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Finite Sample Performance of Frequency and Time Domain Tests for Seasonal Fractional Integration*

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Abstract

Testing the order of integration of economic and financial time series has become a conventional procedure prior to any modelling exercise. In this paper, we investigate and compare the finite sample properties of the frequency domain tests proposed by Robinson (1994) and the time domain procedure proposed by Hassler, Rodrigues and Rubia (2008) when applied to seasonal data.

JEL Classification: C20, C22

Keywords: LM tests, nonstationarity, fractional integration

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1 Introduction

Seasonal movements are considered to be an important component of many time-series in econometric modelling and forecasting exercises. For most economic and financial variables, seasonal patterns are predominantly stochastic and tend to exhibit strongly persistent correlation structures, thereby suggesting non-stationary behavior. Since Nelson and Plosser (1982), there has been great interest in formally testing for the presence of (fractional) unit roots in economic and financial time series, owing to its statistical and practical implications.

Several testing procedures for fractional integration have been proposed in the literature. An important class includes the semi-parametric tests derived under the Lagrange-multiplier (LM) principle. These tests have the advantage of not requiring pre-estimates of the long-memory parameters and to build upon fairly general assumptions. We focus on the frequency-domain test proposed by Robinson (1991, 1994), and on its time-domain regression-based equivalent introduced by Hassler, Rodrigues and Rubia (2009). Both tests present important similitudes: They are general enough to be applied to seasonal and periodic time-series, share the same null asymptotic distribution, are consistent, and are fully efficient under Gaussian restrictions. Nevertheless, there may be advantages in using one method over the other when dealing with small samples. The theoretical complexity embedded in the general framework does not allow this important topic to be addressed analytically, so experimental simulation is required. As remarked in Nielsen (2004) for the zero-frequency case, the Monte Carlo analysis in Tanaka (1999) and Breitung and Hassler (2002) reveal that the time-domain tests tend to be superior to the frequency-domain procedure, both in size and power.

Aiming to contribute to the better understanding of the properties of the LM tests for fractional integration, this paper analyses the finite-sample properties of the frequency- and time-domain tests in the seasonal (quarterly) case, extending for the former the analysis in Gil-Alana (2000). The regression-based test shows a correct performance in the seasonal case for empirically relevant processes, and tends to be superior in size performance.

The remaining of the paper is organized as follows. In Section 2 we provide a brief review of the tests analyzed. Section 3 provides results on the finite sample behavior focusing on quarterly seasonality. Section 4 concludes the paper.

2 LM tests for fractional integration

Given an observable process $\{y_t\}_{t=1}^{T}$ with seasonal period $S > 1$, a seasonal fractional integrated model can be given by

$$(1 - L^S)^{\delta} y_t = u_t; \quad u_t \sim \left(0, \sigma^2\right); \quad y_{(t \leq 0)} = 0 \tag{1}$$

where L denotes the back-shift operator, $\{u_t\}$ is a covariance-stationary process, and $\delta \in \mathbb{R}$ is called long-memory coefficient. If $|\delta| < 1/2$, $\{y_t\}$ is covariance stationary and mean-reverting, with the effect of the shocks disappearing in the long-run. The parameter δ is only restricted to be a real-valued number in our setting.

Hassler (1994) termed model (1) as 'rigid' because it imposes a common long-memory parameter on the frequencies $\gamma_s \in [0, \pi]$ that characterize the seasonal behavior of the data, *i.e.*, on the roots of $(1 - L^S)$. He proposed a 'flexible' generalization which allows for different orders of fractional integration at these frequencies, namely,

$$\varphi(L;\boldsymbol{\delta}) = (1-L)^{\delta_1}\left[\prod_{i=2}^{\delta_{n-1}} \mathcal{F}_{\gamma_i}(L;\delta_i)\right](1+L)^{\delta_n}, \tag{2}$$

with $n := [S/2]+1$, $[\cdot]$ denoting the integer value of the argument, $\mathcal{F}_{\gamma_i}(L;\delta_i) = (1-2\cos\gamma_i L + L^2)^{\delta_i}$, $\gamma_i \in (0,\pi)$, $i = 2,...,n-1$. The filter in (2) was also used by Robinson (1994) and Hassler *et al.* (2009).

Thus, consider $\varphi(L;\boldsymbol{\delta})y_t = u_t$ as a generalization of (1), and let $\mathbf{d} = (d_1,...,d_n)'$, $\mathbf{d} \in \mathbb{R}^n$, be an arbitrary vector of long-memory coefficients. For $i = 1,...,n$, assume that we want to test that $\{y_t\}$ is integrated of order d_i at the i-th frequency, denoted $\mathrm{I}_{\gamma_i}(d_i)$, against the alternative that the process is $\mathrm{I}_{\gamma_i}(d_i+\theta_i)$, for some unknown, significant 'bias' term $|\theta_i| > 0$. Given the pre-specified $\mathbf{d}$, and denoting $\boldsymbol{\theta} = (\theta_1,...,\theta_n)'$, the null hypothesis of interest is

$$\mathrm{H}_0 : \boldsymbol{\delta} = \mathbf{d}, \text{ or } \mathrm{H}_0 : \boldsymbol{\theta} = \mathbf{0}. \tag{3}$$

