**Debt sustainability, structural breaks and non-linear fiscal adjustment**

**A testing application to Greek fiscal policy**

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## Abstract

Non-linear public debt adjustment and structural breaks in fiscal policy may affect tests of public debt sustainability. Existing studies address these issues separately. No study has considered both. We address this gap by focusing on Greece, one of the most highly-indebted EMU countries. We find evidence of previously undetected non-linear fiscal adjustment; and two structural breaks in fiscal policy. Excluding these from the analysis, or allowing for non-linearities only, affects the nature of the empirical findings. Accounting for both, we find Greek public debt to be sustainable. This is in contrast to the findings of previous studies on Greece.

**Keywords:** Public debt; fiscal policy, sustainability; non-linear; structural breaks

**JEL Classification**: E60; F41; N10

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## 1. INTRODUCTION

Whether public debt is sustainable or not is an issue of significance. Sound public finances are thought to be favouring economic growth by contributing to price stability through minimizing inflationary seignorage; allowing reduction in distortion-causing taxation; and yielding investment-inducing low real interest rates. An unsustainable fiscal position implies that at some point in the future, the government will have to take corrective measures. Uncertainty about the timing and the form of these measures could harm economic growth by preventing optimal investment decisions. Institutional arrangements like the fiscal rules to which individual US state budgets are expected to adhere to, or the budget restrictions imposed on EMU members by the Budget and Stability Pact are based on such concerns.[1]

In recent years, a growing empirical literature testing the validity of the government's intertemporal budget constraint (IBC) has developed. Many papers conclude that the IBC is violated.[2] However, these findings may be due to biases in the testing procedure. First, public debt may present non-linear behaviour. This is related to Bohn's (1998) hypothesis that governments are likely to respond more vigorously to budget deficits when fiscal imbalances are large rather than small. Second, fiscal policy may be subject to structural breaks. Both factors may result in traditional tests of public debt sustainability being biased towards rejecting sustainability.

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[1] See the Resolution of the European Council on the Stability and Growth Pact, Amsterdam, 17th June 1997, and the joint European Commission-European Council Report to the Stockholm European Council of March 2001. For a recent discussion of fiscal rules in EMU, see, among others, Eichengreen and Wyplosz (1998) and Brunila et al (2001).

[2] The majority of these studies focus on the USA, for which Hamilton's and Flavin's initial contribution in 1986 was followed by the studies of Trehan and Walsh (1988, 1991), Kremers (1989), Wilcox (1989), Haug (1991), Ahmed and Rogers (1995), Quintos (1995), Bohn (1998) and Sarno (2001). Other studies include Corsetti and Roubini (1991) on OECD countries, Buiter and Patel (1992) on India, de Haan and Siermann (1993) on the Netherlands, and Makrydakis et al (1999) on Greece.

The existing literature has largely overlooked these issues. These are addressed by a handful of papers only. Non-linear fiscal adjustment is modelled by Bohn (1998) and Sarno (2001), whereas structural breaks are examined by Ahmed and Rogers (1995), Quintos (1995) and Makrydakis et al (1999). By addressing one of the two possible sources of bias, the findings of these papers are superior to those that address none. However, non-linear behaviour and structural breaks, can *individually* lead to false rejection of the sustainability hypothesis. By accounting only for one of the two, these papers do not remove the risk of bias altogether. To achieve this, non-linear adjustment and structural breaks must be modelled simultaneously. Up to now, such an analysis has not been carried out.

In this paper we address this gap by focusing on Greece, a heavily-indebted EMU country whose high debt-level has prompted the European Commission (2001, pp. 39-41) to consider special fiscal rules, different to those applying to the rest of the EMU countries, according to which Greece should "rigorously adhere" to the target of a structurally-balanced budget "at all times".[3] The extend of discussion, and the unusually direct language used in the Commission's Report, suggests that this is an issue of importance beyond the narrow Greek perspective, as it relates directly to the conduct of the single monetary policy on behalf of the European Central Bank.[4] The issue of sustainability recently returned to the forefront of public debate, in the light of the proposed reforms of the Budget Stability Pact. In this debate, which is currently ongoing, emphasis seems to shift from the level of government deficits to the level of public debt, particularly in relation to heavily indebted countries like Greece.

[3] Belgium and Italy are the other two EMU countries included in this proposal.
[4] For a detailed discussion on this point, see European Commission 2001 (pp. 109-201).

Public debt sustainability in Greece has previously been examined by Corsetti and Roubini (1991) and Makrydakis et al (1999), both of which found Greek public debt to be unsustainable. However, none of the two allowed for non-linear fiscal adjustment. Regarding structural breaks, Corsetti and Roubini did not consider them at all, whereas Makrydakis et al address them using the test of Zivot and Andrews (1992). This allows for a single break only, which Makrydakis et al find in 1978. But this single-break hypothesis may be invalid. Figure 1 presents the movements of the discounted debt-to-GDP series in Greece,[5] for the period 1970-2000.[6] The figure suggests fiscal stability in the 1970s, followed by a worsening of the fiscal outlook in the 1980s and a partial recovery in the 1990s. Therefore, Greek public debt may have been subject to multiple structural breaks and non-linear adjustment. This is precisely the kind of complex fiscal environment for which the existing literature does not account and where traditional sustainability tests, or tests addressing sources of potential bias only partially, may yield misleading inference.

Our empirical approach allows for both non-linear fiscal adjustment and multiple structural breaks in fiscal policy, which we identify endogenously. In doing so, we obtain a number of interesting new findings. We find evidence in favour of Bohn's

[5] We follow the standard way to calculate the discounted market value of the debt-to-GDP series which in period $t$ is defined as $\left[\frac{1}{(1+\rho_t)}\right]\left[\prod_{i=1}^{t}\frac{1}{(1+\rho_{t-i})}\right]\left(\frac{D}{Y}\right)_t$, where $\rho$ is the ex-post real interest rate, $\left[\prod_{i=1}^{t}\frac{1}{(1+\rho_{t-i})}\right]$ is the discount factor, taking the value of 1 for 1970, $D$ is the level of public debt and $Y$ the level of GDP, so that $D/Y$ is the undiscounted public debt to GDP ratio. Real interest rates are calculated ex-post, and are defined as the difference between the discount rate of the Bank of Greece and the GDP deflator growth rate. To calculate ex-post real interest rates, we would ideally like to use yields on long-term government bonds rather than discount rates, but such a series was not available for the whole of the post-1970 period. The series for the discount rate is taken by the International Financial Statistics Databank provided by Datastream. The rest of the variables are obtained by the European Commission Databank provided by Datastream.

[6] For a review of Greek fiscal policy over the past three decades, see Christodoulakis (1994), Alogoskoufis (1995) and Mourmouras and Arghyrou, (2000).

hypothesis, with Greek authorities correcting large deficits more vigorously than small ones. We also find evidence of two, rather than one, structural breaks in Greek fiscal policy, the second of which suggests that the convergence programmes implemented in the 1990s have had a beneficial effect on Greek public debt sustainability. Augmenting traditional tests by accounting only for non-linearities results in rejecting sustainability. By contrast, incorporating both non-linearity and structural breaks results in accepting sustainability. This stands in contrast to the conclusion of the existing studies on Greece, and highlights the bias risks involved in existing studies allowing for none or only one of the two possible sources of bias. We conclude that Greek public debt is sustainable.

The remainder of the paper is structured as follows: Section 2 discusses our methodology. Section 3 presents our empirical results. In particular, section 3.1 presents standard tests of debt sustainability. Section 3.2 repeats the analysis allowing for non-linear fiscal adjustment. Section 3.3 tests for sustainability accounting for structural breaks in Greek fiscal policy. Section 3.4 estimates a general model of fiscal adjustment allowing both for structural breaks and non-linearities. Finally, Section 4 summarises and offers concluding remarks.

