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Smooth transition, non-linearity and current account sustainability: Evidence from the European countries

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In this paper we examine three types of nonlinearities, i.e., nonlinearity stemming from structural breaks, sign nonlinearity and size nonlinearity, for ten European countries and their importance to current account sustainability. For this purpose, we apply a battery of linear and nonlinear unit root tests. Our results show that the structural break nonlinearity and size nonlinearity are vital to the current account-GDP ratios of European countries in testing for the null hypothesis of a unit root. Nevertheless, the current account-GDP ratios of these countries do not exhibit the sign nonlinearity. That is, by taking account of the nonlinear trend, the threshold autoregressive and momentum threshold autoregressive models do not detect any asymmetry in the response of the current account imbalance to deviations from its long-run nonlinear trend.

1. Introduction

Current account sustainability has long been the focus of wide attention from academics, government and business, alike. It refers to whether an economy is able to meet its intertemporal budget constraint in the long run without a drastic change in private-sector behavior or policy changes, such as a sharp currency depreciation or a reduction in government expenditures. Trehan and Walsh (1991) show that the stationarity of the current account is a sufficient condition for the intertemporal budget constraint to hold. In this sense, sustainability refers to the mean reversion of the current account balance over time, whereas the nonstationary behavior of the current account implies that, during the sample period observed, the country has violated its intertemporal budget constraint (see, e.g., Taylor, 2002). That is, a nonstationary process is the best approximation to the data generating process of the current account for the finite sample, which implies that some form of (unexpected) adjustment will have to take place in the future.

Based on Trehan and Walsh (1991), a myriad of studies have devoted many efforts to this issue and the empirical literature has developed in two directions. First, many researchers either employ the linear unit root and cointegration tests to investigate the mean-reverting behavior of the current account (see, for example, Apergis et al., 2000; Arize, 2002; Baharumshah et al., 2003; Bergin and Sheffrin, 2000; Dulger and Ozdemir, 2005; Ismail and Baharumshah, 2008; Karunaratne, 2010; Liu and Tanner, 2001; Nag and Mukherjee, 2012) or adopt the method of a linear panel unit root or panel cointegration to test whether or not the current account imbalance is sustainable in the long run (e.g., Holmes, 2006a,b; Holmes et al., 2010; Kalyoncu, 2006; Lau and Baharumshah, 2005; Lau et al., 2006).[1]

Second, many researchers stress that the dynamic adjustment of the current account imbalance may follow a nonlinear process. For instance, Chortareas et al. (2004) point out that there are at least three channels that make the current account series a nonlinear process. The first source of nonlinearity is the twin-deficit channel. A second channel that leads to nonlinearity is the level of a country's indebtedness, which reflects the willingness of foreign lenders to hold domestic assets. The third channel comes from the transaction cost.[2] Therefore, a growing body of studies (see, for example, Chen, 2011a,b; Christopoulos and León-Ledesma, 2010; Chortareas et al., 2004; Holmes and Panagiotidis, 2009; Kim et al., 2009; Raybaudi et al., 2004; Takeuchi, 2010) have turned their attention to the adoption of more sophisticated nonlinear models to test the current account's sustainability. Basically, the empirical evidence from this line of research indicates that, by taking the nonlinear property into account, the US (e.g., Christopoulos and León-Ledesma, 2010) and Latin American countries (e.g., Chortareas et al., 2004) are no longer in violation of current account sustainability. For the benefit of readers, we summarize the recent contributions to the

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[1] Readers are referred to Chen (2011a) for a brief summary of recent contributions to current account sustainability after 2000.

[2] Readers are referred to Milesi-Ferretti and Razin (1998), Mann (2002) and Freund (2005) for explanations of nonlinearity may be relevant for analyzing the time series properties of the current account.

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sustainability hypothesis of the current account imbalance by using the nonlinear approach in Table 1.

Although recent studies have pointed out the importance of nonlinearity in testing for current account sustainability, thorough investigations on which type of nonlinearity is really vital to the determination of current account sustainability are rare in the literature. Clarida et al. (2006) consider nonlinearities in the form of threshold effects, but are the dynamics of current account adjustment dependent upon the sign of deviations from long-run equilibrium? Holmes and Panagiotidis (2009) also consider nonlinearities that stem from structural breaks by using the Breitung (2002) non-parametric cointegration test. The purpose of this paper is to contribute to the empirical literature on examining whether or not the deficits in the current account are sustainable by taking a variety of nonlinearities into consideration. We test three types of nonlinearities, i.e., *the nonlinearity that stems from structural breaks*, *size nonlinearity* and *sign nonlinearity*, for the G-7 countries and examine their importance in letting the current account imbalance be sustainable.

In order to examine the effect of these three types of nonlinearities on current account sustainability, the empirical approach followed is threefold. First, rather than attempting to model any structural change in trend as an instantaneous trend break, we employ logistic smooth transition models proposed by Leybourne et al. (1998) to model the nonlinearity that stems from structural breaks. These models permit the possibility of a smooth transition between two different trend paths over time. Leybourne and Mizen (1999) point out that "when considering aggregate behavior, the time path of structural changes in economic series is likely to be better captured by a model whose deterministic component permits gradual rather than instantaneous adjustment."[3]

The second type of nonlinearity is related to the concept of *asymmetric adjustment towards equilibrium*, and implies that the current account reacts in a different manner depending on the sign of the disequilibrium. In order to consider the possibility of an asymmetric adjustment towards equilibrium when testing for unit roots, we adopt the nonlinear unit root tests proposed by Sollis (2004) and Cook and Vougas (2009).

Finally, when the current account deficit is larger than some threshold value, market participants may view the current account as a problem and policymakers may try to reduce the size of these deficits by a sharp depreciation of the domestic currency to avoid a financial crisis. Kim et al. (2009, p. 167) point out that "such nonlinearity implies an equilibrium level of the current account in the neighborhood of which the behavior of the current account is close to a random walk, becoming increasingly mean reverting with the absolute size of the deviation from equilibrium." This type of nonlinearity is well-characterized by the exponential smooth transition autoregressive (ESTAR) model. Therefore, we apply the nonlinear unit root test proposed by Kapetanios et al. (2003), Rothe and Sibbertsen (2006) and Kruse (2011) to take into account the possibility of an asymmetric speed of adjustment towards equilibrium.

The major findings of this study are as follows. First, the current account series for seven (Australia, Belgium, Czech Republic, New Zealand, Norway, Greece and Ireland) of ten European countries are stationary processes and are thus sustainable based on the traditional unit roots. Second, with the exception of Finland, Portugal and Spain, the current account-GDP ratios of the European countries exhibit structural break nonlinearity, indicating that we are inclined to accept the null hypothesis of the unit root if we overlook the structural break nonlinearity. Finally, none of the current account-GDP ratios of ten European countries exhibit sign nonlinearity. However, eight of ten countries exhibit size nonlinearity. This finding implies that the policymakers or markets care about the asymmetric speed of adjustment towards equilibrium instead of asymmetric adjustment around a threshold towards equilibrium.

The remainder of this paper is organized as follows. Section 2 briefly discusses the theoretical model of the current account. Section 3 discusses three types of nonlinearities in the literature. Section 4 introduces the econometric methodology that we employ, and Section 5 describes the data and the empirical test results. Section 6 presents the conclusions that we draw from this research.

2. Theoretical background

The intertemporal model of the current account provides the optimal current account path based on the behavior of a representative agent who is infinitely-lived and smoothes consumption over time by lending or borrowing abroad. This approach considers the current account from a savings–investment perspective. Following earlier studies such as Trehan and Walsh (1991) and Hakkio and Rush (1991), let us consider an economy with the following two-period budget constraint:

$$C_t + I_t + G_t + B_t = Y_t + (1 + r_t)B_{t-1}, \tag{1}$$

where C_t, I_t, G_t, B_t, Y_t and r_t are consumption, investment, government expenditure, net foreign assets, income, and the world interest rate, respectively. Rearranging Eq. (1) we have

$$B_t = (1 + r_t)B_{t-1} + Y_t - C_t - I_t - G_t = (1 + r_t)B_{t-1} + NX_t \tag{2}$$

where NX_t is the country's net exports defined as $NX_t = Y_t - C_t - I_t - G_t$. Let $R_t = 1 + r_t$ with expected value $E(R_{t+j}|I_{t-1}) = R$ for all t and $i \geq 1$ and Ω_{t-1} be the information set available at time $(t - 1)$. Following Trehan and Walsh (1991, p. 209), we may iterate this equation forward in time, solving recursively, to obtain the result that the current credit (debt) position must be offset, in expected value terms, by future deficits (surpluses). Iterating Eq. (2) forward, we can derive

$$B_{t-1} = -\sum_{j=0}^{\infty} R^{-(j+1)} E\left(NX_{t+j}|\Omega_{t-1}\right) + \lim_{j\to\infty} R^{-(j+1)} E\left(B_{t+j}|\Omega_{t-1}\right). \tag{3}$$

We define the LRBC hypothesis so that the last term in Eq. (3) must equal zero,

$$LRBC: \lim_{j\to\infty} R^{-(j+1)} E\left(B_{t+j}|\Omega_{t-1}\right) = 0, \tag{4}$$

which states that the present discounted value of the stock of assets must converge to zero as t tends to infinity. Eq. (4) is also referred to as a Non-Ponzi game condition. Trehan and Walsh (1991) show that given that the current account $CA_t = B_t - B_{t-1}$, a sufficient condition for Eq. (4) to hold is that the current account is stationary. If the growth rate of an economy is positive, then current account sustainability holds if the ratio $y_t = \frac{CA_t}{Y_t}$ is stationary. This means that sustainability is possible with perpetual current account deficits as long as they do not grow faster than output in terms of expected value. In this case, the sustainability hypothesis implies that the debt-to-GDP ratio is constant in the long-run. Nonstationarity should be interpreted as meaning that, during the sample period observed, the behavior of the current account is not compatible with the inter-temporal budget constraint (Christopoulos and León-Ledesma, 2010).

