

Testing for two-regime threshold cointegration in the parallel and official markets for  
foreign currency in Greece

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**Abstract**

This paper models the short-run as well as the long-run relationship between the parallel and official markets for US dollars in Greece in a threshold VECM framework. Modeling exchange rates within this context can be motivated by the fact that the transition mechanism is controlled by the parallel market premium. The results show that linearity is rejected in favour of a TVECM specification, which forms statistically an adequate representation of the data. Two regimes are implied by the model; the “typical” regime, which applies most of the time and the “unusual” one associated with economic and political events that took place in Greece during the 1980s. Another implication is that in the parallel exchange rate there are strong asymmetries between the two regimes in the speed of adjustment to the long-run equilibrium. Finally, Granger causality runs from the official to the parallel market in both regimes but not vice versa.

**Keywords:** Parallel market premium, nonlinearity, threshold cointegration, regime switching, vector error correction models

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## **1. Introduction**

During the last decade a growing literature has emerged in an attempt to study the importance of the existence of a “parallel” market for foreign currency in one country or in a group of countries. Parallel currency markets, especially for US dollars, are widespread in a number of countries or regions as a result of direct and indirect government intervention in the foreign exchange market. When access to the official exchange market is limited and there are various foreign exchange controls on international transactions on goods, services and assets, then those who need foreign exchange and are not able to obtain all they desire from official sources have an incentive to find an alternative source whereas those having an excess of foreign exchange prefer to sell it at a price higher than the official rate. The size of this market varies from country to country and depends on the type of exchange and trade restrictions imposed and the degree to which these restrictions are enforced by the authorities (for a general overview of the theory of parallel currencies market see Agenor, 1992; Montiel, Agenor and Haque, 1993; and Phylaktis, 1996). Furthermore, it has been made clear that the existence of such markets has important economic and welfare implications, whereas their impact may appear to be substantially important in countries with sustained high inflation or in countries in which the official exchange rate is used as a policy instrument. Thus, in high inflation economies with increased uncertainty, the operation of a parallel market satisfies the excess demand for foreign currency given that economic agents use increased holdings of foreign currency as an efficient mean for hedging against domestic inflation. Thus, a large number of papers have provided important evidence for the

workings of such a market in Latin America, in the Pacific basin countries, in Africa, in Greece and other less developed countries.<sup>1</sup>

A parallel market for US dollars existed in Greece since World War II until the early 1990s. Its size has been considerable with the premium being on average 15%. However, Greece's joining of the EEC in 1981 eventually led to the adoption of specific policies that aimed to the abolition of all trade and foreign exchange controls, i.e. a distinct shift in the policy concerning these measures. In particular with respect to the controls on capital flows, the implementation of the financial liberalization process that took place in January 1986 coupled with the complete restructuring of the financial and banking sector has gradually led to the elimination of the black market for dollars by the end of 1993. Kouretas and Zarangas (1998, 2001a,b) and Kanas and Kouretas (2001a,b) have provided extensive evidence about the operation of the parallel market for dollars in Greece by adopting the portfolio balance and the monetary approach to the exchange rate determination. Specifically, with the application of cointegration analysis they provide substantial evidence in favour of the existence of a stable *linear* long-run relationship between the official and parallel exchange rates as well as support for the purchasing power parity and the monetary model as valid frameworks to analyze movements of either exchange rate.

The purpose of this paper is to provide further insights in the short-run dynamics of the parallel and official of the Greek drachma-US dollars exchange rates during the period April 1975 to December 1993. Although this market has ceased to exist its study

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<sup>1</sup> Although, such a market is commonly called "black" instead of "parallel" it is often more appropriate to use the latter rather than the former since as Dornbusch et al. (1983, p. 26) point out with the term "parallel market" we denote a type of "...intermediate position of legality in that it is illegal but also conspicuously public and, it would appear, officially tolerated".

can still provide several important policy lessons as to the type of distortions that capital controls create, the difference of speed of adjustment of the two rates to the long-run equilibrium as well as their causal relationship and the possibility of the introduction of nonlinearities that events like devaluations, exchange rate regime switches and political instability in the relationship between the two rates may cause. Furthermore, we can draw conclusions on the impact that financial liberalization can have on the workings of the foreign exchange market and therefore to economic development. As in Kouretas and Zarangas (2001b), the portfolio balance asset market theory (Dornbusch *et al.* 1983; Phylaktis, 1992) is the theoretical framework that drives the parallel market while the current account affects the parallel rate through its impact on the stock of parallel market dollars. An important implication of the portfolio balance models is that under the assumption of a fixed stock of parallel foreign currency in the short run, the parallel market premium follows saddle path behaviour. As Moore and Phylaktis (2000) show, this implies that following surprise devaluation the contemporaneous impact of the short-run official rate on the parallel rate is less than proportional, i.e., the premium declines. Given that in Kouretas and Zarangas (2001b) a *linear* cointegrating relationship between the official and parallel exchange rates has been established in this paper we study the short-run dynamics of the two rates by providing tests for linear against nonlinear adjustment of the error correction model by considering alternative non-linear functional forms of the disequilibrium error.

There is a good economic reasoning for considering the possibility of a non-linear rather than a linear type of adjustment to the long-run equilibrium. Non-linear adjustment allows for the parallel exchange rate to adjust in a different way to positive or

negative and to large or small deviations from its long-run equilibrium level. Furthermore, the motivation to model exchange rates in Greece within a non-linear framework lies on the fact that during the period under examination we have observed a transition from direct official intervention in the foreign-exchange market to a fully liberalized financial environment. Thus, if we assume that the transition mechanism is dictated by the parallel market premium, following a discrete devaluation or other abrupt events of economic or political nature then we can differentiate between the impact of the parallel market premium on both exchange rates during periods when the premium is positive and on the impact on these exchange rates when the premium is negative.

