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Revisited: Are shocks to energy consumption permanent or temporary? New evidence from a panel SURADF approach

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Abstract

This paper explores whether the hypothesis of energy consumption stationarity is supported in different regions. The stationarity properties indicate that the impact of a reduction in energy consumption or a realignment policy is only temporary, and over time the series will revert back to the trend path. This paper first applies the panel seemingly unrelated regressions augmented Dickey-Fuller (Panel SURADF) test developed by Breuer et al. [Breuer, J.B., McNown, R., Wallace, M.S., 2001. Misleading inferences from panel unit-root tests with an illustration from purchasing power parity. Review of International Economics 9 (3), 482–493], which allows us to account for possible cross-sectional effects and to identify how many and which members of the panel contain a unit root. The main conclusion is that the stationarity of energy consumption will be affected by the differences among the five regions made up of 84 countries during the period 1971–2003. Similar conclusions are reached when we analyze country-groups based on levels of development. Moreover, the results reveal that conventional panel unit root tests can lead to misleading inferences which are biased towards stationarity, even if only one series in the panel is strongly stationary. Lastly, some policy implications emerge from our results.

JEL classification: Q43; C23; C5

Keywords: Energy consumption; Panel SURADF test; Unit root; Stationarity; Regions

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1. Introduction

There is a growing body of literature on the stationarity properties of energy consumption. Several studies have applied univariate unit root tests to energy consumption, which can be grouped into four different strands by region. The first strand of the literature has focused on East Asia and the Pacific,[1] the second strand has targeted the Latin American countries and the Caribbean,[2] and the third and fourth strands of this literature have looked at Europe as well as Central and South Asia.[3] There has been a proliferation of studies using different techniques, time periods, and different sample countries, with most studies employing univariate unit root tests that reach mixed conclusions. The details are provided in Table 1. The findings from the previous studies allow us to deduce whether energy consumption is stationary.

Our motivation in this paper is to further the boundaries of econometric methodologies and provide new insights into energy consumption series. The specific aims and contributions of this paper are three-fold. First, we apply the panel seemingly unrelated regressions augmented Dickey-Fuller (Panel SURADF hereafter) test developed by Breuer et al. (2001), which allows us to account for possible cross-sectional effects and to identify how many and which members of the panel contain a unit root.[4] Second, our results reveal that conventional panel unit root tests can lead to misleading inferences. Finally, the use of Monte Carlo simulations to derive the empirical distribution of the tests also allows us to correct for finite-sample bias.

We examine whether disparities in energy consumption are persistent, thereby reflecting the permanence of shocks to energy consumption. A few studies have started applying panel unit root tests to energy consumption, for example, Joyeux and Ripple (2007), Narayan and Smyth (2007), Chen and Lee (2007), Lee and Chang (2007, in press), Al-Iriani (2006), and Lee (2005) who each examine energy consumption stationarity by applying traditional panel unit root tests. However, it must be kept in mind that all of these studies – in the testing for a unit root and in the testing of the stationarity hypothesis – are joint tests of a unit root for all members of the panel and are incapable of determining the mix of $I(0)$ and $I(1)$ series in a panel setting. Moreover, they cannot identify how many and which series in the panel are stationary processes, resulting in mixed empirical findings. According to Table 1, the empirical evidence on energy consumption is only based on four regions apart from Sub-Saharan Africa and the Middle East and North Africa. Unlike most previous studies, our study's contribution is that we first apply the Panel SURADF test as developed by Breuer et al. (2001) to re-examine the unit root properties of energy consumption, using panel data during the period 1971–2003 from 84 countries in five regions (geographic contiguity).[5] We also group the data according to the country's level of development, which is proxied through the level of per capita income (see Appendix B).

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[1] See Masih and Masih (1996), Asafu-Adjaye (2000), Yang (2000), Soytas and Sari (2003), Narayan and Smyth (2005), Lee and Chang (2005), and Yoo (2006).

[2] See Soytas and Sari (2003) and Galindo (2005).

[3] See Altinay and Karagol (2004), Masih and Masih (1996) and Asafu-Adjaye (2000).

[4] Such a modus has already been used extensively in the study of macroeconomics and international finance up to now. However, to date, in the aspect of an energy agenda, we have not found that the panel SURADF test has been applied.