## 2. TESTING METHODOLOGIES

### 2.1. Benchmark tests

Standard tests of public debt sustainability are based on the one-period government budget constraint given by:

$$D_{t+1} = (1+\rho)\, D_t + g_t - r_t \tag{1}$$

In (1), $D$ is the level of public debt, $\rho$ the real interest rate, $g$ real government expenditure excluding interest payments and $r$ real government revenue, including seignorage. Taking expectations in (1) and using recursive forward substitution yields:

$$D_t = -E_t \sum_{j=0} (1+\rho)^{-(j+1)}(g_{t+j} - r_{t+j}) + \lim_{j\to\infty} E_t (1+\rho)^{-(j+1)} D_{t+j+1} \tag{2}$$

Equation (2) is the government intertemporal budget constraint (IBC). It states that the outstanding stock of government debt equals the sum of the (discounted) present values of expected primary surpluses, plus the limit value of debt at some terminal future date. For public debt to be sustainable, the limit term should converge to zero:

$$\lim_{j\to\infty} E_t (1+\rho)^{-(j+1)} D_{t+j+1} = 0 \tag{3}$$

Equation (3) has mainly been tested using two methodologies. The first, proposed by Hamilton and Flavin (1986) and used, among others, by Kremers (1988), Wilcox (1989), Haug (1991) and Corsetti and Roubini (1991), is to apply unit root tests on the series of discounted market value of public debt. Sustainability implies a stationary debt process without deterministic components. The second, initially suggested by Trehan and Walsh (1988, 1991) and Hakkio and Rush (1991), is based upon the proposition that for the stock of debt to converge to zero, the value of its flow component, i.e. the government's budget deficit, must on average be zero. Let us define $R_t$ to be real government revenue (including seignorage) and $G_t$ real government expenditure (inclusive of interest). If $R_t$ and $G_t$ are both I(1), then, a necessary and sufficient condition for the budget deficit, ($G_t$–$R_t$), to be reverting to zero is equation (4) below to be cointegrated, with the cointegrating vector taking the form [1, 0, -1], and $u_t$ being a white-noise error term.[7]

$$R_t = \alpha + \beta G_t + u_t \tag{4}$$

Equation (4) can be estimated using a variety of ways. In the estimations that follow, we use the Dynamic OLS (DOLS) estimator, which is asymptotically equivalent to Johansen's (1988) maximum-likelihood estimator and is known to have a superior performance in small samples like ours (Stock and Watson, 1993; Saikkonen, 1991).[8] Since our system is bivariate, the issue of multi-cointegration does not arise. The DOLS regression is given by equation (5) below:

$$R_t = \alpha + \beta G_t + \sum_{i=-k}^{k} \gamma_i \Delta G_{t-i} + u_t \tag{5}$$

Equation (5) augments the standard OLS estimator by adding a number of lead and lag differences of the regressors.[9] These control for any endogenous feedback from the dependent to the independent variables and result in consistent estimates of the

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[7] Quintos (1995), defines this to be the "strong-form" sustainability condition. She also derives another form of sustainability, defined as "weak-form" sustainability, which only requires β to be different than zero. However, she acknowledges that the absence of strong-form sustainability has important policy implications, as in the presence of weak-form sustainability the government will face problems in marketing its debt. In this paper we focus on the traditional (strong-) form of sustainability, which is more relevant to the policy issues discussed in the introduction section.

[8] In subsequent estimations we check the robustness of our findings using the Johansen estimator. To preserve space, the Johansen estimates are not reported but are available upon request.

[9] Note that the order of difference required for each regressor in generating the lead and lag term depends on the order of integration of the corresponding regressor. For example, if a regressor is I(2) then the lead and lag terms must be differenced twice (i.e., $\Delta(\Delta x_t)$). For further details see Stock and Watson (1993).

cointegrating vectors, even under conditions of two-way exogeneity between the left- and right-hand side terms (see Ahmed and Rogers 1995, p.361). The estimated co-integrating vector is given by $CV_t = R_t - \alpha - \beta G_t$, which is interpreted as a measure of fiscal disequlibrium. If the term $u_t$ in (5) presents autocorrelation, we use the Dynamic Generalised LS (DGLS) estimator that allows for an autoregressive error using Feasible Generalised Least Squares. We test the cointegration hypothesis between $R_t$ and $G_t$ applying unit root tests on $CV_t$. Linear restrictions on the cointegrating parameters are then tested using a Wald test, which is $\chi^2$-distributed with one degree of freedom. Failure to obtain cointegration results in rejecting the sustainability hypothesis.

If $R_t$ are $G_t$ are cointegrated the Granger representation theorem applies, and short-run fiscal adjustment can be modelled using an Error Correction Model (ECM) like (6):

$$\Delta R_t = k + \sum_{i=1}^{k} \gamma_i \Delta R_{t-i} + \sum_{j=1}^{m} \delta_i \Delta G_{t-j} + \zeta CV_{t-1} + \nu_t \tag{6}$$

In (6) $\Delta$ is the first difference operator, CV the estimated cointegrating vector obtained by (5) and $\nu_t$ a random error term. Hence, a third way to test for public debt sustainability is to estimate (6) and test whether $\zeta$ is significant or not. A non-significant $\zeta$ parameter suggests lack of cointegration between $R_t$ and $G_t$ and results in rejecting the sustainability hypothesis.

### 2.2 Tests and models of non-linear fiscal adjustment

Bohn (1998) argued that governments tend to respond more vigorously to budget deficits when the level of debt is high rather than low. If such non-linear debt dynamics exist, standard tests like those discussed above are biased towards rejecting sustainability (Sarno, 2001).

The hypothesis of non-linear debt adjustment can be tested using the procedure described in Saikonnen and Luukkonen (1988), Luukkonen et al (1988), Granger and Teräsvirta (1993) and Teräsvirta (1994). This involves estimating

$$\hat{u}_t = \gamma_{00} + \sum_{j=1}^{\phi}\left(\gamma_{0j}\hat{u}_{t-j} + \gamma_{1j}\hat{u}_{t-j}\hat{u}_{t-d} + \gamma_{2j}\hat{u}_{t-j}\hat{u}_{t-d}^2 + \gamma_{3j}\hat{u}_{t-j}\hat{u}_{t-d}^3\right) + \gamma_4\,\hat{u}_{t-d}^2 + \gamma_5\,\hat{u}_{t-d}^3 + v_t \quad (7)$$

where $\hat{u}_t$ can be defined as the discounted debt-to-GDP ratio, or the estimated fiscal disequilibrium obtained by equation (5); $d$ is the delay parameter of the transition function to be used and $v(t) \sim niid\ (0,\sigma^2)$. Linearity implies the null hypothesis $H_0$: $[\gamma_{1j} = \gamma_{2j} = \gamma_{3j} = \gamma_4 = \gamma_5 = 0]$ for all $j \in (1,2...\phi)$. This can be tested using an LM-type test. Having determined $\phi$ through inspection of the partial autocorrelation function of $\hat{u}_t$, (7) can be estimated for all plausible values of $d$.[10] Non-linearity is rejected if any of the resulting LM-statistics is statistically significant. The optimum value of $d$ is then determined on the basis of the highest LM score.

[10] Granger and Teräsvirta (1993) and Teräsvirta (1994) advise against choosing $\phi$ using an information criteria such as the Akaike, since this may induce a downward bias.