We model non-linearities in the parallel market premium by adopting the threshold cointegration approach put forward by Balke and Forby (1997) that allows the combination of non-linearity and cointegration, hence allowing for non-linear adjustment to the long-run equilibrium. The most important statistical implication for this class of models is testing for the presence of a threshold effect (the null of linearity) and therefore this approach has a number of appealing features and it has generated significant applied interest. Thus, several recent papers, Balke and Wohar (1998); Baum et al. (2001); Baum and Karasulu (1998); Enders and Falk (1998); Hansen and Seo (2002); Lo and Zivot (2001); Martens et al. (1998); Michael et al. (1997); O'Connell (1998) and Tsay (1998) among others, have presented evidence revealing threshold-type nonlinearities in real exchange rates, in the term structure, in purchasing power parity doctrine and the law of one price, in covered interest parity as well as in modeling interest rate policy. Balke and Forby (1997) test for threshold cointegration in a univariate setting while Lo and Zivot (2001) extend their approach to a multivariate threshold cointegration with a known

cointegrating vector. However, to conduct our analysis we adopt the recently developed extension of the above models proposed by Hansen and Seo (2002). This approach tests for two-regime threshold cointegration and it considers a vector error-correction model (VECM) with one cointegrating vector and a threshold effect based on the error-correction term. Furthermore, the estimates and the tests of this approach are for the complete multivariate threshold model as opposed to Balke and Forby (1997) univariate methodology.

The main findings of the paper are summarized as follows. First, there is strong evidence in favour of threshold-type of nonlinearities in the parallel market premium implying that the adjustment to equilibrium can be described better in a nonlinear form than in a linear one. Second, the estimation of the two-regime threshold VECM model accurately describes the two regimes based on the different pattern of adjustment of the premium when this takes positive or negative values and finally the estimated model captures all the events that are responsible for the presence of nonlinear features in the premium such as the joining of EEC, the two discrete devaluations in 1983 and 1985, the financial liberalization process in the late 1980s and the political instability followed the failure of the stabilization programme of 1985-1987.

The rest of the paper is organized as follows. Section 2 discusses the evolution of the parallel market for US dollars in Greece. Section 3 presents the econometric methodology. Section 4 presents and discusses the empirical results. Section 5 concludes the paper.

## **2. The Parallel Market for Foreign Currency in Greece**

Following the accumulation of an enormous government budget deficit and the financing of the German occupation troops through loans, which eventually led to a 3 year period of sustained hyperinflation (1945-1948) in Greece, a parallel market for US dollars has emerged and operated continuously since the end of World War II. Coupled with unstable political and social conditions, this monetary situation led the people to lose confidence in the national currency and most of the transactions were made in US dollars or in gold sovereigns. This situation continued even after the implementation of the major reconstruction plan in the 1950s, which had as a distinct feature the devaluation of the drachma by 100 percent against the dollar.

Following the collapse of the Bretton-Woods agreement and the establishment of a system of flexible exchange rates in international transactions, Greece has allowed the Greek drachma to float against major currencies since April 1975. The link to the US dollar was abandoned and a variable trade-weighted system was adopted, where the US dollar had the greatest weight. Greece's joining of the European Economic Community in 1981 led the Bank of Greece to adjust the trade-weighted system and place a greater weight on the Deutschemark and other European currencies and smaller weight on the dollar. However, the movement to the managed float was accompanied by the imposition of trade and foreign exchange restrictions thus the official exchange rate was not purely market-determined but was still rather administratively determined. Therefore, the parallel market for dollars which developed after World War II was still very much in effect, undermining these restrictions while smuggling of goods was taking place. The two oil price shocks, the chronic high inflation and corresponding current account deficits

gave a new momentum to the activities in the parallel market for US dollars during the second half of the 1970s and the first half of the 1980s. By 1984 the size of the market was substantial and, according to the estimates by Pavlopoulos (1987), the annual volume of transactions was approaching 400 million US dollars. Figure 1 shows the evolution of the parallel and official drachma-dollar exchange rates from 1975 to 1993, while Figure 2 shows the evolution of the parallel market premium for the same period. The premium is positive apart from short periods in the second half of the 1980s when it turned to a discount. During that period there were two discrete devaluations of the drachma, which were implemented in January 1983 and October 1995 and each one was equal to 15%. The negative premium is explained by the fact that for some periods after 1985 the Bank of Greece forced the commercial banks not to accept foreign currency without proper identification of the source of the foreign currency. In that case the seller was willing to undersell his foreign currency in the black market. In addition, the case of a negative premium after the second devaluation may also be explained by the likelihood that the parallel market agents were expecting a higher percentage of devaluation of the drachma than the realized one, which led to selling dollars at a discount. In January 1986 a liberalization process for capital flows began which was completed in May 1994 when all capital controls on short-term capital were lifted, which led to the virtual elimination of the market by the end of 1993 (Papaioannou and Gatzonas, 1997).

### **3. Econometric Methodology**

A natural approach to modeling economic variables appears to be the definition of different states of the world or regimes, and to allow for the likelihood that the dynamic



behaviour of economic variables depend on the regime that occurs at any given point in time. Recently, two main classes of regime-switching models have been proposed in the literature. The first class of models is the Markov-switching models, originally employed in the business cycle context by Hamilton (1989), which assumes that the regime cannot actually be observed but is determined by an underlying stochastic process. This implies that one can never be certain that a particular regime has occurred at a particular point in time, but can only assign probabilities to the occurrence of the different regimes. These models have been explored and extended in Markov-Switching Vector Error Correction (MS-VECM) models (Krolzig, 1997).

The second approach considers modeling explicitly the regime as a continuous function of an observable variable as in threshold autoregressive (TAR) models, initially proposed by Tong and Lim (1980)<sup>2</sup>. Consequently, the regimes that have occurred in the past and present are known with certainty (though they have to be found by statistical techniques). Therefore, within the context of this paper the TAR models have an advantage over the Markov switching models because we mainly focus on the exploration of the nature of the underlying regimes. Modeling exchange rates within the threshold context can be motivated by the fact that the transition mechanism is controlled by the parallel market premium. For example, we can differentiate between the impact of the parallel market premium on the exchange rates during periods when the premium is positive and large, as access to the official foreign exchange market is limited and its impact on exchange rates during which the premium is small. Therefore, in this paper, we employ the recently developed by Hansen and Seo (2002) multivariate threshold

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<sup>2</sup> Subsequently developed in Tsay (1989) and Tong (1990). Lo and Zivot (2001) provide a detailed of the threshold cointegration literature while Granger (2001) provides an overview of nonlinear macroeconomic models.

cointegration approach which has the advantage that unlike Balke and Forby (1997) and all other TAR models that provide MLE estimations for the complete bivariate model.