It should be noted that in Trehan and Walsh's (1991) model, the Non-Ponzi game condition (abbreviated as NPGC) is preliminarily assumed. This assumption necessarily implies that their investigation was conducted only in regard to the necessary condition and not the

[3] In the context of economic time series this has considerable intuitive appeal. In general, changes in economic aggregates are influenced by the changes in the behavior of a very large number of agents. It is highly unlikely that all individual agents will react simultaneously to a given economic stimulus; while some may be able to (and may want to) react instantaneously, others will be prone to different degrees of institutional inertia (dependent, for instance, on the efficiency of the markets in which they have to operate) and so will adjust with different time lags (Leybourne and Mizen, 1999, p 804).

sufficient condition. The sample period in this paper covers almost forty years and it is a rough assumption that the sufficient condition is satisfied. This issue has already been carefully examined in Ahmed and Rogers (1995) and Matsubayashi (2005). It should also be noted that care is needed when deciding upon the probability of NPGC.

3. Three types of nonlinearities

There are several different types of nonlinearities in the literature. First, nonlinearity may affect the variable in the form of *structural changes* in the deterministic components. From an economic point of view, if the current account imbalance-to-GDP ratio is a stationary process around a nonlinear deterministic trend, then it implies a time-varying equilibrium current account-GDP ratio. From an econometric point of view, if the true data generating process is a linear process with structural breaks (e.g., Perron, 1989) or nonlinear (e.g., Bierens, 1997; Pippenger and Goering, 1993), then the traditional unit root or cointegration tests may suffer from size distortion and low power problems.

Second, if the mean-reverting process that governs the current account adjustment to the long run equilibrium is nonlinear, then the adjustment process may depend both upon the *size* and *sign* of the current account imbalance. Clarida et al. (2006) point out that both government policies and market forces can induce faster current account corrections when deficits reach certain 'danger zone', leading to nonlinear adjustment dynamics in the current account. Christopoulos and León-Ledesma (2010) claim that changes in the agents' perceptions regarding risk, portfolio allocation decisions, future policy changes, and transaction costs in international financial flows, etc., can lead to changes in the dynamics of current account mean reversion and hence equilibrium values of the current account. Thus, for large changes in the current account imbalance away from equilibrium we might expect the speed of mean reversion to be faster as markets (or governments) would not be willing to finance deviations from equilibrium for long periods. Thus, the process of nonlinear adjustment depends on *the size of the disequilibrium*.

Finally, sign nonlinearity could be motivated by asymmetric market friction or the action of policy-makers may also impart nonlinear adjustment dynamics. In particular, where, for example, central banks have an explicit current account imbalance-GDP ratio target (e.g., 6% of GDP), they may pay more attention to rising current account-GDP ratios than to falling ratios due to their different implications for default risk. Specifically, this implies that the current account imbalance exhibits asymmetric adjustment. It reacts in a different manner depending on *the sign of the disequilibrium* or shock.

4. Econometric methodology

4.1. Structural break nonlinearity with LSTR unit root test

As mentioned in the previous section, nonlinearity may affect a variable in the form of *structural changes* in the deterministic components. That is, a broken time trend is a particular case of a nonlinear time trend. In order to take account of the possibility of nonlinear trends, we apply the Leybourne et al. (1998) (LNV hereafter) nonlinear trend modeling approach. Leybourne et al. (1998) develop a unit root test against the alternative hypothesis of stationarity around a logistic smooth transition (LSTR) nonlinear trend. It is appealing as it permits structural shifts to occur gradually over time. Leybourne et al. (1998) consider three models:

$$\text{Model A}\;\; y_t = \alpha_1 + \alpha_2 S_t(\gamma,\tau) + \nu_t, \tag{5}$$

$$\text{Model B}\;\; y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma,\tau) + \nu_t, \tag{6}$$

$$\text{Model C}\;\; y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma,\tau) + \beta_2 t S_t(\gamma,\tau) + \nu_t, \tag{7}$$

where ν_t is a zero mean I(0) process, $S_t(\gamma, \tau)$ is the logistic smooth transition function:

$$S_t(\gamma,\tau) = [1 + \exp\{-\gamma(t-\tau T)\}]^{-1}. \tag{8}$$

The parameter τ determines the timing of the transition midpoint. Since $\gamma > 0$, we have $S_{-\infty}(\gamma,\tau) = 0$, $S_{+\infty}(\gamma,\tau) = 1$, and $S_{\tau T}(\gamma,\tau) = 0.5$. The speed of transition is determined by the parameter γ. If ν_t is a zero-mean I(0) process, then in Model A y_t is stationary around a mean which changes from the initial value α_1 to the final value $\alpha_1 + \alpha_2$. Model B is similar, with the intercept changing from α_1 to $\alpha_1 + \alpha_2$, but it allows for a fixed slope term. In Model C, in addition to the change in intercept from α_1 to $\alpha_1 + \alpha_2$, the slope also changes simultaneously, and with the same speed of transition, from β_1 to $\beta_1 + \beta_2$.

The null hypothesis and alternative hypothesis are as follows:

$$H_0\;\; y_t = \mu_t, \mu_t = \mu_{t-1} + \varepsilon_t, \mu_0 = \psi, \tag{9}$$

$$H_1\;\text{Model A, Model B or Model C}, \tag{10}$$

or

$$H_0\;\; y_t = \mu_t, \mu_t = \kappa + \mu_{t-1} + \varepsilon_t, \mu_0 = \psi, \tag{11}$$

$$H_1\;\text{Model B or Model C}. \tag{12}$$

LNV suggests a two-step testing strategy, first estimating Eqs. (5)–(8) by nonlinear least squares, and then applying an ADF test with no deterministic component to the resulting residual,

$$\Delta\hat{\nu}_t = \hat{\rho}\hat{\nu}_{t-1} + \sum_{i=1}^{k}\hat{\delta}_i\Delta\hat{\nu}_{t-i} + \hat{\eta}_t. \tag{13}$$

The statistics are labeled s_α, $s_{\alpha(\beta)}$ and $s_{\alpha\beta}$ corresponding to Model A to C, respectively.

4.2. Sign nonlinearity with LSTR–TAR and LSTR–MTAR unit root test

The second type of nonlinearity is related to the concept of *asymmetric adjustment towards equilibrium*, and implies that the current account reacts in a different manner depending on the sign of the disequilibrium. In order to consider the possibility of an asymmetric adjustment towards equilibrium when testing the unit root, we adopt the unit root test proposed by Sollis (2004) and Cook and Vougas (2009). They combine the ideas of Enders and Granger (1998) and Leybourne et al. (1998) and develop tests of the null hypothesis of a unit root, that under the alternative hypothesis allow for stationary asymmetric adjustment around a smooth transition between deterministic linear trends.

We consider two asymmetric versions in order to capture sign asymmetry. The first is the threshold autoregressive (TAR) model:

$$\Delta\hat{\nu}_t = I_t\hat{\rho}_1\hat{\nu}_{t-1} + (1-I_t)\hat{\rho}_2\hat{\nu}_{t-1} + \sum_{i=1}^{k}\hat{\delta}_i\Delta\hat{\nu}_{t-i} + \hat{\eta}_t, \tag{14}$$

where I_t is the Heaviside indicator function,

$$I_t = \begin{cases} 1, & \text{if}\;\; \hat{\nu}_{t-1} \geq 0, \\ 0, & \text{if}\;\; \hat{\nu}_{t-1} < 0, \end{cases} \tag{15}$$

and $\hat{\nu}_t$ is the residual from the first step by using the nonlinear least squares for Eq. (7). Eqs. (5)–(7), (14) and (15) refer to the LSTR–TAR model. If $H_0 : \rho_1 = \rho_2 = 0$ in Eq. (14), then $\hat{\nu}_t$ and therefore y_t contains a unit root. The statistics are referred to as F_α, $F_{\alpha(\beta)}$ and $F_{\alpha\beta}$ and correspond to Models A to C, respectively. Sollis (2004) shows that the *F*-statistic does not have an asymptotic standard normal distribution and he tabulates the asymptotic critical values of the t statistics via stochastic simulations. If $H_0: \rho_1 = \rho_2 = 0$ is rejected and $\rho_1 = \rho_2 < 0$ hold, then $\hat{\nu}_t\,(y_t)$ is a stationary LSTR–TAR process with symmetric adjustment. If $H_0: \rho_1 = \rho_2 = 0$ is rejected and $\rho_1 < 0, \rho_2 < 0, \rho_1 \neq \rho_2$ holds, then $\hat{\nu}_t\,(y_t)$ is a stationary LSTR–TAR process displaying asymmetric adjustment.