2.1 Robinson's frequency-domain test

Let $f(\lambda;\tau,\sigma^2)$ be the spectral density of u_t, i.e., $f(\lambda;\tau,\sigma^2) = \sigma^2 g(\lambda;\tau)/2\pi$, $-\pi < \lambda \le \pi$, where $g(\cdot)$ is a known function of the frequency λ and the $q\times 1$ vector τ. The nuisance parameters $(\tau,\sigma^2)'$ can be estimated given the residuals $\widehat{u}_t = \varphi(L;\mathbf{d})y_t$, with $\mathbf{d}$ determined under the null, by $\widehat{\tau} = \arg\min_{\tau\in\boldsymbol{\Gamma}}\sigma^2(\tau)$ and $\sigma^2(\widehat{\tau})$, where $\boldsymbol{\Gamma}$ is a compact subset of $\mathbb{R}^q$ and

$$\sigma^2(\tau) = \left(\frac{2\pi}{T}\right)\sum\nolimits_{j=1}^{T-1} g(\lambda_j;\tau)^{-1} I_{\widehat{u}}(\lambda_j),\ I_{\widehat{u}}(\lambda_j) = \left|\frac{1}{\sqrt{2\pi T}}\sum\nolimits_{t=1}^{T}\widehat{u}_t e^{i\lambda_j t}\right|^2,\ \lambda_j = \frac{2\pi j}{T}. \tag{4}$$

Under regularity conditions and $\mathrm{H}_0 : \boldsymbol{\theta} = \mathbf{0}$, Robinson (1994) established that,

$$\widehat{\mathcal{R}}_n = \left(\frac{T}{\widehat{\sigma}^4}\right)\widehat{a}'\widehat{A}^{-1}\widehat{a} \Rightarrow \chi^2_{(n)} \tag{5}$$

where '$\Rightarrow$' denotes weak convergence as $T\to\infty$, and

$$\widehat{a} = -\left(\frac{2\pi}{T}\right)\sum\nolimits_j^{*}\psi(\lambda_j)g(\lambda;\widehat{\tau})^{-1} I_{\widehat{u}}(\lambda_j) \tag{6}$$

with

$$\widehat{A} = \frac{2}{T}\sum\nolimits_j^{*}\psi(\lambda_j)\psi(\lambda_j)' - \frac{2}{T}\sum\nolimits_j^{*}\psi(\lambda_j)\widehat{\xi}(\lambda_j)'\left\{\frac{1}{T}\sum\nolimits_j^{*}\widehat{\xi}(\lambda_j)\widehat{\xi}(\lambda_j)'\right\}^{-1}\frac{1}{T}\sum\nolimits_j^{*}\widehat{\xi}(\lambda_j)\psi(\lambda_j)' \tag{7}$$

where the sum on $*$ is over $\lambda_j = 2\pi j/T$ in $]-\pi,\pi]$, $\lambda_j \notin (\gamma_s - 2\pi/T, \gamma_s + 2\pi/T)$, $s = 1,2,...,n$ and γ_s denoting the poles associated with the roots of $(1-L^S)$. Finally,

$$\psi(\lambda_j) = \mathrm{Re}(\frac{\partial}{\partial\boldsymbol{\theta}}\log\varphi(e^{i\lambda_j};\mathbf{d}+\boldsymbol{\theta})) \text{ and } \widehat{\xi}(\lambda_j) = (\partial/\partial\tau)\log g(\lambda_j;\widehat{\tau}). \tag{8}$$

For quarterly data, $\boldsymbol{\theta} = (\theta_1,\theta_2,\theta_3)'$, $\varphi(e^{i\lambda};\mathbf{1}) = (1-e^{i\lambda 4})$ and $\psi_1(\lambda_j) = \log\left|2\sin\frac{\lambda_j}{2}\right|$, $\psi_2(\lambda_j) = \log\left|2\cos\frac{\lambda_j}{2}\right|$ and $\psi_3(\lambda_j) = \log|2\cos\lambda_j|$. We shall consider $u_t \sim iid\,(0,\sigma^2)$ and, more generally, AR(p)-type patterns, for which $g(\lambda;\tau) = \left|1-\sum\nolimits_{k=1}^{p}\tau_k e^{ik\lambda}\right|^{-2}$ and the l-th element of $\xi(\lambda)$ is $2g(\lambda;\tau)(\cos(l\lambda) - \sum\nolimits_{k=1}^{p}\tau_k\cos((l-k)\lambda))$.

2.2 Regression-based test

An asymptotically equivalent time domain procedure to the frequency domain test previously described was proposed by Hassler *et al.* (2009). This procedure is based on a p-th order augmented LS regression of the form:

$$\varepsilon_{\mathbf{d},t} = \sum_{s=1}^{n} \phi_s \varepsilon^*_{\gamma_s,t-1} + \sum_{i=1}^{p} \zeta_i \varepsilon_{\mathbf{d},t-i} + e_{tp}, \quad t = p+1, ..., T \tag{9}$$

where $\varepsilon_{\mathbf{d},t} = \varphi(L; \mathbf{d}) y_t$, with $\mathbf{d}$ fixed under the null. The number of lags p can be chosen using Schwert's (1989) rule to control for (unknown) short-run correlation; see Demetrescu, Hassler and Kuzin (2008). The main regressors $\varepsilon^*_{\gamma_s,t-1}$ are determined as $\varepsilon^*_{\gamma_s,t-1} = \sum_{j=1}^{t-1} \omega_j (\gamma_s) \varepsilon_{\mathbf{d},t-j}$, where for any frequency $\gamma_s \in [0, \pi]$, we formally define the non-stochastic sequence $\omega_j(\gamma) = 1/j$ if $\gamma = 0$, $\omega_j(\gamma) = 2\cos(j\gamma)/j$ if $\gamma \in (0, \pi)$, and $\omega_j(\gamma) = (-1)^j/j$ if $\gamma = \pi$.