Given this, we now address several issues related to the definition and properties of threshold Vector Error Correction Models (TVECM). Let  $x_t = (e_{p,t}, e_{o,t})'$  be a 2-dimensional  $I(1)$  time series, where  $e_{p,t}$  and  $e_{o,t}$  refer to the logarithm of the exchange rate in the parallel and official markets for US dollars, respectively. It is assumed that there exists a long-run relationship between these time series with a cointegrating scalar of  $\beta$ . A linear VECM of order  $l + 1$  is of the form

$$\Delta x_t = A' X_{t-1} + u_t \quad (1)$$

where

$$X_{t-1} = \begin{pmatrix} 1 \\ w_{t-1} \\ \Delta x_{t-1} \\ \Delta x_{t-2} \\ \vdots \\ \Delta x_{t-l} \end{pmatrix}$$

where  $\Delta$  is the first order difference operator, the regressor  $X_{t-1}$  is  $k \times 1$  and  $A$  is  $k \times 2$  where  $k = 2l + 4$ . The error  $u_t$  is assumed to be a  $(2 \times 1)$  vector martingale difference sequence (MDS) with finite covariance matrix  $\Sigma = E(u_t u_t')$ . Note that  $w_{t-1} = e_{p,t-1} - \beta e_{o,t-1}$  is the error correction term. Setting  $\beta = 1$  the  $I(0)$  error correction term is the parallel

market premium in percentage terms. The parameters  $(A, \Sigma)$  are estimated by maximum likelihood under the assumption that the errors  $u_t$  are *iid* Gaussian.

Following Hansen and Seo (2002), consider now an extension of model (1), given by

$$\Delta x_t = \begin{cases} A'_1 X_{t-1} + u_t, & \text{if } w_{t-1} \leq \gamma \\ A'_2 X_{t-1} + u_t, & \text{if } w_{t-1} > \gamma \end{cases}$$

where  $\gamma$  is the threshold parameter. This may alternatively be written as

$$\Delta x_t = A'_1 X_{t-1} d_{1t}(\gamma) + A'_2 X_{t-1} d_{2t}(\gamma) + u_t \quad (2)$$

where

$$d_{1t}(\gamma) = I(w_{t-1} \leq \gamma)$$

$$d_{2t}(\gamma) = I(w_{t-1} > \gamma)$$

where  $I(\cdot)$  denotes the indicator function.

The model given by (2) is a two-regime Threshold VECM. Values of the threshold variable  $w_{t-1}$  (e.g. the parallel market premium) below or above the threshold parameter  $\gamma$  allow the coefficients to switch between these two regimes. In principle, the threshold variable can also be a function of a linear time trend, which gives rise to a model with changing parameters over time. Equation (2) may be written as follows

$$\Delta x_t = A(w_{t-1})X_{t-1} + u_t$$

where  $A(w_{t-1}) = A_1 d_{1t}(\gamma) + A_2 d_{2t}(\gamma)$ . It is seen that the TVECM may also be interpreted as a linear VECM with time-varying parameters. Differently, the TVECM can be seen as an alternative approach to assessing structural stability of the parameters of the linear VECM.

Hansen and Seo (2002) propose an algorithm to estimate the TVECM by Maximum Likelihood, under the assumption that the errors  $u_t$  are *iid* Gaussian. The Gaussian likelihood is

$$L_n(A_1, A_2, \Sigma, \gamma) = -\frac{n}{2} \log |\Sigma| - \frac{1}{2} \sum_{t=1}^n u_t(A_1, A_2, \gamma)' \Sigma^{-1} u_t(A_1, A_2, \gamma) \quad (3)$$

where

$$u_t(A_1, A_2, \gamma) = \Delta x_t - A_1' X_{t-1} d_{1t}(\gamma) - A_2' X_{t-1} d_{2t}(\gamma)$$

In order to maximize the log-likelihood, Hansen and Seo (2002) suggest, first, to hold  $\gamma$  fixed and compute the constrained *MLE* for  $(A_1, A_2, \Sigma)$ . This is just *OLS* regression

$$\hat{A}_1(\gamma) = \left( \sum_{t=1}^n X_{t-1} X_{t-1}' d_{1t}(\gamma) \right)^{-1} \left( \sum_{t=1}^n X_{t-1} \Delta x_t' d_{1t}(\gamma) \right) \quad (4)$$

$$\hat{A}_2(\gamma) = \left( \sum_{t=1}^n X_{t-1} X_{t-1}' d_{2t}(\gamma) \right)^{-1} \left( \sum_{t=1}^n X_{t-1} \Delta x_t' d_{2t}(\gamma) \right) \quad (5)$$

$$\hat{u}_t(\gamma) = u_t(A'_1(\gamma), A'_2(\gamma), \gamma)$$

and

$$\hat{\Sigma}(\gamma) = \frac{1}{n} \sum_{t=1}^n \hat{u}_t(\gamma) \hat{u}'_t(\gamma) \quad (6)$$

Note that (4) and (5) are the *OLS* regressions of  $\Delta x_t$  on  $X_{t-1}$  for the sub-samples for which  $w_{t-1} \leq \gamma$  and  $w_{t-1} > \gamma$ , respectively.

Once the estimates of  $(A_1, A_2, \Sigma)$  are obtained, in a second stage, the *MLE* of  $\gamma$  is the minimizer of  $\log |\hat{\Sigma}(\gamma)|$  subject to the constraint ensuring that

$$\pi_0 \leq P(w_{t-1} \leq \gamma) \leq 1 - \pi_0$$

where  $\pi_0 > 0$  is a trimming parameter. For the empirical distribution of  $w_{t-1}$ , we set  $\pi_0 = 0.05$ . Specifically, a grid search is carried out using 300 equally spaced values of  $\gamma$  within the observed range of the parallel market premium. This procedure guarantees that the values of the Indicator function contain enough sample variation for each choice of  $\gamma$ . The model with the lowest value of  $\log |\hat{\Sigma}(\gamma)|$  from the grid search procedure is used to provide the estimate of  $\gamma$ .

Granger (1993) strongly recommends a specific-to-general strategy for building non-linear time series models. This implies starting with a simple or restricted model and proceeding to more complicated ones only if the diagnostics indicate that the maintained model is inadequate. In the present situation, an additional (statistical) motivation for

adopting such an approach is that the identification problem under the null hypothesis of linearity, which prevent us from starting with a full TVECM and reducing its size. It can be seen from equation (2) that a linear VECM is nested in the TVECM. Thus, an important first step in practical model-building would consist of testing for linearity before actually applying the more complicated threshold model. This is also because if a linear model would suffice there would be more statistical theory available for building a reasonable model than if a non-linear model was appropriate.

