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Meta-analytic cointegrating rank tests for dependent panels

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Abstract

This paper proposes two new panel cointegrating rank tests which are robust to cross-sectional dependency. The dependence in the data generating process is modeled using unobserved common factors. The new tests are based on a meta-analytic approach, in which the p-values of the individual likelihood-ratio (LR) type test statistics computed from defactored data are combined to develop the panel statistics. A simulation study shows that the tests have reasonable size and power properties in finite samples.

Keywords: Panel cointegration; p-value; common factors; rank test; cross-sectional dependence

JEL Classification: C12, C15, C33

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1 Introduction

Since the beginning of the 21st century panel cointegration techniques have been widely used to test and estimate long-run macroeconomic relationships. By using time observations from different cross-sections, it is possible to increase the power of the conventional cointegration tests. However, the cross-sectional dependencies within the macro-panels should be taken into account to avoid wrong statistical inference.

There are mainly two different types of panel cointegration tests in the literature. The first type of tests are called residual-based tests and the second type of tests are called systems (likelihood-based) tests. The latter ones have some advantages in comparison to the former ones. The systems tests are not only suitable to find out the number of cointegrating relations, i.e. the cointegrating rank of the system, but also the test decisions are invariant to the variable used to normalize the long-run relationship.

In order to use the advantages of the systems tests, our aim is to develop new panel cointegrating rank tests which allow for cross-sectional dependence.

In this study the testing procedure outlined in Arsova and Örsal (2013) is followed to propose new panel cointegration tests. Arsova and Örsal (2013) base their testing procedure on the panel analysis of nonstationarity in idiosyncratic and common components (PANIC) approach of Bai and Ng (2004) and propose a panel cointegrating rank test which is the standardized version of the average individual LR-type test statistics of Saikkonen and Lütkepohl (2000) computed from defactored data.

In contrast to Arsova and Örsal (2013), the new testing procedure in this study is based on the approach of Maddala and Wu (1999) and Choi (2001), in which the new panel test statistics are based on combining p-values of the individual Saikkonen-Lütkepohl LR statistics using defactored data.

The panel tests based on combining p-values are more advantageous than those based on standardizing the average of the individual test statistics. The former approach allows to have a more heterogeneous structure in the panel. Within this heterogeneous structure different deterministic terms can be included into the data generating process (DGP) of each cross-section and also the lag order can vary over cross-sections. These tests may even be applied to unbalanced panels.

Via Monte Carlo simulations we compare the finite sample properties of the new tests with the test of Arsova and Örsal (2013) and show that the meta-analytic tests have slightly better properties in some cases.

This paper is organized as follows. Section 2 presents the DGP and the assumptions of the new panel cointegration tests. Section 3 explains the testing procedure. Section 4 presents the finite sample properties of the panel cointegration tests and compares the test of Arsova and Örsal (2013) with the new tests. Finally, Section 5 concludes.

Note that throughout the paper $\|A\| = [tr(A'A)]^{1/2}$ stands for the Euclidean norm of an $(n \times n)$ matrix, and M is a generic constant which is independent of the time and cross-section dimensions of the panel.

2 Model

The new panel cointegration tests are based on the same DGP as in Arsova and Örsal (2013):

$$
\begin{aligned}
Y_{it}^{cd} &= Y_{it} + \Lambda_i' F_t, \quad i = 1, \dots, N, \quad t = 1, \dots T_i, & (1)\\
Y_{it} &= \mu_{0i} + \mu_{1i} t + X_{it}, & (2)\\
X_{it} &= A_{i1} X_{i,t-1} + \ldots + A_{i,\bar{p}_i} X_{i,t-\bar{p}_i} + \varepsilon_{it}, & (3)\\
(1-L) F_t &= C(L) u_t \quad \text{with} \quad C(L) = \sum_{j=0}^{\infty} C_j L^j, & (4)
\end{aligned}
$$

where the m-dimensional vector $Y_{it}^{cd} = (Y_{1,it}^{cd}, \dots, Y_{i,mt}^{cd})'$ denotes the observed cross-sectionally dependent data for unit i. Note that this model is the vector-valued extension of the model of Bai and Ng (2004). Cross-sectional dependence is allowed for through the $(k \times 1)$ vector of unobserved common factors F_t. Due to the $(k \times m)$ matrix of individual-specific factors loadings Λ_i, some factors may not influence all the cross-sections. The common factors may be either stationary, non-stationary or a combination of stationary and non-stationary processes. T_i denotes that the number of time observations may vary over cross-sections. For simplicity we suppress the index i and henceforth T stands for the number time observations.