Alternatively, Cook and Vougas (2009) combine Eqs. (5)–(7), (17) and (19) and propose a logistic smooth transition–momentum TAR (LSTR–MTAR) model as follows:

$$\Delta\hat{\nu}_t = M_t\hat{\rho}_1\hat{\nu}_{t-1} + (1-M_t)\hat{\rho}_2\hat{\nu}_{t-1} + \sum_{i=1}^{k}\hat{\delta}_i\Delta\hat{\nu}_{t-i} + \hat{\eta}_t, \tag{16}$$

where M_t is the Heaviside indicator function,

$$M_t = \begin{cases} 1, & \text{if} \quad \Delta\hat{\nu}_{t-1} \geq 0, \\ 0, & \text{if} \quad \Delta\hat{\nu}_{t-1} < 0. \end{cases} \tag{17}$$

The statistics are referred to as F^*_α, $F^*_{\alpha(\beta)}$ and $F^*_{\alpha\beta}$ corresponding to Model A to C, respectively. Critical values must be tabulated via Monte Carlo simulations.

The threshold autoregressive model (TAR) allows the degree of autoregressive decay to depend on the state of the current account imbalance, measuring the "deep" cycles. For instance, if the autoregressive decay is fast when the imbalance is above trend and slow when the imbalance is below trend, troughs will be more persistent than peaks. Likewise, if the autoregressive decay is slow when the imbalance is above trend and fast when the deficit is above trend, peaks will be more persistent than troughs. On the other hand, the momentum threshold autoregressive model (MTAR) allows the current account imbalance to display differing amounts of autoregressive decay depending on whether the imbalance is increasing or decreasing, measuring the "sharpness" of cycles (Payne and Mohammadi, 2006).

4.3. Size nonlinearity with ESTAR unit root test

The final type of nonlinearity is related to the possibility of an *asymmetric speed of adjustment towards equilibrium*, i.e., the further the current account deviates from its fundamental equilibrium, the faster will be the speed of mean reversion. This implies that the current account may be a unit root process for a given threshold of values (inner regime), but a unit root when the current account reaches the outer regime. In order to take account of the possibility of an asymmetric speed of adjustment towards equilibrium when testing for the unit roots, we apply the exponential smooth transition autoregressive (ESTAR) unit root tests proposed by Kapetanios et al. (2003) (KSS hereafter), Rothe and Sibbertsen (2006) and Kruse (2011).

Kapetanios et al. (2003) have developed a new technique for the null hypothesis of a unit root against an alternative of a nonlinear but globally stationary smooth transition autoregressive process. In particular, Kapetanios et al. (2003) test for the null hypothesis of $\gamma = 0$ in the following model:

$$\Delta y_t = \beta y_{t-1}\left[1 - \exp\left(-\gamma y^2_{t-1}\right)\right] + \varepsilon_t. \tag{18}$$

The test is carried out by a t-test of the coefficient of y^3_{t-1} being zero in the auxiliary regression

$$\Delta y_t = \delta y^3_{t-1} + \sum_{j=1}^{p}\rho_j\Delta y_{t-j} + \eta_t, \tag{19}$$

with the p augmentations in order to correct for serially correlated errors. The null hypothesis to be tested with Eq. (19) is $H_0: \delta = 0$ (unit root in outer regime) against the alternative of $H_1: \delta < 0$ (stationarity in outer regime). Kapetanios et al. (2003) show that the t-statistic for $\delta = 0$ against $\delta < 0$ does not have an asymptotic standard normal distribution and they tabulate the asymptotic critical values of the t statistics via stochastic simulations. In the presence of constants and trends, the

Table 1
Summary of contributions to current account sustainability by using the nonlinear approach after 2000.

Studies	Countries and samples covered	Methodology	Sustainability
Apergis et al. (2000)	Greece, 1969–1994	Gregory–Hansen cointegration test with regime shift	Held
Baharumshah et al. (2003)	Indonesia, Malaysia, the Philippines, and Thailand, 1961–1999	Unit root test, Gregory–Hansen cointegration test with regime shift	Violated
Chen (2010)	The US and the UK: 1960–2008, Canada: 1961–2008, France: 1978–2008	Bierens (1997) nonlinear unit root test	Inconclusive
Chen (2011a)	Italy, 1971–2008, Germany, 1991–2008 Canada, Japan, the UK, the US, 1970–2008 France, 1975–2008	Markov switching ADF unit root test	Japan and Germany held Red signal: Canada, France, Italy, Germany, the UK and the US
Chen (2011b)	Australia, 1970–2009; Hungary, 1993–2009; Belgium, Finland and Portugal, 1975–2009; Czech Republic, 1991–2009, Spain, 1983–2009; New Zealand, 1971–2009	Markov switching ADF unit root test	Red signal: Australia, Spain, Czech Republic, Finland, Hungary, Portugal, New Zealand
Christopoulos and León-Ledesma (2010)	US, 1960–2008	Kilic's (2011) ESTAR unit root test	Held
Chortareas et al. (2004)	Argentina, Bolivia, Brazil, Chile, Colombia, El Salvador, Guatemala, Mexico, Nicaragua, Panama, Peru, and Venezuela, 1970–2000	Kapetanios and Shin (2006) threshold unit root test	Held
Herzer and Nowak-Lehmann (2006)	Chile, 1975–2004	Unit root test Gregory–Hansen cointegration test with regime shift	Held
Kim et al. (2009)	Indonesia, Korea, Malaysia, the Philippines, Thailand, 1981–2003	Park and Shintani (2005) nonlinear unit root test	Held
Liu and Tanner (2001)	G-7 countries, 1970–1990	Unit root test with and without break	The US, the UK, Germany, Japan, Canada violated
Onel and Utkulu (2006)	Turkey, 1970–2002	Zivot–Andrews unit root test, Gregory–Hansen cointegration test with regime shift	weakly held
Raybaudi et al. (2004)	Argentina, 1992–2001, Brazil, 1995–2002 Japan, the UK, the US, 1970–2008	Markov switching ADF unit root test	Brazil, Japan, the UK held Argentina, the US violated
Holmes and Panagiotidis (2009)	The US, 1960Q4–2007Q2	Breitung (2002) non-parametric cointegration test	Held
Takeuchi (2010)	The US, 1961–2008	Bayesian Markov Switching unit root test	The probability of sustainability is high

Readers are referred to Tables 1 and 2 of Chen (2011a) for a summary of recent contributions on current account sustainability after 2000 by using the linear approach.

Table 2
Results of the linear unit root tests.

Country	Linear trend			Quadratic trend and breaks tests		
	ADF	SP(1)	DF–GLS	SP(2)	ZA, Model C	LP, Model C
Australia	−4.184***	−3.893**	−3.570**	−4.519**	−5.421*	−6.322
Belgium	−1.530	−5.698**	−6.315**	−8.868**	−4.059	−5.667
Czech Republic	−3.934**	−3.824**	−3.637**	−4.939**	−5.544*	−7.194**
Finland	−1.917	−2.872	−2.467	−2.164	−4.372	−5.713
New Zealand	−4.188**	−4.304**	−3.964**	−4.419**	−5.244*	−6.834*
Norway	−2.643	−3.922**	−3.935**	−3.923*	−5.263*	−6.447
Greece	−3.713**	−6.239**	−5.996**	−7.173**	−5.448*	−5.640
Ireland	−1.983	−5.283**	−5.219**	−4.599**	−4.303	−4.131
Portugal	−2.874	−2.640	−2.823	−2.420	−4.070	−5.806
Spain	−3.115	−1.739	−1.944	−2.462	−3.472	−4.888

(1) *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively. (2) ADF, SP(1) and DF–GLS denote the augmented Dickey–Fuller test, Schmidt–Phillips τ test with linear trend and Elliott et al. (1996) DF–GLS test, respectively. (3) SP(2), ZA and LP denote the Schmidt–Phillips τ test with quadratic trend, Zivot and Andrews (1992) and Lumsdaine and Papell (1997) tests, respectively. (4) The 5% critical values for the ADF, SP(1) and DF–GLS tests are −3.43, −3.04 and −2.89, respectively. (5) The 5% critical values for the SP(2), ZA and LP tests are −3.55, −5.08 and −6.75, respectively.

Table 3
p-values for a battery of nonlinear tests.

