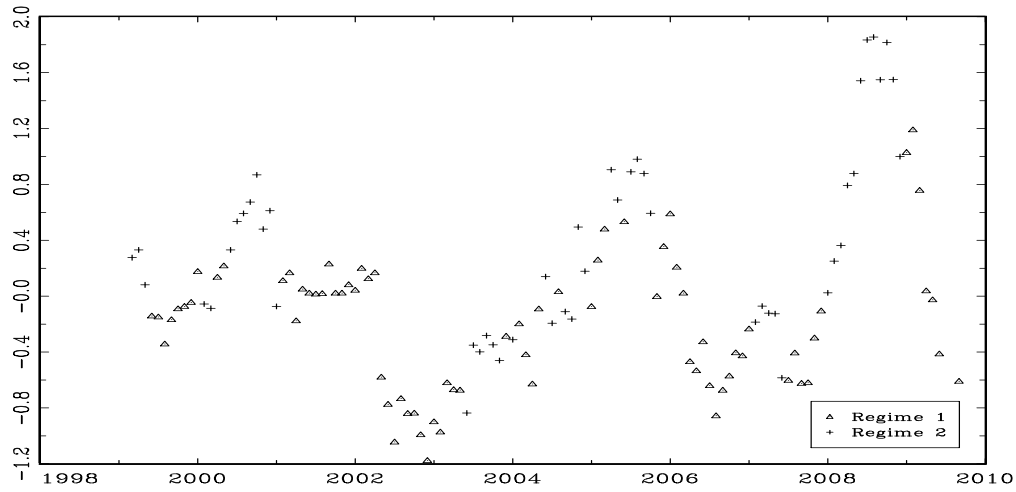
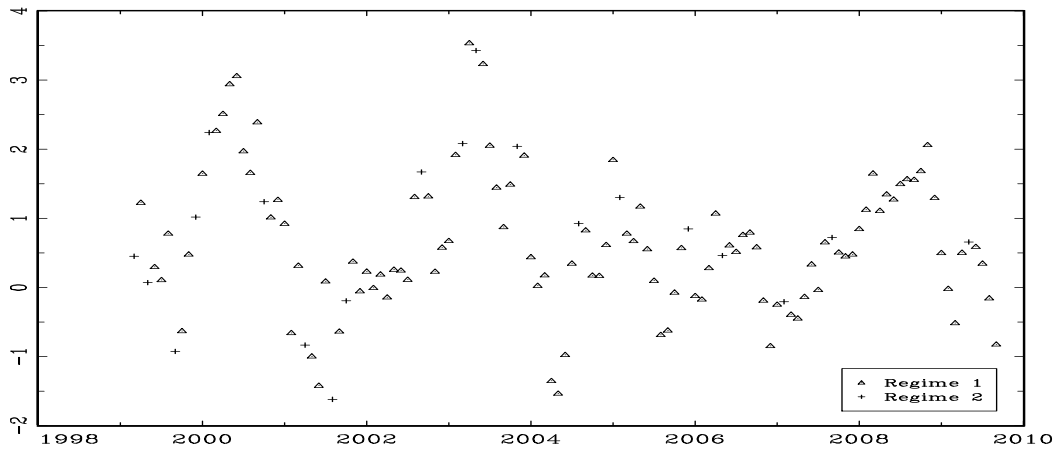


Figure 6. Division of Inflation Rate Differentials vis-a-vis the Euro Area's Inflation Rate into Regimes