Non-linear debt behaviour can be modelled in two ways. The first, adopted by Sarno (2001), is to model directly the debt series. An alternative approach, which we prefer because it relates to Bohn's hypothesis more directly, is to estimate the logistic STECM model (L-STECM) described by equations (8)-(11) below:

$$\Delta R_t = \theta_t M_{Lt} + (1-\theta_t) M_{Ut} + \varepsilon_t \tag{8}$$

$$M_{Lt} = \alpha_1 + \sum_{i=1}^{n} \beta_{Li} \Delta R_{t-i} + \sum_{i=0}^{p} \gamma_{Li} \Delta G_{t-i} + \zeta_L \hat{u}_{t-1} \tag{9}$$

$$M_{Ut} = \alpha_2 + \sum_{i=1}^{n} \beta_{Ui} \Delta R_{t-i} + \sum_{i=0}^{p} \gamma_{Ui} \Delta G_{t-i} + \zeta_U \hat{u}_{t-1} \tag{10}$$

$$\theta_t = pr\ \{\tau \geq \hat{u}_{t-d}\} = 1 - \frac{1}{1+e^{-\sigma[\hat{u}_{t-d}-\tau]}} \tag{11}$$

Equations (9) and (10) are error-correction models similar to (6). They define two fiscal regimes, separated by the regime threshold $\tau$. In line with Bohn's hypothesis, $\tau$ corresponds to a critical deficit value above which the deficit is considered by authorities to be too large. As long as this threshold is not reached, public revenue is adjusted according to $M_U$ in (10). In this upper regime the error correction coefficient $\zeta_U$ should either be non-significant (no correction of deficit) or relatively small in absolute terms (slow correction of deficit). When the budget deficit surpasses its critical threshold value, revenue adjusts according to $M_L$ in (9). Bohn's suggestion implies that in this lower regime the error correction coefficient $\zeta_L$ should be statistically significant and relatively large in absolute terms (fast deficit reduction). Equation (8) models period-to-period changes in public revenue as a weighted average of $M_L$ and $M_U$. The regime weight $\theta$ is defined in (11) as the probability that the transition variable $\hat{u}_{t-d}$ takes a value below the regime threshold. $\Delta R_t$ is mainly determined by $M_U$ if $\hat{u}_{t-d} > \tau$ and mainly by $M_L$ if $\hat{u}_{t-d} \leq \tau$. The parameter $\sigma$ denotes the speed of transition between the two regimes. The L-STECM simplifies to the linear model in (6) if $\beta_{Li} = \beta_{Ui}$ and $\gamma_{Li} = \gamma_{Ui}$ for all $i$ and $\zeta_L = \zeta_U$.

**2.3. Tests and models of structural breaks in fiscal policy**

Standard unit root tests are biased towards rejecting stationarity if the deterministic components of the series tested is subject to structural breaks (see Perron, 1989). The problem becomes even more complex when the dates of the breaks are unknown. Makrydakis et al (1999), who examined public debt sustainability in Greece using the discounted debt-to-GDP series, address this issue using the test proposed by Zivot and Andrews (1992). This allows for endogenous identification of a single, unknown, break point. However, as Figure 1 suggests, Greek fiscal policy may have been subject to two breaks. By not accounting for this second possible break, the results reported by Makrydakis et al may include biases.

We test for multiple structural breaks in fiscal policy endogenously using the Chi-square test proposed by Quintos (1995). For this test, the DOLS estimator in equation (5) is augmented as suggested by equation (12) below:

$$R_t = \alpha + \beta\, G_t + \sum_{i=-k}^{k} \gamma_i \Delta G_{t-i} + \delta (DG)_t + v_t \qquad (12)$$

$$D_t = 1 \quad \text{if} \quad t \in (1, \ldots, T)$$

$$= 0 \quad \text{if} \quad t \in (T+1, \ldots, N)$$

In (12), $(DG)_t$ is a slope dummy variable, taking the value of $G_t$ up to the date of the tested break point ($T$) and zero afterwards; and $N$ is the last sample observation. The test involves estimating (12) consecutively, where following Andrews (1993) we trim 15% of the initial and final parts of the sample. In each estimation round, the sample size remains constant but the definition of ($DG$) changes: for the first estimation round, the last observation in $DG_t$ is set to be zero; the rest of the observations are set to be equal to $G_t$. The estimation is repeated, substituting in each estimation round the values of $G_t$ by zero backwards. Hence, for the last estimation round, only the first observation of $DG_t$ takes the value of $G_t$; all the rest are set to zero. In each estimation round we test the statistical significance of the dummy variable. We do so using a Wald test, which is $\chi^2$ distributed with one degree of freedom. The null hypothesis describes structural stability ($H_0$: $\delta = 0$). Structural breaks are identified in those dates for which the estimated Wald statistic is higher than the 5% critical value of $\chi^2(1)$.

If structural breaks are found, the sustainability analysis has to be augmented to account for them. Assuming that the number of structural breaks that have been identified is $j$, the DOLS estimator in (5) takes the form of (13) below:

$$R_t = \alpha + \beta G_t + \sum_{i=1}^{j} \delta_i D_{it} G_t + \sum_{i=-k}^{k} \gamma_i \Delta G_{t-i} + v_t \qquad (13)$$

In (13), $i$=1,.., $j$; $D_{it}$ = 0 if $t \in$ (1,..., $T_i$); and $D_{it}$ = $G_t$ if $t$ ($T_i$+1, ..., $N$), where $T_i$ is the date in which the $i$th identified structural break occurs. Equation (13) picks up the long-run (total multiplier) effect of structural breaks in fiscal policy. Ceteris paribus, a significant and positive (negative) coefficient of slope dummy implies a move towards (away from) debt sustainability. The cointegrating vector augmented for structural breaks is given by $CVBR_t = R_t - \alpha - \beta G_t - \sum_{i=1}^{j} \delta_i D_{it} G_t$. Debt sustainability is consistent with $CVBR_t$ being stationary; the $\beta$ coefficient (adjusted for dummies) being equal to one ($\beta + \sum_{i=1}^{j} \delta_i = 1$); and $\alpha = 0$.

If stationary is not rejected for $CVBR_t$, when (6) is estimated using $CVBR_t$ the error correction coefficient $\zeta$ must be statistically significant. However, it is possible for structural breaks to coincide with non-linear fiscal adjustment, in which case $\zeta$ will not be constant but a function of the value of the budget deficit. Non-linear behaviour for $CVBR_t$ is a testable hypothesis, which we can test using equation (7). If linearity is rejected, the L-STECM model discussed in section 2.2 is re-estimated, using $CVBR_t$ rather than $CV_t$. By addressing both structural breaks and non-linearities, we expect this general model to be the most suitable means of modelling fiscal adjustment.

## 3. EMPIRICAL FINDINGS

### 3.1. Benchmark tests: Linear analysis without structural breaks

We start by running a number of unit root (ADF) tests, specified to include no constant; a constant; and a constant and a trend on the discounted debt series depicted in Figure 1. All tests reject stationarity, suggesting non-sustainability for Greek public debt.[11] We proceed to the second benchmark methodology discussed in section 2.1,

[11] To preserve space, these tests are not reported here. These tests, and all other findings to which we refer but do not present in this paper, are available by the author upon request.

involving cointegration analysis between $R_t$ and $G_t$. We use data taken from the International Financial Statistics Databank of the IMF.[12] The data frequency is quarterly and covers 1970Q1- 2000Q4.[13] $R_t$ includes seignorage, approximated by the change in monetary base ($M_0$); $G_t$ includes interest payments. Figure 2 plots the logs of $R_t$ and $G_t$. Both seem to include seasonality, for which we account in our estimations. The unit root tests we have run (not reported) suggest that both $R_t$ and $G_t$ are I(1). The series move together in the 1970s but subsequently exhibit a growing divergence. Following 1996, co-movement seems to have been restored. Hence, Figure 2 is consistent with Figure 1, suggesting fiscal stability in the 1970s, followed by a worsening of the fiscal outlook in the 1980s and a partial recovery in the 1990s.

