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ANTONIO AZNAR
MARÍA-ISABEL AYUDA

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Antonio Aznar*
María-Isabel Ayuda*

Abstract

The objective of this paper is to extend the analysis of the behaviour of the PONI (Point Optimal Near Integration) test to the case where the model has some deterministic terms. We show that the PONI test is, asymptotically, robust with respect to structural breaks in the constant term but not with respect to breaks in the linear time trend. So, we propose a new version of the PONI test that take into account the presence of these structural breaks when the break date is known. The behaviour of this new version is compared with the KPSS test and we conclude that the proposed test has a better trade-off between size and power than the KPSS test.

Keywords: Near integration, Point optimal, Monte Carlo, Unit root, Structural Breaks

JEL classification: C12, C15, C22

Corresponding author: M^{a} Isabel Ayuda Bosque, Dept. Economic Analysis, Faculty of Economics and Business Studies , Gran Vía 2-4, Universidad de Zaragoza, Zaragoza (50005), Spain. E-mail: mayuda@unizar.es

*Dept. of Economic Analysis. Universidad de Zaragoza. 50005-Zaragoza. Spain.

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1.- Introduction

This paper is dedicated to extend some results related to the PONI (Point Optimal Near Integration) test developed in Aznar and Ayuda (2008). The PONI test is an stationary test, that is, a test for which stationarity of a time series forms the null hypothesis and the presence of a unit root forms the alternative. Examples of stationary tests in the literature are Kwiatkoski et al (1992) (thereafter KPSS), Tanaka (1990) and Leybourne and McCabe (1994) among others.

In the cited paper of Aznar and Ayuda, the test statistic is derived for a model with no deterministic terms. Using the Neyman-Pearson approach the test statistic is defined and then, its limiting behaviour is derived under both, the null and the alternative hypotheses.

In this paper, we extend these results to the case where the model has some deterministic terms, in particular, a constant and a linear time trend. After deriving the limiting behaviour, we study how robust the test is in face of structural breaks in those deterministic terms. It is shown that the PONI test is, asymptotically, robust with respect to structural breaks in the constant but it is not robust with respect to breaks in the linear time trend. We propose a new version of the PONI test that accounts for the presence of these structural breaks when the break point is known.

The paper is based on previous developments proposed in the literature to deal with the presence of structural breaks. In his pioneering work, Perron (1989) illustrates the need to allow for a structural break when testing for a unit root in economic time series. In particular, he demonstrated that the Dickey-Fuller test (DF) cannot reject the null hypothesis of a unit root under the alternative of trend stationarity with a structural change. He showed that the DF-test is biased toward accepting the false null hypothesis of a unit root if a time series exhibits stationary fluctuation around a trend containing a structural break.

Lee et al. (1997) showed that stationary tests ignoring the existing break diverge and thus are biased toward rejecting the null hypothesis of stationarity in favour of the false alternative unit root hypothesis. See also Badillo et al. (2002). Lee and Strazicich (2001) and Kurozumi (2002) have developed testing procedures for the null hypothesis of stationarity with a break against nonstationarity. Carrion-i-Silvestre and Sansó (2007) extended the KPSS test to the case where there exist two structural breaks and change either the level and/or the slope of the time series.

The plan of the paper is as follows. Section 2 is dedicated to present the model, the test statistic and derive its limiting behaviour when the model has no structural breaks. In Section 3 we examine how robust the PONI test is in face of structural breaks in the constant and in the linear time trend. For a model with structural breaks we propose a version of the PONI test in Section 4 and its limiting properties are examined when the break date is known. Some simulation results are reported in Section 5 and the main conclusions follow in Section 6. The proofs of the results in the paper are provided in an Appendix.

2.- The model and the PONI test

Consider the following model (DGP),

$$\mathrm{y_t = z_t\beta + u_t \quad t = 1, 2, ..., T} \tag{1}$$

$$\mathrm{u_t = \phi_1 u_{t-1} + ... + \phi_p u_{t-p} + \varepsilon_t} \tag{2}$$

where $\mathrm{z_t}$ is a vector that includes deterministic terms, ε_t is an i.i.d. sequence with mean zero, variance σ^2 and finite fourth moment. We suppose that a structural change may occur at time $\mathrm{T_B (1 < T_B < T)}$ and that $\lambda = \mathrm{T_B / T}$ is fixed. Hence $\mathrm{z_t = (1, t, D_t, D_t^*)'}$ where $\mathrm{D_t = 0}$ if $\mathrm{t \le T_B}$ and $\mathrm{D_t = 1}$ if $\mathrm{t > T_B}$ and $\mathrm{D_t^* = 0}$ if $\mathrm{t \le T_B}$ and $\mathrm{D_t^* = t - T_B}$ if $\mathrm{t > T_B}$. In matrix form, (1) can be written as:

$$\mathrm{y = Z\beta + u} \tag{3}$$

where Z is the $\mathrm{T \times 4}$ matrix of observations of $\mathrm{z_t}$ and $\beta = (\alpha, \delta, \alpha_1, \delta_1)'$.

Equivalently, (2) can be written as:

$$\mathrm{\Delta u_t = (\phi^* - 1)u_{t-1} + \phi_1^* \Delta u_{t-1} + ... + \phi_{p-1}^* \Delta u_{t-p+1} + \varepsilon_t} \tag{4}$$

where $\phi^* = \sum_{i=1}^{p} \phi_i$ and $\phi_j^* = -\sum_{i=j+1}^{p} \phi_i$.

We assume that the null parameter ϕ^* is given by $\phi^* = 1 - c_{TRUE} T^{-\frac{1}{2}}$, where c_{TRUE} is a constant. Note that this local-to-unity framework differs from that usually employed in the literature as can be seen, for example, in Müller (2005) and Harris et al. (2007). The null hypothesis specifies that $c_{TRUE} \neq 0$ while the alternative hypothesis states that $c_{TRUE} = 0$.

Following the Neyman-Pearson approach, (the details of the derivation can be seen in Aznar and Ayuda (2008)) , we obtain the following test statistic:

$$PONI = \frac{\sum_{p+1}^{T} e_{t-1}(\Delta e_t - \hat{\phi}_1^* \Delta e_{t-1} - ...... - \hat{\phi}_{p-1}^* \Delta e_{t-p+1})}{\hat{\sigma}\,(\sum_{p+1}^{T} e_{t-1}^2)^{\frac{1}{2}}} + \frac{c(\sum_{p+1}^{T} e_{t-1}^2 / T)^{\frac{1}{2}}}{\hat{\sigma}} \tag{5}$$

where $e = My$ with $M = I - Z(Z'Z)^{-1}Z'$ and the $\hat{\phi}_i^{*\prime} s$ are the OLS estimators of the regression of e_t on $e_{t-1}, \Delta e_{t-1}, ..., \Delta e_{t-p+1}$ and $\hat{\sigma}$ is the estimated standard deviation of this regression. *c* is a constant that permits to choose a particular value of the null parameter.

The critical region we propose is to reject the null hypothesis when:

$$\mathrm{PONI > N_\varepsilon} \tag{6}$$

where $\mathrm{N_\varepsilon}$ is the critical point corresponding to a standard Normal distribution corresponding to an a priori chosen significance level.

The following theorem provides the limiting behaviour of the PONI test under the null hypothesis.

THEOREM 1: Suppose that the DGP is given by (1) –(2) with $\mathrm{z_t = (1, t)'}$ and that the statistic of the PONI test is defined using the same z_t. Then, under the null hypothesis of near-integration we have that:

$$\begin{aligned} &if\ c < c_{TRUE} \Rightarrow \Pr ob\{PONI > N_\varepsilon\} \to 0 \\ &if\ c = c_{TRUE} \Rightarrow \Pr ob\{PONI > N_\varepsilon\} \to \varepsilon \\ &if\ c > c_{TRUE} \Rightarrow \Pr ob\{PONI > N_\varepsilon\} \to 1 \end{aligned}$$

Proof: See the Appendix.

REMARK 1: Theorem 1 shows that when $c = c_{TRUE}$ then the probability of rejecting the null hypothesis when it holds is approximated by ε.

However, when $c < c_{TRUE}$, that is, when the true value of the null parameter is smaller than the value of that parameter assumed to define the PONI test, then the probability of rejecting tends to zero. On the other hand, when $c > c_{TRUE}$, then the probability of rejecting the null hypothesis tends to one. Note that the width of the interval in which the probability tends to one is a decreasing function of the square root of the sample size. That is why we affirm that the PONI test achieves what Müller (2005) calls the “ideal asymptotic rejection profile”.

In the following theorem, we derive the limiting behaviour of the PONI statistic when the data are generated by the alternative hypothesis.

THEOREM 2: Under the alternative hypothesis that $\phi^* = 1$, the probability of rejecting converges to 1 as $T \to \infty$.

Proof: See the Appendix.