To assess the evidence for threshold VECM, linearity is tested by employing the Lagrange multiplier (*SupLM*) test developed by Hansen and Seo (2002). The LM statistic employed is

$$SupLM = \sup_{\gamma_L \leq \gamma \leq \gamma_U} LM(\gamma) \quad (7)$$

For this test, the search region  $[\gamma_L, \gamma_U]$  is set so that  $\gamma_L$  is the  $\pi_0 = 0.05$  percentile of the parallel market premium and  $\gamma_U$  is the  $1 - \pi_0 = 0.95$  percentile. Under the null hypothesis, there is no threshold, so the model reduces to the conventional linear VECM. As the function  $LM(\gamma)$  is non-differentiable in  $\gamma$ , the maximization of (5) is obtained though a grid evaluation over  $[\gamma_L, \gamma_U]$ .

Given that asymptotic critical values of the sampling distribution of the *SupLM* statistic cannot in general be tabulated, a residual bootstrap algorithm as well as a fixed-regressor experiment (where the regressors used in the bootstrapping exercise are held fixed at their sample values) are performed. As pointed by Hansen and Seo (2002), an advantage of the second method is that it allows for heteroskedasticity of unknown form in much the same way as White's, (1980) heteroskedasticity-consistent standard errors.

#### 4. Empirical Results

We examine end-of-month official and black-market exchange rate quotations for the bilateral exchange rate of the Greek drachma relative to the US dollar for the period April 1975, when Greece adopted a floating exchange rate system to December 1993. Official exchange rate series are obtained from the CD-ROM of the International Monetary Fund's International Financial Statistics while the parallel exchange rate data are obtained from the *World Currency Yearbook*. Both series are taken in natural logarithms.

In order to avoid the problem of non-stationarity, which is a well known feature of the exchange rate series, it is necessary to make use of first- (or higher) differentiated data. To examine, whether the exchange rate series are stationary, we apply alternative unit root and stationarity tests. The first test is the standard augmented Dickey-Fuller test for the null hypothesis of a unit root against the alternative of stationarity of the exchange rate series. We then apply the more powerful DF-DLS<sub>u</sub> proposed by Elliott (1999). This test is an adaptation of the DF-GLS test constructed by Elliott *et al.* (1996) for the case where the initial observation is drawn from its unconditional distribution under the alternative hypothesis. Finally we apply the Kwiatkowski *et al.* (1992) KPSS test for the null hypothesis of level or trend stationarity against the alternative of non-stationarity. The results of the unit root and stationarity tests are presented in Table 1. The results show that we are unable to reject the null hypothesis of non-stationarity with the ADF and DF-GLS<sub>u</sub> tests and we reject the null hypothesis of stationarity with the KPSS test for the levels of both series. The results are reversed when we take the first difference of each exchange rate series which leads us to the conclusion that the official and black

drachma/dollar exchange rates are realizations of  $I(1)$  processes. Given the results of this preliminary analysis we will subsequently only consider the first difference for each exchange rate,  $\Delta e_t = 100 * (e_t - e_{t-1})$  which corresponds to the approximate percentage nominal return on each currency obtained from time  $t$  to  $t-1$ .

Table 2 reports several preliminary statistics for monthly percentage changes in the official and parallel exchange rates. The skewness and kurtosis measures indicate that both series are positively skewed and highly leptokurtic relative to the normal distribution.<sup>3</sup> Furthermore, the Kolmogorov D-statistic as well the Bera-Jarque normality test rejects the assumption of normality. Rejection of normality can be partially attributed to intertemporal dependencies in the moments of the series. Table 2 also presents the Ljung-Box portmanteau test statistics  $Q$  and  $Q^2$  (for the squared data) to test for first- and second-moment dependencies in the distribution of the exchange rate series. The  $Q$  statistic indicates that percentage monthly returns of both rates are serial correlated. The  $Q^2$  statistic for the official and parallel exchange rate is significant, providing evidence of strong second-moment dependencies (conditional heteroskedasticity) in the distribution of the exchange rate series. Finally, the standard deviation indicates that there is greater variance of exchange rate returns in the black market than in the official market. As Peel and Speight (1997) point out the presence of non-normality as well as of intertemporal dependencies are also consistent with non-linearities in the evolution of each exchange rate series and their difference which is the parallel market premium.

To address the issue of linear or non-linear adjustment to the long-run equilibrium we first estimate and test a linear VECM model allowing for a maximum lag length

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<sup>3</sup> The leptokurticity is more evident for the parallel rate.



$l = 3$ , although we settled down on  $l = 2$  since the third-order lags are not statistically significant. The estimates of the linear model are given in Table 3. It is important to note that the linear model has a statistically significant error correction term in the parallel exchange rate equation but minimal dynamics of either  $\Delta e_p$  and  $\Delta e_o$ , while in the equation of the official exchange rate has negligible error-correction effects and statistically insignificant dynamics.

The next step of our analysis is to test the hypothesis of linearity against threshold-type of non-linearity with the application of the *SupLM* test given by (7), for the complete bivariate specification. The  $p$ -values were calculated using both the fixed-regressor and a residual bootstrap experiment with 10000 simulation replications. Table 3 reports the results, which show support for the threshold cointegration hypothesis;  $p$ -values are 0.053 and 0.055 for the fixed regressor and residual bootstraps, respectively, and this provides strong statistical evidence of threshold-type nonlinearity.

Table 3 also reports the estimated Threshold VECM given by (2). Based on the *AIC* and *BIC* criteria we select a lag length  $l = 2$  for the TVECM model. Furthermore, we consider both fixing the cointegrating vector ( $\beta = 1$ ) as well as letting  $\hat{\beta}$  be estimated.<sup>4</sup> The estimated threshold  $\hat{\gamma}$  equals 0.115. This implies that the first regime

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<sup>4</sup> The first step of our analysis should have been a test for the presence of linear cointegration between the two exchange rates. However, Kouretas and Zarangas (2001b) using the Johansen's methodology for the same set of data and found one cointegrating vector between the two exchange rates with estimated  $\beta = 1$ . For this reason we focus our analysis on the estimated model setting  $\beta = 1$ , although the model with estimated  $\hat{\beta}$  provides similar results, which are available upon request. For robustness, we have also estimated a TVECM with  $l = 3$  obtaining similar coefficient estimates and test results although the third-order lags were not statistically significant. To save space we do not report them here but they are available upon request.

occurs when  $e_p \leq e_o + 0.115$ , i.e. when the parallel market exchange rate is less than 11.5 percentage above the official exchange rate. This case accounts for 93% of the observations and is called the “typical regime”. The second regime is when  $e_p > e_o + 0.115$ , i.e. when the parallel exchange rate is more than 11.5 percentage above the official exchange rate. This case applies only to 7% of the observations of the sample, and we call it the “unusual” or the “extreme” regime.