We now estimate (5) using DOLS. In view of the frequency of our data, we set a lag and lead order of five (note however that the findings reported below are not sensitive to changes of this order). DOLS resulted in autocorrelated residuals, for which we corrected using DGLS. The results are reported in Table 1, col. (a). The reported ADF statistic soundly rejects the cointegration hypothesis. This suggests that Greek public debt is not sustainable. This finding is consistent with the findings obtained by Corsetti and Roubini (1991) and Makrydakis et al in (1999).

We now estimate the ECM model in (6). We follow a general-to-specific approach, starting with twelve lags for each variable and eliminating at each estimation stage the

[12] Our series refer to general government revenue and expenditure. We have calculated real values dividing nominal values by the Consumer Price Index. We would have preferred to use a GDP deflator series but that was not available for the whole of our sample on a quarterly basis.

[13] At the time of writing this paper, International Financial Statistics have not been reporting data for Greek government expenditure and revenue for the period following 1998. For the period 1999-2000 our data is taken from various editions of the Bulletin of Conjunctural Indicators published by the Bank of Greece. These series are consistent with those used by IMF and account for the revisions of Greek fiscal data for the years 1999-2000 decided by the European Commission in 2003.

least significant term.[14] The parsimonious equation is reported in Table 2, col (a).[15] The error correction term is statistically significant, suggesting cointegration between $R_t$ and $G_t$. This provides evidence in favour of sustainability and contradicts our previous finding. The same contradictory findings are obtained when the cointegrating vector is estimated using the Johansen rather than the DGLS estimator. To summarise, the benchmark tests leave the question of sustainability of Greek public debt open.

### 3.2. Non-linear analysis without structural breaks

We now test whether the ambiguity of the previous section can be clarified by accounting for non-linear debt behaviour. Table 3, col. (a) reports the results of the non-linearity tests on $CV_t$. The latter's partial autocorrelation function (not reported to preserve space) suggested a $\phi$ value equal to 4. We report LM-scores and their associated p-values for values of $d = 1\ldots8$. We find strong-evidence of non-linearity, with the highest LM-score obtained for $d = 1$.

Table 2, col. (b) reports the estimates of the short-run (L-STECM) model discussed in 2.2 using $CV_t$. We adopt a general to specific approach and report the parsimonious equation. Although the point-estimate of the error correction term in the lower regime

[14] All equations in Table 2 include an intercept dummy, taking the value of 1 for 1997Q4 and zero otherwise. This captures the exceptionally high level of public expenditure recorded for that quarter. The latter may be related to the speculative attack sustained by the drachma in November 1997. During that attack, the Bank of Greece spent a significant amount of its foreign currency reserves. Omitting this dummy variable does not change the nature of results reported in Table 2, but results in non-normally distributed residuals.

[15] Note that this equation, and all equations reported in Table 2, include the current value of $\Delta \log G$ in the set of regressors. The estimations we undertook strongly reject exclusion of this variable from the analysis, as its omission creates significant misspecification problems. Its inclusion imposes that government expenditure is weakly exogenous in the long-run cointegrating vector. We have tested this hypothesis and concluded that it is valid for the period covered by our data set (the results are available upon request).

is higher in absolute terms than the one in the upper (-0.470 versus -0.257), it is not significant. This suggests lack of deficit correction for large deficit values, which is consistent with an explosive public debt path. To conclude, when the benchmark analysis is augmented by allowing for non-linear debt dynamics but not structural breaks in fiscal policy, the sustainability hypothesis for Greek public debt is rejected.

### 3.3. Linear analysis with structural breaks

We now test for structural breaks in Greek fiscal policy. Figure 3 plots the values of the sequentially estimated Chi-square tests given by (12) against the 5 and 1 per cent critical values. Structural stability is rejected for a number of observations in the early 1980s and 1990s. Given that structural breaks in fiscal policy cannot fall too close together, we treat all break points falling within three years as representatives of the same break. The exact timing of the break is then selected to be the observation presenting the highest test value. We identify two structural breaks, in 1980(2) and 1990(3). Both breaks are consistent with the indications provided by Figures 1 and 2.

As a further robustness check, we apply the second test for structural breaks proposed by Quintos (1995), the LR+ test. Its estimation (see Figure A1 in the Appendix), confirms the existence of two breaks, now located in 1982(4) and 1991(3). These are close to the timing of the breaks identified above. Therefore, we consider the latter to be robust. Their timing is at first sight plausible: The first coincides with the well-documented major fiscal expansion undertaken in Greece the early 1980s. The second coincides with the initiation of the convergence programmes implemented in the 1990s, aiming to secure Greece's accession to the EMU.

We now investigate the effect of the two breaks on Greek public debt. Table 1, col. (b) reports the estimates of equation (13). Two findings stand out. The first relates to the estimated sign of the two dummy variables. The dummy referring to 1982Q2 has a negative and significant sign, suggesting a move away from sustainability in the 1980s. This finding is not new. The same break has also been identified by Makrydakis et al (who place it in 1978); and its negative consequences have been extensively debated by authors like Chistodoulakis (1994) and Alogoskoufis (1995). By contrast, the dummy referring to 1990Q3 has a positive and statistically significant sign. This provides original econometric evidence according to which, starting from 1990, the convergence programmes implemented by the Greek authorities in the 1990s have had a positive long-term improvement effect on Greek public debt dynamics.[16] This finding has not been previously reported in the literature.

The second important finding from Table 1, col. (b) is that accounting for the two structural breaks, makes Greek public debt sustainable: At the conventional 5 per cent level, the reported ADF statistic is now statistically significant; the $\beta$ coefficient adjusted for dummies ($\beta+\delta_1+\delta_2$) is not statistically different from unity; and the constant term is not statistically different from zero ($\alpha=0$). The sustainability finding is not sensitive to the choice of estimator, as it is still obtained when (13) is estimated using the Johansen estimator.[17] Further support is provided by the ECM equation accounting for breaks: replacing the term $CV_{t-1}$ with $CVBR_{t-1}$ in (6) maintains the significance of the error correction term (see Table 2, col. c). Overall, when the

[16] Using the Johansen estimation methodology, defining the breaks to have taken in 1982(4) and 1991(3), as suggested by the LR+ test in the Appendix, and restricting the cointegrating rank to one, we find the dummy variables to be statistically significant, with point estimates of -0.030 for the 1982(4) dummy and 0.022 for the 1991(3) one.

[17] Using the Johansen estimator, and allowing for the structural breaks identified by the LR+ test in the Appendix, the point estimate of the $\beta$ coefficient, when adjusted for dummies, is 0.91. The unity restriction for ($\beta+\delta_1+\delta_2$) is not rejected at the 5 per cent level; and the constant term is not significant.

benchmark testing procedure is augmented to allow for multiple structural breaks but not non-linear fiscal adjustment, we conclude that Greek public debt is sustainable.

### 3.4. Non-linear analysis with structural breaks

We now test for fiscal policy sustainability allowing for both structural breaks and non-linear fiscal adjustment. We start by testing for non-linear behaviour in $CVBR_t$ using equation (7). Inspection of the latter's partial autocorrelation function (not reported here) suggests a value for $\phi$ equal to 4. The linearity tests are presented in Table 3, col. (b). Linearity is rejected at the 5% level or lower by the overwhelming majority of the statistics reported, yielding an optimum $d$ value equal to 4. We thus confirm our finding in section 3.2 that fiscal policy in Greece presents non-linear behaviour. This finding is new and, as we will see below, has important policy implications.