In Equation 2 μ_{0i} and μ_{1i} denote the heterogeneous deterministic terms. X_{it} is the unobserved idiosyncratic component which has a VAR representation (see Equation 3), whose lag order may differ over cross-sections. The components of the X_{it} process can be integrated at most of order one and they are cointegrated with cointegrating rank r_i for all $0 \leq r_i \leq m$. The error terms ε_{it} follow a martingale difference sequence, where $E(\varepsilon_{it}|\varepsilon_{is}, s < t) = 0$ and $E(\varepsilon_{it}\varepsilon_{it}'|\varepsilon_{is}, s < t) = \Omega_i$ with Ω_i being a positive definite matrix for $i = 1, \dots, N$. The ε_{it}'s are neither serially correlated nor cross-sectionally dependent. In other words, the sole source of cross-sectional dependence within the panel is the common component $\Lambda_i' F_t$. We assume that the number of common factors is known. In practice it can be determined by the information criteria of Bai and Ng (2002) or Onatski (2010).

The test is based on the VECM representation of X_{it}:

$$
\Delta X_{it} = \Pi_i X_{i,t-1} + \sum_{j=1}^{\bar{p}_{i-1}} \Gamma_{ij} \Delta X_{i,t-j} + \varepsilon_{it}, \quad t = \bar{p}_i + 1, \dots, T, \quad i = 1, \dots, N, \quad (5)
$$

where $\Gamma_{ij} = -(A_{i,j+1} + \ldots + A_{i,\bar{p}_i})$. The $(m \times m)$ matrix $\Pi_i = -(I_m - A_{i1} - \ldots, -A_{i,\bar{p}_i})$ is the cointegrating matrix for each cross-section which can be decomposed as $\Pi_i = \alpha_i \beta_i'$ with α_i and β_i being full rank $(m \times r_i)$ matrices.

Assumptions:

1. The assumptions on the common factors are:

(a) $u_t \sim iid(0, \Sigma_u)$, $E\|u_t\|^4 \leq M < \infty$.
(b) $Var(\Delta F_t) = \sum_{j=0}^{\infty} C_j \Sigma_u C_j' > 0$.
(c) $\sum_{j=0}^{\infty} j \|C_j\| < M < \infty$.
(d) $C(1)$ has rank k_1, $0 \leq k_1 \leq k$.

2. The assumptions on the factor loadings are:

(a) Λ_i is deterministic and $\|\Lambda_i\| \leq M < \infty$, or Λ_i is stochastic and $E\|\Lambda_i\|^4 \leq M < \infty$.
(b) $N^{-1} \sum_{i=1}^{N} \Lambda_i \Lambda_i' \xrightarrow{p} \Sigma_\Lambda$ as $N \to \infty$, where Σ_Λ is a $(k \times k)$ non-random positive definite matrix.

3. Λ_i, u_t and ε_{it} are mutually independently distributed across i and t.

3 Testing Procedure

Before testing for the panel cointegrating rank, in an initial step the cross-sectional dependence within the panel should be eliminated. Therefore, the data are defactored using the PANIC approach of Bai and Ng (2004). In PANIC the common components are estimated using principal components. A detailed description on the way how the factors and loadings are estimated can be found in Arsova and Örsal (2013). By subtracting the estimates of the common components, i.e $\hat{\Lambda}_i' \hat{F}_t$, from the observed data, the cross-sectional dependence is eliminated from the panel. In the next step, the GLS-based LR type cointegration test of Saikkonen and Lütkepohl (2000) is employed on the defactored data for each panel unit separately. Finally, the corresponding p-values of the individual test statistics are computed by the response surface approach outlined in Trenkler (2008).