In the typical regime,  $\Delta e_p$  has statistically significant error-correction effects but minimal dynamics while  $\Delta e_o$  appears to have significant dynamics. Furthermore,  $\Delta e_o$  appears to have statistically insignificant error-corrections effects and dynamics. In the unusual regime asymmetry is implied in the sense that there is an even stronger error-correction effect in the parallel exchange rate equation with almost all dynamic coefficients being statistically significant. Once again the equation for the official exchange rate produces statistical insignificant dynamics and negligible error-correction effects. Clearly this implies that there is no short-run Granger causality running from the parallel market to the official market, but from the above seems that the official market Granger causes the parallel one in the short-run. This finding was not obvious in the linear VECM, but only comes up when we take account of the nonlinearity in the underlying processes.

Additionally, it is interesting to note that according to the diagnostics given in the lower panel of Table 3, the evidence of nonlinearity appears to be strengthn since the null hypothesis of equality of the coefficients on the error correction terms and of the dynamic coefficients across the two regimes is highly rejected.

An important finding of the estimated TVECM models is that the error correction term for the parallel exchange rate is negative and this result is consistent with the portfolio balance models. Specifically, this implies that it is the parallel market rate that adjusts to any short-run deviations from the long-run equilibrium. Moreover, the negative sign implies that if the parallel market premium is above its equilibrium level, the parallel market declines rate declines. This is what we would expect when the parallel market rate overshoots its long-run equilibrium as it is predicted by the portfolio balance models (Moore and Phylaktis, 2000). Finally, another interesting implication of a statistically significant error-correction term in the equation of the parallel exchange rate but not in the one of the official rate (in either regime) is that the official rate Granger causes the parallel exchange rate, implying that the one-period-lagged value of the official rate can be used to help forecast the current values of the parallel market rate.

Table 4 provides an estimated regime classification according to the TVECM; typical regime (regime 0) and unusual regime (regime 1), while Figure 3 provides a graphical illustration of these regimes. It is very interesting that our estimated Threshold VECM has classified the two regimes extremely well since the extreme regime captures all the important economic and political events of the 1980s which are considered to be the main source of non-linearities in the relationship between the two exchanges rates. Thus, the first significant change of regime occurs as a result of the Greece's joining the EEC in January 1981 resulting to a shift in the exchange rate policy followed by the Bank of Greece, which adjusted the trade-weighted system by placing greater weight on the Deutschemark and other European countries and lesser weight to the US dollar. The next important event is the devaluation of the drachma against the dollar that took place in

January 1983 and this is also captured by our model and is placed again in regime 1 (the extreme case). The same occurs with the devaluation of October 1985, which is again captured by regime 1. Finally, two other important events are also classified in the unusual regime. These are the implementation of the financial liberalization process which started in January 1986 and the economic and political instability that began in Greece in the mid-1988 and it was the outcome of the failure of the stabilization programme of 1985-1987 and the consequent expectations of the economic agents for another devaluation of the drachma coupled with a loosening of the fiscal policy and the subsequent increase of the country's external debt to partly to finance government expenditures as a result of the forthcoming elections of 1989.

## **5. Conclusions**

In this paper we model threshold nonlinearity in the parallel and official markets for foreign currency in Greece during the period April 1975 to December 1993 using monthly data. The main findings of our analysis can be summarized as follows. First, we estimated a threshold VECM for the relationship between the parallel and official exchange rate markets for US dollars in Greece. The results show that linearity is rejected in favour of threshold-type nonlinearity and the estimated two-regime TVECM forms statistically an adequate representation of the data with distinct regimes. The regime classification tells us that the "typical" regime concerns 93% of the sample with the "unusual" one associated with the economic and political events that took place in Greece during the 1980s. Error-correction effect appears only in the parallel rate in both linear and threshold VECM but the threshold model uncovers strong asymmetries in that the

speed of adjustment to the long-run equilibrium is higher in the “unusual” regime than in the “typical” one. Another implication is that Granger causality in the short-run as well as in the long-run runs from the official to the parallel market in both regimes but not vice versa. The finding concerning the short-run Granger causality from the official to the parallel market is not obvious in the linear VECM.

## References

- Agenor, P. R., 1992, Parallel currency markets in developing countries: theory, evidence and policy implications, *Essays in International Finance*, 188, Princeton University.
- Balke, N.S. and T.B. Forby, 1997, Threshold cointegration, *International Economic Review*, 38, 627-645.
- Balke, N.S. and M.E. Wohar, 1998, Nonlinear dynamics and covered interest rate parity, *Empirical Economics*, 23, 535-559.
- Baum, C.F., and M. Karasulu, 1998, Modelling federal reserve discount policy, *Computational Economics*, 11, 53-70.
- Baum, C.F., J.T. Barkoulas and M. Caglayan, 2001, Nonlinear adjustment to purchasing power parity in the post-Bretton Woods era, *Journal of International Money and Finance*, 20, 379-399.
- Dornbusch, R., Dantas, D.V., Pechman, C., Rocha, R.R. and D. Simoes, 1983, The black market for dollars in Brazil, *Quarterly Journal of Economics*, 98, 25-40.
- Elliott, G., 1999, Efficient tests for a unit root when the initial observation is drawn from its unconditional distribution, *International Economic Review*, 44, 767-784.
- Elliott, G., J.T. Rothenberg and J.H. Stock, 1996, Efficient tests for an autoregressive unit root, *Econometrica*, 64, 813-836.
- Enders, W. and B. Falk, 1998, Threshold-autoregressive, median-unbiased and cointegration tests of purchasing power parity, *International Journal of Forecasting*, 14, 171-186.
- Granger C.W.J., 1993, Strategies for modeling non-linear time series relationships, *The Economic Record*, 69, 233-238.
- Granger, C.W.J., 2001, An overview of nonlinear macroeconomic empirical models, *Macroeconomic Dynamics*, 5, 466-481.
- Hansen, B.E. and B. Seo, 2002, Testing for two-regime threshold cointegration in vector error-correction models, *Journal of Econometrics*, 110, 293-318.
- Hamilton J., 1989, A new approach to the economic analysis of nonstationary time series and the business cycle, *Econometrica*, 57, 357-384.