The null $\mathrm{H}_0 : \boldsymbol{\theta} = \mathbf{0}$ can be addressed through a joint test on the significance of the estimated ϕ_s parameters. Thus, let $\boldsymbol{\beta}_T$ be the $(n+p)$ vector of estimated parameters in (9), and $\mathbf{R}$ an $n \times (n+p)$ matrix such that $[\mathbf{R}]_{ij} = 1$ for all $i = j$ and zero otherwise. The LM test statistic is

$$\Upsilon^{(n)}_{Wp} = [\mathbf{R}\boldsymbol{\beta}_T]' \left[\frac{1}{T} \mathbf{R} \widehat{\mathbf{V}}_{\mathbf{T}} \mathbf{R}' \right]^{-1} [\mathbf{R}\boldsymbol{\beta}_T] \tag{10}$$

where $\widehat{\mathbf{V}}_{\mathbf{T}}$ is the Eicker-White estimate of the covariance matrix of $\boldsymbol{\beta}_T$, i.e.,

$$\widehat{\mathbf{V}}_{\mathbf{T}} = \left(\frac{1}{T} \sum_{t=p+1}^{T} \mathbf{X}_{tp} \mathbf{X}'_{tp} \right)^{-1} \left(\frac{1}{T} \sum_{t=p+1}^{T} \widehat{e}^2_{tp} \mathbf{X}_{tp} \mathbf{X}'_{tp} \right) \left(\frac{1}{T} \sum_{t=p+1}^{T} \mathbf{X}_{tp} \mathbf{X}'_{tp} \right)^{-1},$$

$\widehat{e}_{tp}$ denotes the LS residuals, and $\mathbf{X}_{tp}$ is the vector of $(n+p)$ regressors.[1] Under the null hypothesis and fairly general sufficient conditions, it can be shown that $\Upsilon^{(n)}_{Wp} \Rightarrow \chi^2_{(n)}$.

3 Finite sample performance

We study two basic quarterly data generating processes. In particular, we consider the quarterly 'flexible' and 'rigid' filters, i.e., $\varphi_1(L; \boldsymbol{\theta}) := (1-L)^{1+\theta_1} (1+L)^{1+\theta_2} (1+L^2)^{1+\theta_3}$ [DGP1], and $\varphi_2(L; \boldsymbol{\theta}) := (1-L^4)^{1+\theta}$ [DGP2], respectively. We then simulate random paths of $\{y_t\}$ according to

$$\varphi_j(L; \boldsymbol{\theta}) y_t = u_t, \quad t = 1, 2, ..., T, \tag{11}$$

$$(1-\alpha L) u_t = \varepsilon_t, \quad \varepsilon_t \sim iid\mathcal{N}(0,1) \tag{12}$$

for $j = \{1, 2\}$, and for the AR(1) coefficient $\alpha \in \{0, 0.5, 0.9\}$ allowing us to consider different degrees of short-run dependence. Let the support $\mathcal{D}_\theta = \{-0.3, -0.2, ..., 0.3\}$. For DGP2, we set $\theta \in \mathcal{D}_\theta$ so that we can examine the empirical size ($\theta = 0$) and size-adjusted power ($|\theta| > 0$) of the tests under the null hypothesis that the data are generated from a seasonally integrated process. Similarly, for DGP1, we consider $\theta_i \in \mathcal{D}_\theta$, for any of the frequencies $\gamma_i \in \{0, \pi/2, \pi\}$

[1] This correction ensures the correct performance of the test under unknown forms of (conditional) heteroskedasticity. If data are believed to be homogenously distributed, then $\widehat{\mathbf{V}}_{\mathbf{T}} = \hat{\sigma}^2 \left(T^{-1} \sum_{t=p+1}^{T} \mathbf{X}_{tp} \mathbf{X}'_{tp} \right)^{-1}$.

involved, $i = 1, 2, 3$. We set $T = \{120, 240, 400\}$ and use 5000 replications to evaluate the performance of the $\widehat{\mathcal{R}}_3$ and $\Upsilon_{Wp}^{(3)}$ test statistics at the nominal size of 5%. For empirical settings, an important question refers to the effects resulting from misspecification of the short-run dynamics in practice. Interestingly, this issue has received little attention in the previous literature. Therefore, we shall consider the cases in which the tests control correctly and incorrectly for AR(1) dynamics, using $p = 1$ and $p = 4$ lags in the test regression, respectively, and the corresponding corrections in Robinson's test. The main results related to DGP1 and DGP2 are summarized in Tables 1 and 2, respectively.

A: Small-sample results for DGP1 (Table 1).

First, we discuss the results for the i.i.d case $(\alpha = 0)$. We note that the empirical size of the regression-based test is remarkably close to the asymptotic 5% level across any of the frequencies involved, even for a small sample of 120 observations. The frequency-domain test, however, presents (moderate) size departures. Under correct specification, $(\alpha = 0,\ p = 0)$, the power of $\Upsilon_{Wp}^{(3)}$ is superior to that of $\widehat{\mathcal{R}}_3$, particularly for the zero-frequency case, $|\theta_1| > 0$, although the gains tend to be smaller on the seasonal frequencies. Under misspecification of the short-run dynamics $(\alpha = 0, p > 0)$, $\Upsilon_{Wp}^{(3)}$ still exhibits good properties, whereas $\widehat{\mathcal{R}}_3$ is largely biased towards underrejection and loses considerable power. For instance, if *p=1* or *p=4* is (wrongly) used to correct for short-run dynamics, the empirical size of the $\widehat{\mathcal{R}}_3$ test is almost annihilated, as it decreases to around 0.6% (results not reported here). The regression-based test always controls correctly for size, and presents acceptable power for most parameter configurations.