	Australia	Belgium	Czech Republic	Finland	New Zealand	Norway	Greece	Ireland	Portugal	Spain
RESET1	0.746	0.181	0.045	0.511	0.975	0.181	0.098	0.066	0.022	0.730
RESET2	0.746	0.000	0.045	0.596	0.975	0.007	0.029	0.004	0.021	0.730
KEENAN	0.358	0.252	0.330	0.330	0.953	0.956	0.024	0.095	0.708	0.279
TSAY	0.357	0.001	0.327	0.541	0.953	0.421	0.008	0.000	0.823	0.277
MCLEOD	0.204	0.000	0.997	0.861	0.061	0.554	0.963	0.002	0.523	0.038
BDS	0.287	0.134	0.349	0.669	0.001	0.086	0.394	0.001	0.458	0.599
WHITE1	0.793	0.103	0.160	0.677	0.263	0.297	0.190	0.099	0.524	0.368
WHITE2	0.897	0.000	0.286	0.876	0.002	0.212	0.164	8.000	0.088	0.606
NEURAL1	0.595	0.141	0.782	0.146	0.818	0.028	0.129	0.018	0.342	0.921
NEURAL2	0.622	0.222	0.881	0.241	0.972	0.020	0.090	0.002	0.192	0.500

(1) RESET1: Ramsey and Schmidt (1976). (2) RESET 2: Thursby and Schmidt (1977). (3) KEENAN: Keenan (1985). TSAY: Tsay (1986). (4) MCLEOD: McLeod and Li (1983). (5) BDS: Brock et al. (1996). (6) WHITE1 and WHITE2 are White's (1987) information matrix tests. (7) NEURAL1 and NEURAL2 are the neural network proposed by White (1989a,b).

data are first demeaned or detrended. We refer to this test as the KSS nonlinear augmented Dickey–Fuller test and label it as $KSS(t_{NL})$.

Rothe and Sibbertsen (2006) propose a Phillips–Perron type, semi-parametric testing procedure to distinguish a unit root process from a mean-reverting exponential smooth transition autoregressive one. The test statistic is as follows:

$$Z_{NL}(t)=\frac{\hat{\sigma}}{\hat{\lambda}}t_{\hat{\beta}}-\frac{3}{2}\sum_{t=1}^{T}y_{t-1}^{2}\left(\hat{\lambda}^{2}-\hat{\sigma}^{2}\right)\left(\hat{\lambda}^{2}\sum_{t=1}^{T}y_{t-1}^{6}\right)^{-1/2}, \tag{20}$$

where $\hat{\lambda}^2$ is the consistent estimator of the long run variance λ^2, and $\hat{\sigma}^2$ is the consistent estimator of the variance σ^2. Their simulation results show that the power of $Z_{NL}(t)$ dominates that of $KSS(t_{NL})$ in the case of where γ is small and where the error sequence is an MA(1).

Kruse (2011) proposes an extension of the KSS unit root test, which relaxes the assumption of a zero location parameter c, i.e., Kruse (2011) considers the following modified ADF regression

$$\Delta y_t=\beta y_{t-1}\left[1-\exp\left(-\gamma y_{t-1}^2-c\right)\right]+\varepsilon_t. \tag{21}$$

Following KSS, it is possible to obtain a Taylor approximation of Eq. (21) as follows:

$$\Delta y_t=\delta_1 y_{t-1}^3+\delta_2 y_{t-1}^2+\sum_{j=1}^{p}\rho_j\Delta y_{t-j}+u_t. \tag{22}$$

Eq. (22) incorporates lags of the dependent variable in order to eliminate serial correlation in the error terms. In order to test the null hypothesis of a unit root, $H_0:\delta_1=\delta_2=0$, against a globally stationary ESTAR process, $H_1:\delta_1<0,\ \delta_2=0$. Kruse (2011) proposes a τ test, which is a version of the Abadir and Distaso (2007) Wald test.

5. Data and results

The data include quarterly observations of the current account balance as percentages of GDP. We focus on ten European countries, Australia, Belgium, Czech Republic, Finland, New Zealand, Norway, Greece, Ireland, Portugal and Spain, in our empirical study. The sample periods are different across countries depending on the availability of data. The sample period is 1970:Q1–2012:Q2 for Australia; 1975:Q1–2012:Q2 for Belgium, Finland, Norway, Ireland, Portugal and Spain; 1991:Q1–2012:Q2 for the Czech Republic; 1975:Q1–2008:Q4 for Greece; and 1971:Q2–2012:Q2 for New Zealand. All data are obtained from Datastream.[4]

As a preliminary analysis, we apply a battery of unit root tests to determine the order of integration of the current account imbalance-GDP ratio. We consider the Augmented Dickey–Fuller (ADF) test as well as the ADF–GLS test of Elliott et al. (1996) in this study. Vougas (2007) highlights the usefulness of the Schmidt and Phillips (1992) (SP hereafter) unit root test in practice. Therefore, we also employ it in this study. These authors propose some modifications of existing unit root tests in order to improve their power and size. An auxiliary regression is run with an intercept and a time trend. To select the lag length (k) we use the 't-sig' approach proposed by Hall (1994). That is, the number of lags is chosen for which the last included lag has a marginal significance level that is less than the 10% level.

The results of applying these tests are reported in the top panel of Table 2. We find that, only for the cases of Australia, Czech Republic, New Zealand and Greece, the null hypothesis of a unit root can be rejected at the 5% level for the ADF test with linear trend. This is

[4] The sample periods are dependent upon the availability of data. When the authors start to study this issue and download the data from the Datastream, unfortunately, the data availability for Greece is ended in 2008Q4.

Table 4
Results of the W_λ linearity test.

Country	W_λ	$W^*_{10\%}$	$W^*_{5\%}$	$W^*_{1\%}$
Australia	0.74	3.29	3.31	3.34
Belgium	4.75	6.98	7.03	7.13
Czech Republic	1.06	9.72	9.75	9.81
Finland	0.34	1.48	1.48	1.50
New Zealand	1.84	5.81	5.83	5.86
Norway	4.67	10.31	10.38	10.50
Greece	3.22	10.87	10.95	11.09
Ireland	14.27**	14.05	14.16	14.38
Portugal	6.68	15.49	15.57	15.71
Spain	1.45	3.03	3.05	3.08

(1) *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

not the case for the SP and ADF–GLS unit root tests. The SP test (see Schmidt and Phillips, 1992), with parametric correction, rejects the unit root hypothesis with both linear and quadratic trend at the five percent significance level for Australia, Belgium, Czech Republic, New Zealand, Norway, Greece and Ireland, suggesting that the current account-GDP ratios for these countries are stationary processes.[5] The results from the ADF–GLS test also reach the same conclusion as the SP test. Based on the linear unit root test results, the current account-GDP ratios of Finland, Portugal and Spain are nonstationary processes.

As Perron (1989) pointed out, in the presence of a structural break, the power to reject a unit root decreases if the stationary alternative is true and the structural break is ignored. To address this issue, we use Zivot and Andrews' (1992) sequential one trend break model and Lumsdaine and Papell's (1997) two trend breaks model to investigate the order of the empirical variables. We use the 't-sig' approach proposed by Hall (1994) to select the lag length (k). We set $k_{max} = 12$ and use the approximate 10% asymptotic critical value of 1.60 to determine the significance of the t-statistic for the last lag. We use the 'trimming region' [0.10 T, 0.90 T] and select the break point endogenously by choosing the value of the break that maximizes the ADF t-statistic. We report the results in the bottom panel of Table 2. The results suggest that for half of the countries, the null hypothesis of a unit root cannot be rejected at the 5% significance level, indicating that the current account-GDP ratios are nonstationary in their respective levels. These findings echo those obtained from the linear unit roots.

We can categorize the hypotheses into four cases:[6] H_1: linear and stationary process. H_2: linear and unit-root nonstationary process. H_3: nonlinear and stationary process. $H4$: nonlinear and unit-root nonstationary process. In order to validate the nonlinear unit root used in this paper, we conduct several nonlinearity tests (i.e., H_1 vs. H_3) for the current account-GDP ratio. Psaradakis and Spagnolo (2002) examine the relative performance of some popular nonlinearity tests. The nonlinearity tests considered include the RESET-type tests, the Keenan test, the Tsay test, the McLeod–Li test, the BDS test, the White dynamic information matrix test, and the neural network test.[7] We adopt these statistics to examine whether any nonlinearity exists in the current account-GDP ratio. The results are reported in Table 3. Table 3 shows that, except for Australia and Finland, some of the p-values of these nonlinear tests are smaller than the 10% significance level or better, indicating that the current account-GDP ratios of the these countries have nonlinear property.[8]

We also test for H_1 against H_4 by using Harvey et al. (2008) test. These authors propose a test with the same limiting distribution regardless of whether the variable is I(0) or I(1). The new test is called W_λ and is distributed as a $\chi^2(2)$. We display the results of applying the W_λ test in Table 4. From the second column we can see that the null of linearity is rejected at the conventional significance level for the case of Ireland.

Table 5
Results of the LSTR unit root test.