The null and alternative hypotheses under consideration are:

$$H_0 : r_i = r = 0, \ \forall i, \quad \text{versus} \quad H_1 : r_i > 0 \quad \text{for some } i. \tag{6}$$

We propose the following panel cointegration test statistics based on a standardized version of Fisher's χ^2 p-value test and the inverse normal test, respectively:

$$P_N^* = \frac{-2 \sum_{i=1}^{N} \ln(p_i^*) - 2N}{\sqrt{4N}}, \tag{7}$$

$$P_{\Phi^{-1}}^* = \frac{\sum_{i=1}^{N} \Phi^{-1}(p_i^*)}{\sqrt{N}}. \tag{8}$$

Here p_i^* denotes the p-value of the individual Saikkonen and Lütkepohl LR-type statistic under the null hypothesis of no cointegration for individual i (henceforth $\mathrm{LR}_{\mathrm{trace,iT}}^{\mathrm{SL}*}(0)$)

and $\Phi(.)$ denotes the cumulative distribution function of the standard normal distribution. The LR-statistics can be computed using either the estimated idiosyncratic component $\hat{X}_{it} = \sum_{s=2}^{t}(y_{is} - \hat{\Lambda}_i'\hat{F}_t)$ for $t = 2, \ldots, T$ and $\hat{X}_{i1} = 0$, where $y_{it} = \Delta Y_{it}^{cd} - \frac{1}{T-1}\sum_{t=2}^{T}\Delta Y_{it}^{cd}$, or the defactored data $Y_{it}^{*} = Y_{it}^{cd} - \hat{\Lambda}_i'\hat{F}_t$. Note that the open source software JMulTi delivers the response surface p-values of the GLS-based LR-type statistic of Saikkonen and Lütkepohl.

The limiting distribution of the proposed tests under the null and alternative hypotheses is established in the next theorem.

Theorem 1. *Under the null hypothesis of no cointegration, and when m and $\bar{p} = \max\{\bar{p}_i | 1 \leq i \leq N\}$ remain fixed, it holds that*

$$P_N^{*} \sim N(0,1), \tag{9}$$
$$P_{\Phi^{-1}}^{*} \sim N(0,1), \tag{10}$$

as $T \to \infty$ followed by $N \to \infty$. Under the alternative hypothesis the P_N^{*} statistic diverges to $+\infty$ and the $P_{\Phi^{-1}}^{*}$ statistic diverges to $-\infty$.

Proof. The theorem is valid under the assumption that the individual statistics are computed from cross-sectionally independent data. To prove this theorem for the statistics based on defactored data the arguments of Bai and Ng (2004, p. 1176) can be followed. Let $\mathrm{LR}_{\mathrm{trace,iT}}^{\mathrm{SL}}(0)$, $i = 1, \ldots, N$, be statistics based on the cross-sectionally independent data and let $\mathrm{LR}_{\mathrm{trace,iT}}^{\mathrm{SL}*}(0)$, $i = 1, \ldots, N$, be statistics based on the estimated idiosyncratic components. According to Theorem 3.1 in Arsova and Örsal (2013), the asymptotic distribution of $\mathrm{LR}_{\mathrm{trace,iT}}^{\mathrm{SL}*}(0)$ is the same as the distribution of $\mathrm{LR}_{\mathrm{trace,iT}}^{\mathrm{SL}}(0)$, and the two statistics are also asymptotically equivalent. This implies the asymptotic independence of $\mathrm{LR}_{\mathrm{trace,iT}}^{\mathrm{SL}*}(0)$ over i and hence the independence of the corresponding p-values. □

As explained in Arsova and Örsal (2013), due to the defactoring procedure the cointegrating matrix β_i cannot be estimated with the consistency rate $O_p(T^{-1})$. Therefore, the rank determination is carried out with a modified sequential testing procedure. By using a suitable estimator for the orthogonal complement[1] of the cointegrating matrix, i.e. $\hat{\beta}_{i\perp}$, it is possible to test for cointegrating rank higher than zero.

Within the modified sequential testing procedure, first the defactored data (i.e Y_{it}^{*}) is tested for no cointegration. If $H_0 : r_i = 0, \forall i$ is rejected, then the next step is to test $H_0 : r_i = \bar{r} = 1$, where $\bar{r} = \max\{r_i | 1 \leq i \leq N\}$. For this purpose, the orthogonal complement of the cointegrating space $\beta_{i\perp}$ is estimated using the r largest eigenvalues of the eigenvalue problem

$$|\lambda \frac{1}{T}\hat{S}_{i,11} - \hat{S}_{i,10}\hat{S}_{i,00}^{-1}\hat{S}_{i,01}| = 0, \tag{11}$$

[1]Let A be an $(m \times n)$ matrix with $\mathrm{rank}(A) = n$, then the orthogonal complement $A_\perp$ is an $(m \times (m-n))$ matrix with $\mathrm{rank}(A_\perp) = m - n$, such that $A_\perp' A = 0$.