Second, we discuss the results under short-run dependences, $\alpha > 0$. Whereas the size of $\Upsilon_{Wp}^{(3)}$ is always close to the 5%, if we do not attempt size-corrections the results for $\widehat{\mathcal{R}}_3$ show a high degree of variability and large departures given the values of α. Owing to the semi-parametric nature of the short-run correction used in these tests, both tests tend to lose considerable efficiency in relation to the i.i.d case, particularly at the zero-frequency case. The size-adjusted power is now more heterogenous depending on the frequency and the values involved. We observe from Table 1 that for $\theta_i < 0$, $i = 2, 3$ the Robinson's size adjusted test generally performs better than the regression based procedure, and the reverse is observed when $\theta_i > 0$, $i = 2, 3$.[2]

B: Small-sample results for DGP2 (Table 2).

The overall picture that emerges under the joint restriction $\theta_1 = \theta_2 = \theta_3 = \theta$ is very similar to that discussed previously. Remarkably, in this context, the performance of the regression-based test improves considerably over the frequency-domain test in the majority of the cases.[3]

4 Concluding remarks

In this paper, we have investigated the finite sample properties of the frequency-domain test proposed by Robinson (1994) and the novel asymptotic time-domain equivalent of Hassler, Rodrigues and Rubia (2009) for testing for seasonal integration in fractional contexts. Under large-sample theory, both tests have similar properties. In small-samples, we observe that the

[2]Non-adjusted power offers a qualitative picture as that described below.

[3]We also analyzed the performance of the test under the alternative that $\theta = c$, $|c| > 0$. The test statistic is then $\Upsilon_{Wp}^{(1)}$ and $\widehat{\mathcal{R}}_1$. Also, the term $\psi(\lambda_j)$ in Robinson's test is one-dimensional and given by $\psi_1(\lambda_j) + \psi_2(\lambda_j) + \psi_3(\lambda_j)$. Similar results are observed, although the tests are more powerful given that the restriction is true.

regression-based test ensures empirical sizes close to the asymptotic nominal level, whereas the size of the frequency-domain test seems to be more unstable. The power of the time-domain test seems to be similar to or better than the frequency-domain test for the parametric configurations considered in this study. Hence, the performance of the regression-based test, coupled with its enormous tractability, makes it an interesting testing procedure for empirical analysis. Also, given that the tests seem to be complementary, both tests may be applied jointly, thereby providing a more complete analysis.

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Table 1: Empirical size and size-adjusted power of the Robinson's test and of the regression-based test at a nominal significance level of 5%.

			DGP1: $(1-L)^{1+\theta_1}(1+L)^{1+\theta_2}(1+L^2)^{1+\theta_3}y_t = u_t$, $(1-\alpha L)u_t = \varepsilon_t$, $\varepsilon_t \sim iid\mathcal{N}(0,1)$													
			$\alpha = 0$						$\alpha = 0.5$				$\alpha = 0.9$			
T=120			$p=0$		$p=1$		$p=4$		$p=1$		$p=4$		$p=1$		$p=4$	
θ_1	θ_2	θ_3	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{R}_3$	$\Upsilon_{Wp}^{(3)}$
−0.3	0	0	.612	.870	.284	.472	.088	.149	.095	.153	.047	.115	.084	.070	.018	.048
−0.2	0	0	.292	.512	.159	.226	.067	.092	.075	.096	.045	.080	.044	.057	.025	.046
−0.1	0	0	.078	.160	.073	.092	.049	.062	.058	.060	.050	.054	.063	.047	.048	.046
0	0	0	**.035**	**.055**	**.050****	**.052**	**.050****	**.048**	**.060****	**.049**	**.065****	**.045**	**.068**	**.046**	**.088**	**.049**
0.1	0	0	.146	.203	.071	.090	.070	.056	.092	.059	.113	.047	.114	.086	.152	.049
0.2	0	0	.514	.650	.137	.225	.135	.082	.160	.075	.175	.058	.310	.195	.266	.053
0.3	0	0	.869	.933	.252	.401	.219	.106	.242	.096	.247	.071	.643	.390	.413	.056
0	-0.3	0	.600	.639	.294	.078	.090	.050	.556	.259	.198	.048	.483	.643	.254	.052
0	-0.2	0	.287	.346	.161	.065	.063	.050	.289	.198	.144	.052	.241	.392	.195	.056
0	-0.1	0	.088	.128	.077	.061	.051	.049	.120	.098	.098	.049	.109	.134	.129	.052
0	0	0	**.035**	**.055**	**.050****	**.052**	**.050****	**.048**	**.060****	**.049**	**.065****	**.045**	**.068**	**.046**	**.088**	**.049**
0	0.1	0	.139	.173	.066	.130	.079	.060	.114	.194	.072	.062	.162	.190	.075	.068
0	0.2	0	.526	.659	.131	.521	.135	.129	.327	.674	.123	.140	.428	.657	.091	.138
0	0.3	0	.854	.972	.251	.922	.223	.239	.626	.966	.216	.226	.735	.952	.152	.188
0	0	-0.3	.643	.639	.796	.681	.131	.046	.796	.573	.273	.049	.548	.368	.275	.056
0	0	-0.2	.317	.312	.446	.352	.078	.048	.456	.276	.169	.049	.282	.163	.184	.053
0	0	-0.1	.100	.111	.159	.125	.053	.049	.167	.097	.100	.048	.136	.066	.125	.051
0	0	0	**.035**	**.055**	**.050****	**.052**	**.050****	**.048**	**.060****	**.049**	**.065****	**.045**	**.068**	**.046**	**.088**	**.049**
0	0	0.1	.056	.131	.104	.119	.073	.045	.082	.110	.068	.046	.066	.073	.080	.056
0	0	0.2	.303	.463	.392	.438	.187	.040	.290	.360	.149	.065	.202	.171	.123	.131
0	0	0.3	.710	.888	.735	.872	.367	.051	.640	.742	.314	.139	.462	.346	.258	.353

Note: p refers to the augmentation considered in both tests to correct for possible autocorrelation. The results for $\widehat{\mathcal{R}}_3$ when $\alpha = 0$ or $\alpha = 0.5$ is considered with either $p = 1$ or $p = 4$ are size adjusted, using the critical values implied by the finite sample distribution when $\alpha = 0$ and $p = 0$. Results with this adjustment when $\alpha = 0.9$ are not reported, since the empirical size was highly distorted (towards 20 %) .