Kanas, A. and G.P. Kouretas, 2001a, Black and official exchange rate volatility and foreign exchange controls: Evidence from Greece, *International Journal of Finance and Economics*, 6, 13-25.

Kanas, A. and G.P. Kouretas, 2001b, Volatility spillovers between the black and official market for foreign currency in Greece, *Journal of Financial Research*, 24, 443-461.

Krolzig H.-M., 1997, *Markov-switching vector autoregression. Modelling, statistical inference and application to business cycle analysis*, Berlin: Springer.

Kouretas, G.P. and L. Zarangas, 1998, A cointegration analysis of the official and parallel exchange markets for dollars in Greece, *International Journal of Economics and Finance*, 3, 261-276.

Kouretas, G.P. and L. Zarangas, 2001a, Long-run purchasing power parity and structural change: The official and parallel foreign exchange markets for dollars in Greece, *International Economic Journal*, 15, 109-128.

Kouretas, G.P. and L. Zarangas, 2001b, Black and official exchange rates in Greece: An analysis of their long-run dynamics, *Journal of Multinational Financial Management*, 11, 295-314.

Kwiatkowski, D., P.C.B. Phillips, P. Schmidt and Y. Shin, 1992, Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root?, *Journal of Econometrics*, 54, 159-178.

Lo, M. and E. Zivot, Threshold cointegration and nonlinear adjustment to the law of one price, *Macroeconomic Dynamics*, 5, 533-576.

Mackinnon, J.G., 1991, Critical values for cointegration tests, in R F. Engle and C.W.J. Granger (eds.). *Long-run Economic Relationships: Readings in Cointegration*, Oxford: Oxford University Press.

Mackinnon, J.G., 1996, Numerical distribution functions for unit root and cointegration tests, *Journal of Applied Econometrics*, 11, 601-618.

Martens, M., P. Kofman and T.C.F. Vorst, 1998, A threshold error-correction model for intraday futures and index returns, *Journal of Applied Econometrics*, 13, 245-263.

Michael, M., R. Nobay and D.A. Peel, 1997, Transactions costs and nonlinear adjustment in real exchange rates: an empirical investigation, *Journal of Political Economy*, 11, 862-879.

Montiel, P.J., Agenor, P.R. and Ul Haque, N., 1993, *Informal Financial Markets in Developing Countries: A Macroeconomic Analysis*, Oxford: Blackwell Publishers.

Moore, M.J. and K. Phylaktis, 2000, Black and official exchange rates in the Pacific Basin: Some tests of dynamic behaviour, *Applied Financial Economics*, 10, 361-369.

Ng, S. and P. Perron, 2001, Lag length selection and the construction of unit root tests with good size and power, *Econometrica*, 69, 1519-1554.

Newey W. and K. West, 1994, Automatic lag selection in covariance matrix estimation, *Review of Economic Studies*, 61, 631-653.

O'Connell, P.G.J., 1998, Market frictions and real exchange rates, *Journal of International Money and Finance*, 17, 71-95.

Papaioannou, M. and E.K. Gatzonas, 1997, Financial innovations involving the Greek drachma, *International Monetary Fund Working paper* 14, January.

Pavlopoulos, P., 1987, *The Underground Economy in Greece: A Quantitative Analysis*, Athens: Institute of Economic and Industrial Studies (in Greek).

Peel, D.A. and A.E.H. Speight, 1997, Non-linearities in East European black-market exchange rates, *International Journal of Economics and Finance*, 2, 39-57.

Phylaktis, K., 1992, The black market for dollars in Chile, *Journal of Development Economics*, 37, 155-172.

Phylaktis, K., 1996, Black market for foreign currency: A survey of theoretical and empirical issues, *Financial Markets, Institutions & Instruments*, 5, 102-124.

Sephton, P.S., 1995, Response surface estimates of the KPSS stationarity test, *Economics Letters*, 47, 255-261.

Tong H., 1990, *Nonlinear time series. A dynamic system approach*, Oxford: Oxford University Press.

Tong H., and K. S. Lim, 1980, Threshold autoregressions, limit cycles and data, *Journal of the Royal Statistical Society B*, 42, 242-292.

Tsay, R., 1989, Testing and modeling multivariate threshold models, *Journal of the American Statistical Association*, 84, 231-240.

White H. (1980), A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity, *Econometrica*, 48, 817-838.



**Table 1.** Unit root and stationarity tests

Variables	ADF t-tests		DF-GLS <sub>u</sub>		KPSS-tests	
	$t_{\mu}$	$t_{\tau}$	$t_{\mu}$	$t_{\tau}$	$\eta_{\mu}$	$\eta_{\tau}$
$e_o$	-0.471 [0]	-1.408 [0]	-0.465 [0]	-1.422 [0]	1.921*	0.262*
$\Delta e_o$	-4.387* [9]	-4.372* [9]	-4.385* [9]	-4.390* [9]	0.128	0.118
$e_p$	-0.507 [12]	-1.885 [12]	-0.429 [12]	-1.882 [12]	1.904*	0.162*
$\Delta e_p$	-5.983* [8]	-5.967* [8]	-7.745* [4]	-7.563* [4]	0.103	0.094

Notes:  $e_o$  and  $e_p$  are, respectively, the official and parallel exchange rate.