where the moment matrices $\hat{S}_{i,jk}$, $j, k \in \{0, 1\}$ are computed from the defactored data in the same way as in Johansen (1995, pp. 96-97). With the help of $\hat{\beta}_{i\perp}$ it is possible to select the appropriate candidates for stochastic trends in the system. In other words, the null hypothesis of higher cointegrating rank $\bar{r}$ can be tested by checking whether $d = m - \bar{r}$ different stochastic trends exist. Therefore, the null of no cointegration is tested on the $d = m - \bar{r}$ dimensional vector $\hat{\beta}'_{i\perp} Y^*_{it}$. This procedure is repeated until the null hypothesis can not be rejected or until $H_0 : \bar{r} = m - 1$ is tested.

4 Simulation Study

4.1 Data generating process

The Monte Carlo study is based on the same DGP as in Arsova and Örsal (2013) in order to allow comparison. The following three-variate DGP is used to generate the data:

$$Y_{it} = \mu_{0i} + \mu_{1i} t + X_{it} + \Lambda'_i F_t, \tag{12}$$

$$X_{it} = \begin{pmatrix} \psi_a & 0 & 0 \\ 0 & \psi_b & 0 \\ 0 & 0 & 1 \end{pmatrix} X_{it-1} + \varepsilon_{it}, \tag{13}$$

$$\varepsilon_{it} \sim N \left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \theta_1 & \theta_2 \\ \theta_1 & 1 & \theta_3 \\ \theta_2 & \theta_3 & 1 \end{pmatrix} \right], \tag{14}$$

$$F_t = B F_{t-1} + u_t, \quad u_t \sim N(0, \sigma^2_F), \tag{15}$$

where the terms θ_i, $i = 1, 2, 3$, induce instantaneous correlation between the stationary and nonstationary components of the system. Within the simulation study we consider cases with both correlation and no correlation between the stationary and nonstationary components. To save space only the simulation results with correlation are reported[2].

Throughout the simulation study we use $T - 1 = \{25, 50, 100, 200, 500\}$ and $N = \{10, 25, 50, 100\}$. The initial values for X_{it} are set to zero. To generate a process with true cointegrating rank zero, we set $\psi_a = \psi_b = 1$. True cointegrating rank one is generated by the combinations $(\psi_a, \psi_b) \in \{(0.7, 1), (0, 95, 1)\}$, and the true cointegrating rank two is generated by the combinations $(\psi_a, \psi_b) \in \{(0.7, 0.7), (0.95, 0.7)\}$. The deterministic terms μ_{0i} and μ_{1i} are set to zero, since the LR-type test statistics of Saikkonen and Lütkepohl (2000) are invariant to the values of the deterministic terms. The number of common factors is $k = 2$ with $\sigma^2_F = 1$. For non-stationary factors $B = I_2$, and for stationary ones $B = 0.9 I_2$. Finally, the factor loadings are independently uniformly distributed random variables, i.e. $\lambda_i \sim i.i.d.U[-1, 3]$. The number of replications is set to 1000. The simulations are executed in GAUSS.

[2]Upon request simulation results without correlation can be provided.

4.2 Simulation results

Table 1 presents the size results of the new tests for different experimental settings with different true cointegrating ranks. The left part of the table shows the size properties of the standardized Fisher-type test (P_N^*) and the right part of the table is presenting the results of the inverse normal test ($P_{\Phi^{-1}}^*$). Both tests have size distortions when the true cointegrating rank is zero and T is small, i.e. $T = 25$. Size distortions are also present when the cross-sectional dimension is higher than the time dimension. With the increase in both the time and cross-sectional dimensions the size of both tests approaches the 5% nominal significance level. Overall, for the true cointegrating rank of zero the inverse normal test has better size properties when $T \geq 50$.

On the contrary, both tests are undersized when the true cointegrating rank is higher than zero. However, with the increase in both T and N the size reaches the 5% nominal level when the stationary process(es) in the system are not near unit root processes. When the underlying DGP has near a unit root, then the size of both tests becomes 3% with the increase in T and N. Higher T and N dimensions are necessary for the empirical size to reach the nominal size.