3.-Robustness with respect to structural breaks

We begin by considering a structural break in the constant term. Suppose that data have been generated by (1)-(2) with $z_t = (1, D_t)'$ and that in order to define the PONI statistic we use $z_t = (1)'$. Note that in this case:

$$e = My = \alpha_1 MD + Mu \tag{7}$$

In the following theorem we provide the limiting behaviour of the PONI test defined with $z_t = (1)'$.

THEOREM 3: When the PONI test is defined with $z_t = (1)'$ and the data are generated by (1)-(2) with $z_t = (1, D_t)'$ then, under the null hypothesis, the PONI test has the same properties as in Theorem 1. That is, it is robust with respect to any break in the constant term.

Proof: See the Appendix.

THEOREM 4: Suppose that the data have been generated by (1)-(2) with $z_t = (1, D_t)'$ and that the PONI test is defined by using $z_t = (1)'$. Then, under the alternative hypothesis that $\phi^* = 1$ the PONI test always rejects the null hypothesis as $T \to \infty$.

Proof: See the Appendix.

Next, we are going to examine the robustness of the PONI test when there are structural breaks in both, the constant and the linear time trend.

THEOREM 5: Suppose that data have been generated by (1)-(2) with $z_t = (1, t, D_t, D_t^*)'$ and that the PONI test is defined using $z_t = (1, t)'$. Then, under the null hypothesis, the PONI test diverges as $T \to \infty$.

Proof: See the Appendix

We can conclude this section by stating that the PONI test is robust with respect to any structural break in the constant term. However, if the model presents breaks in the constant and the linear time trend then the null hypothesis is always rejected. The conclusion is that we should pay a special attention to the case where there exists a potential structural break in the trend coefficient.

4.- The PONI test with structural breaks

In this Section we present a new version of the PONI test that takes into account the presence of structural breaks in both the constant and the linear time trend assuming that the break date is known.

The data are generated by (1)-(2) with $z_t = (1, t, D_t, D_t^*)'$ and the statistic of the PONI test is defined as in (4) and (5) with the same z_t. In this case we have:

$$e = My = Mu \tag{8}$$

THEOREM 6: Suppose that the DGP is (1)-(2) with $z_t = (1, t, D_t, D_t^*)'$ and the statistic of the PONI test is defined using the same z_t. Then, under the null hypothesis we obtain the same results commented in Theorem 1.

Proof: Similar to that provided for Theorem 1.

For the cases where the c value chosen to define the PONI test does not coincide with the c_{TRUE}, the same comments contained in Remark 1 can be repeated here.

THEOREM 7: Suppose that data are generated by (1)-(2) with $\mathrm{z}_t = (1, \mathrm{t}, \mathrm{D}_t, \mathrm{D}_t^*)'$ and the same z_t is used to define the PONI test; then, when $\phi^* = 1$ the probability of rejecting the null hypothesis of near-integration goes to 1 as $T \to \infty$.

Proof: See the Appendix.

It can be seen that the performance of the test does not change when the break affects only to the constant term. However, the result changes dramatically when the break affects to the time trend; in this case, the null hypothesis is always rejected.

5.- Monte Carlo experiments

In this section, we provide Monte Carlo simulation results to illustrate the finite sample performance of the PONI test in a model with a constant and a linear trend. The pseudo-iid N(0,1) random numbers were generated using Gauss procedure RNDNS, and all calculations were conducted using Gauss software Version 7.0. We have studied the behaviour of the test for three sample sizes, T = 50, 100, 500, and all the experiments are based in 10,000 replications.

We divided the Monte Carlo study into four parts; firstly we analyze the behaviour of the PONI test, in terms of size and power with a model with deterministic terms; secondly, we analyse the robustness of the proposed test when there is a structural change in the level of the model for different values of λ; in the third Monte Carlo exercise, we study the robustness of the PONI test, when the structural change affects not only to the constant term but also to the linear trend term. Finally, the last simulation exercise analyses the behaviour of the proposed test, when the break date is known. In all cases we compare the finite sample performance of our test to that of the modified KPSS test for near integration that uses prewhitened Heterokedasticity and Autocorrelation Consistent of Sul et al. (2005). This is the version proposed in Carrión-i-Silvestre and Sansó (2007).

Exercise 1: In the first Monte Carlo study, we consider the following DGP:

$$\begin{aligned}
&y_t = \alpha + \delta t + u_t, \quad t = 1, 2, ..., T, \\
&u_t = \phi_1 u_{t-1} + \varepsilon_t, \quad t = 2, ..., T, \quad \varepsilon_t \sim iidN(0,1) \\
&\varepsilon_1 = 0,
\end{aligned}$$

The values considered for ϕ are $\phi_1 = 0.9, 0.93, 0.95, 0.97, 0.98, 1$. Thus, when $\phi_1 = 1$ we will have the power of the test and for the rest of the values we will have the size of the test. The PONI statistic we use is the one in (5) with $\mathrm{z}_t = (1, \mathrm{t})'$ and c is set as 0.95 so that a theoretical size of 5% is guaranteed for a value of the null parameter, $\phi = 0.95$ when T=100.

Critical values of the KPSS test are taken from Kiatkowski et al. (1992).

The results for $\alpha = 1$ and $\delta = 0$, can be seen in Table 1 and Table 2 reports those corresponding to $\alpha = 1$ and $\delta = 1$.

Table 1: Size and power of the tests with no structural breaks in a model with constant term ($\alpha = 1$, $\delta = 0$).

TM	ϕ	**PONI**	**KPSS**
50	0.9	0	0.06
50	0.93	0.03	0.12
50	0.95	0.06	0.17
50	0.97	0.09	0.24
50	0.98	0.12	0.27
50	**1**	**0.20**	**0.39**
100	0.9	0	0.04
100	0.93	0.01	0.09
100	0.95	0.05	0.18
100	0.97	0.13	0.30
100	0.98	0.19	0.37
100	**1**	**0.36**	**0.55**
500	0.9	0	0.04
500	0.93	0	0.03
500	0.95	0	0.04
500	0.97	0.04	0.17
500	0.98	0.22	0.36
500	**1**	**0.86**	**0.88**

Table 2: Size and power of the tests with no structural breaks in a model with constant and lineal trend term ($\alpha = 1$, $\delta = 1$)

TM	ϕ	**PONI**	**KPSS**
50	0.9	0	0.02
50	0.93	0	0.02
50	0.95	0.02	0.03
50	0.97	0.03	0.04
50	0.98	0.03	0.05
50	**1**	**0.03**	**0.06**
100	0.9	0	0.02
100	0.93	0.01	0.04
100	0.95	0.03	0.07
100	0.97	0.07	0.12

100	0.98	0.10	0.15
100	**1**	**0.13**	**0.20**
500	0.9	0	0.04
500	0.93	0	0.03
500	0.95	0	0.03
500	0.97	0.09	0.14
500	0.98	0.30	0.32
500	**1**	**0.74**	**0.73**

Analysing these tables it can be seen that as the sample size increases the rejection rate becomes smaller for values of the null parameter close to the alternative and the power becomes larger. The performance of the PONI test slightly improves that of the KPSS test.

Exercise 2: In this case we assess the robustness of the PONI test defined in (5) with $z_t = (1)'$ assuming that the DGP is:

$$y_t = \alpha + \alpha_1 D_t + u_t \quad t = 1, 2, ..., T$$

$$u_t = \phi u_{t-1} + \varepsilon_t \quad \varepsilon_t \sim \text{iidN}(0,1) \quad \varepsilon_1 = 0,$$

Table 3: Size and power of the tests with a break in the constant term

			$\alpha_1 = 1$		$\alpha_1 = 5$		$\alpha_1 = 10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.1	**100**	**0.9**	0	0.04	0	0.14	0	0.67
0.1	**100**	**0.93**	0	0.09	0	0.19	0	0.62
0.1	**100**	**0.95**	0.04	0.18	0.02	0.26	0	0.66
0.1	**100**	**0.97**	0.13	0.30	0.08	0.35	0.02	0.64
0.1	**100**	**0.98**	0.19	0.37	0.13	0.41	0.04	0.67
0.1	**100**	**1**	**0.37**	**0.55**	**0.30**	**0.57**	**0.16**	**0.74**
0.1	**500**	**0.9**	0	0.04	0	0.14	0	0.16
0.1	**500**	**0.93**	0	0.03	0	0.08	0	0.17
0.1	**500**	**0.95**	0	0.04	0	0.09	0	0.23
0.1	**500**	**0.97**	0.04	0.17	0.05	0.21	0.08	0.35
0.1	**500**	**0.98**	0.22	0.36	0.23	0.39	0.27	0.47
0.1	**500**	**1**	**0.86**	**0.88**	**0.85**	**0.88**	**0.85**	**0.87**
			$\alpha_1 = 1$		$\alpha_1 = 5$		$\alpha_1 = 10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.5	**100**	**0.9**	0	0.05	0.06	0.50	0.40	0.96
0.5	**100**	**0.93**	0.01	0.12	0.12	0.51	0.45	0.92
0.5	**100**	**0.95**	0.05	0.20	0.20	0.51	0.48	0.87