We proceed to estimate the L-STECM model analysed in section 2.2 using $CVBR_t$ in equations (9) and (10). Our findings are reported in Table 2, col. (d). This passes all misspecification tests and by producing the lowest regression standard error out of all the four reported equations, has the best regression fit. It therefore validates our a-priori expectations that accounting for both structural breaks and non-linear dynamics, is the most suitable way to model Greek public debt dynamics.[18]

As far as the question of sustainability is concerned, the error correction term is now significant in both regimes. This confirms the findings obtained in section 3.3,

[18] The inclusion of the intercept dummy accounting for 1997Q4 ensures that our non-linear findings are not the result of any outlier in the data set. As mentioned earlier, excluding this dummy does not affect the nature of our findings but results in non-normally distributed residuals (see footnote 14).

according to which fiscal policy in Greece is sustainable. This is a new and important finding as it stands in contrast with the findings of both Corsetti and Roubini (1991), and Makrydakis et al (1999). These studies accounted for zero and a single structural break respectively. Our sustainability finding highlights the importance of incorporating the full set of breaks into the analysis.

The results reported in the previous section suggest that as long as both structural breaks are accounted for into the analysis, the sustainability finding is not sensitive to the inclusion of non-linear fiscal dynamics. However, the existence of the latter conveys important insights for Greek fiscal policy which cannot be identified in their absence. The first relates to Bohn's hypothesis for which col. (d) in Table 2 provides strong evidence in favour of. In the upper regime ($M_U$), the estimated speed of adjustment is significant and similar in size (-0.18) to those obtained by the rest of the equations reported in Table 2. However, in the lower regime ($M_L$), fiscal adjustment is more than three times faster (-0.57) and statistically significant. These suggest that Greek fiscal authorities always correct budget deficit but large deficits are corrected much faster than small ones. This is a new finding, not captured by previous studies on Greece, and also not captured by the short-run model that accounts for structural breaks only, ignoring non-linearities (col. c in Table 2).

The second implication relates to the estimated regime threshold. This is negative, statistically significant and quite precisely defined at -0.116. The negative sign suggests that Greek authorities make no distinction between surpluses and small/medium- size deficits, both of which belong to the upper regime.[19] Given that the point estimates in Table 1, col. (b) used to calculated $CVBR_t$ are not precisely of the [1 0 -1] form, this estimated threshold cannot be strictly interpreted as a budget deficit of 11.6 per cent of GDP. However, the qualitative policy implication of our findings is clear: Greek authorities wait for the budget deficit to assume quite significant values before they take determined measures (as suggested by the high speed of adjustment in the lower regime), to correct it. This is another new finding, previously unreported in the literature, and also not captured by the short-run model that accounts for structural breaks only, ignoring non-linearities (col. c in Table 2).

Finally, the third implication relates to forecasts of Greek fiscal variables. Figure 4 presents the estimates of $CVBR_t$ against the estimated threshold value of our preferred L-STECM model. Most observations lie in the upper regime. In such periods, using the linear model reported in Table 2, col. (c), where the estimated speed of adjustment is similar to that of the L-STECM upper regime would not entail high forecasting risks. However, for a non-negligible minority of observations, the disequilibrium term takes values in the lower regime. In such periods, which correspond to significant deterioration of the budget deficit, using the linear model could lead to significantly biased fiscal projections. Such biases would not be accounted for had we not added non-linearities in the analysis accounting for structural breaks.

[19] Remember that the dependent variable in our long-run model is public revenue $R_t$. Therefore, the disequilibrium term $CVBR_t = R_t - \alpha - (\beta+\delta_1+\delta_2)\times G_t$ is defined in terms of surplus rather than deficit. A negative sign for this disequilibrium term corresponds to a deficit.

## 4. SUMMARY AND CONCLUDING REMARKS

Compliance of pubic finances with the government's intertemporal budget constraint (ICB) has been rejected by a number of empirical studies. Such findings may include biases if they do not allow for the effects of non-linear public debt adjustment and structural breaks in fiscal policy. The existing literature has largely overlooked these issues. The relatively few studies that address them do so separately. There exists no paper testing for their combined effect simultaneously.

We address this gap by focusing on Greece, one of Europe's most highly indebted countries, whose public debt has been found by previous studies to be unsustainable. We obtain a number of new and interesting findings. We find evidence of non-linear fiscal adjustment, with Greek authorities correcting large deficits faster than small ones. We also find evidence of two, rather than the previously reported single, structural breaks in Greek fiscal policy, the second of which suggests that the convergence programmes implemented in the 1990s have had a beneficial effect on Greek public debt. Overall, we find that Greek public debt is sustainable. This stands in contrast to the findings of previous studies on Greece. Our analysis highlights the risks of bias involved in existing tests of public debt sustainability not accounting for the full set of structural breaks and non-linearities in fiscal policy.

The analysis in this paper can be extended towards a number of directions. As a first step, one may use the methodological approach employed here to revisit public debt sustainability for the USA and other European countries. More specific issues could be then be addressed, including the nature of the variables responsible for its existence (e.g. expenditure versus revenue, interest versus non-interest expenditure etc.). Finally, empirical findings like the ones obtained in this paper could be used to motivate formal modelling of non-linear debt dynamics, for which existing theoretical models of fiscal policy, like Barro's (1979) tax smoothing model, have not accounted.

We end with a word of caution. Our main empirical finding, namely that Greek public debt is sustainable, should not be interpreted as a sign that Greek authorities have now any margin to pursue an expansionary fiscal policy. For reasons mentioned in the introduction section, high levels of public debt are regarded to be an obstacle for the achievement of sustainable economic growth. The Greek experience confirms these theoretical predictions. Following the debt-increasing fiscal-policy shift we found in 1980, Greece recorded a below-average growth performance. By contrast, since the debt-reducing fiscal-policy shift we identified in 1990, Greece has been achieving accelerating growth rates. Nevertheless, despite its recent reduction, public debt in Greece remains by European standards excessive. This renders the sustainability of the recently achieved growth rates fragile. For the latter to be maintained in the long-term, further debt reduction is an essential pre-requisite.

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**Figure 1: Public debt to GDP in Greece, 1970-2000**