[5] The panel SURADF test is significantly more powerful than conventional panel unit root tests. Breuer et al. (2001) claim that, by analogy to simple regression, when an F-statistic rejects the null that a vector of coefficients is equal to zero, it does not follow that each coefficient is non-zero. Similarly, when the unit-root null hypothesis is rejected, it may be erroneous to conclude that all series in the panel are stationary. In addition, Taylor and Sarno (1998), Taylor (2003) and Taylor and Taylor (2004) show that the recent methodological refinements of the Levin et al. (2002) test fail to fully address the 'all-or-nothing' nature of the test. Because they are joint tests of the null hypothesis, they are not informative with regard to the number of series that are stationary processes when the null hypothesis is rejected.

Table 1
Comparison of earlier empirical results from various univariate unit root tests for energy consumption (annual data)

Region	Author(s)	Countries	Period	Result
East Asia and Pacific	Masih and Masih (1996)	Indonesia, Malaysia, Singapore and the Philippines	1955–1990	Non-stationarity
	Chan and Lee (1997)	China	1953–1994	Non-stationarity
	Cheng and Lai (1997)	Taiwan	1955–1993	Non-stationarity
	Glasure and Lee (1997)	South Korea and Singapore	1961–1990	Non-stationarity
	Asafu-Adjaye (2000)	Indonesia, the Philippines and Thailand, Taiwan	1971–1995	Non-stationarity
	Yang (2000)	Taiwan	1954–1997	Non-stationarity
	Soytas and Sari (2003)	Japan and South Korea	1950–1994	Non-stationarity
	Oh and Lee (2004)	South Korea	1981–2000	Non-stationarity
	Lam and Shiu (2004)	China	1971–2000	Non-stationarity
	Lee and Chang (2005)	Taiwan	1960–2001	Mixed results
	Narayan and Smyth (2005)	Australia	1966–1999	Non-stationarity
	Yoo (2006)	Indonesia, Malaysia, Singapore, and Thailand	1971–2002	Non-stationarity
Latin America and Caribbean	Soytas and Sari (2003)	Argentina	1950–1994	Non-stationarity
	Galindo (2005)	Mexico	1965–2001	Non-stationarity
Europe and Central Asia	Soytas and Sari (2003)	Italy, Turkey, France, and Germany	1950–1994	Non-stationarity
	Altinay and Karagol (2004)	Turkey	1950–2000	Stationarity
	Soytas and Sari (2007)	Turkey	1968–2002	Mixed results among different lag selection procedures
	Lise and van Montfort (2007)	Turkey	1970–2003	Non-stationarity
	Zamani (2007)	Iran	1967–2003	Non-stationarity
South Asia	Masih and Masih (1996)	India and Pakistan India	1955–1990	Non-stationarity
	Asafu-Adjaye (2000)	India	1971–1995	Non-stationarity

This paper explores whether the hypothesis of energy consumption stationarity is supported in different regions. The stationarity properties indicate that the impact from a reduction in energy consumption or a realignment policy is only temporary, and over time the series will revert back to the trend path. In order to increase the power of unit root tests, it has been necessary to develop panel data unit root tests.[6] Even though several panel data unit root tests, such as the feasible generalized least squares test (FGLS) by Levin et al. (2002) and the *t*-bar test proposed by Im et al. (2003), have been developed to exploit the extra power in the panel properties of the data,

[6] It is well known that time series unit root tests have low power, especially in small samples; see Campbell and Perron (1991) and DeJong et al. (1992).

Narayan and Smyth (2007) comment that there have been few attempts to apply the panel data unit root test to energy consumption. Consequently, when Joyeux and Ripple (2007) apply the Levin et al. (2002) and Im et al. (2003) panel unit root tests to eight Asian countries, their results are fragile, because they fail to address the issue of cross-sectional dependence. Furthermore, O'Connell (1998) indicates that ignoring cross-sectional dependence in conventional panel unit root tests can result in severe size biases and loss of power.[7]

Narayan and Smyth (2007) implement univariate and panel data unit root tests to annual panel data for 182 countries over the period 1979–2000 to investigate the stationarity properties of per capita energy consumption. The univariate unit root test can only reject the unit root null for 56 countries or 31% of the sample at the 10% level or better. However, the univariate unit root test has low power with short time spans of data, and therefore a failure to reject the unit root null should be treated with caution. Those who utilize the Im et al. (2003) t-bar test do so, because it does not assume that all cross-sectional units converge towards the equilibrium value at the same speed under the alternative hypothesis, and thus it is less restrictive than either the Levin et al. (2002) test or the FGLS test. With the t-bar test, they find overwhelming evidence that energy consumption is stationary.