	LSTR		
Country	s_α	$s_{\alpha(\beta)}$	$s_{\alpha\beta}$
Australia	−5.234***	−5.235***	−5.239**
Belgium	−2.107	−4.239	−3.967
Czech Republic	−4.550**	−5.104**	−5.076**
Finland	−2.492	−3.820	−4.251
New Zealand	−4.427**	−4.449*	−5.051**
Norway	−3.495	−3.458	−3.756
Greece	−4.457**	−5.071**	−5.095**
Ireland	−2.579	−2.974	−3.314
Portugal	−3.944	−3.610	−3.619
Spain	−2.015	−1.976	−3.235
10% cv	−3.851	−4.337	−4.572
5% cv	−4.161	−4.629	−4.867
1% cv	−4.761	−5.201	−5.435

(1) *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively. (2) LNV-ADF denotes the nonlinear unit root test proposed by Leybourne et al. (1998). (3) The critical values for the LSTR statistics are obtained from Leybourne et al. (1998).

As mentioned in the Introduction, nonlinearity occurs in the form of *structural changes* in the deterministic components. That is, a broken time trend is a particular case of a nonlinear time trend. In order to take the possibility of nonlinear trends into consideration, we apply the logistic smooth transition unit root, championed by Leybourne et al. (1998), in this study. This approach permits structural shifts to occur gradually over time instead of instantaneously. We summarize the test results in Table 5. Based on the s_α, $s_{\alpha(\beta)}$ and $s_{\alpha\beta}$ statistics, it is found that for four of the ten countries, the null hypothesis of a unit root is rejected at least at the 10% significance level or better, indicating that the current account-GDP ratios of these four countries (i.e., Australia, Czech Republic, New Zealand and Greece), are stationary processes around a logistic smooth transition nonlinear trend. Although the breaks alone can account for rejection of the unit root null, the evidence in favor of current-account sustainability is not sufficiently strong.

Figs. 1 to 10 include the time series plots of the current account-GDP ratios (black line) and the estimated logistic smooth transition functions (blue line) of Model C for the ten European countries.[9] Intuitively, if the true data generating process follows the logistic smooth transition function nonlinear process, then the estimated logistic smooth transition trends are close to the raw data. As such, it is highly possible to reject the null hypothesis of nonstationarity. Taking Australia as an example (Fig. 1), the estimated logistic smooth transition trend of Model C is quite close to the raw data. These plots echo the rejections of the null hypothesis of a unit root at the 1% significance level by the $s_{\alpha(\beta)}$ and $s_{\alpha\beta}$ statistics as shown in Table 5. This is also true for the cases of Czech Republic, New Zealand and Greece.

Let us turn our attention to the sign nonlinearity of the current account-GDP imbalance. The LSTR–TAR specification is examined by first testing the null hypothesis of a unit root, $\rho_1 = \rho_2 = 0$, in Eq. (14) and comparing the appropriate critical values from Sollis (2004). The results are included in the top panel of Table 6. From the results for the F_α, $F_{\alpha(\beta)}$ and $F_{\alpha\beta}$ as shown in Table 6, with the exception of Norway, the null hypothesis of a unit root can be rejected at the 10% significance level or better. The results imply that the current account-GDP ratios are nonlinear stationary processes for nine of the ten countries (i.e., Australia, Belgium, Czech Republic, Finland, New Zealand, Greece, Ireland, Portugal and Spain). However, the null hypothesis of symmetry, $\rho_1 = \rho_2$, is not rejected at the conventional significance level. Thus, the evidence suggests that the 'deep' cycles (adjustments) around the threshold value of the current account-GDP imbalance are symmetric.

[5] Our results echo Vougas (2007) that the SP test does reject difference stationarity in favor of linear trend stationarity.

[6] We owe this point to one of our referees.

[7] Readers are referred to Psaradakis and Spagnolo (2002) for detailed descriptions of these tests.

[8] It should be noted that linearity or nonlinearity has no bearing on current account sustainability as long as it is stationary. We owe this point to one of our referees.

[9] The detailed estimation results of the logistic smooth transition model, i.e., Eqs. (5)–(8), are available from the author upon request.

Next, the MTAR specification which has favorable power and size properties relative to the alternative of symmetric adjustment (Enders and Siklos, 2001, p. 166) is examined. The LSTR–MTAR model allows the adjustment to depend on the previous period's change in the current account deficit. The results of the test statistics (F^*_α, $F^*_{\alpha(\beta)}$ and $F^*_{\alpha\beta}$) for the LSTR–MTAR model are reported in the bottom panel of Table 6. For the ten European countries we considered in this study, the null hypothesis of a unit root, $\rho_1 = \rho_2 = 0$, in Eq. (16) is rejected at the 10% or better significance level. These findings indicate that the current account-GDP ratios for these countries again exhibit nonlinear stationarity. The null hypothesis of symmetry, $\rho_1 = \rho_2$ is only rejected at the 5% significance level for New Zealand in the case of the $F^*_{\alpha\beta}$ statistic. However, for the rest of the cases, the null hypothesis of symmetry $\rho_1 = \rho_2$ is not rejected at the 10% significance level or better. Thus, it appears that the 'sharpness' cycles (adjustments) around the threshold values of the current account-GDP ratios are symmetric.

In sum, the empirical results for the respective LSTR–TAR and LSTR–MTAR models reveal that the current account-GDP ratios for the ten European countries are sustainable after taking into account the nonlinear trend. The evidence in favor of current-account sustainability is increased after taking account of the sign nonlinearity and structural break nonlinear at the same time. Nevertheless, they adjust symmetrically around the threshold value after taking into account the nonlinear trend.

Finally, we examine the size nonlinearity which is related to the possibility of an asymmetric speed of adjustment towards equilibrium. That is, the further the current account deviates from its fundamental equilibrium, the faster will be the speed of mean reversion. We apply the $KSS(t_{NL})$ (Kapetanios et al., 2003), $Z_{NL}(t)$ (Rothe and Sibbertsen, 2006) and τ (Kruse, 2011) statistics to the raw data, demean and detrend data of the current account-GDP ratio. The results are reported in Table 7, and point to the rejection of the null hypothesis of a unit root against the alternative of a globally stationary ESTAR process around a nonlinear deterministic trend in four of ten countries. This implies that the size nonlinearity is a vital feature of the current account-GDP ratios of Belgium, Czech Republic, Finland, New Zealand, Norway, Greece, Ireland and Portugal. If we overlook this feature, then we will be inclined to reach a spurious conclusion that the current account imbalance is a nonstationary process and is thus not sustainable. In fact, it is a nonlinear mean-reverting process that favors the sustainability hypothesis.

5.1. Robustness checking

What is the impact of the Euro debt crisis on the empirical test?[10] In order to know the impact of the Euro debt crisis on the empirical results, we re-do the linear and nonlinear unit root tests for all countries before the beginning of the Euro crisis. We summarize the results in Table 9.[11] We find that, in general, our empirical results are unchanged with the exception of the Czech Republic. That is, our empirical test results remain robust with or without taking into consideration of the Euro debt crisis.

5.2. Comparison of results with selective literature

Some comparisons with previous studies have been drawn from our empirical tests. First of all, our empirical results of Australia and Greece agree with Karunaratne (2010) and Panagiotis et al. (2009). Karunaratne (2010) tests the Intertemporal Optimization Model in the Australian context for the study period 1959Q3–2007Q1. Empirical tests based on the application of the net present value criterion using vector autoregressions, unit root and cointegration econometrics reveal that Australia's current account deficit revealed that the current account deficits were unsustainable during the fixed exchange period and over the whole study period 1960Q3–2007Q4, but not during the floating exchange rate period post-1983Q4. The result of the structural break nonlinearity unit root test of our paper is consistent with Karunaratne (2010), which indicates that Australia's current-account deficit is sustainable. Panagiotis et al.'s (2009) empirical evidence shows that trade deficit sustainability holds over the period 1960–2007.[12]

Second, the test results of this paper for nine of ten countries (i.e., Australia, Belgium, Finland, Greece, Ireland, Portugal, Spain, New Zealand, Norway) are in line with those of Holmes et al. (2010) by taking account of nonlinearity. Holmes et al. (2010) employ an AR-based bootstrap approach of Hadri (2000) to examine the stationarity of current account deficits of 13 EU countries (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Portugal, Spain, Sweden, and the United Kingdom) and non-EU countries (Australia, Canada, Iceland, Japan, New Zealand, Norway, Switzerland, and the United States). Within a panel context, and after allowing for the potential effect of cross-sectional dependencies, they find support of the view that the current account deficits of the EU countries are sustainable in the long run.

Third, Chen (2011b) examines whether or not the current account deficits for eight OECD countries (Australia, Belgium, Czech Republic, Finland, Hungary, New Zealand, Portugal and Spain) can be characterized by a unit root process with regime switching. The evidence from the Markov switching unit root regression suggests that it is very likely that the long run budget constraint will not hold for Australia, Czech Republic, Finland, Hungary, New Zealand, Portugal and Spain, thus signifying a red signal that the current account deficits observed during the period were probably not on a sustainable path.