0.5	**100**	**0.97**	0.13	0.31	0.28	0.53	0.51	0.82
0.5	**100**	**0.98**	0.20	0.38	0.32	0.54	0.52	0.79
0.5	**100**	**1**	**0.38**	**0.56**	**0.42**	**0.61**	**0.52**	**0.73**
0.5	**500**	**0.9**	0	0.12	0	0.92	0.31	1
0.5	**500**	**0.93**	0	0.07	0	0.73	0.48	1
0.5	**500**	**0.95**	0	0.06	0.02	0.62	0.60	1
0.5	**500**	**0.97**	0.04	0.19	0.20	0.59	0.69	0.96
0.5	**500**	**0.98**	0.23	0.37	0.39	0.61	0.73	0.91
0.5	**500**	**1**	**0.86**	**0.88**	**0.86**	**0.88**	**0.88**	**0.89**
			$\alpha_1 = 1$		$\alpha_1 = 5$		$\alpha_1 = 10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.9	**100**	**0.9**	0	0.04	0.01	0.04	0.08	0.05
0.9	**100**	**0.93**	0.01	0.09	0.05	0.10	0.15	0.11
0.9	**100**	**0.95**	0.05	0.18	0.10	0.18	0.21	0.17
0.9	**100**	**0.97**	0.13	0.30	0.18	0.27	0.28	0.24
0.9	**100**	**0.98**	0.20	0.36	0.24	0.34	0.31	0.29
0.9	**100**	**1**	**0.38**	**0.55**	**0.38**	**0.51**	**0.40**	**0.44**
0.9	**500**	**0.9**	0	0.04	0	0.08	0	0.05
0.9	**500**	**0.93**	0	0.03	0	0.05	0	0.13
0.9	**500**	**0.95**	0	0.04	0	0.07	0.07	0.21
0.9	**500**	**0.97**	0.04	0.16	0.09	0.21	0.28	0.34
0.9	**500**	**0.98**	0.22	0.36	0.29	0.38	0.46	0.46
0.9	**500**	**1**	**0.86**	**0.88**	**0.86**	**0.88**	**0.87**	**0.87**

The results are presented in Table 3. In all cases it can be seen that as the sample size increases the empirical size becomes smaller, except for values of the null parameter close to the value under the alternative, and the power becomes larger. The unique exception is when the values of α is large, say $\alpha = 10$ for $\lambda = 0.5$.

Exercise 3: we consider the following DGP:

$$y_t = \alpha + \delta t + \alpha_1 D_t + \delta_1 D_t^* + u_t \quad t = 1, 2, ..., T$$

$$u_t = \phi u_{t-1} + \varepsilon_t \quad \varepsilon_t \sim \text{iidN}(0,1) \quad \varepsilon_1 = 0,$$

In this case, we assess the robustness of the PONI test as defined in (5) with $z_t = (1, t)'$.

The results are presented in Table 4. The results coincide with those anticipated by Theorem 5, in the sense, that the probability of rejecting the null hypothesis, no matter the DGP we consider, goes to1.

Table 4: Size and power of the tests with a break in both the constant term and linear trend term

			$\alpha_1=\delta_1=1$		$\alpha_1=\delta_1=5$		$\alpha_1=\delta_1=10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.1	**100**	**0.9**	0	0.15	0	1	0	1
0.1	**100**	**0.93**	0	0.16	0	1	0	1
0.1	**100**	**0.95**	0.01	0.18	0	1	0	1
0.1	**100**	**0.97**	0.04	0.22	0	1	0	1
0.1	**100**	**0.98**	0.05	0.24	0	1	0	1
0.1	**100**	**1**	**0.08**	**0.28**	**0**	**1**	**0**	**1**
0.1	**500**	**0.9**	0.34	1	1	1	1	1
0.1	**500**	**0.93**	0.48	1	1	1	1	1
0.1	**500**	**0.95**	0.60	1	1	1	1	1
0.1	**500**	**0.97**	0.74	1	1	1	1	1
0.1	**500**	**0.98**	0.81	1	1	1	1	1
0.1	**500**	**1**	**0.91**	**0.97**	**1**	**1**	**1**	**1**
			$\alpha_1=\delta_1=1$		$\alpha_1=\delta_1=5$		$\alpha_1=\delta_1=10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.5	**100**	**0.9**	1	1	1	1	1	1
0.5	**100**	**0.93**	1	1	1	1	1	1
0.5	**100**	**0.95**	1	1	1	1	1	1
0.5	**100**	**0.97**	1	1	1	1	1	1
0.5	**100**	**0.98**	1	1	1	1	1	1
0.5	**100**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
0.5	**500**	**0.9**	1	1	1	1	1	1
0.5	**500**	**0.93**	1	1	1	1	1	1
0.5	**500**	**0.95**	1	1	1	1	1	1
0.5	**500**	**0.97**	1	1	1	1	1	1
0.5	**500**	**0.98**	1	1	1	1	1	1
0.5	**500**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
			$\alpha_1=\delta_1=1$		$\alpha_1=\delta_1=5$		$\alpha_1=\delta_1=10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.9	**100**	**0.9**	0.35	0.03	0.99	1	1	1
0.9	**100**	**0.93**	0.40	0.08	0.99	1	1	1
0.9	**100**	**0.95**	0.44	0.12	0.98	1	1	1
0.9	**100**	**0.97**	0.48	0.17	0.98	1	1	1

0.9	**100**	**0.98**	0.49	0.20	0.98	1	1	1
0.9	**100**	**1**	**0.50**	**0.24**	**0.98**	**1**	**1**	**1**
0.9	**500**	**0.9**	1	1	1	1	1	1
0.9	**500**	**0.93**	1	1	1	1	1	1
0.95	**500**	**0.95**	1	1	1	1	1	1
0.95	**500**	**0.97**	1	1	1	1	1	1
0.95	**500**	**0.98**	1	1	1	1	1	1
0.95	**500**	**1**	**1**	**0.98**	**1**	**1**	**1**	**1**

Exercise 4: Here we consider the case when the DGP is the same as in Exercise 3 and the same model is used to define the PONI statistic assuming that the break point is known. The critical values of the KPSS test are those in Lee and Strazicich (2001). For the model with a constant term these critical points are: c.p. = 0.3809 when $\lambda = 0.1$ or $\lambda = 0.9$ and c.p. = 0.1891 when $\lambda = 0.5$. For the model with a constant and a linear trend term, we have: c.p. = 0.1223 when $\lambda = 0.1$ or $\lambda = 0.9$ and c.p. = 0.0615 when $\lambda = 0.5$.

The value of c used to define the PONI test is 0.75 when the model has only a constant term and 0.95 when the model has both a constant and a linear trend. These values approximately guarantee a 5% empirical size for $\phi^* = 0.95$ and T = 100. The results are presented, respectively, in Tables 5 and 6.

When the generating model has only a constant (Table 5) it can be seen that the performance of the test is very similar in the three cases although the trade-off between size and power depends on the position of the break; note that in the extremes the power is higher while we observe some over rejection for high values of the null hypothesis.

Table 5: Size and power of the tests with a known break in the constant term

			$\alpha_1 = 1$		$\alpha_1 = 5$		$\alpha_1 = 10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.1	**100**	**0.9**	0	0.03	0	0.03	0	0.03
0.1	**100**	**0.93**	0	0.08	0	0.08	0	0.08
0.1	**100**	**0.95**	0.03	0.15	0.03	0.15	0.03	0.15
0.1	**100**	**0.97**	0.09	0.27	0.09	0.27	0.09	0.27
0.1	**100**	**0.98**	0.13	0.33	0.13	0.33	0.13	0.33
0.1	**100**	**1**	**0.24**	**0.51**	**0.24**	**0.51**	**0.24**	**0.51**
0.1	**500**	**0.9**	0	0	0	0	0	0
0.1	**500**	**0.93**	0	0	0	0	0	0
0.1	**500**	**0.95**	0	0.04	0	0.04	0	0.04
0.1	**500**	**0.97**	0.02	0.15	0.02	0.15	0.02	0.15