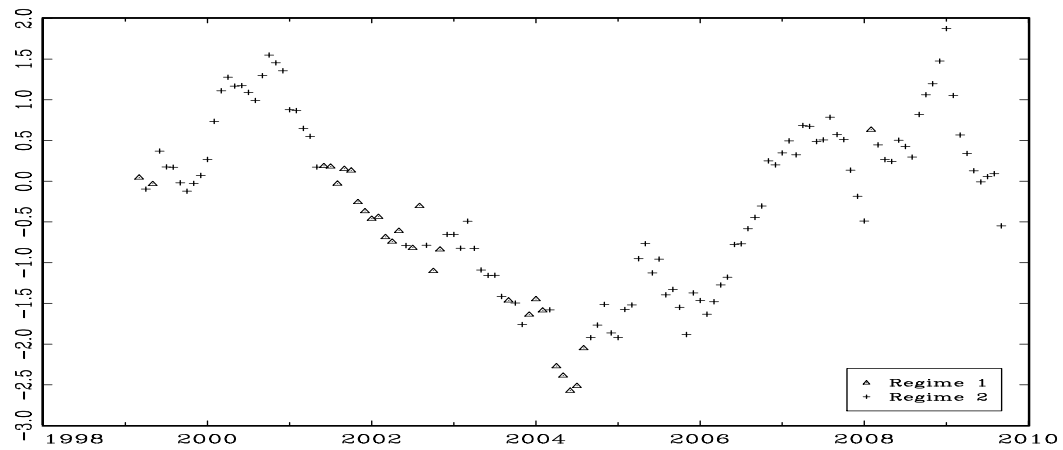
Part 1: Belgium



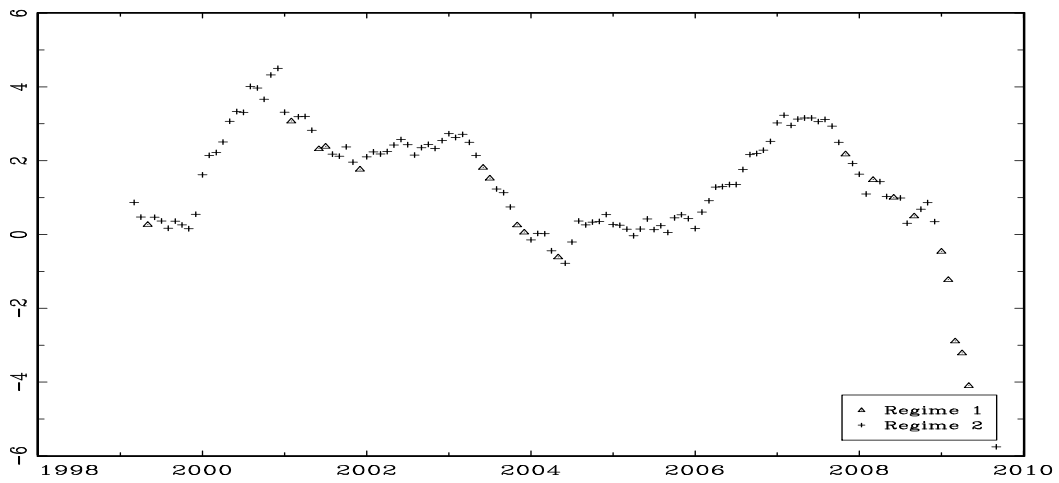
Part 2: Cyprus



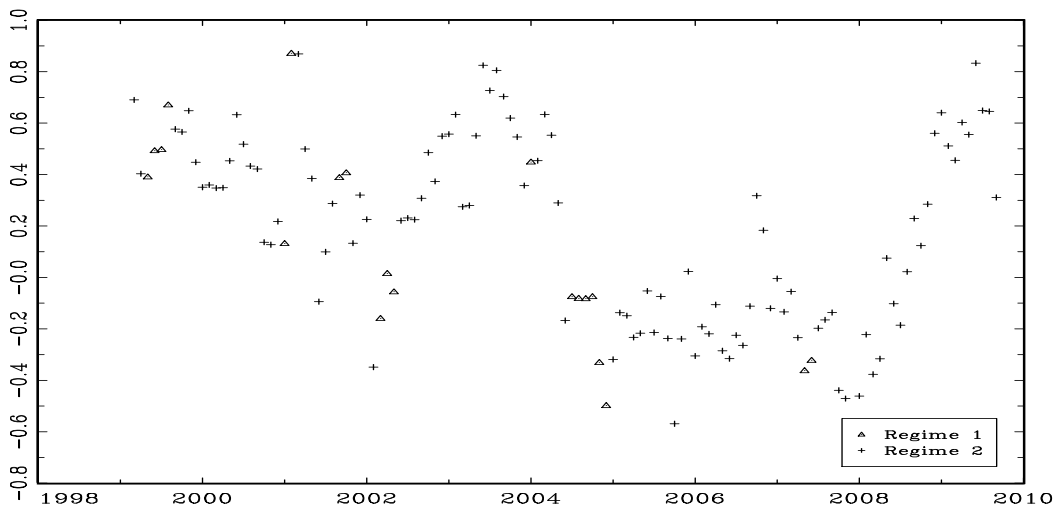
Part 3: Finland



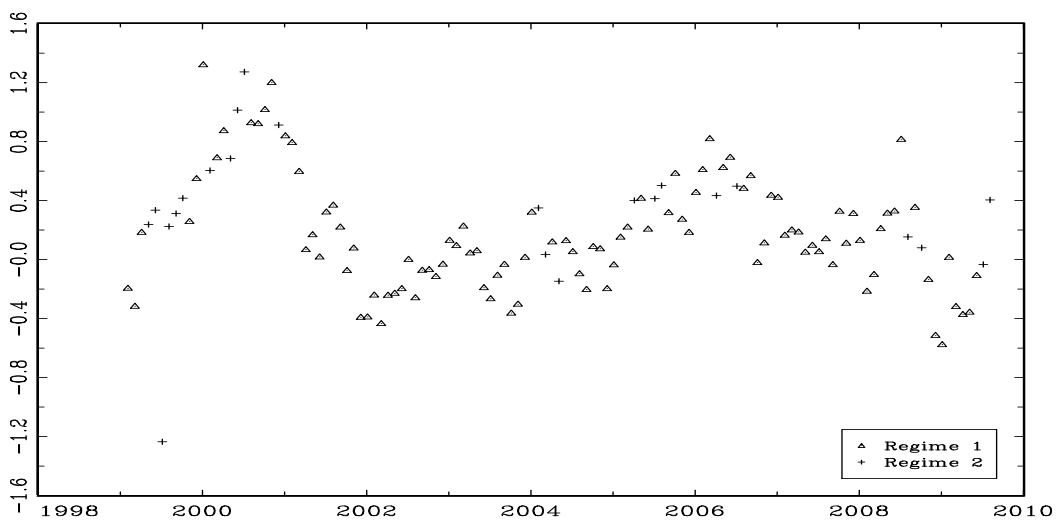