Fourth, Cuestas (2013) applies Kapetanious et al.'s (2003) and Sollis' (2009) approaches, respectively, to examine the current account sustainability of European transition economies from 1999Q1 to 2011Q3. The former captures the size nonlinearity, the latter characterizes the sign nonlinearity. Our empirical results echo his empirical evidence that the current account GDP ratio of the Czech Republic exhibits size and sign nonlinearities. Moreover, the test results of our paper show that the current account deficit sustainability holds for the Czech Republic, which is consistent with Cuestas (2013).

Finally, for the benefit of the readers, we summarize the recent contributions to current account sustainability by using the nonlinear approach in Table 10. Compared to previous researches, Table 10 shows that a unique contribution of this study is that we test for the three types of nonlinearities one by one for the ten European countries.

6. Concluding remarks

This paper examines three types of nonlinearities, i.e., nonlinearity stemming from structural breaks, sign nonlinearity and size nonlinearity, of the current account imbalances for ten European countries and tries to answer the question: Which one is essential to enabling the current account imbalance to be sustainable? For the readers' information, we summarize all of the empirical evidence of this paper in Table 8 and reach the following key conclusions.

First, by using a battery of univariate unit root tests, we find evidence in favor of stationary current account-GDP ratios in seven (Australia, Belgium, Czech Republic, New Zealand, Norway, Greece and Ireland) of the ten European countries. The results are somewhat different from the previous literature (e.g., Chen, 2011b) in that the traditional linear unit root is inclined to accept the null hypothesis of nonstationarity. This diversity is partly due to differences in methodology and partly due to different samples employed in our paper.

[10] We thank an anonymous referee for pointing this to us.

[11] The detailed test results are omitted for brevity and available from the authors upon request.

[12] Readers are referred to Karunaratne (2010) and Panagiotis et al. (2009) for a brief reference on the Australia and Greek economies.

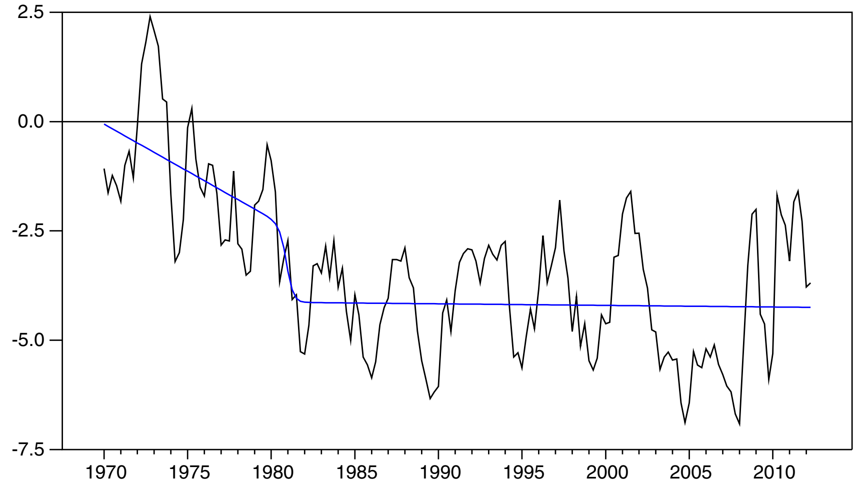

Fig. 1. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Australia.

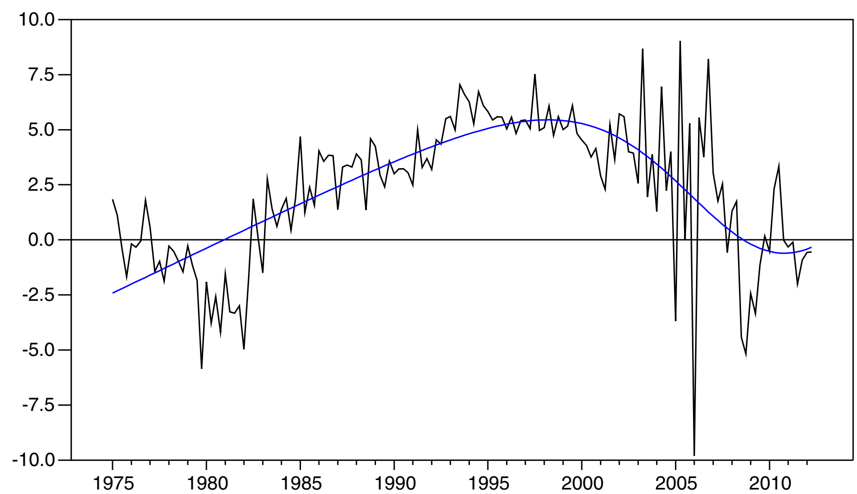

Fig. 2. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Belgium.

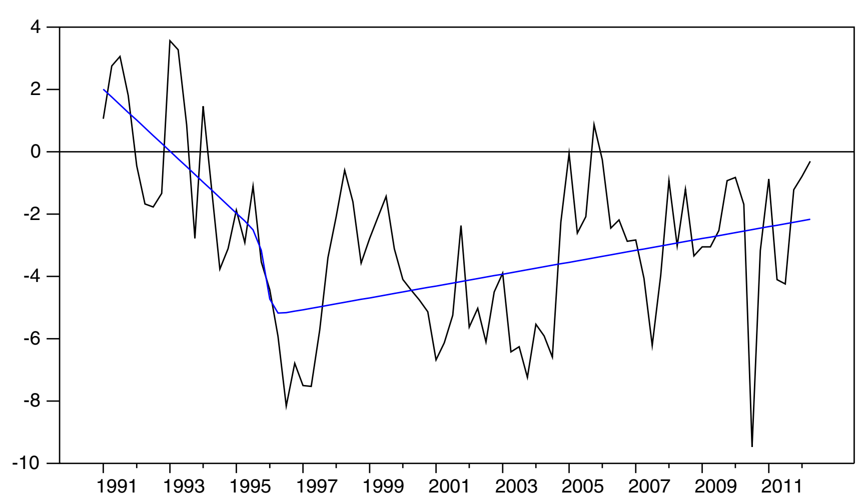

Fig. 3. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Czech Republic.

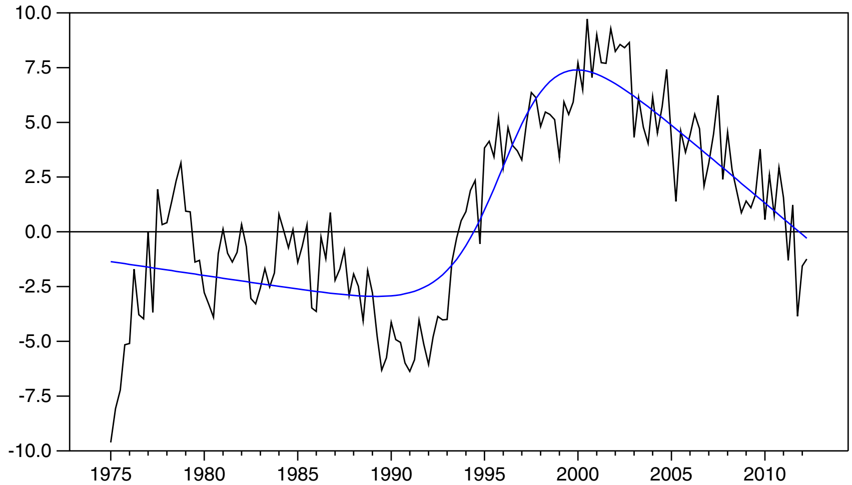

Fig. 4. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Finland.

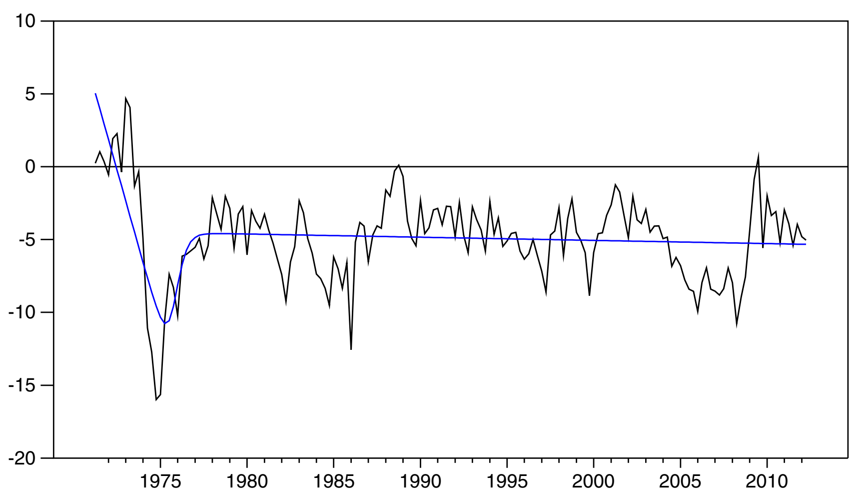

Fig. 5. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: New Zealand.