0.1	500	0.98	0.16	0.33	0.16	0.33	0.16	0.33
0.1	500	1	**0.75**	**0.82**	**0.75**	**0.82**	**0.75**	**0.82**
			$\alpha_1 = 1$		$\alpha_1 = 5$		$\alpha_1 = 10$	
λ	TM	ϕ	PONI	KPSS	PONI	KPSS	PONI	KPSS
0.5	100	0.9	0	0.01	0	0.01	0	0.01
0.5	100	0.93	0	0.02	0	0.02	0	0.02
0.5	100	0.95	0	0.04	0	0.04	0	0.04
0.5	100	0.97	0.02	0.08	0.02	0.08	0.02	0.08
0.5	100	0.98	0.03	0.10	0.03	0.10	0.03	0.10
0.5	100	1	**0.04**	**0.16**	**0.04**	**0.16**	**0.04**	**0.16**
0.5	500	0.9	0	0.03	0	0.03	0	0.03
0.5	500	0.93	0	0.02	0	0.02	0	0.02
0.5	500	0.95	0	0.01	0	0.01	0	0.01
0.5	500	0.97	0.01	0.11	0.01	0.11	0.01	0.11
0.5	500	0.98	0.09	0.28	0.09	0.28	0.09	0.28
0.5	500	1	**0.52**	**0.77**	**0.52**	**0.77**	**0.52**	**0.77**
			$\alpha_1 = 1$		$\alpha_1 = 5$		$\alpha_1 = 10$	
λ	TM	ϕ	PONI	KPSS	PONI	KPSS	PONI	KPSS
0.9	100	0.9	0	0.05	0	0.05	0	0.05
0.9	100	0.93	0	0.09	0	0.09	0	0.09
0.9	100	0.95	0.01	0.15	0.01	0.15	0.01	0.15
0.9	100	0.97	0.03	0.24	0.03	0.24	0.03	0.24
0.9	100	0.98	0.05	0.29	0.05	0.29	0.05	0.29
0.9	100	1	**0.11**	**0.46**	**0.11**	**0.46**	**0.11**	**0.46**
0.9	500	0.9	0	0.04	0	0.04	0	0.04
0.9	500	0.93	0	0.04	0	0.04	0	0.04
0.9	500	0.95	0	0.04	0	0.04	0	0.04
0.9	500	0.97	0.02	0.15	0.02	0.15	0.02	0.15
0.9	500	0.98	0.13	0.32	0.13	0.32	0.13	0.32
0.9	500	1	**0.69**	**0.82**	**0.69**	**0.82**	**0.69**	**0.82**

Table 6: Size and power of the tests with a known break in the constant term and linear trend term

			$\alpha_1 = \delta_1 = 1$		$\alpha_1 = \delta_1 = 5$		$\alpha_1 = \delta_1 = 10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.1	**100**	**0.9**	0	0.03	0	0.03	0	0.03
0.1	**100**	**0.93**	0	0.05	0	0.05	0	0.05
0.1	**100**	**0.95**	0.02	0.07	0.02	0.07	0.02	0.07
0.1	**100**	**0.97**	0.04	0.12	0.04	0.12	0.04	0.12
0.1	**100**	**0.98**	0.05	0.14	0.05	0.14	0.05	0.14
0.1	**100**	**1**	**0.07**	**0.17**	**0.07**	**0.17**	**0.07**	**0.17**
0.1	**500**	**0.9**	0	0.04	0	0.04	0	0.04
0.1	**500**	**0.93**	0	0.04	0	0.04	0	0.04
0.1	**500**	**0.95**	0	0.03	0	0.03	0	0.03
0.1	**500**	**0.97**	0.05	0.11	0.05	0.11	0.05	0.11
0.1	**500**	**0.98**	0.19	0.26	0.19	0.26	0.19	0.26
0.1	**500**	**1**	**0.59**	**0.62**	**0.59**	**0.62**	**0.59**	**0.62**
			$\alpha_1 = \delta_1 = 1$		$\alpha_1 = \delta_1 = 5$		$\alpha_1 = \delta_1 = 10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.5	**100**	**0.9**	0	0.03	0	0.03	0	0.03
0.5	**100**	**0.93**	0	0.03	0	0.03	0	0.03
0.5	**100**	**0.95**	0	0.03	0	0.03	0	0.03
0.5	**100**	**0.97**	0	0.03	0	0.03	0	0.03
0.5	**100**	**0.98**	0	0.03	0	0.03	0	0.03
0.5	**100**	**1**	**0**	**0.03**	**0**	**0.03**	**0**	**0.03**
0.5	**500**	**0.9**	0	0.02	0	0.02	0	0.02
0.5	**500**	**0.93**	0	0.01	0	0.01	0	0.01
0.5	**500**	**0.95**	0	0	0	0	0	0
0.5	**500**	**0.97**	0.01	0.03	0.01	0.03	0.01	0.03
0.5	**500**	**0.98**	0.05	0.08	0.05	0.08	0.05	0.08
0.5	**500**	**1**	**0.19**	**0.26**	**0.19**	**0.26**	**0.19**	**0.26**
			$\alpha_1 = \delta_1 = 1$		$\alpha_1 = \delta_1 = 5$		$\alpha_1 = \delta_1 = 10$	
λ	**TM**	ϕ	**PONI**	**KPSS**	**PONI**	**KPSS**	**PONI**	**KPSS**
0.9	**100**	**0.9**	0	0.05	0	0.05	0	0.05
0.9	**100**	**0.93**	0	0.05	0	0.05	0	0.05
0.9	**100**	**0.95**	0	0.07	0	0.07	0	0.07
0.9	**100**	**0.97**	0	0.09	0	0.09	0	0.09

0.9	**100**	**0.98**	0.01	0.12	0.01	0.12	0.01	0.12
0.9	**100**	**1**	**0.02**	**0.15**	**0.02**	**0.15**	**0.02**	**0.15**
0.9	**500**	**0.9**	0	0.05	0	0.05	0	0.05
0.9	**500**	**0.93**	0	0.04	0	0.04	0	0.04
0.9	**500**	**0.95**	0	0.04	0	0.04	0	0.04
0.9	**500**	**0.97**	0.04	0.12	0.04	0.12	0.04	0.12
0.9	**500**	**0.98**	0.15	0.26	0.15	0.26	0.15	0.26
0.9	**500**	**1**	**0.51**	**0.63**	**0.51**	**0.63**	**0.51**	**0.63**

6.- Conclusions

In this paper we have extended the properties of the PONI test, previously developed in Aznar and Ayuda (2008), to a model with a constant and a linear time trend. PONI is an stationary **Point Optimal** procedure to test for the null of **Near Integration**.

We adopt an alternative local-to-unity framework to that considered in the literature, based on an expression of the null parameter as $1-\frac{c_{TRUE}}{\sqrt{T}}$ .Then we have derived the asymptotic behaviour of the test procedure under both the null and the alternative hypothesis when the model has no structural breaks. It has been shown that the test achieves what Müller (2005) calls the “ideal asymptotic rejection profile”, in the sense that the PONI test rejects the null hypothesis with a very low probability when it is true and with a probability of one when the data are generated by the alternative hypothesis.

We have shown that the PONI test is robust to structural breaks in the constant term. However, when these structural breaks affect the linear trend, the null hypothesis is always rejected when data are generated by the null hypothesis.

In Section 4, we have presented a version of the PONI test that takes into account the presence of structural breaks in both the constant and the linear time trend assuming that the break date is known.

In the last section of the paper we have reported the results from some simulation exercises. These results confirm the analytical derivations presented in previous sections.

APPENDIX

In the following lemmas we present some results that are useful for the proof of the theorems in the text.

LEMMA A1: Let *Z* be the $T \times 4$ matrix of observations of $z_t = (1, t, D_t, D_t^*)'$ and let *P* be the following diagonal matrix:

$$P = \mathrm{diag}(T^{-1/2}, T^{-3/2}, T^{-1/2}, T^{-3/2})$$

Then

$$\mathrm{PZ'ZP} \to \mathrm{A}$$

where *A* is a 4×4 matrix of constants.