Table 2: Empirical size and size-adjusted power of the Robinson's test and of the regression-based test at a nominal significance level of 5%.

DGP2: $(1-L^4)^{1+\theta} y_t = u_t$, $(1-\alpha L)u_t = \varepsilon_t$, $\varepsilon_t \sim iid\mathcal{N}(0,1)$														
	$\alpha=0$						$\alpha=0.5$				$\alpha=0.9$			
	$p=0$		$p=1$		$p=4$		$p=1$		$p=4$		$p=1$		$p=4$	
T=120	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$
$\theta=-0.3$	.627	.818	.790	.803	.198	.372	.794	.716	.293	.404	.384	.414	.189	.430
$\theta=-0.2$	.315	.457	.474	.444	.096	.183	.488	.394	.155	.197	.193	.211	.130	.218
$\theta=-0.1$	.099	.158	.174	.148	.059	.084	.185	.141	.083	.088	.099	.086	.104	.086
$\theta=0$	**.033**	**.055**	**.050***	**.052**	**.050***	**.048**	**.067***	**.049**	**.063***	**.045**	**.073**	**.046**	**.091**	**.049**
$\theta=0.1$	.048	.194	.063	.182	.122	.074	.085	.156	.085	.077	.079	.107	.110	.096
$\theta=0.2$	.146	.616	.194	.598	.305	.164	.223	.510	.193	.206	.127	.316	.197	.288
$\theta=0.3$	.407	.926	.453	.916	.561	.291	.475	.856	.415	.404	.249	.609	.475	.604
T=240														
$\theta=-0.3$	.974	.995	.994	.996	.633	.794	.992	.985	.796	.818	.918	.798	.716	.847
$\theta=-0.2$	.721	.851	.830	.843	.314	.413	.835	.762	.464	.453	.574	.441	.374	.499
$\theta=-0.1$	.236	.281	.321	.272	.096	.133	.325	.248	.166	.141	.182	.140	.132	.150
$\theta=0$	**.036**	**.056**	**.050***	**.055**	**.050***	**.045**	**.056***	**.049**	**.056***	**.046**	**.065**	**.049**	**.074**	**.047**
$\theta=0.1$	.126	.356	.149	.340	.100	.118	.153	.281	.076	.132	.125	.177	.079	.168
$\theta=0.2$	.556	.906	.594	.898	.283	.359	.599	.839	.192	.437	.443	.579	.316	.579
$\theta=0.3$	.926	.998	.939	.998	.569	.626	.940	.992	.457	.756	.815	.902	.772	.912
T=400														
$\theta=-0.3$	.999	1.00	1.00	1.00	.940	.973	1.00	1.00	.984	.982	.999	.978	.984	.990
$\theta=-0.2$	.961	.986	.979	.984	.648	.698	.980	.963	.774	.743	.922	.729	.746	.785
$\theta=-0.1$	.431	.479	.496	.467	.200	.200	.492	.406	.291	.225	.344	.226	.235	.252
$\theta=0$	**.045**	**.052**	**.050***	**.050**	**.050***	**.045**	**.049***	**.053**	**.054***	**.046**	**.062**	**.053**	**.062**	**.047**
$\theta=0.1$	.271	.568	.300	.554	.076	.196	.299	.469	.094	.224	.239	.275	.136	.287
$\theta=0.2$	.907	.987	.916	.986	.255	.601	.925	.971	.309	.695	.835	.809	.641	.830
$\theta=0.3$	.999	1.00	.990	1.00	.556	.883	.999	1.00	.647	.944	.989	.986	.973	.991

Note: p refers to the augmentation considered in both tests to correct for possible autocorrelation. The results for $\widehat{\mathcal{R}}_3$ when $\alpha=0$ or $\alpha=0.5$ is considered with either $p=1$ or $p=4$ are size adjusted, using the critical values implied by the finite sample distribution when $\alpha=0$ and $p=0$. Results with this adjustment when $\alpha=0.9$ are not reported, since the empirical size was again highly distorted (towards 20%) .

Auxiliary Table: Empirical size and power of the Robinson's test and of the regression-based test at a nominal significance level of 5%.

DGP1: $(1-L)^{1+\theta_1}(1+L)^{1+\theta_2}(1+L^2)^{1+\theta_3} y_t = u_t$, $(1-\alpha L)u_t = \varepsilon_t$, $\varepsilon_t \sim iid\mathcal{N}(0,1)$