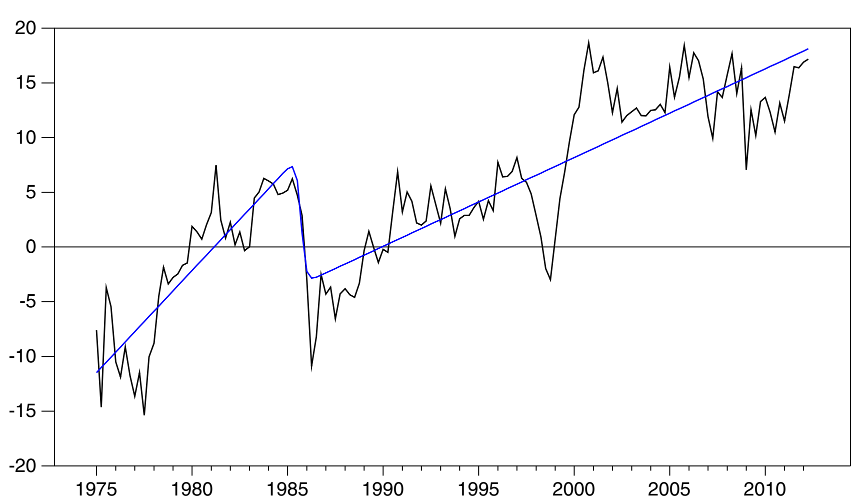

Fig. 6. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Norway.

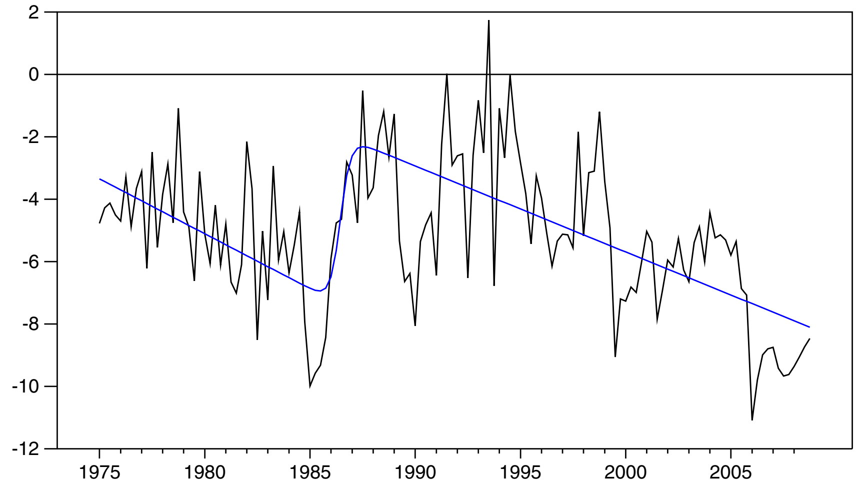

Fig. 7. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Greece.

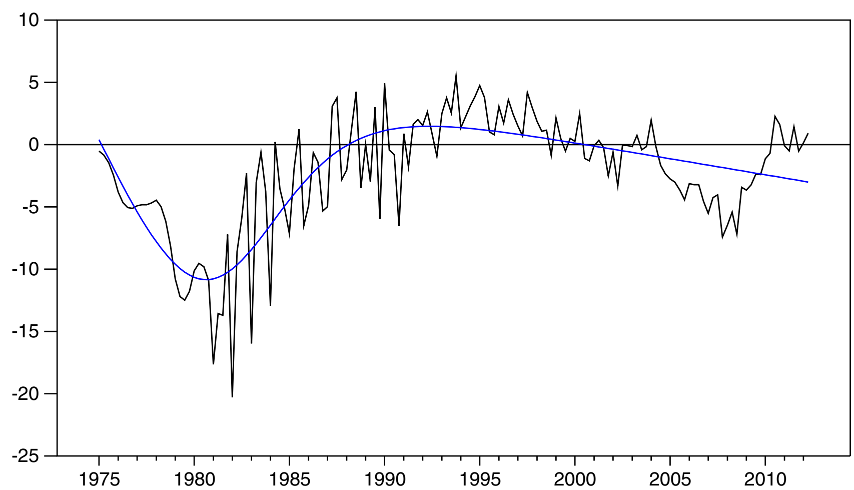

Fig. 8. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Ireland.

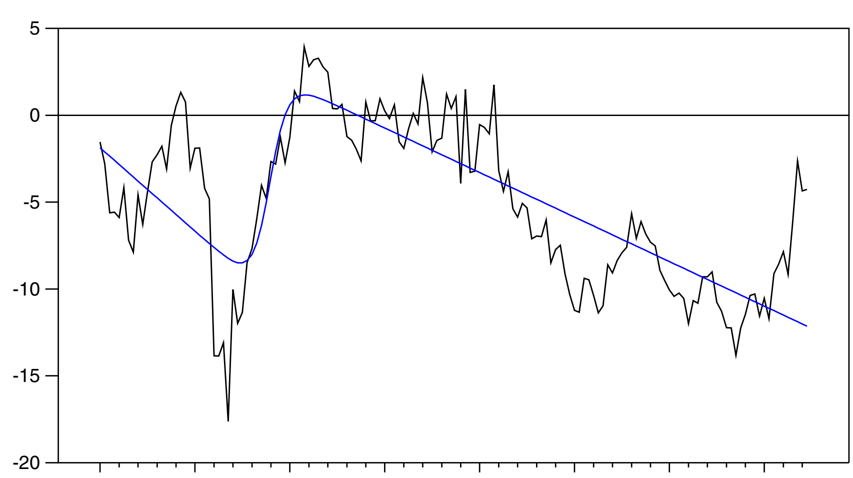

Fig. 9. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Portugal.

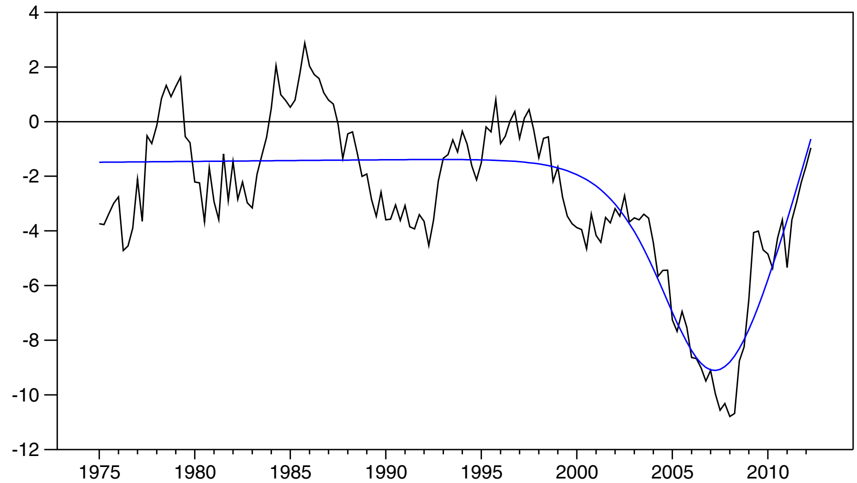

Fig. 10. Current account-GDP ratio (black line) and the fitted logistic smooth transition function (blue line) for Model C: Spain.

Table 6
Results of the LSTR–TAR and LSTR–MTAR unit root tests.

Country	LSTR–TAR			LSTR–MTAR		
	F_α $(\rho_1=\rho_2)$	$F_{\alpha(\beta)}$ $(\rho_1=\rho_2)$	$F_{\alpha\beta}$ $(\rho_1=\rho_2)$	F_α^* $(\rho_1=\rho_2)$	$F_{\alpha(\beta)}^*$	$F_{\alpha\beta}^*$ $(\rho_1=\rho_2)$
Australia	14.391***	15.319***	21.490***	15.625***	14.574***	21.370
	(0.885)	(0.261)	(0.662)	(0.148)	(0.932)	(0.967)
Belgium	7.394	20.887***	23.542***	7.955	21.776***	24.307***
	(0.823)	(0.697)	(0.667)	(0.302)	(0.218)	(0.249)
Czech Republic	7.952*	10.997*	12.289*	9.163*	11.303*	12.056
	(0.987)	(0.266)	(0.602)	(0.158)	(0.389)	(0.624)
Finland	4.838	11.285*	12.370*	5.168	10.885*	12.426*
	(0.893)	(0.394)	(0.847)	(0.426)	(0.856)	(0.716)
New Zealand	10.615**	11.557*	12.461*	10.865**	12.523*	14.099**
	(0.367)	(0.833)	(0.233)	(0.263)	(0.191)	(0.040)**
Norway	6.698	7.865	8.330	10.178**	9.715	9.074
	(0.680)	(0.439)	(0.368)	(0.523)	(0.539)	(0.742)
Greece	9.009*	9.695	13.815**	8.972*	9.585	13.400**
	(0.506)	(0.661)	(0.391)	(0.538)	(0.996)	(0.822)
Ireland	12.958***	16.014***	22.525***	13.052***	16.474***	23.132***
	(0.738)	(0.520)	(0.449)	(0.603)	(0.281)	(0.222)
Portugal	7.765*	9.959	8.072	8.212*	10.955*	8.783
	(0.775)	(0.925)	(0.428)	(0.258)	(0.188)	(0.031)
Spain	8.289*	4.984	7.304	8.366*	5.375	7.399
	(0.895)	(0.942)	(0.890)	(0.695)	(0.777)	(0.664)

(1) *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively. (2) LSTR–TAR denotes the nonlinear unit root tests proposed by Sollis (2004). (3) LSTR–MTAR denotes the nonlinear unit root tests proposed by Cook and Vougas (2009). (4) The number in the parenthesis is the p-value for testing the null hypothesis of $\rho_1=\rho_2$. (5) The critical values for the LSTR–TAR and LSTR–MTAR statistics are obtained from Sollis (2004) and Cook and Vougas (2009).