- $t_{\mu}$  and  $t_{\tau}$  are the standard augmented Dickey-Fuller test statistics when the relevant auxiliary regression contains a constant and a constant and a trend respectively. The number of lagged differenced terms required for serial correlation correction in the ADF auxiliary regressions is selected on the basis of a general to specific testing strategy which is terminated when a sequence of t-ratio elimination tests on the lagged differenced terms leads to a rejection at the 10% significance level and the residuals of the resultant specification satisfy standard misspecification testing (Ng and Perron, 2001). The selected lag order appears within square brackets underneath the statistics. The response surface regressions of MacKinnon (1991,1996) are used for determining the significance of the ADF test statistics. The 5% critical values are -2.87 and -3.43 for the case of an equation with only a constant and for an equation with a constant and trend respectively.
- $\eta_{\mu}$  and  $\eta_{\tau}$  are the KPSS test statistics for level and trend stationarity respectively (Kwiatkowski *et al*, 1992). For the computation of these statistics a Newey and West (1994) robust kernel estimate of the "long-run" variance is used. The kernel estimator is constructed using a quadratic spectral kernel with VAR(1) prewhitening and automatic data-dependent bandwidth selection [see, Newey and West, 1994 for details]. The asymptotic and finite sample critical values for these tests are taken from Table 2 in Sephton (1995). The 5% critical values for level and trend stationarity are 0.461 and 0.148 respectively
- The DF-GLS<sub>u</sub> by Elliott (1999) is a test with an unconditional alternative hypothesis. The critical values for the DF-GLS<sub>u</sub> test at the 1%,5% and 10% significance level are: -3.28, -2.73, -2.46 (with constant) and -3.71,-3.17, -2.91 (with constant and trend), respectively (Elliott,1999).

(\*) indicates significance at the 95% confidence level.

**Table 2.** Summary statistics on monthly exchange rate changes

Statistic	$\Delta e_o$	$\Delta e_p$
Mean	0.009	-0.009
Standard deviation	0.032	0.056
Skewness	1.38*	-0.40
Kurtosis	7.90*	17.63*
D-statistic	0.296*	0.258*
B-J	295.26	2781.47*
$Q(24)$	59.32*	50.87*
$Q^2(24)$	33.74*	93.27*

Notes:  $\Delta e_t = 100 * [\log e_t - \log e_{t-1}]$ ; D-statistic is the Kolmogorov-Smirnov statistic for the null of normality; B-J is the Bera-Jarque test for the null hypothesis of normality;  $Q(24)$  and  $Q^2(24)$  are the Ljung-Box test statistics for up to 24th-order serial correlation in the  $\Delta e_t$  and  $\Delta e_t^2$  series, respectively. An asterisk denotes statistical significance at the 5% critical level.

**Table 3.** Linear and threshold VECM for parallel exchange rate (*EP*) and official exchange rate (*EO*) for Greek drachma versus US dollar.

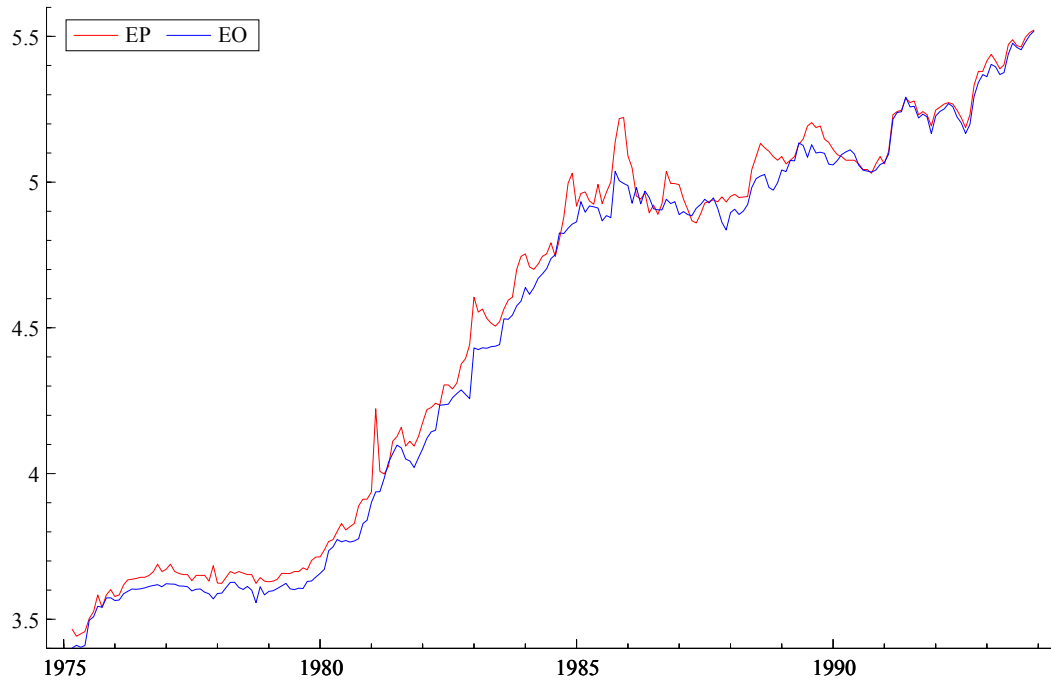
Variables	<u>Linear VECM</u>		<u>Threshold VECM</u>			
	$e_p$ model	$e_o$ model	<u>1<sup>st</sup> regime (93% obs)</u>		<u>2<sup>nd</sup> regime (7% obs)</u>	
			$e_p$ model	$e_o$ model	$e_p$ model	$e_o$ model
<i>Intercept</i>	0.018 (0.005) *	0.003 (0.003)	0.013 (0.004) *	0.002 (0.004)	0.241 (0.054) *	0.066 (0.066)
$w_{t-1}$	-0.251 (0.103) *	0.119 (0.073)	-0.151 (0.067) *	0.112 (0.073)	-1.836 (0.449) *	-0.226 (0.466)
$e_{p,t-1}$	-0.032 (0.129)	-0.008 (0.086)	0.005 (0.086)	-0.007 (0.099)	0.556 (0.227) *	0.132 (0.228)
$e_{p,t-2}$	-0.018 (0.070)	-0.063 (0.062)	-0.072 (0.057)	-0.059 (0.070)	0.646 (0.257) *	0.040 (0.160)
$e_{o,t-1}$	0.208 (0.134)	-0.005 (0.092)	0.281 (0.128) *	0.032 (0.098)	-0.704 (0.266) *	-0.354 (0.256)
$e_{o,t-2}$	0.166 (0.096)	0.103 (0.078)	0.212 (0.098) *	0.172 (0.084) *	-0.368 (0.350)	-0.265 (0.229)
<u>Linearity tests (<math>p</math>-values)</u>						
Fixed-regressor bootstrap				0.053**		
Residual bootstrap				0.055**		
<u>Threshold (estimate)</u>				0.115		
<u>Diagnostics (<math>p</math>-values)</u>						
Equality of parameters on error correction terms				0.004*		
Equality of dynamic parameters				0.000*		

*Notes:* Estimation period 1975:06 – 1993:12; values in parentheses are Eicker-White standard errors; diagnostic test results are presented as  $p$ -values; (\*) indicates significance level below 5 percent and (\*\*) indicates significance level below 10 percent respectively.