Proof: Note that:

$$\mathrm{PZ'ZP} = \begin{bmatrix} \frac{T}{T} & \frac{\sum^{t} t}{T^2} & \frac{T(1-\lambda)}{T} & \frac{\sum^{T(1-\lambda)} t}{T^2} \\ & \frac{\sum^{t} t^2}{T^3} & \frac{\sum^{T(1-\lambda)} (t+\lambda T)}{T^2} & \frac{\sum^{T(1-\lambda)} t(t+\lambda T)}{T^3} \\ & & \frac{T(1-\lambda)}{T} & \frac{\sum^{T(1-\lambda)} t}{T^2} \\ & & & \frac{\sum^{T(1-\lambda)} t^2}{T^3} \end{bmatrix}$$

So that:

$$\frac{\sum z_{1t}^2}{T} = \frac{T}{T} \to 1 = A[1,1]; \quad \frac{\sum z_{1t} z_{2t}}{T^2} = \frac{\sum t}{T^2} \to \frac{1}{2} = A[1,2]$$

$$\frac{\sum z_{1t} z_{3t}}{T} = \frac{T(1-\lambda)}{T} \to (1-\lambda) = A[1,3]; \frac{\sum z_{1t} z_{4t}}{T^2} = \frac{\sum^{T(1-\lambda)} t}{T^2} \to \frac{(1-\lambda)^2}{2} = A[1,4]$$

$$\frac{\sum z_{2t}^2}{T^3} = \frac{\sum t^2}{T^3} \to \frac{1}{3} = A[2,2]; \frac{\sum z_{2t} z_{3t}}{T^2} = \frac{\sum^{T(1-\lambda)} (t+\lambda T)}{T^2} = \frac{\sum^{T(1-\lambda)} t}{T^2} + \frac{T(1-\lambda)\lambda T}{T^2} \to \frac{1-\lambda^2}{2} = A[2,3]$$

$$\frac{\sum z_{2t} z_{4t}}{T^3} = \frac{\sum^{T(1-\lambda)} t^2}{T^3} + \frac{\lambda T \sum^{T(1-\lambda)} t}{T^3} \to \frac{2(1-\lambda)^3}{6} + \frac{\lambda(1-\lambda)^2}{2} = \frac{2-3\lambda+\lambda^3}{6} = A[2,4];$$

$$\frac{\sum z_{3t}^2}{T} = \frac{T(1-\lambda)}{T} \to (1-\lambda) = A[3,3]; \frac{\sum z_{3t} z_{4t}}{T^2} = \frac{\sum^{T(1-\lambda)} t}{T^2} \to \frac{(1-\lambda)^2}{2} = A[3,4];$$

$$\frac{\sum z_{4t}^2}{T^3} = \frac{\sum^{T(1-\lambda)} t^2}{T^3} \to \frac{(1-\lambda)^3}{3} = A[4,4]$$

LEMMA A2: Let $u_t = \sum_{i=0}^{\infty} \phi^i \varepsilon_{t-i}$ with $\phi = 1 - b_T$, $b_T = T^{-1/2}$ and ε_t is an i.i.d. sequence with mean zero, variance σ^2 and finite fourth moment. Define:

$$u_t^* = b_T u_t = \sum \psi_i \varepsilon_{t-1} \quad with \quad \psi_i = b_T \phi^i$$

$$\gamma_j \equiv E\left(u_t^* u_{t-j}^*\right) = \sigma^2 \sum_{s=0}^{\infty} \psi_s \psi_{s+j} \quad \text{for } j=0,1,2,\ldots$$

$$\gamma^* \equiv \sigma \sum_{j=0}^{\infty} \psi_j = \sigma\psi(1)$$

Then

(i) $PZ'\varepsilon = \begin{bmatrix} \dfrac{1}{T^{1/2}} \sum^{T} \varepsilon_t \\ \dfrac{1}{T^{3/2}} \sum^{T} t\varepsilon_t \\ \dfrac{1}{T^{1/2}} \sum^{T(1-\lambda)} \varepsilon_t \\ \dfrac{1}{T^{3/2}} \sum^{T(1-\lambda)} t\varepsilon_t \end{bmatrix} \xrightarrow{d} B$

where B is a 4×1 vector.

(ii) Let $P^* = \begin{bmatrix} T^{-3/4} & 0 & 0 & 0 \\ 0 & T^{-7/4} & 0 & 0 \\ 0 & 0 & T^{-3/4} & 0 \\ 0 & 0 & 0 & T^{-7/4} \end{bmatrix}$ then $P^*Z'u = \begin{bmatrix} \dfrac{1}{T^{3/4}} \sum^{T} u_t \\ \dfrac{1}{T^{7/4}} \sum^{T} tu_t \\ \dfrac{1}{T^{3/4}} \sum^{T(1-\lambda)} u_t \\ \dfrac{1}{T^{7/4}} \sum^{T(1-\lambda)} tu_t \end{bmatrix} \xrightarrow{d} C$

where C is a 4×1 vector.

(iii)

$$\frac{1}{T}\sum \varepsilon_t^2 \xrightarrow{p} \sigma^2$$

$$\frac{1}{T^{3/2}}\sum u_t u_{t-j} \xrightarrow{p} \gamma_j \qquad j = 0,1,2,\ldots$$

$$\frac{1}{T^{3/4}}\sum u_{t-j}\varepsilon_t \xrightarrow{d} N(0,\sigma^2\gamma^*) \qquad j = 0,1,2,\ldots$$

$$\sum \Delta u_{t-i}\Delta u_{t-j} \text{ is } O_p(T) \quad \text{if } i = j \quad \text{and} \quad O_p(T^{1/2}) \quad \text{if } i \neq j$$

$$\sum u_{t-1}\Delta u_{t-j} \text{ is } O_p(T)$$

Proof:

Let $W(.)$ be a standard Brownian motion.

(i) $\dfrac{1}{T^{1/2}}\sum \varepsilon_t \xrightarrow{d} \sigma W(1) = B[1]$ because of the Central Limit Theorem.

$\dfrac{1}{T^{3/2}}\sum t\varepsilon_t \xrightarrow{d} \sigma\left(W(1) - \int_0^1 W(r)dr \right) = B[2]$. See Proposition 17.1 c) of Hamilton (1994).

$$\frac{1}{T^{1/2}}\sum^{T(1-\lambda)}\varepsilon_t = \frac{1}{T^{1/2}}\sum^{T}\varepsilon_t - \frac{1}{T^{1/2}}\sum^{T\lambda}\varepsilon_t \xrightarrow{d} \sigma\left(W(1)-W(\lambda)\right) = B\left[3\right]$$

$$\frac{1}{T^{3/2}}\sum^{T(1-\lambda)}t\varepsilon_t = \frac{1}{T^{3/2}}\sum^{T}t\varepsilon_t - \frac{1}{T^{3/2}}\sum^{T\lambda}t\varepsilon_t \xrightarrow{d} \sigma\left(W(1)-\int_0^1 W(r)dr\right) -$$
$$-\sigma\left(W(\lambda)-\int_0^\lambda W(r)dr\right) = B\left[4\right]$$

(ii) $\frac{1}{T^{3/4}}\sum^{T}u_t = \frac{1}{T^{1/2}}\sum u_t^* \xrightarrow{d} \gamma^* W(1) = C\left[1\right]$ using Proposition 17.3 (a) of Hamilton (19994). The u_t^* process is the same as that considered by Hamilton in this proposition because:

$$\sum_i^\infty \psi_i^2 = b_T\sum_i^\infty \phi^{*2i} \to \frac{1}{2}$$

$$\frac{1}{T^{7/4}}\sum^{T}tu_t = \frac{1}{T^{3/2}}\sum^{T}tu_t^* \xrightarrow{d} \gamma^*\left\{W(1)-\int_0^1 W(r)dr\right\} = C\left[2\right]$$

Using Proposition 17.3 (g) of Hamilton.

$$\frac{1}{T^{3/4}}\sum^{T(1-\lambda)}u_t = \frac{1}{T^{1/2}}\sum^{T}u_t^* - \frac{1}{T^{1/2}}\sum^{T\lambda}u_t^* \xrightarrow{d} \gamma^*\left\{W(1)-W(\lambda)\right\} = C\left[3\right]$$

$$\frac{1}{T^{7/4}}\sum^{T(1-\lambda)}tu_t = \frac{1}{T^{3/2}}\sum^{T}tu_t^* - \frac{1}{T^{3/2}}\sum^{T\lambda}u_t^* \xrightarrow{d} \gamma^*\left\{W(1)-\int_0^1 W(r)dr\right\} +$$
$$+\gamma^*\left\{W(1)-\int_0^\lambda W(r)dr\right\} = C\left[4\right]$$

(iii) $\frac{1}{T}\sum\varepsilon_t^2 \xrightarrow{p} \sigma^2$. This result is a direct convergence of the stationary character of ε_t.

$\frac{1}{T^{3/2}}\sum u_t u_{t-j} = \frac{1}{T}\sum u_t^* u_{t-j}^* \xrightarrow{p} \gamma_j$ using proposition 17.3 (c) of Hamilton.

$\frac{1}{T^{3/4}}\sum u_{t-1}\varepsilon_t = \frac{1}{T^{1/2}}\sum u_{t-1}^*\varepsilon_t \xrightarrow{d} N(0,\sigma^2\gamma_0)$ using proposition 17.3 (b) of Hamilton.

$\sum u_{t-1}\Delta u_{t-j} = \bar{\phi}^*\sum u_{t-1}u_{t-j} + \sum u_{t-1}\varepsilon_{t-j}$ if j = 1, then, this expression is $O_p(T)$ and the second term is $O_p(T^{3/2})$. Hence, the conclusion is that $\sum u_{t-1}\Delta u_{t-j}$ is $O_p(T)$ no matter the value of j.