### Part 4: Ireland



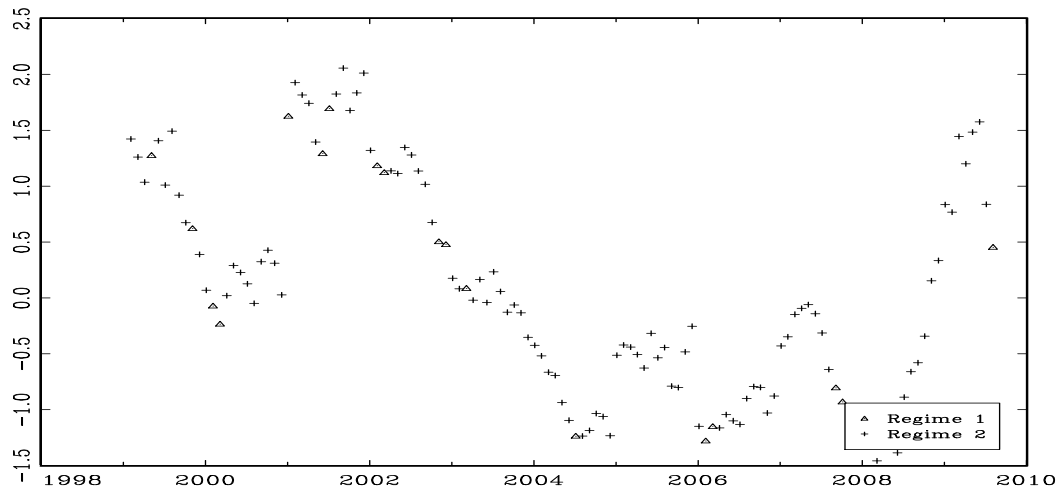
### Part 5: Italy



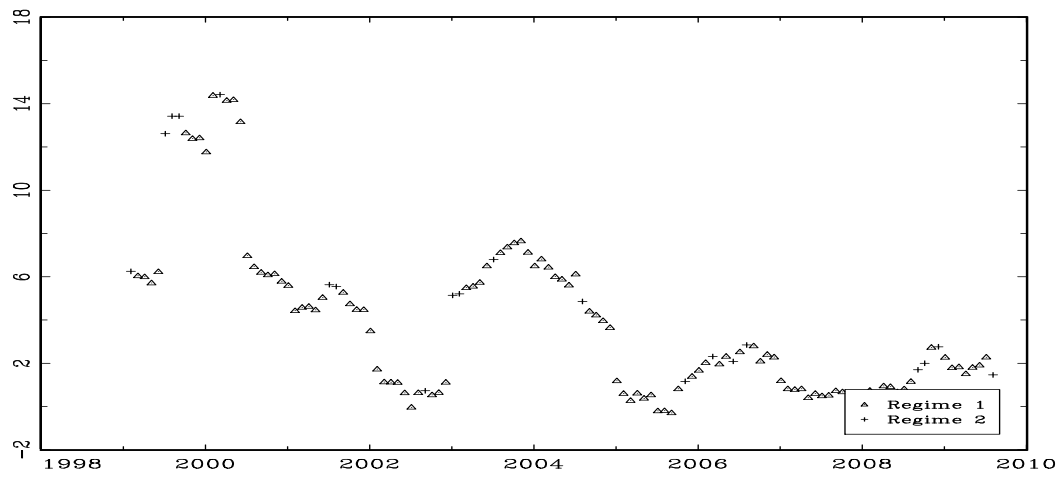
### Part 6: Luxembourg



### Part 7: Netherlands



### Part 8: Slovakia



### Part 9: Spain