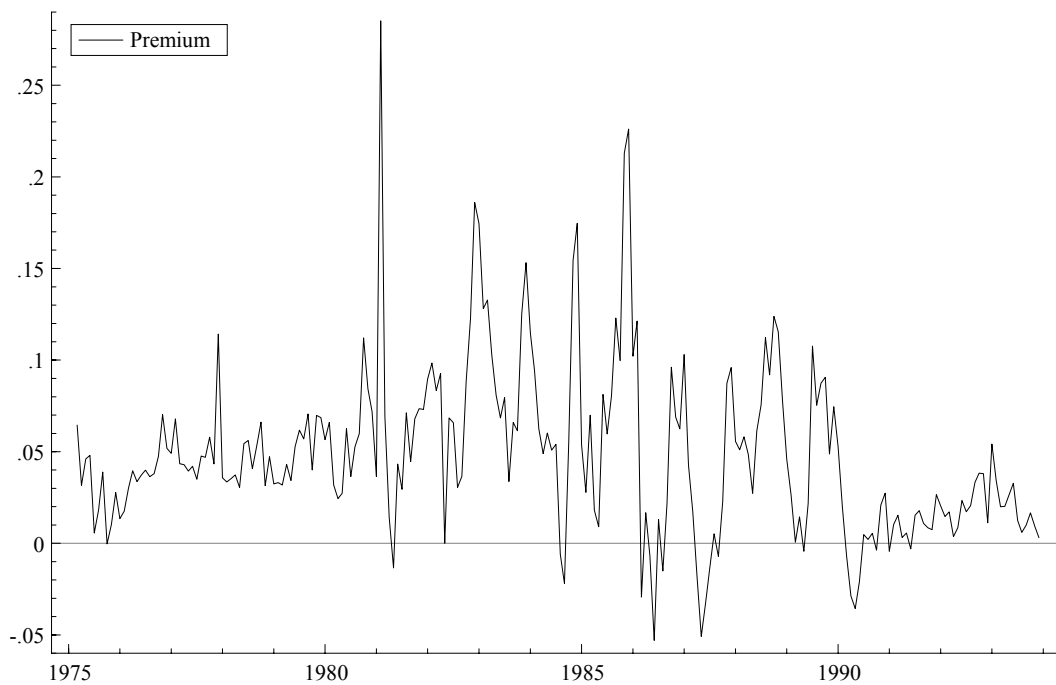
**Table 4.** Regime classification.

Period	Regime 0 or Regime 1
1975.06 – 1981.02	Regime 0
1981.03	Regime 1
1981.04 – 1982.11	Regime 0
1982.12 – 1983.04	Regime 1
1983.05 – 1983.11	Regime 0
1983.12 – 1984.01	Regime 1
1984.02 – 1984.11	Regime 0
1984.12 – 1985.01	Regime 1
1985.02 – 1985.09	Regime 0
1985.10	Regime 1
1985.11	Regime 0
1985.12 – 1986.01	Regime 1
1986.02	Regime 0
1986.03	Regime 1
1986.04 – 1988.10	Regime 0
1988.11 – 1988.12	Regime 1
1989.01 – 1993.12	Regime 0

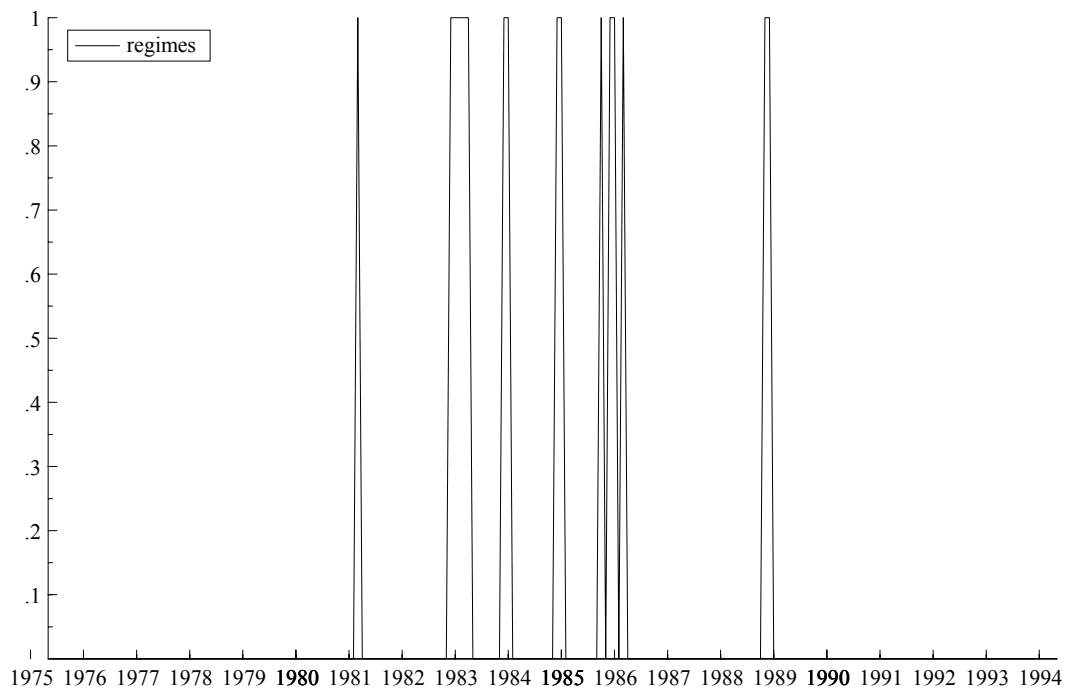
*Notes:* Regime chronology according to threshold VECM for parallel exchange rate ( $e_p$ ) and official exchange rate ( $e_o$ ) for Greek drachma versus US dollar.



**Fig. 1:** Time plot of parallel exchange rate ( $e_p$ ) and official exchange rate ( $e_o$ ) for Greek drachma versus US dollar (in logarithms).



**Fig. 2:** The time plot of the parallel market premium.



**Fig. 3:** Regime chronology.