$\sum \Delta u_{t-i}\Delta u_{t-j} = \bar{\phi}^{*2}\sum u_{t-i-1}u_{t-j-1} + \bar{\phi}^*\sum u_{t-i-1}\varepsilon_{t-j} + \bar{\phi}^*\sum u_{t-j-1}\varepsilon_{t-i} + \sum \varepsilon_{t-i}\varepsilon_{t-j}$ if i = j, this expression is dominated asymptotically by the last term that is $O_p(T)$. If $i \neq j$ then all left hand side terms have an order equal to $O_p(T^{1/2})$.

LEMMA A3: Let $\Delta u_t = \phi(L)\varepsilon_t = \sum_0^{\infty} \phi_i \varepsilon_{t-i}$ with the $\phi_i' s$ and ε_t satisfying the same assumptions than in Lemma A.2. Let γ_j be defined as $E(\Delta u_t, \Delta u_{t-j})$ for $j = 0,1,2,...$ and let γ^* be defined as in Lemma A2. Define P^+ as the following diagonal matrix $P^+ = diag(T^{-3/2}, T^{-5/2}, T^{-3/2}, T^{-5/2})$ .Then,

(i)

$$P^+ Z'u = \begin{bmatrix} \frac{1}{T^{3/2}} \sum^{T} u_t \\ \frac{1}{T^{5/2}} \sum^{T} tu_t \\ \frac{1}{T^{3/2}} \sum^{T(1-\lambda)} u_t \\ \frac{1}{T^{5/2}} \sum^{T(1-\lambda)} tu_t \end{bmatrix} \xrightarrow{d} D$$

where D is 4×1 vector.

(ii) $\sum u_t^2$ is $O_p(T^2)$ and $\sum u_{t-1}\varepsilon_t$ is $O_p(T)$

PROOF:

(i)

$$\frac{1}{T^{3/2}} \sum u_t \xrightarrow{d} \gamma^* \int_0^1 W(r)dr$$ See Hamilton (1994) Proposition 17.3 (f).

$$\frac{1}{T^{5/2}} \sum tu_t \xrightarrow{d} \gamma^* \int_0^1 W(r)dr$$ See Hamilton (1994) Proposition 17.3 (i).

$$\frac{1}{T^{3/2}} \sum^{T(1-\lambda)} u_t = T^{-3/2} \sum^{T} u_t - T^{-3/2} \sum^{\lambda T} u_t \xrightarrow{d} \gamma^* \left\{ \int_0^1 W(r)dr - \int_0^{\lambda} W(r)dr \right\}$$

$$\frac{1}{T^{5/2}} \sum^{T(1-\lambda)} tu_t = T^{-5/2} \sum^{T} tu_t - T^{-5/2} \sum^{\lambda T} tu_t \xrightarrow{d} \gamma^* \left\{ \int_0^1 rW(r)dr - \int_0^{\lambda} W(r)dr \right\}$$

(ii) $$\frac{1}{T^2} \sum u_t^2 \xrightarrow{d} \gamma^{*2} \int_0^1 W(r)^2 dr$$ See Hamilton (1994) Proposition 17.3 (h).

$$\frac{1}{T} \sum u_{t-1}\varepsilon_t \xrightarrow{d} \frac{1}{2} \left\{ \gamma^{*2} \left[W(1) \right]^2 - \gamma_0 \right\}$$ see Hamilton (1994). Proposition 17.3(e).

PROOF OF THEOREM 1: (i) Let us first show the consistency of the OLS estimators of the ϕ_1^*'s and of σ^2 in the regression of Δe_t on $e_{t-1,}\Delta e_{t-1},...,\Delta e_{t-p+1}$. Let $\hat{\phi}^{**}$ be defined as: $\hat{\phi}^{**}=\left(\hat{\phi}^*,\hat{\phi}_1^*,...,\hat{\phi}_{p-1}^*\right)$ a vector of *p* OLS estimators that can be written as:

$$\hat{\phi}_1^{**}=\begin{bmatrix} \sum e_{t-1}^2 & \sum e_{t-1}\Delta e_{t-1} & \cdots & \sum e_{t-1}\Delta e_{t-p+1} \\ & \sum \Delta e_{t-1}^2 & & \\ & & \ddots & \\ & & & \sum \Delta e_{t-p+1}^2 \end{bmatrix}^{-1}\begin{bmatrix} \sum e_{t-1}\Delta e_t \\ \vdots \\ \vdots \\ \sum \Delta e_{t-p+1}\Delta e_t \end{bmatrix} \tag{A.1}$$

Now, since $e = My = Mu$, we have:

$$\sum e_{t-1}^2 = u'_{-1}Mu_{-1} = u'_{-1}u_{-1} - u'_{-1}Z(Z'Z)^{-1}Z'u_{-1} \tag{A.2}$$

The first right hand side term is $O_p(T^{3/2})$ by Lemma A2 (iii), and the second right hand side term is $O_p(T^{1/2})$ using Lemma A1 and Lemma A2 (ii). Hence, $\sum e_{t-1}^2$ behaves asymptotically as $\sum u_{t-1}^2$.

Using the same arguments, it can easily shown that $\sum \Delta e_{t-1}^2$, $\sum e_{t-j}\Delta e_{t-j}$ and $\sum \Delta e_{t-j}\Delta e_t$ behave asymptotically respectively as $\sum u_{t-j}^2$, $\sum u_{t-j}\Delta u_{t-j}$ and $\sum \Delta u_{t-j}\Delta u_t$. That implies that the OLS estimators of the regression of Δe_t on $e_{t-1},\Delta e_{t-1},...,\Delta e_{t-p+1}$ have the same asymptotic properties than the OLS estimators in the regression in (4).Since from Lemma A2, each $\sum \Delta u_{t-j}^2$ is $O_p(T)$ and each $\sum \Delta u_{t-j}\varepsilon_t$ is $O_p(T^{1/2})$, these OLS estimators are $O_p(T^{-1/2})$. These consistency results permit to go on with the proof after substituting $\hat{\phi}_1^*,...,\hat{\phi}_{p-1}^*$ and $\hat{\sigma}$ by their respective parameters.

Consider now the numerator of the first term of the PONI test:

$$\begin{aligned} & e'_{-1}\left(\Delta e-\phi_1^*\Delta e_{-1}-...-\phi_{p-1}^*\Delta e_{-p+1}\right)=u'_{-1}M\left(M\Delta u-\phi_1^*M\Delta u_{-1}-...-\phi_{p-1}^*M\Delta u_{-p+1}\right)= \\ & =u'_{-1}M\left(M\left(\phi^*-1\right)u_{-1}+M\varepsilon\right)=\left(\phi^*-1\right)u'_{-1}Mu_{-1}+u'_{-1}M\varepsilon \end{aligned} \tag{A.3}$$

Substituting into the PONI statistic we obtain:

$$\text{PONI} \equiv \frac{{}^{u'_{-1}M\varepsilon}\!\big/\!{}_{T^{3/4}}}{\sigma\left(u'_{-1}Mu_{-1}/T^{3/2}\right)^{1/2}} + \frac{T^{1/4}(c - c_{TRUE})\left(u'_{-1}Mu_{-1}/T^{3/2}\right)^{1/2}}{\sigma} \tag{A.4}$$

The first term of the right hand side of (A.4) converges to a standard Normal distribution because of Lemma A.2. The result of the Theorem follows because as we have shown in Lemma A2 (iii) $u_{-1}'Mu_{-1}$ is $O_p(T^{3/2})$.

PROOF OF THEOREM 2:

First, let us examine the convergence of A.1 when $\phi^* = 1$.

Since the regression of Δe_t on $e_{t-1}, \Delta e_{t-1}, \ldots, \Delta e_{t-p+1}$ when $\phi^* = 1$ can be written as:

$$M\Delta u_t = \phi_1^* M\Delta u_{t-1} - \ldots - \phi_{-p+1}^* M\Delta u_{t-p+1} + M\varepsilon_t \tag{A.5}$$

The estimators in (A.1) are:

$$\hat{\phi}^{**} = \begin{bmatrix} 0 \\ \phi_1^* \\ \vdots \\ \phi_{p-1}^* \end{bmatrix} + \begin{bmatrix} \sum e_{t-1}^2 & \sum e_{t-1}\Delta e_{t-1} & \ldots & \sum e_{t-1}\Delta e_{t-p+1} \\ & \sum \Delta e_{t-1}^2 & & \vdots \\ & & \ddots & \vdots \\ & & & \sum \Delta e_{t-p+1}^2 \end{bmatrix}^{-1} \begin{bmatrix} \sum e_{t-1}M\varepsilon_t \\ \sum \Delta e_{t-1}M\varepsilon_t \\ \vdots \\ \sum \Delta e_{t-p+1}M\varepsilon_t \end{bmatrix}$$

Using Lemma A.3 it can be seen that $\sum e_{t-1}^2$ is $O_p(T^2)$ and that $\sum e_{t-1}M\varepsilon_t$ is $O_p(T)$.On the other hand, since $\Delta e_{t-j}, j = 1, \ldots, p-1$ is stationary, $\sum \Delta e_{t-j}^2$ is $O_p(T)$ and $\sum \Delta e_{t-1}M\varepsilon_t$ is $O_p(T^{1/2})$ so that, the OLS estimators $\hat{\phi}_1^*, \ldots, \hat{\phi}_{p-1}^*$ are consistent. With respect to $\hat{\sigma}$ we have:

$$\hat{\sigma}^2 = \frac{\hat{w}'\hat{w}}{T}$$

where

$$\hat{w} = \Delta e - \hat{\phi}_1^* \Delta e_{-1} - \ldots - \hat{\phi}_{p-1}^* \Delta e_{-p+1} + \varepsilon = \left(\hat{\phi}_1^* - \phi_1^*\right)\Delta e_{-1} + \ldots + \\ + \left(\hat{\phi}_{p-1}^* - \phi_{p-1}^*\right)\Delta e_{-p+1} + \varepsilon$$

Thus, the sum of squares $\hat{w}'\hat{w}$ is asymptotically dominated by $\varepsilon'\varepsilon$ that is $O_p(T)$. Hence, $\hat{\sigma}^2$ is $O_p(1)$ and $\hat{\sigma}$ is, also, $O_p(1)$.