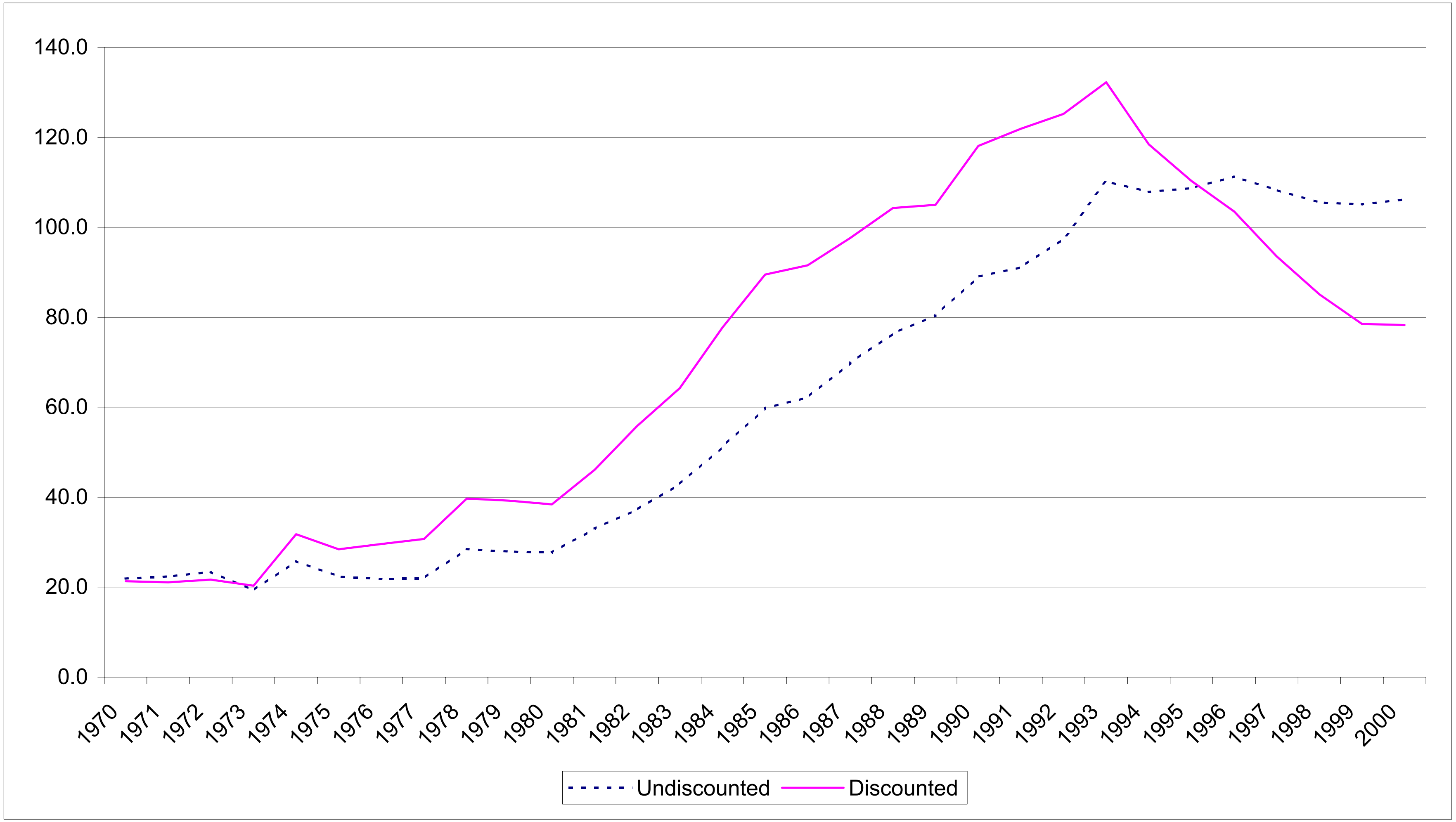


**Figure 2: Real government expenditure and revenue in Greece, 1970-2000 (in logs)**

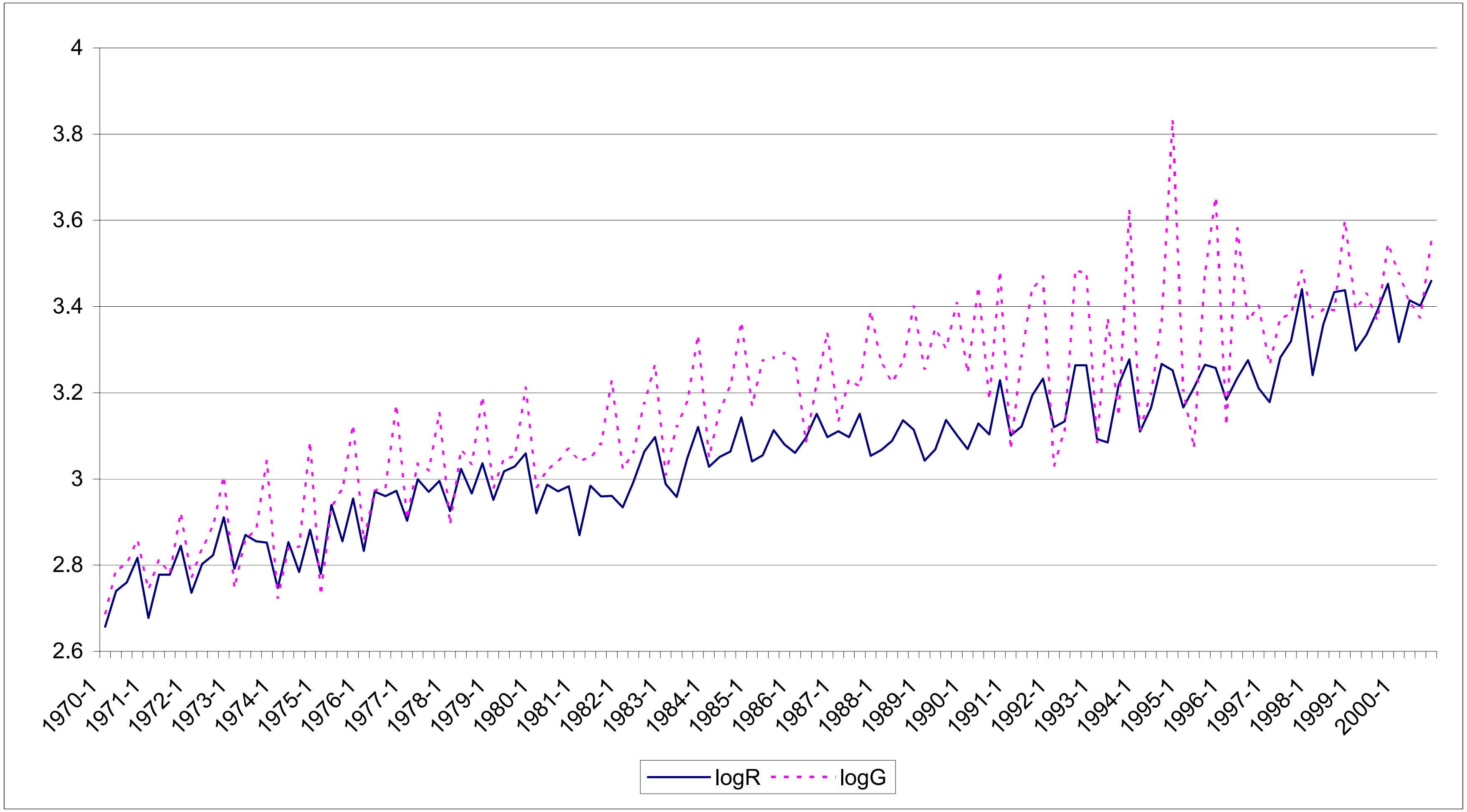


**Table 1**

**Long-run models (GDLS estimates)**

| | (a)<br>Model without breaks | (b)<br>Model with breaks |
|---|---|---|
| | | |
| Constant | 0.454 (0.300) | 0.331 (0.264) |
| logG | 0.827 (0.093) | 0.872 (0.088) |
| D1980Q2×logG | | -0.020 (0.008) |
| D1990Q3×logG | | 0.016 (0.005) |
| | | |
| ARCH F-test | 0.58 [0.68] | 0.60 [0.66] |
| Norm Chi-sq test | 1.40 [0.50] | 1.55 [0.46] |
| Hetero F-test | 0.50 [0.97] | 0.82 [0.71] |
| | | |
| $H_0$: $\beta = 0$ | 78.9** [0.00] | |
| $H_0$: $\beta = 1$ | 3.43 [0.06] | |
| $H_0$: $\beta + \delta_1 + \delta_2 = 0$ | | 122.6** [0.00] |
| $H_0$: $\beta + \delta_1 + \delta_2 = 1$ | | 2.84 [0.09] |
| | | |
| Unit root tests on $\hat{u}_t$ [95 per cent CV] | -2.39 [-2.89] | -3.42* [-2.89] |

Note: Standard errors in parenthesis, p-values in square brackets (unless otherwise state); * and ** denote statistical significance at the 5 and 1 per cent level respectively