While a number of studies that have examined the unit root properties of energy consumption have employed univariate unit root tests, only a limited number have used unit root tests with panel data to investigate the stationary processes of energy consumption. Hence, the main contribution of our study is to pool together data from different regions. The Panel SURADF test has two major advantages. First, it allows us to account for possible cross-sectional effects and to identify how many and which members of the panel contain a unit root. Second, this paper addresses whether the hypothesis of energy consumption stationarity is supported in different regions during the period 1971–2003. The remainder of the paper is structured as follows. Section 2 consists of a brief discussion of the importance of the stationarity of energy consumption. Section 3 provides the methodology of the Panel SURADF test. Section 4 presents the data and empirical results. The conclusions for empirical research as well as the policy implications are discussed in the final section.

2. Why does the stationarity of energy consumption matter?

Understanding the correct series behavior of energy consumption can be vital in order to distinguish among theories that most accurately describe observed behavior. Energy is known to influence the productivity of capital and labor, among other things. In facilitating newly-developed econometric techniques, the purpose of most of the research studies has been to investigate whether macroeconomic variables take precedence over energy consumption if energy consumption can boost those variables. In other words, energy consumption has always aligned relationships with an economic system and is vitally correlated with the economic system. Soytas and Sari (2003) investigate the causal relationship between GDP and energy consumption in the top 10 emerging markets and the G-7 countries. Oh and Lee (2004) look at the Granger causal relationship between energy consumption and economic growth for South Korea in the past two decades. The statistical and econometric methodology used in the research on this subject has been very diverse, yet the only procedure that has been unanimously adopted has been to test

[7] However, for small samples, he reported an empirical size slightly exceeding 0.5 for values of severe size biases close to unity.

whether energy consumption is stationary or not. Furthermore, Lise and van Montfort (2007) try to reveal the linkage between energy consumption and GDP by undertaking a co-integration analysis for Turkey with annual data over the period 1970–2003.[8] Thus, we should pay attention to test the time series properties of energy consumption. If energy consumption is mean-reverting (trend stationary), then a series should return to its trend path over time and it should be possible to predict future movements in energy consumption based on past behavior. Conversely, if energy consumption is a non-stationary process, then shocks to energy consumption are likely to be permanent.

A common feature of the panel unit root tests is that in practice they maintain the null hypothesis of a unit root in all panel members. Thus, their rejection indicates that at least one panel member is stationary, with there being no information about how many series there are or which ones are stationary. Unlike extant panel unit root tests that deliver conclusions only regarding the panel as a whole, our test provides information regarding the number and identity of the panel members that reject or do not reject the null hypothesis of a unit root. When a series is non-stationary, testing for the presence of cointegration among the variables could be conducted. Others may employ the traditional regression model.

The stationary characteristic of energy consumption should be seriously considered when formulating economic policies. First, the unit root is transferred to other macroeconomic variables when energy consumption is non-stationary. Thus, a failure to reject the null hypothesis implies a non-stationary series where shocks in energy consumption have permanent effects. This is consistent with path dependency or hysteresis in energy consumption. Second, a rejection of the null supports the alternative hypothesis of a stationary series where shocks in a country's energy consumption have temporary effects. If energy consumption is non-stationary and is characterized by hysteresis or path dependency, then shocks have permanent effects on energy consumed. Third, if shocks to energy consumption are temporary, then a stabilization energy policy has no long-lasting effects. When energy consumption temporarily deviates from the trend path, the government's administrative policy should be to not adopt unnecessary targets. Finally, energy consumption exhibits stationarity, making it possible for the series to forecast future movements in energy consumption established on past behavior. When energy consumption temporarily deviates from the trend path, the government's policy should be to not adopt unnecessary targets.[9]

3. Methodology

At the beginning of our analysis we investigated for unit roots because: (1) Stock and Watson (1989) argue that the causality tests are very sensitive to the stationarity of the series; and (2) Nelson and Plosser (1982) state the fact that many macroeconomic series are non-stationary.

Breuer et al. (2001) claim that the common problem of the conventional panel tests mentioned above is that they maintain the null of the unit root in all panel members. Therefore, their rejection

[8] Other papers that can be seen in Zamani (2007) investigate the causal relationship between the consumption of different kinds of energy and GDP for the case of Iran. Markandya et al. (2006) analyze income growth and energy intensity for the transition countries in light of their integration into the European Union. Lee and Chang (2007, in press) employ the panel generalized method of moments (GMM) techniques in order to re-investigate the dynamic interactions between energy consumption per capita and real GDP per capita in 22 developed and 18 developing countries.