As in Theorem 1, we can proceed to prove Theorem 2 substituting $\hat{\phi}_1^*,\ldots,\hat{\phi}_{p-1}^*$ and $\hat{\sigma}$, by their respective parameters.

The numerator of the test statistic will be the second term of (A.3), that is $u'_{-1}M\varepsilon$, that by Lemma A.3 (i) is $O_p(T)$. On the other hand, $e'_{-1}e_{-1} = u'_{-1}Mu_{-1}$ and using Lemma A3 this expression is $O_p(T^2)$. Then, the PONI test is asymptotically equivalent to:

$$\frac{u'_{-1}M\varepsilon / T}{\sigma\left(u'_{-1}Mu_{-1} / T^2\right)^{1/2}} + \frac{c\sqrt{T}\left(u'_{-1}Mu_{-1} / T^2\right)^{1/2}}{\sigma}$$

Using the results previously derived, we see that the first term converges to a well defined limit while the second term diverges and the result follows.

PROOF OF THEOREM 3:

Using the same arguments than in the proof of Theorem 1 it can be shown that $\hat{\phi}_j^* \xrightarrow{p} \phi_j^*$ *j=1,2,…,p-1* and $\hat{\sigma} \xrightarrow{p} \sigma$. Hence, the proof can be carried out after substituting the estimators by their respective parameters.

The numerator of the first term of the PONI statistic can be written as:

$$u'_{-1}M\left(M\Delta u + \alpha_1 M\Delta D - \phi_1^* M\Delta u_{-1} - \phi_1^*\alpha_1 M\Delta D_{-1} - \ldots - \phi_{p-1}^* M\Delta u_{p-1} - \phi_{p-1}^*\alpha_1 M\Delta D_{-p+1}\right) \quad \text{(A.6)}$$

Given the definition of AD in (A.13), it is clear that $M\Delta D_{-j} \quad j = 1,2,\ldots,p-1$ is $O_p(1)$, thus, (A.6) is asymptotically equivalent to

$$\left(\phi^* - 1\right)u'_{-1}Mu_{-1} + u'_{-1}M\varepsilon + O_p(1) \quad \text{(A.7)}$$

Note that the probability order of $u'_{-1}Mu_{-1}$ and $u'_{-1}M\varepsilon$ is the same as that of $u'_{-1}u_{-1}$ and $u'_{-1}\varepsilon$, respectively

On the other hand:

$$e'_{t-1}e_{t-1} = \left(Mu_{-1} + \alpha_1 MD_{-1}\right)'\left(Mu_{-1} + \alpha_1 MD_{-1}\right) = u'_{-1}Mu_{-1} + 2\alpha_1 u'_{-1}MD_{-1} + \alpha_1^2 D'_{-1}MD_{-1} \quad \text{(A.8)}$$

The first term on the right hand side is asymptotically equivalent to $u'_{-1}u_{-1}$ and is $O_p(T^{3/2})$. The second term is $O_p(T^{3/4})$ and the third term is $O_p(T)$. Hence the whole expression is asymptotically dominated by the first term.

Using all these results we see that the PONI test asymptotically is equivalent to:

$$\frac{T^{1/4}\left(-c_{TRUE}\right)\left(u'_{-1}u_{-1} / T^{3/2}\right)}{\sigma\left(\frac{u'_{-1}u_{-1}}{T^{3/2}}\right)^{1/2}} + \frac{u'_{-1}\varepsilon / T^{3/4}}{\sigma\left(\frac{u'_{-1}u_{-1}}{T^{3/2}}\right)^{1/2}} + \frac{cT^{1/4}\left(\frac{u'_{-1}u_{-1}}{T^{3/2}}\right)^{1/2}}{\sigma} \quad \text{(A.9)}$$

Analysing this expression it is seen that is equivalent to that written in (A.4). Hence, we can conclude that the PONI test is robust with respect to structural breaks that affect the constant.

PROOF OF THEOREM 4:

Using similar arguments to those employed in Theorem 2, it can be seen that the OLS estimator of ϕ_i^* and σ are consistent and so we can go on with the proof of the Theorem changing the estimators by their respective parameters.

Asymptotically, we have:

$$\begin{aligned} PONI &= \frac{e'_{-1}\left(\Delta e - \phi_1^* \Delta e_{-1} - \ldots - \phi_{p-1}^* \Delta e_{-p+1}\right)/T}{\sigma\left(e'_{-1}e_{-1}/T^2\right)^{1/2}} + \frac{c\sqrt{T}\left(e'_{-1}e_{-1}/T^2\right)^{1/2}}{\sigma} = \\ &\frac{u'_{-1}M\varepsilon/T}{\sigma\left(u'_{-1}Mu_{-1}/T^2\right)^{1/2}} + \frac{c\sqrt{T}\left(u'_{-1}Mu_{-1}/T^2\right)^{1/2}}{\sigma} \end{aligned} \tag{A.10}$$

and this clearly goes to ∞ as $T \to \infty$, because the first term converges to a well defined limit while the second is $\sqrt{T}$ times a well defined limit expression.

PROOF OF THEOREM 5: In this case, we have:

$$e = \alpha_1 MD + \delta_1 MD^* + Mu \tag{A.11}$$

Let us define ΔD and ΔD^* as:

$$\Delta D = D - D_{-1} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \text{ and } \Delta D^* = D^* - D^*_{-1} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \tag{A.12}$$

so that

$$\Delta e = \alpha_1 M\Delta D + \delta_1 M\Delta D^* + M\Delta u \tag{A.13}$$

Then , we have:

$$\begin{aligned} &\sum e_{t-1}^2 = e'_{-1}e_{-1} = \alpha_1^2 D'_{-1}MD_{-1} + \delta_1^2 D^{*\prime}_{-1}MD^*_{-1} + u'_{-1}Mu_{-1} + 2\alpha_1\delta_1 D'_{-1}MD^*_{-1} + \\ &+2\alpha_1 D'_{-1}Mu_{-1} + 2\delta_1 D^{*\prime}_{-1}Mu_{-1} \end{aligned} \tag{A.14}$$

Note that:

$$\begin{aligned} &D_{-1}'MD_{-1} = D_{-1}'D_{-1} - D_{-1}'Z(Z'Z)^{-1}Z'D_{-1} = \\ &= T(1-\lambda) - \left(T(1-\lambda) \quad \sum^{T(1-\lambda)}\left(t+\lambda T\right)\right)\begin{pmatrix} T & \sum t \\ & \sum t^2 \end{pmatrix}^{-1}\begin{pmatrix} T(1-\lambda) \\ \sum\left(t+\lambda T\right) \end{pmatrix} \end{aligned}$$

Using Lemma A.1 it is seen that the probability order of this expression is dominated by that of the first term that is $O_p(T)$.

The second term is:

$$\mathrm{D}_{-1}^{*}{}'\mathrm{M}\mathrm{D}_{-1}^{*} = \mathrm{D}_{-1}^{*}{}'\mathrm{D}_{-1}^{*} - \mathrm{D}_{-1}^{*}{}'\mathrm{Z}(\mathrm{Z}'\mathrm{Z})^{-1}\mathrm{Z}'\mathrm{D}_{-1}^{*} =$$

$$= \sum^{\mathrm{T}(1-\lambda)} \mathrm{t}^2 - \left(\sum^{\mathrm{T}(1-\lambda)} \mathrm{t} \quad \sum^{\mathrm{T}(1-\lambda)} \mathrm{t}\left(\mathrm{t}+\lambda\mathrm{T}\right) \right) \begin{pmatrix} \mathrm{T} & \sum \mathrm{t} \\ & \sum \mathrm{t}^2 \end{pmatrix}^{-1} \begin{pmatrix} \sum^{\mathrm{T}(1-\lambda)} \mathrm{t} \\ \sum^{\mathrm{T}(1-\lambda)} \mathrm{t}\left(\mathrm{t}+\lambda\mathrm{T}\right) \end{pmatrix}$$

By Lemma A.1 this expression is $\mathrm{O_p}(\mathrm{T}^3)$.