T=120			$\alpha=0$						$\alpha=0.5$				$\alpha=0.9$			
			$p=0$		$p=1$		$p=4$		$p=1$		$p=4$		$p=1$		$p=4$	
θ_1	θ_2	θ_3	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{\mathcal{R}}_3$	$\Upsilon_{Wp}^{(3)}$	$\widehat{R}_3$	$\Upsilon_{Wp}^{(3)}$
−0.3	0	0	.612	.870	.058	.472	.011	.149	.013	.153	.005	.115	.040	.070	.018	.048
−0.2	0	0	.292	.512	.020	.226	.005	.092	.008	.096	.004	.080	.044	.057	.025	.046
−0.1	0	0	.078	.160	.008	.092	.005	.062	.010	.060	.006	.054	.063	.047	.048	.046
0	0	0	**.035**	**.055**	**.007**	**.052**	**.006**	**.048**	**.012**	**.049**	**.011**	**.045**	**.068**	**.046**	**.088**	**.049**
0.1	0	0	.146	.203	.023	.090	.009	.056	.027	.059	.023	.047	.114	.086	.152	.049
0.2	0	0	.514	.650	.053	.225	.036	.082	.027	.075	.044	.058	.310	.195	.266	.053
0.3	0	0	.869	.933	.155	.401	.072	.106	.098	.096	.091	.071	.643	.390	.413	.056
0	-0.3	0	.600	.639	.053	.078	.007	.050	.195	.259	.045	.048	.483	.643	.254	.052
0	-0.2	0	.287	.346	.023	.065	.007	.050	.066	.198	.026	.052	.241	.392	.195	.056
0	-0.1	0	.088	.128	.008	.061	.005	.049	.018	.098	.015	.049	.109	.134	.129	.052
0	0	0	**.035**	**.055**	**.007**	**.052**	**.006**	**.048**	**.012**	**.049**	**.011**	**.045**	**.068**	**.046**	**.088**	**.049**
0	0.1	0	.139	.173	.016	.130	.009	.060	.046	.194	.010	.062	.162	.190	.075	.068
0	0.2	0	.526	.659	.053	.521	.031	.129	.188	.674	.031	.140	.428	.657	.091	.138
0	0.3	0	.854	.972	.163	.922	.069	.239	.447	.966	.066	.226	.735	.952	.152	.188
0	0	-0.3	.643	.639	.346	.681	.013	.046	.412	.573	.043	.049	.548	.368	.275	.056
0	0	-0.2	.317	.312	.124	.352	.006	.048	.166	.276	.024	.049	.282	.163	.184	.053
0	0	-0.1	.100	.111	.030	.125	.005	.049	.043	.097	.017	.048	.136	.066	.125	.051
0	0	0	**.035**	**.055**	**.007**	**.052**	**.006**	**.048**	**.012**	**.049**	**.011**	**.045**	**.068**	**.046**	**.088**	**.049**
0	0	0.1	.056	.131	.023	.119	.011	.045	.019	.110	.011	.046	.066	.073	.080	.056
0	0	0.2	.303	.463	.222	.438	.047	.040	.145	.360	.041	.065	.202	.171	.123	.131
0	0	0.3	.710	.888	.564	.872	.164	.051	.445	.742	.152	.139	.462	.346	.258	.353

Note: p refers to the augmentation considered in both tests to correct for possible autocorrelation.

Auxiliary Table: Empirical size and power of the Robinson's test and of the regression-based test at a nominal significance level of 5%.

			DGP1: $(1-L)^{1+\theta_1}(1+L)^{1+\theta_2}(1+L^2)^{1+\theta_3}\, y_t = u_t,\ (1-\alpha L)u_t = \varepsilon_t,\ \varepsilon_t \sim iid\mathcal{N}(0,1)$													
			$\alpha=0$						$\alpha=0.5$				$\alpha=0.9$			
T=240			$p=0$		$p=1$		$p=4$		$p=1$		$p=4$		$p=1$		$p=4$	
θ_1	θ_2	θ_3	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{R}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$
−0.3	0	0	.965	.997	.405	.856	.030	.337	.060	.308	.008	.216	.062	.105	.012	.059
−0.2	0	0	.707	.872	.153	.470	.014	.154	.034	.145	.006	.118	.081	.081	.021	.053
−0.1	0	0	.191	.308	.036	.146	.008	.074	.019	.069	.007	.065	.077	.052	.039	.050
0	0	0	**.038**	**.056**	**.020**	**.055**	**.007**	**.045**	**.019**	**.049**	**.011**	**.046**	**.063**	**.049**	**.066**	**.047**
0.1	0	0	.314	.369	.055	.135	.020	.064	.040	.068	.032	.058	.119	.115	.131	.047
0.2	0	0	.867	.917	.165	.427	.072	.133	.098	.124	.088	.091	.447	.315	.238	.048
0.3	0	0	.996	.998	.328	.716	.177	.231	.185	.199	.158	.145	.865	.651	.385	.048
0	-0.3	0	.970	.919	.397	.096	.028	.055	.815	.518	.083	.051	.956	.947	.313	.062
0	-0.2	0	.698	.607	.149	.079	.015	.054	.366	.413	.042	.057	.619	.722	.204	.070
0	-0.1	0	.194	.209	.041	.070	.008	.050	.077	.162	.020	.052	.182	.256	.119	.059
0	0	0	**.038**	**.056**	**.020**	**.055**	**.007**	**.045**	**.019**	**.049**	**.011**	**.046**	**.063**	**.049**	**.066**	**.047**
0	0.1	0	.310	.312	.061	.209	.016	.075	.143	.355	.014	.086	.298	.372	.053	.099
0	0.2	0	.866	.929	.174	.830	.071	.246	.536	.937	.058	.272	.802	.944	.093	.258
0	0.3	0	.994	1.00	.319	.998	.181	.486	.885	1.00	.164	.457	.980	1.00	.210	.394
0	0	-0.3	.983	.924	.975	.934	.100	.059	.964	.871	.238	.064	.979	.673	.563	.071
0	0	-0.2	.750	.594	.648	.617	.035	.054	.622	.509	.083	.059	.705	.308	.296	.063
0	0	-0.1	.225	.171	.132	.184	.011	.049	.146	.144	.029	.052	.233	.088	.133	.053
0	0	0	**.038**	**.056**	**.020**	**.055**	**.007**	**.045**	**.019**	**.049**	**.011**	**.046**	**.063**	**.049**	**.066**	**.047**
0	0	0.1	.180	.214	.151	.194	.014	.044	.107	.165	.013	.051	.153	.103	.052	.074
0	0	0.2	.785	.774	.755	.756	.074	.048	.649	.622	.051	.087	.670	.277	.098	.215
0	0	0.3	.989	.993	.975	.992	.245	.081	.967	.956	.191	.277	.953	.560	.274	.647

Note: p refers to the augmentation considered in both tests to correct for possible autocorrelation.