[9] We would like to thank an anonymous referee for suggesting that we create this new Section 2.

indicates that at least one panel member is stationary, with no information being provided regarding how many series there are or which ones are stationary.[10] In expanding upon this issue, Breuer et al. (2001, 2002) develop a panel unit root test that involves the estimation of the ADF regression in a SUR framework and then test for the individual unit root within the panel members. The heterogeneous serial correction across the panel members is handled according to the estimation procedure. Generally speaking, the traditional panel unit root test can only tell us about the attributes of the series for the whole panel set, while the SURADF modus allows us to recognize whether the individual series is stationary or not. More importantly, the test minimizes the possibility of a misleading conclusion of stationarity when only one panel member behaves in a stationary manner.

The SURADF test is based on the system of ADF equations which can be represented as:

$$\begin{aligned}
\Delta X_{1,t} &= \alpha_1 + \beta_1 X_{1,t-1} + \gamma t + \sum_{j=1}^{k1} \varphi_{1,j} \Delta X_{1,t-j} + \varepsilon_{1,t}, & t &= 1,2,\ldots,T \\
\Delta X_{2,t} &= \alpha_2 + \beta_2 X_{2,t-1} + \gamma t + \sum_{j=1}^{k2} \varphi_{2,j} \Delta X_{2,t-j} + \varepsilon_{2,t}, & t &= 1,2,\ldots,T \\
&\vdots & &\vdots \\
\Delta X_{N,t} &= \alpha_N + \beta_N X_{N,t-1} + \gamma t + \sum_{j=1}^{kN} \varphi_{N,j} \Delta X_{N,t-j} + \varepsilon_{N,t}, & t &= 1,2,\ldots,T,
\end{aligned} \tag{1}$$

where X denotes energy consumption, $\beta_i = \rho_i - 1$, ρ_i is the autoregressive coefficient for series $i (i=1,2,\ldots,N)$ t denotes the deterministic time trend, and ε is an error term. Eq. (1) tests the null hypothesis of a unit root against a trend stationary series. The model allows for heterogeneous fixed-effects and heterogeneous lags for each cross-sectional unit in the panel. This system is estimated using the SUR procedure, and we test the N null and alternative hypotheses individually as:

$$\begin{aligned}
&H_0^1\colon \beta_1 = 0; H_A^1 : \beta_1 < 0, \\
&H_0^2\colon \beta_2 = 0; H_A^2 : \beta_2 < 0, \\
&\vdots \qquad\qquad \vdots \\
&H_0^N\colon \beta_N = 0; H_A^N : \beta_N < 0.
\end{aligned} \tag{2}$$

The test statistics are computed from the SUR estimated system while the critical values are generated by Monte Carlo simulations. The estimated 1%, 5%, and 10% critical values are obtained from the simulations and 10,000 replications using the lag and covariance structure from the panel of energy consumption. As Breuer et al. (2001) show that the imposition of an identical lag structure across panel members could bias the test statistics, we select the lag structures for each equation based on the method of Perron (1989).[11] Breuer et al. (2001) remind us that outcomes differing from the univariate ADF test may arise for several reasons. First, a non-zero covariance matrix introduces more information into the estimation and results in lower standard errors. Second, the coefficient of the lag term moves either closer to or farther away from zero. Third, the critical values for the Panel SURADF test change. They are higher in absolute value

[10] Mark (2001) argues that one potential pitfall with the panel test is that the rejection of the non-stationarity hypothesis does not mean that all series are stationary. It is possible that out of N time-series, only one is stationary and (N-1) have a unit-root process.

[11] The lag parameters are selected based on the recursive t-statistic as suggested by Perron (1989). The maximum lag length for the general to specific methodology was set at 8.