## Table 2

## Short-run Error Correction Models

| | (a) Linear without structural breaks | (b) Non-linear without structural breaks | (c) Linear with structural breaks | (d) Non-linear with structural breaks |
|---|---|---|---|---|
| | | | | |
| | | $M_U$ | | $M_U$ |
| Constant | 0.006 (0.004) | -0.003 (0.004) | 0.005 (0.004) | 0.003 (0.004) |
| $\Delta$ $\log R_{t-1}$ | -0.480 (0.087) | -0.174 (0.051) | -0.468 (0.083) | -0.400 (0.097) |
| $\Delta$ $\log R_{t-2}$ | -0.365 (0.096) | | -0.356 (0.091) | 0.057 (0.027) |
| $\Delta$ $\log R_{t-3}$ | -0.369 (0.093) | | -0.351 (0.089) | -0.397 (0.093) |
| $\Delta$ $\log R_{t-4}$ | 0.221 (0.081) | 0.459 (0.071) | 0.221 (0.078) | 0.243 (0.084) |
| $\Delta$ $\log G$ | 0.156 (0.033) | 0.220 (0.034) | 0.181 (0.033) | 0.146 (0.041) |
| $\Delta$ $\log G_{t-11}$ | 0.110 (0.026) | 0.134 (0.024) | 0.116 (0.025) | -0.487 (0.090) |
| $\Delta$ $\log G_{t-12}$ | 0.065 (0.026) | 0.090 (0.028) | 0.071 (0.025) | 0.103 (0.026) |
| $CV_{t-1}$ | -0.165 (0.056)** | -0.257 (0.063)** | | |
| $CVBR_{t-1}$ | | | -0.224 (0.058)** | -0.180 (0.069)* |
| | | | | |
| | | $M_L$ | | $M_L$ |
| Constant | | -0.045 (0.045) | | 0.085 (0.016) |
| $\Delta$ $\log R_{t-1}$ | | | | -0.498 (0.143) |
| $\Delta$ $\log R_{t-2}$ | | -0.753 (0.170) | | |
| $\Delta$ $\log G$ | | 0.201 (0.098) | | 0.109 (0.055) |
| $\Delta$ $\log G_{t-8}$ | | | | -0.328 (0.075) |
| $CV_{t-1}$ | | -0.470 (0.284) | | |
| $CVBR_{t-1}$ | | | | -0.567 (0.195)** |
| | | | | |
| $\tau$ | | -0.131 (0.021)** | | -0.116 (0.006)** |
| | | | | |
| $\sigma$ | | 10.00 (15.73) | | 20.00 (31.92) |
| | | | | |
| $R^2$ | 0.81 | 0.80 | 0.82 | 0.84 |
| Regression SE (sigma) | 0.0354 | 0.0375 | 0.0344 | 0.0339 |
| | | | | |
| AR F-test | 0.70 [0.62] | 1.64 [0.16] | 0.61 [0.70] | 0.50 [0.77] |
| ARCH F-test | 1.16 [0.33] | 0.64 [0.64] | 0.77 [0.54] | 1.22 [0.31] |
| Norm Chi-Sq Test | 0.29 [0.86] | 0.08 [0.96] | 0.39 [0.82] | 0.09 [0.10] |
| White Hetero F-test | 0.67 [0.87] | 0.85 [0.66] | 0.58 [0.89] | 0.50 [0.95] |

Notes: Standard errors in parentheses, p-values in square brackets; * and ** denote statistical significance at the 5 and 1 per cent level respectively; AR-F tests for autocorrelated residuals; ARCH-F tests for AutoRegressive Conditional Heteroscedasticity; Norm Chi-Sq tests for normally distributed residuals; and White Hetero is White's tests for heteroscedasticity. All equations are estimated including an intercept dummy for 1997Q4 (see footnote 14 in the text)

**Table 3**

**Linearity tests**

| | | |
|---|---|---|
| | (a) | (b) |
| | Cointegrating Vector without breaks ($CV_t$) | Cointegrating Vector with breaks ($CVBR_t$) |
| *d* | | |
| | | |
| 1 | 3.078 (0.001)** | 2.834 (0.004)** |
| 2 | 2.277 (0.016)* | 2.840 (0.003)** |
| 3 | 1.273 (0.255) | 1.891 (0.049)* |
| 4 | 1.602 (0.109) | 3.163 (0.001)** |
| 5 | 1.533 (0.113) | 1.504 (0.123) |
| 6 | 2.128 (0.016)* | 3.125 (0.001)** |
| 7 | 1.184 (0.299) | 1.159 (0.319) |
| 8 | 2.901 (0.001)** | 2.321 (0.011)* |

Note: The Table reports the F-scores of the LM test in equation (7); p-values are reported in parenthesis; * and ** denote statistical significance at the 5 and 1 per cent level respectively