Table 2 shows the power results of the tests when the hypothesized rank is below the true cointegrating rank. H(0) and H(1) denote that the null hypothesis is rank zero and one, respectively. For both tests the power approaches quickly unity even for small samples when there is no near unit root process in the DGP. If there is a near unit root process, then the tests cannot detect its presence very well for small T. With the increase in both T and N the power approaches unity even in the presence of a near unit root process. When the true cointegrating rank is two and the hypothesized rank is one, the inverse normal test has higher power in comparison to the standardized Fisher-type test mainly for $T \leq 100$.

Since we use the same DGP and the same simulation setup as in Arsova and Örsal (2013), we can compare their simulation results for the PSL_{def}^J test with our results. Note that the PSL_{def}^J test is a panel test based on the standardization of the average of the individual Saikkonen and Lütkepohl LR-type test statistics. For true cointegrating rank zero the $P_{\Phi^{-1}}^*$ test has slightly better size properties than the PSL_{def}^J, especially when N is small. The size of all the tests is almost equal when the true cointegrating rank of the system is one. The only difference is that the $P_{\Phi^{-1}}^*$ test is slightly more undersized than the other two tests when $T \geq 200$. The $P_{\Phi^{-1}}^*$ test has also better size properties in the presence a near unit root process for $r_0 = 2$ and $T \geq 100$.

Among the three tests P_N^* demonstrates the lowest power, whereas the $P_{\Phi^{-1}}^*$ test has the highest power for true cointegrating rank two and when the hypothesized rank is one. For the remaining simulation setups the power of the PSL_{def}^J and $P_{\Phi^{-1}}^*$ tests is comparable.

5 Conclusions

This paper makes use of a common factor framework and a meta-analytic approach to propose new panel cointegrating rank tests. The tests are based on combinations of the p-values of the individual LR-test statistics of Saikkonen and Lütkepohl (2000). The testing procedure allows to test the idiosyncratic and the common factors separately for cointegration. With the help of this useful approach it is possible to find out the main driving sources of the long-run stationary relations. The Monte Carlo study shows that the proposed tests have reasonable finite sample properties - the power of the tests is high even when the time dimension of the panel is small. A comparison of the new P_N^* and $P_{\Phi_{-1}}^*$ tests with the PSL_{def}^J test of Arsova and Örsal (2013) leads to the conclusion that the $P_{\Phi_{-1}}^*$ has slightly better finite sample properties in some cases. We therefore recommend the use of the inverse normal test in practice, since it may be applied to heterogeneous and even unbalanced panels.

Table 1: Size of the tests for different true cointegrating rank conditions.

		P_N^*					$P_{\Phi^{-1}}^*$				
			$r_0 = 1,\ \psi_b = 1$		$r_0 = 2,\ \psi_b = 0.7$			$r_0 = 1,\ \psi_b = 1$		$r_0 = 2,\ \psi_b = 0.7$	
$T-1$	N	$r_0 = 0$	$\psi_a = 0.7$	$\psi_a = 0.95$	$\psi_a = 0.7$	$\psi_a = 0.95$	$r_0 = 0$	$\psi_a = 0.7$	$\psi_a = 0.95$	$\psi_a = 0.7$	$\psi_a = 0.95$
25	10	0.118	0.012	0.002	0.000	0.000	0.089	0.017	0.001	0.000	0.000
	25	0.188	0.004	0.000	0.000	0.000	0.165	0.004	0.000	0.000	0.000
	50	0.219	0.001	0.000	0.000	0.000	0.218	0.004	0.000	0.000	0.000
	100	0.286	0.003	0.000	0.000	0.000	0.297	0.004	0.000	0.002	0.000
50	10	0.078	0.032	0.000	0.015	0.000	0.056	0.030	0.001	0.027	0.002
	25	0.092	0.032	0.001	0.012	0.000	0.068	0.021	0.002	0.025	0.001
	50	0.091	0.014	0.000	0.002	0.000	0.080	0.016	0.000	0.020	0.000
	100	0.136	0.006	0.000	0.002	0.000	0.128	0.007	0.000	0.015	0.000
100	10	0.061	0.038	0.006	0.034	0.007	0.056	0.023	0.005	0.025	0.017
	25	0.080	0.028	0.002	0.021	0.004	0.065	0.025	0.002	0.026	0.014
	50	0.069	0.022	0.000	0.024	0.001	0.066	0.020	0.000	0.031	0.013
	100	0.093	0.010	0.000	0.010	0.001	0.079	0.010	0.001	0.025	0.009
200	10	0.083	0.057	0.022	0.029	0.020	0.056	0.035	0.018	0.029	0.021
	25	0.072	0.028	0.006	0.028	0.007	0.054	0.018	0.005	0.032	0.017
	50	0.063	0.031	0.008	0.030	0.005	0.056	0.022	0.013	0.039	0.018
500	10	0.076	0.046	0.027	0.043	0.034	0.049	0.028	0.018	0.035	0.027
	25	0.062	0.037	0.019	0.047	0.024	0.050	0.038	0.018	0.045	0.029
	50	0.064	0.041	0.016	0.039	0.014	0.063	0.040	0.020	0.053	0.032