Finally,

$$\mathrm{u}_{-1}{}'\mathrm{M}\mathrm{u}_{-1} = \mathrm{u}_{-1}{}'\mathrm{u}_{-1} - \mathrm{u}_{-1}{}'\mathrm{Z}(\mathrm{Z}'\mathrm{Z})^{-1}\mathrm{Z}'\mathrm{u}_{-1}$$

Using Lemmas A.1 and A.2, it can be seen that the first term is $\mathrm{O_p}(\mathrm{T}^{3/2})$ while the second term is $\mathrm{O_p}(\mathrm{T}^{1/2})$.

We can conclude saying that (A.14) is asymptotically, dominated by the second term that is $\mathrm{O_p}(\mathrm{T}^3)$.

Consider now:

$$\sum \mathrm{e}_{\mathrm{t}-1}\Delta\mathrm{e}_{\mathrm{t}} = \mathrm{e}'_{-1}\Delta\mathrm{e} = \alpha_1^2\mathrm{D}'_{-1}\mathrm{M}\Delta\mathrm{D} + \delta_1^2\mathrm{D}_{-1}^{*}{}'\mathrm{M}\Delta\mathrm{D}^{*} + \mathrm{u}'_{-1}\mathrm{M}\Delta\mathrm{u} + \alpha_1\delta_1\,\mathrm{D}'_{-1}\mathrm{M}\Delta\mathrm{D}^{*} + \\ + \alpha_1\mathrm{D}'_{-1}\mathrm{M}\Delta\mathrm{u} + \alpha_1\delta_1\,\mathrm{D}_{-1}^{*}{}'\mathrm{M}\Delta\mathrm{D} + \delta_1\,\mathrm{D}_{-1}^{*}{}'\mathrm{M}\Delta\mathrm{u} + \alpha_1\mathrm{u}'_{-1}\mathrm{M}\Delta\mathrm{D} + \delta_1\mathrm{u}'_{-1}\mathrm{M}\Delta\mathrm{D}^{*} \tag{A.15}$$

The first term is:

$$\mathrm{D}'_{-1}\mathrm{M}\Delta\mathrm{D} = \mathrm{D}'_{-1}\Delta\mathrm{D} - \mathrm{D}'_{-1}\mathrm{Z}(\mathrm{Z}'\mathrm{Z})^{-1}\mathrm{Z}\Delta\mathrm{D}$$

Taking into account the definition of D_{-1} and $\Delta\mathrm{D}$ and Lemma A.1, it is clear that the first term of (A.15) is $\mathrm{O_p}(1)$.

The second term is:

$$\mathrm{D}_{-1}^{*}{}'\mathrm{M}\Delta\mathrm{D}^{*} = \mathrm{D}_{-1}^{*}{}'\Delta\mathrm{D}^{*} - \mathrm{D}_{-1}^{*}{}'\mathrm{Z}(\mathrm{Z}'\mathrm{Z})^{-1}\mathrm{Z}'\Delta\mathrm{D}^{*}$$

Since $\mathrm{D}_{-1}^{*}{}'\Delta\mathrm{D}^{*} = \sum^{\mathrm{T}(1-\lambda)} \mathrm{t}$, its order is $\mathrm{O_p}(\mathrm{T}^2)$ and this is the order of the second term.

The third term is:

$$\mathrm{u}'_{-1}\mathrm{M}\Delta\mathrm{u} = \mathrm{u}'_{-1}\Delta\mathrm{u} - \mathrm{u}'_{-1}\mathrm{Z}(\mathrm{Z}'\mathrm{Z})^{-1}\mathrm{Z}\Delta\mathrm{u}$$

This expression has the same probability order than $(\phi^{*}-1)u'_{-1}Mu_{-1}$ that is $O_p(T)$. So we conclude that the order of (A.15) is $\mathrm{O_p}(\mathrm{T}^2)$. The same holds for any $\sum \mathrm{e}_{\mathrm{t}-1}\Delta\mathrm{e}_{\mathrm{t}-\mathrm{j}}$ j 0 1,2,…,p-1.

Finally consider:

$$\sum \Delta\mathrm{e}_{\mathrm{t}}^2 = \Delta\mathrm{e}'\Delta\mathrm{e} = \left(\mathrm{e}-\mathrm{e}_{-1}\right)'\left(\mathrm{e}-\mathrm{e}_{-1}\right) = \mathrm{e}'\left(\mathrm{e}-\mathrm{e}_{-1}\right) - \mathrm{e}'_{-1}\left(\mathrm{e}-\mathrm{e}_{-1}\right) \tag{A.16}$$

Since both terms of the right hand side are $\mathrm{O_p}(\mathrm{T}^2)$, $\sum \Delta\mathrm{e}_{\mathrm{t}}^2$ is $\mathrm{O_p}(\mathrm{T}^2)$.

Combining all these results we can say that each estimator $\hat{\phi}_i^* \; i = 1, 2, ..., p-1$ is $\mathrm{O_p}(1)$, so that we can write

$$\frac{\mathrm{e}'_{-1}\left(\Delta \mathrm{e} - \phi_1^* \Delta \mathrm{e}_{-1} - ... - \phi_{\mathrm{p}-1}^* \Delta \mathrm{e}_{-\mathrm{p}+1}\right) / \mathrm{T}^2}{\sigma\left(\mathrm{e}'_{-1}\mathrm{e}_{-1} / \mathrm{T}^3\right)^{1/2} \frac{\mathrm{T}^{3/2}}{\mathrm{T}^2}} + \frac{\mathrm{cT}\left(\mathrm{e}'_{-1}\mathrm{e}_{-1} / \mathrm{T}^3\right)^{1/2}}{\sigma}$$

And the result follows because both terms diverge as $\mathrm{T} \to \infty$.

PROOF OF THEOREM 7:

Using the same arguments employed to prove Theorem 2 it can be seen that the estimators of $\phi_1^*, ..., \phi_{\mathrm{p}-1}^*$ in (A.1) are asymptotically equivalent to those of the same parameters defined from (A.5). Hence these estimators are consistent, such that each $\hat{\phi}_\mathrm{j}^* - \phi_\mathrm{j}^*$ is $\mathrm{O_p}(\mathrm{T}^{-1/2})$ for *j=1,2,…(p-1)* . The same result holds for $\hat{\sigma}$. And the proof can be derived using the parameters instead of the estimators.

Note that, by (A.5)

$$\begin{aligned} &\mathrm{e}'_{-1}\left(\Delta \mathrm{e} - \phi_1^* \Delta \mathrm{e}_{-1} - ... - \phi_{\mathrm{p}-1}^* \Delta \mathrm{e}_{-\mathrm{p}+1}\right) = \\ &= \mathrm{u}'_{-1}\mathrm{M}(\mathrm{M}\Delta \mathrm{u} - \phi_1^* \mathrm{M}\Delta \mathrm{u}_{-1} - ... - \phi_{\mathrm{p}-1}^* \mathrm{M}\Delta \mathrm{u}_{-\mathrm{p}+1}) = \mathrm{u}'_{-1}\mathrm{M}\varepsilon \end{aligned}$$

Using Lemma (A.3) it is seen that this expression is $\mathrm{O_p}(\mathrm{T})$.

On the other hand:

$$\mathrm{e}'_{-1}\mathrm{e}_{-1} = \mathrm{u}'_{-1}\mathrm{M}\mathrm{u}_{-1} = \mathrm{u}'_{-1}\mathrm{u}_{-1} - \mathrm{u}'_{-1}\mathrm{Z}(\mathrm{Z}'\mathrm{Z})^{-1}\mathrm{Z}'\mathrm{u}_{-1}$$

Using Lemma (A.3) it is seen that term are $\mathrm{O_p}(\mathrm{T}^2)$.

The statistic of the PONI test asymptotically is equivalent to:

$$\frac{\mathrm{u}'_{-1}\mathrm{M}\varepsilon / \mathrm{T}}{\sigma\left(\mathrm{u}'_{-1}\mathrm{M}\mathrm{u}_{-1} / \mathrm{T}^2\right)^{1/2}} + \frac{\mathrm{c}\sqrt{\mathrm{T}}\left(\mathrm{u}'_{-1}\mathrm{M}\mathrm{u}_{-1} / \mathrm{T}^2\right)^{1/2}}{\sigma}$$

The result follows because the first term converges to a finite expression while the second term diverges as $\mathrm{T} \to \infty$.

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