Table 7
Results of the ESTAR-type unit root tests.

	$KSS(t_{NL})$			$Z_{NL}(t)$			τ		
Country	Raw data	Demean	Detrend	Raw data	Demean	Detrend	Raw data	Demean	Detrend
Australia	−1.724	−1.277	−2.288	−1.062	−0.991	−1.879	3.981	2.459	5.618
Belgium	−3.254***	−3.895***	−3.655**	−8.080***	−8.405***	−8.074***	16.831***	16.943***	14.722**
Czech Republic	−2.896***	−3.318**	−3.226*	−2.726**	−3.024**	−2.652	10.207**	12.025**	10.288
Finland	−1.619	−2.050	−1.374	−2.522**	−2.774*	−2.777	4.091	4.843	2.339
New Zealand	−2.794**	−3.358**	−3.246*	−2.974***	−3.823***	−3.656**	8.004*	11.440**	11.738*
Norway	−1.467	−2.424	−4.064***	−1.666	−3.531***	−4.137***	6.725	5.856	16.480**
Greece	−0.228	−3.085**	−3.482**	−0.107	−5.588***	−5.566***	0.108	13.424**	12.596*
Ireland	−2.262**	−2.480	−2.806	−5.331***	−5.635***	−6.211***	6.483	7.251	8.773
Portugal	−2.446**	−4.172***	−3.887**	−2.370**	−4.533***	−3.944***	11.115**	17.363***	18.581***
Spain	−1.250	−1.544	−2.048	−1.059	−1.275	−2.023	1.886	4.435	4.258

(1) *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively. (2) $KSS(t_{NL})$: Kapetanios et al. (2003). $Z_{NL}(t)$: Rothe and Sibbertsen (2006). τ: Kruse (2011). (3) The critical values for the three statistics are obtained from Kapetanios et al. (2003) and Kruse (2011).

Table 8
Summary of a variety of nonlinearities.

		SB nonlinearity	Sign nonlinearity		Size nonlinearity		
Country	Stationarity	LSTR	LSTR–TAR	LSTR–MTAR	$KSS(t_{NL})$	$Z_{NL}(t)$	τ
Australia	yes	yes	yes/no	yes/no			
Belgium	yes		yes/no	yes/no	yes	yes	yes
Czech Republic	yes	yes	yes/no	yes/no	yes	yes	yes
Finland			yes/no	yes/no		yes	
New Zealand	yes	yes	yes/no	yes/no	yes	yes	yes
Norway	yes			yes/no	yes	yes	yes
Greece	yes	yes	yes/no	yes/no	yes	yes	yes
Ireland	yes		yes/no	yes/no	yes	yes	
Portugal			yes/no	yes/no	yes	yes	yes
Spain			yes/no	yes/no			

(1) SB nonlinearity indicates nonlinearity stems from structural breaks. (2) The term "yes" indicates that the null of a unit root is rejected and in favor of linear or nonlinear stationary process. (3) The term "yes/no" indicates that we reject the null of nonstationarity favoring the sustainability hypothesis but the current account-GDP ratios adjust symmetrically around the threshold value after taking account of the nonlinear trend.

Table 9
Summary of a variety of nonlinearities (data ended in 2008Q4).

		SB nonlinearity	Sign nonlinearity		Size nonlinearity		
Country	Stationarity	LSTR	LSTR–TAR	LSTR–MTAR	$KSS(t_{NL})$	$Z_{NL}(t)$	τ
Australia	yes	yes	yes/no	yes/no			
Belgium	yes		yes/no	yes/no		yes	
Czech Republic	yes	yes					
Finland			yes/no	yes/no		yes	
New Zealand	yes	yes	yes/no	yes/no	yes	yes	yes
Norway	yes			yes/no	yes	yes	yes
Greece	yes	yes	yes/no	yes/no	yes	yes	yes
Ireland	yes		yes/no	yes/no	yes	yes	
Portugal			yes/no	yes/no	yes	yes	yes
Spain			yes/no	yes/no			

(1) SB nonlinearity indicates nonlinearity stems from structural breaks. (2) The term "yes" indicates that the null of a unit root is rejected and in favor of linear or nonlinear stationary process. (3) The term "yes/no" indicates that we reject the null of nonstationarity favoring the sustainability hypothesis but the current account-GDP ratios adjust symmetrically around the threshold value after taking account of the nonlinear trend.

Second, the current account-GDP ratios of Australia, Czech Republic, New Zealand and Greece exhibit smooth structural break nonlinearity, indicating that smooth break nonlinearity is essential in testing the null hypothesis of the unit root. If we overlook structural break nonlinearity (smooth breaks) in testing, then we will be inclined to accept the null of nonstationarity and wrongly conclude that the sustainability hypothesis does not hold.

Third, none of the current account-GDP ratios of the ten European countries exhibit sign nonlinearity. However, eight (Belgium, Czech Republic, Finland, New Zealand, Norway, Greece, Ireland and Portugal) of the ten countries do have size nonlinearity. This implies that the policymakers or markets care about the asymmetric speed of adjustment towards equilibrium instead of asymmetric adjustment around a threshold towards equilibrium. In sum, our empirical results of the

Table 10
Comparisons with previous researches by using the nonlinear approach.

Studies	SB nonlinearity	Sign nonlinearity	Size nonlinearity	Other nonlinearity
Apergis et al. (2000)	√			
Baharumshah et al. (2003)	√			
Chen (2010)	√			
Chen (2011a)				√
Chen (2011b)				√
Christopoulos and León-Ledesma (2010)			√	
Chortareas et al. (2004)		√	√	
Clarida et al. (2006)			√	
Cuestas (2013)		√	√	
Herzer and Nowak-Lehmann (2006)	√			
Kim et al. (2009)			√	
Liu and Tanner (2001)	√			
Onel and Utkulu (2006)	√			
Raybaudi et al. (2004)				√
Holmes and Panagiotidis (2009)	√			
Takeuchi (2010)				√
This paper	√	√	√	

Other nonlinearity indicates that the nonlinearity is neither clearly defined nor does it belong to structural break, sign and size nonlinearities.
√ denotes the condition is satisfied.

linear and non-linear unit root tests (Table 8) show that the ten European countries considered in this paper can achieve the current account sustainability over the examined time span.

A word of caution is that we test for the three types of nonlinearities one by one in this paper.[13] For this purpose, we apply a battery of linear and nonlinear unit root tests. First, we test for a unit root against the alternative of nonlinearity stems from structural break by using Leybourne et al.'s (1998) approach. Next, we test for a unit root against the alternative of the sign nonlinearity by using the LSTR–TAR and LSTR–MTAR models proposed by Sollis (2004) and Cook and Vougas (2009), respectively. The alternative hypothesis of the LSTR–TAR or LSTR–MTAR model is that it allows for stationary asymmetry adjustment around a smooth transition between deterministic trend. Therefore, the LSTR–TAR and LSTR–MTAR models allow us to test for the null hypothesis of a unit root against the alternative of the structural break nonlinearity and sign nonlinearity at the same time. Finally, we apply the exponential smooth transition autoregressive (ESTAR) unit root tests proposed by Kapetanios et al. (2003) (KSS hereafter), Rothe and Sibbertsen (2006) and Kruse (2011) to test for a unit root against the alternative of the size nonlinearity. The three nonlinear unit root tests are proven to be powerful for their respective purpose in the literature. Hence, there is no size problem with the three nonlinear unit root tests. However, we do not test for a unit root against the alternative of the size nonlinearity and sign nonlinearity simultaneously of the current account deficit. That is, we do not take into account the size and sign nonlinearities in the autoregressive parameter at the same time. To the author's best knowledge, Lundbergh et al. (2003) and Sollis (2008) propose a time-varying smooth transition autoregressive (TV–STAR) model, which is able to test for the null of a unit root against the alternative of the nonlinear mean reverting process of the ESTAR type subject to structural change. Hence, readers can adopt the TV–STAR model to test for nonlinear mean reversion (size nonlinearity) and structural change simultaneously. Moreover, Sollis (2009), Cerrato et al. (2010) and Shintani (2013) propose a nonlinear unit root test that encompasses both the size nonlinearity and sign asymmetric effect. We plan to construct an encompassing test for null hypothesis of a unit root against the alternative of the three nonlinearities at the same time in the next study and we leave this topic as a research avenue in the future.

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[13] We owe this point to one of our referees.

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