**Figure 3: Chi-square test for fiscal policy breaks**

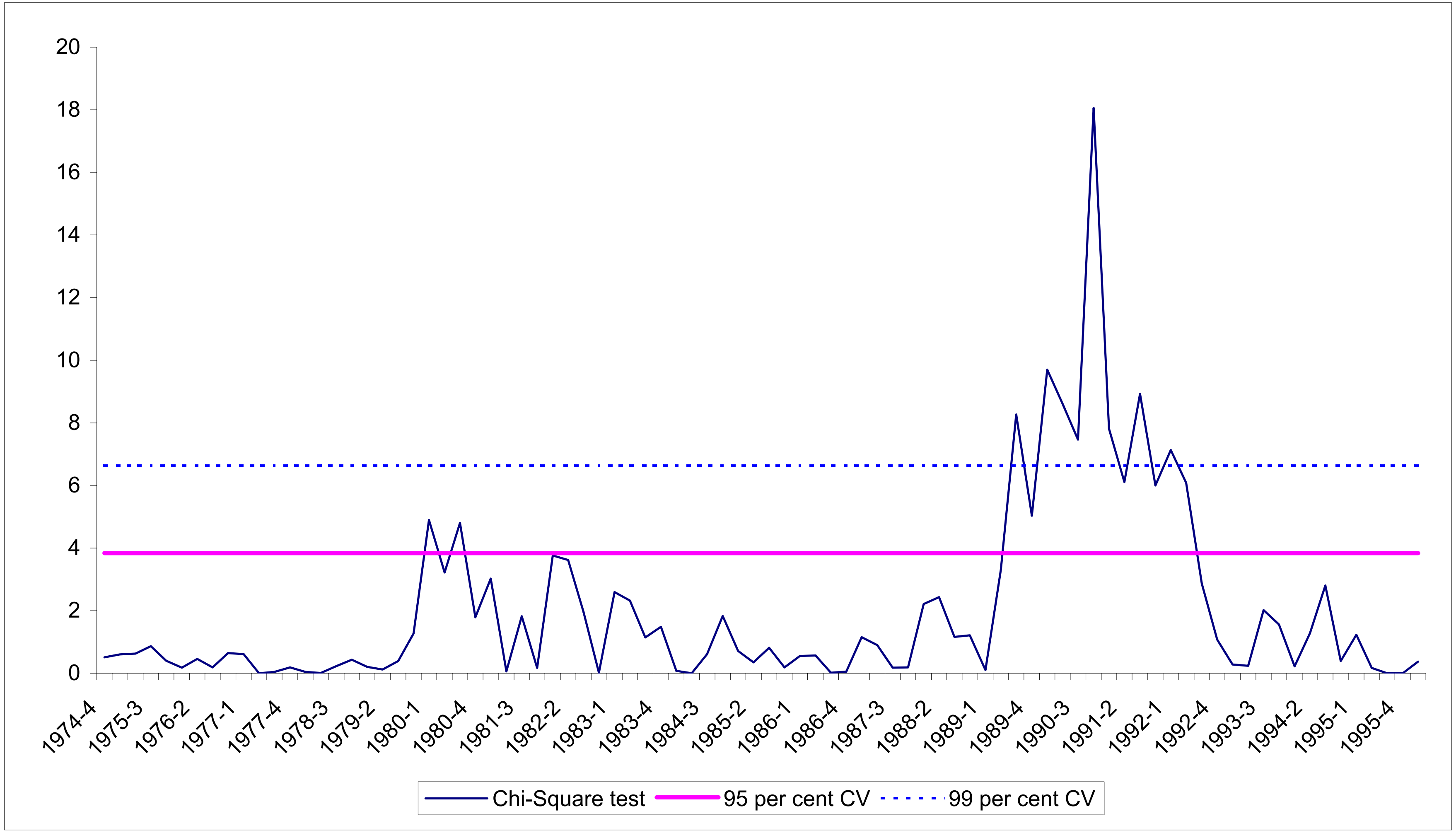
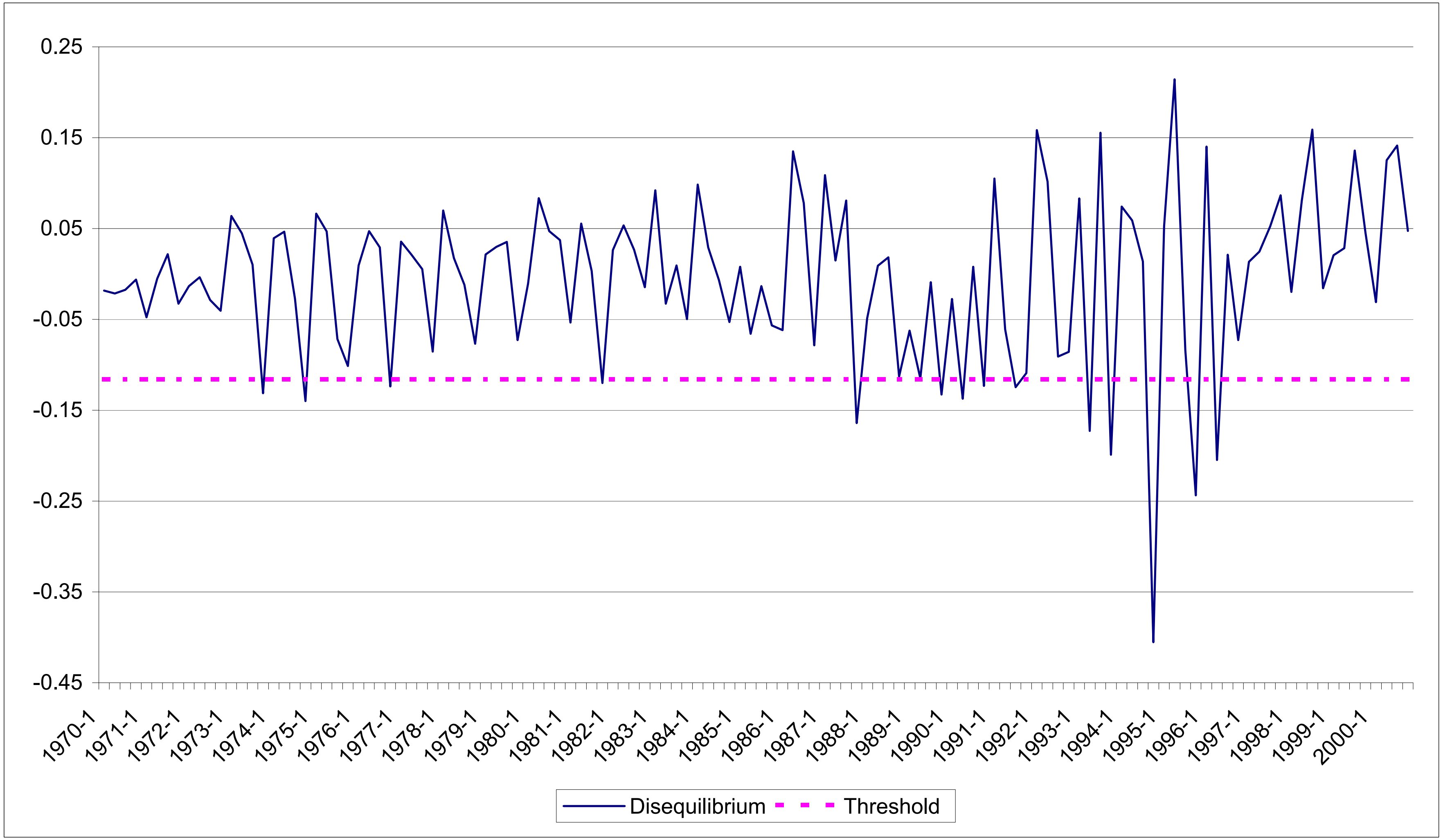


**Figure 4: Fiscal disequlibrium versus fiscal regime threshold**



**APPENDIX**

In her 1995 paper Quintos proposes a sequential rank constancy test to determine endogenously the existence of structural breaks in cointegrating relationships. In Quintos' notation, consider the case of an $n$-dimensional I(1) process $\{X_t\}$ that satisfies the following error correction formulation:

$$\Delta X_t = \mu_t + \Pi^*_j(L)\,\Delta X_{t-1} + \Pi\, X_{t-1} + \varepsilon_t \qquad \text{(A1)}$$

where $\mu' = (\mu_\alpha , \mu_\beta)$, $\Pi^*_j(L) = \sum_{i=1}^{j-1} \Pi^*_i L^{i-1}$ and $\Pi^*_i = -\sum_{l=i+1}^{j} \Pi_l$ for $i$=1,…,$j$-1.

The null to be tested is that both the rand and the parameters of Π, i.e. the number and the coefficients of the cointegrating relationships, are stable over time against the alternative of up to $J$ structural breaks. More formally:

$$H_0^q: \qquad \rho(\Pi_1)_1 = \ldots = \rho(\Pi_{J+1})_{J+1} = q$$
$$\Pi_1 = \ldots = \Pi_{J+1} = \Pi$$

$$H_a^{q_1,\ldots,q_{J+1}}: \qquad \rho(\Pi_1)_1 = q_1,\ \ldots = \rho(\Pi_{J+1})_{J+1} = q_{J+1}$$
$$\Pi_1 \neq \ldots \neq \Pi_{J+1} \neq \Pi$$

where $0 \leq q \leq n$, $q$ is the number of cointegrating relations under the null, and $J$ the number of structural shifts assumed to occur at times $t = m_j + 1$ for $j$=1,..., $J$.

Quintos proposed to test the null of stability using a likelihood ratio test, denoted as LR+, which is a version of Johansen's (1991) rank test. The LR+ test is given by:

$$\text{LR+} = T \ln (1 - \hat{\lambda}_1) - p_1 \ln (1 - \hat{\lambda}_{11}) \qquad \text{(A2)}$$

In (A2), $T \ln (1 - \hat{\lambda}_1)$ and $p_1 \ln (1 - \hat{\lambda}_{11})$ respectively denote the value of the trace statistic when the system is estimated for the whole of the sample ($0 \ldots T$) and for the sub-period ($0 \ldots p_1$). The test follows a $\chi^2$ distribution with degrees of freedom $q$ times $n$. LR+ is estimated recursively and structural breaks are defined to have taken place when the estimated value of LR+ exceeds the critical value.

Figure 1A presents the values of the LR+ test estimated for our sample period 1970Q1-2000Q4. The estimates are based on the full-sample trace statistic obtained by the estimation of a VAR model including Greek real government revenue $R_t$, real expenditure $G_t$, a constant restricted to the cointegration space and unrestricted seasonal dummies. The estimated VAR is of order 6, as suggested by the Akaike information criterion and the system-reduction F-tests, and passes all misspecification tests. Following Andrews (1993), we have trimmed 15 per cent from the beginning and the end of the sample. We find two structural breaks, in 1982Q4 and 1991Q4. These are close to the breaks identified using the Chi-Square test, i.e. 1980Q2 and 1990Q3. Hence, the two tests of structural breaks provide consistent qualitative findings.

**Figure A1: LR+ test for fiscal policy breaks**