Table 2
List of selected regions and countries from *world development indicators*

East Asia, South Asia and *Pacific*				
Australia	Brunei	China	India	Indonesia
Japan	North Korea	South Korea	Malaysia	Myanmar
Nepal	New Zealand	Pakistan	Philippines	Singapore
Sri Lanka	Thailand	Vietnam		
Americas and *Caribbean*				
Argentina	Bolivia	Brazil	Canada	Chile
Colombia	Costa Rica	Cuba	Dominican Republic	Ecuador
El Salvador	Haiti	Mexico	Netherlands Antilles	Nicaragua
Panama	Peru	United States		
Middle East and *North Africa*				
Algeria	Bahrain	Egypt, Arab Rep.	Iran, Islamic Rep.	Iraq
Israel	Kuwait	Libya	Malta	Morocco
Qatar	Saudi Arabia	Tunisia	United Arab Emirates	Yemen, Rep.
Europe and *Central Asia*				
Austria	Belgium	Cyprus	Denmark	Finland
France	Germany	Iceland	Ireland	Italy
Luxembourg	Poland	Portugal	Romania	Spain
Sweden	Turkey	United Kingdom		
Sub-Saharan Africa				
Angola	Benin	Cameroon	Congo, Dem. Rep.	Congo, Rep.
Ethiopia	Gabon	Ghana	Kenya	Mozambique
Senegal	South Africa	Sudan	Zambia	Zimbabwe

terms than the single-equation ADF test. In all cases, the power of the SURADF exceeds that of the ADF test (Breuer et al., 2002).

4. Data and empirical results

As can be seen in Table 2, our study uses annual time series for 84 countries in five regions. Annual data for energy consumption are obtained from World Development Indicators (WDI, 2006) and all variables are expressed in log form. We use the time period 1971–2003 because that is the period for which the empirical data are available.

We start by testing for the presence of a unit root in energy consumption using the ADF (Dickey and Fuller, 1979), DF-GLS (Elliott et al., 1996), P–P (Phillips and Perron, 1988), KPSS (Kwiatkowski et al., 1992) and NP (Ng and Perron, 2001) unit root tests.[12] Next, and very importantly, in conducting the unit root tests it is the selections of the optimal lag length and the optimal bandwidth that have the greatest effects on the results. The estimation method adopted in this research utilizes not only the modified Akaike information criterion (MAIC), put forth by Ng and Perron (2001), in the ADF, DF-GLS, and the NP tests for the selection of the optimal lag length, but also the kernel-based criteria, put forth by Newey and West (1994), in the P–P and the KPSS tests for the selection of the bandwidth. Table A1 (see Appendix A) reports the results of these univariate unit root tests with intercept and trend. There are different results for different methods, as well as for different regions.

[12] The null of the KPSS test is $I(0)$, while the null of the remaining four tests is $I(1)$.

Table 3
Panel SURADF tests and critical values (East, South Asia and Pacific)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Australia	−2.279	−4.775	−4.090	−3.698
Brunei	−10.440***	−4.743	−4.055	−3.721
China	−0.761	−4.261	−3.662	−3.319
India	−1.253	−4.568	−3.890	−3.545
Indonesia	−1.377	−4.870	−4.131	−3.786
Japan	−1.912	−4.551	−3.903	−3.541
North Korea	−2.495	−3.924	−3.283	−2.967
South Korea	−3.402	−5.148	−4.456	−4.093
Malaysia	−0.360	−4.278	−3.653	−3.314
Myanmar	0.363	−4.327	−3.675	−3.348
Nepal	−2.025	−4.599	−3.917	−3.588
New Zealand	−1.463	−4.319	−3.702	−3.368
Pakistan	−2.552	−4.030	−3.414	−3.104
Philippines	−1.365	−3.934	−3.317	−3.009
Singapore	−1.605	−4.286	−3.618	−3.289
Sri Lanka	0.136	−4.366	−3.676	−3.338
Thailand	−0.447	−4.590	−3.928	−3.579
Vietnam	1.744	−4.280	−3.639	−3.332

Notes: *** indicates significance at the 1% level. Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

Table 4
Panel SURADF tests and critical values (Americas and Caribbean)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Argentina	−2.449	−4.953	−4.253	−3.899
Bolivia	−2.904	−4.250	−3.643	−3.297
Brazil	−2.220	−4.477	−3.832	−3.483
Canada	−1.877	−4.760	−4.081	−3.731
Chile	1.047	−4.648	−4.014	−3.676
Colombia	−3.137	−4.208	−3.546	−3.199
Costa Rica	0.462	−4.191	−3.561	−3.240
Cuba	−3.242**	−3.756	−3.190	−2.840
Dominican Republic	−1.689	−4.506	−3.833	−3.483
Ecuador	−5.558***	−4.595	−3.938	−3.595
El Salvador	−2.660	−4.723	−4.045	−3.661
Haiti	−2.539	−4.177	−3.552	−3.219
Mexico	−3.994***	−3.871	−3.286	−2.972
Netherlands Antilles	−2.403	−4.131	−3.550	−3.212
Nicaragua	−0.418	−3.947	−3.317	−2.985
Panama	−1.070	−4.542	−3.918	−3.548
Peru	−3.090	−3.997	−3.471	−3.138
United States	−1.577	−4.731	−4.053	−3.704