Notes: r_0 denotes true cointegrating rank of the DGP. The results are based on the DGP which allows correlation between the stationary and nonstationary components of the process. For the process with $r_0 = 0$, we set $(\theta_1, \theta_2, \theta_3) = (0, 0, 0)$, since the parameters θ_i, $i = 1, 2, 3$ show the correlation only between the stationary and nonstationary components. If $r_0 = 1$, then $(\theta_1, \theta_2, \theta_3) = (0.8, 0.3, 0)$, and if $r_0 = 2$, then $(\theta_1, \theta_2, \theta_3) = (0, 0.8, 0.3)$.

Table 2: Power of the tests when the hypothesized rank is below the true rank

		P_N^*						$P_{\Phi^{-1}}^*$					
		$r_0 = 1,\ \psi_b = 1$		$r_0 = 2,\ \psi_b = 0.7$				$r_0 = 1,\ \psi_a = 1$		$r_0 = 2,\ \psi_b = 0.7$			
		$\psi_a = 0.7$	$\psi_a = 0.95$	$\psi_a = 0.7$		$\psi_a = 0.95$		$\psi = 0.7_a$	$\psi = 0.95_a$	$\psi_a = 0.7$		$\psi_a = 0.95$	
T-1	N	H(0)	H(0)	H(0)	H(1)	H(0)	H(1)	H(0)	H(0)	H(0)	H(1)	H(0)	H(1)
25	10	0.632	0.130	0.789	0.038	0.283	0.003	0.618	0.111	0.786	0.041	0.264	0.004
	25	0.960	0.190	0.992	0.044	0.520	0.004	0.972	0.173	0.993	0.085	0.540	0.007
	50	1.000	0.284	1.000	0.080	0.744	0.002	1.000	0.284	1.000	0.214	0.789	0.004
	100	1.000	0.402	1.000	0.112	0.935	0.000	1.000	0.420	1.000	0.353	0.965	0.007
50	10	0.995	0.143	0.999	0.565	0.739	0.025	0.995	0.119	0.999	0.642	0.757	0.040
	25	1.000	0.246	1.000	0.932	0.990	0.074	1.000	0.238	1.000	0.977	0.996	0.139
	50	1.000	0.404	1.000	1.000	1.000	0.099	1.000	0.426	1.000	1.000	1.000	0.272
	100	1.000	0.650	1.000	1.000	1.000	0.192	1.000	0.696	1.000	1.000	1.000	0.534
100	10	1.000	0.393	1.000	0.998	0.999	0.361	1.000	0.395	1.000	0.999	0.999	0.421
	25	1.000	0.798	1.000	1.000	1.000	0.768	1.000	0.830	1.000	1.000	1.000	0.862
	50	1.000	0.985	1.000	1.000	1.000	0.962	1.000	0.990	1.000	1.000	1.000	0.988
	100	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
200	10	1.000	0.946	1.000	1.000	1.000	0.972	1.000	0.958	1.000	1.000	1.000	0.982
	25	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
500	10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	25	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Notes: r_0 denotes true cointegrating rank of the DGP. r_0 denotes true cointegrating rank of the DGP. The results are based on the DGP which allows correlation between the stationary and nonstationary components of the process. For the process with $r_0 = 0$, we set $(\theta_1, \theta_2, \theta_3) = (0, 0, 0)$, since the parameters $\theta_i,\ i = 1, 2, 3$ show the correlation only between the stationary and nonstationary components. If $r_0 = 1$, then $(\theta_1, \theta_2, \theta_3) = (0.8, 0.3, 0)$, and if $r_0 = 2$, then $(\theta_1, \theta_2, \theta_3) = (0, 0.8, 0.3)$.

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