Auxiliary Table: Empirical size and power of the Robinson's test and of the regression-based test at a nominal significance level of 5%.

			DGP1: $(1-L)^{1+\theta_1}(1+L)^{1+\theta_2}(1+L^2)^{1+\theta_3} y_t = u_t$, $(1-\alpha L)u_t = \varepsilon_t$, $\varepsilon_t \sim iid\mathcal{N}(0,1)$													
			$\alpha=0$						$\alpha=0.5$				$\alpha=0.9$			
T=400			$p=0$		$p=1$		$p=4$		$p=1$		$p=4$		$p=1$		$p=4$	
θ_1	θ_2	θ_3	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$
-0.3	0	0	.999	1.00	.842	.987	.130	.593	.172	.521	.029	.396	.105	.183	.010	.065
-0.2	0	0	.950	.991	.423	.736	.042	.268	.074	.233	.016	.180	.113	.126	.017	.058
-0.1	0	0	.383	.504	.089	.219	.013	.095	.033	.084	.012	.078	.097	.068	.031	.049
0	0	0	**.047**	**.052**	**.025**	**.050**	**.009**	**.045**	**.027**	**.053**	**.017**	**.046**	**.066**	**.053**	**.065**	**.047**
0.1	0	0	.510	.583	.119	.226	.028	.087	.044	.089	.043	.072	.151	.148	.126	.049
0.2	0	0	.985	.990	.369	.670	.086	.231	.119	.207	.107	.158	.646	.460	.231	.052
0.3	0	0	1.00	1.00	.603	.910	.217	.399	.218	.338	.228	.261	.970	.851	.397	.058
0	-0.3	0	.999	.994	.832	.122	.124	.060	.996	.799	.239	.060	1.00	.998	.444	.075
0	-0.2	0	.953	.840	.413	.103	.049	.054	.782	.663	.084	.071	.923	.940	.242	.089
0	-0.1	0	.382	.318	.099	.089	.014	.052	.192	.282	.034	.061	.333	.439	.114	.076
0	0	0	**.047**	**.052**	**.025**	**.050**	**.009**	**.045**	**.027**	**.053**	**.017**	**.046**	**.066**	**.053**	**.065**	**.047**
0	0.1	0	.524	.506	.118	.324	.027	.103	.278	.542	.021	.133	.487	.577	.051	.144
0	0.2	0	.981	.995	.356	.960	.084	.395	.834	.996	.061	.429	.970	.997	.098	.429
0	0.3	0	1.00	1.00	.590	1.00	.210	.714	.992	1.00	.197	.690	1.00	1.00	.216	.614
0	0	-0.3	1.00	.994	1.00	.996	.422	.077	1.00	.981	.662	.080	1.00	.890	.875	.082
0	0	-0.2	.975	.818	.971	.832	.142	.063	.959	.727	.267	.068	.972	.472	.499	.073
0	0	-0.1	.421	.269	.350	.291	.029	.050	.317	.222	.069	.053	.404	.133	.174	.058
0	0	0	**.047**	**.052**	**.025**	**.050**	**.009**	**.045**	**.027**	**.053**	**.017**	**.046**	**.066**	**.053**	**.065**	**.047**
0	0	0.1	.410	.334	.378	.310	.012	.046	.292	.253	.017	.054	.353	.139	.061	.084
0	0	0.2	.974	.946	.974	.941	.073	.065	.951	.849	.054	.136	.958	.427	.149	.339
0	0	0.3	1.00	1.00	1.00	1.00	.264	.145	1.00	.998	.198	.481	1.00	.760	.349	.864

Note: p refers to the augmentation considered in both tests to correct for possible autocorrelation.

Auxiliary Table: Empirical size and power of the Robinson's test and of the regression-based test at a nominal significance level of 5%.

	DGP2: $(1-L^4)^{1+\theta} y_t = u_t$, $(1-\alpha L)u_t = \varepsilon_t$, $\varepsilon_t \sim iid\mathcal{N}(0,1)$,											
	$\alpha = 0$				$\alpha = 0.5$				$\alpha = 0.9$			
	$p = 1$		$p = 4$		$p = 1$		$p = 4$		$p = 1$		$p = 4$	
T=120	$\widehat{\mathcal{R}}_1$	$\Upsilon_{Wp}^{(1)}$	$\widehat{\mathcal{R}}_1$	$\Upsilon_{Wp}^{(1)}$	$\widehat{\mathcal{R}}_1$	$\Upsilon_{Wp}^{(1)}$	$\widehat{\mathcal{R}}_1$	$\Upsilon_{Wp}^{(1)}$	$\widehat{\mathcal{R}}_1$	$\Upsilon_{Wp}^{(1)}$	$\widehat{\mathcal{R}}_1$	$\Upsilon_{Wp}^{(1)}$
$\theta = -0.3$	.898	.933	.266	.568	.901	.849	.428	.571	.861	.034	.685	.292
$\theta = -0.2$	.633	.640	.145	.302	.658	.554	.250	.357	.610	.044	.481	.245
$\theta = -0.1$	.292	.228	.075	.111	.303	.220	.124	.174	.297	.094	.271	.218
$\theta = 0$	**.062**	**.052**	**.059**	**.049**	**.074**	**.054**	**.067**	**.047**	**.102**	**.054**	**.132**	**.049**
$\theta = 0.1$	.015	.264	.102	.089	.015	.222	.058	.070	.035	.343	.058	.184
$\theta = 0.2$	.060	.738	.231	.240	.058	.637	.071	.146	.051	.506	.047	.182
$\theta = 0.3$	.273	.965	.490	.427	.238	.919	.127	.272	.201	.657	.092	.200
T=240												
$\theta = -0.3$	.998	.999	.786	.933	.999	.993	.896	.902	.996	.024	.972	.487
$\theta = -0.2$	.943	.944	.474	.619	.947	.868	.628	.637	.918	.058	.807	.388
$\theta = -0.1$	.515	.433	.193	.208	.537	.379	.279	.287	.500	.212	.410	.319
$\theta = 0$	**.065**	**.055**	**.082**	**.048**	**.074**	**.053**	**.089**	**.046**	**.088**	**.050**	**.104**	**.044**
$\theta = 0.1$	.089	.486	.073	.178	.075	.411	.035	.106	.054	.703	.038	.241
$\theta = 0.2$	.557	.955	.185	.510	.550	.906	.034	.324	.418	.865	.207	.230
$\theta = 0.3$	.929	.999	.472	.770	.922	.997	.078	.585	.838	.939	.577	.236
T=400												
$\theta = -0.3$	1.00	1.00	.977	.997	1.00	1.00	.996	.988	1.00	.022	.998	.679
$\theta = -0.2$	.997	.997	.791	.867	.998	.980	.880	.855	.991	.102	.968	.540
$\theta = -0.1$	.734	.674	.356	.329	.744	.557	.446	.425	.694	.408	.583	.435
$\theta = 0$	**.066**	**.055**	**.091**	**.048**	**.065**	**.050**	**.081**	**.050**	**.072**	**.054**	**.099**	**.049**
$\theta = 0.1$	.287	.704	.044	.294	.267	.615	.029	.154	.191	.934	.107	.295
$\theta = 0.2$	.930	.996	.103	.760	.923	.986	.118	.515	.846	.988	.655	.266
$\theta = 0.3$	1.00	1.00	.374	.946	.999	1.00	.228	.828	.995	.998	.951	.266

Note: p refers to the augmentation considered in both tests to correct for possible autocorrelation.

Auxiliary Table: Empirical size and power of the Robinson's test and of the regression-based test at a nominal significance level of 5%.

DGP2: $(1-L^4)^{1+\theta} y_t = u_t$, $(1-\alpha L)u_t = \varepsilon_t$, $\varepsilon_t \sim iid\mathcal{N}(0,1)$														
	$\alpha=0$						$\alpha=0.5$				$\alpha=0.9$			
	$p=0$		$p=1$		$p=4$		$p=1$		$p=4$		$p=1$		$p=4$	
T=120	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$	$\widehat{\mathcal{R}}_3$	$\Upsilon^{(3)}_{Wp}$
$\theta=-0.3$	.627	.818	.385	.803	.012	.372	.402	.716	.037	.404	.384	.414	.189	.430
$\theta=-0.2$	.315	.457	.133	.444	.006	.183	.147	.394	.015	.197	.193	.211	.130	.218
$\theta=-0.1$	.099	.158	.025	.148	.004	.084	.032	.141	.010	.088	.099	.086	.104	.086
$\theta=0$	**.033**	**.055**	**.007**	**.052**	**.005**	**.048**	**.012**	**.049**	**.011**	**.045**	**.073**	**.046**	**.091**	**.049**
$\theta=0.1$	.048	.194	.023	.182	.020	.074	.031	.156	.021	.077	.079	.107	.110	.096
$\theta=0.2$	.146	.616	.100	.598	.088	.164	.121	.510	.062	.206	.127	.316	.197	.288
$\theta=0.3$	.407	.926	.283	.916	.273	.291	.315	.856	.225	.404	.249	.609	.475	.604
T=240														
$\theta=-0.3$	.974	.995	.960	.996	.250	.794	.962	.985	.461	.818	.918	.798	.716	.847
$\theta=-0.2$	.721	.851	.656	.843	.060	.413	.651	.762	.152	.453	.574	.441	.374	.499
$\theta=-0.1$	.236	.281	.150	.272	.012	.133	.156	.248	.032	.141	.182	.140	.132	.150
$\theta=0$	**.036**	**.056**	**.017**	**.055**	**.006**	**.045**	**.023**	**.049**	**.011**	**.046**	**.065**	**.049**	**.074**	**.047**
$\theta=0.1$	.126	.356	.090	.340	.030	.118	.102	.281	.024	.132	.125	.177	.079	.168
$\theta=0.2$	.556	.906	.497	.898	.156	.359	.515	.839	.098	.437	.443	.579	.316	.579
$\theta=0.3$	.926	.998	.899	.998	.423	.626	.907	.992	.355	.756	.815	.902	.772	.912
T=400														
$\theta=-0.3$	.999	1.00	1.00	1.00	.786	.973	1.00	1.00	.921	.982	.999	.978	.984	.990
$\theta=-0.2$	.961	.986	.953	.984	.320	.698	.953	.963	.521	.743	.922	.729	.746	.785
$\theta=-0.1$	.431	.479	.368	.467	.056	.200	.365	.406	.107	.225	.344	.226	.235	.252
$\theta=0$	**.045**	**.052**	**.028**	**.050**	**.011**	**.045**	**.028**	**.053**	**.017**	**.046**	**.062**	**.053**	**.062**	**.047**
$\theta=0.1$	.271	.568	.254	.554	.030	.196	.236	.469	.043	.224	.239	.275	.136	.287
$\theta=0.2$	.907	.987	.888	.986	.170	.601	.895	.971	.214	.695	.835	.809	.641	.830
$\theta=0.3$	.999	1.00	1.00	1.00	.449	.883	.999	1.00	.525	.944	.989	.986	.973	.991

Note: p refers to the augmentation considered in both tests to correct for possible autocorrelation.

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