Notes: **, and *** indicate significance at the 5% and 1% levels, respectively. Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

Table 5
Panel SURADF tests and critical values (Middle East and North Africa)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Algeria	−4.605***	−3.968	−3.408	−3.088
Bahrain	−2.828	−4.955	−4.317	−3.944
Egypt, Arab Rep.	−4.567***	−3.969	−3.367	−3.055
Iran, Islamic Rep.	−1.294	−4.424	−3.787	−3.464
Iraq	−3.618*	−4.437	−3.769	−3.436
Israel	0.490	−4.885	−4.209	−3.840
Kuwait	−2.913	−4.142	−3.528	−3.208
Libya	−6.080***	−5.045	−4.348	−3.980
Malta	−1.713	−4.427	−3.852	−3.518
Morocco	−1.850	−4.504	−3.876	−3.518
Qatar	−2.072	−4.362	−3.751	−3.395
Saudi Arabia	−4.816***	−4.307	−3.633	−3.315
Tunisia	−2.014	−3.936	−3.358	−3.030
United Arab Emirates	−5.123***	−4.008	−3.390	−3.097
Yemen, Rep.	−0.469	−4.327	−3.707	−3.374

Notes: * and *** indicate significance at the 10% and 1% levels, respectively. Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

As shown in Table A1, the ADF unit root tests can only reject the unit root null for approximately 14.29% of the countries at the 5% level or better. The DF-GLS tests can only reject the null hypothesis for 10.71% of the countries at the 5% level or better. The P–P tests can only reject the unit

Table 6
Panel SURADF tests and critical values (Europe and Central Asia)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Austria	−1.282	−5.717	−4.996	−4.588
Belgium	−2.929	−6.005	−6.005	−4.873
Cyprus	−0.451	−4.558	−3.926	−3.600
Denmark	−5.077*	−5.795	−5.111	−4.694
Finland	−1.657	−4.763	−4.127	−3.768
France	−1.640	−5.401	−4.692	−4.293
Germany	−7.008***	−5.535	−4.870	−4.502
Iceland	−2.597	−4.313	−3.670	−3.358
Ireland	−1.752	−5.583	−4.890	−4.491
Italy	−1.030	−5.015	−4.332	−3.964
Luxembourg	−2.915	−4.709	−4.044	−3.671
Poland	−3.693	−4.937	−4.226	−3.864
Portugal	−1.826	−4.058	−3.485	−3.154
Romania	−3.711	−4.909	−4.214	−3.862
Spain	−3.107	−5.496	−4.753	−4.352
Sweden	−3.496*	−4.491	−3.799	−3.455
Turkey	−1.144	−4.420	−3.769	−3.407
United Kingdom	−3.819	−5.576	−4.888	−4.490

Notes: * and *** indicate significance at the 10% and 1% levels, respectively. Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

Table 7
Panel SURADF tests and critical values (Sub-Saharan Africa)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Angola	1.358	−3.635	−3.031	−2.732
Benin	−0.513	−4.215	−3.577	−3.219
Cameroon	−2.528	−4.104	−3.515	−3.194
Congo, Dem. Rep.	−0.857	−3.934	−3.296	−2.983
Congo, Rep.	−3.243	−4.335	−3.718	−3.371
Ethiopia	0.125	−4.161	−3.574	−3.262
Gabon	−3.422	−4.537	−3.851	−3.509
Ghana	0.836	−4.101	−3.542	−3.200
Kenya	−0.985	−4.123	−3.546	−3.206
Mozambique	−2.665	−4.679	−4.034	−3.665
Senegal	−0.090	−4.453	−3.810	−3.460
South Africa	−2.801	−3.922	−3.307	−3.002
Sudan	0.337	−4.356	−3.699	−3.361
Zambia	−1.385	−4.028	−3.405	−3.106
Zimbabwe	−1.574	−4.368	−3.767	−3.412

Notes: Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

root null for 7.14% of the countries at the 5% level or better, while the NP tests can only reject the unit root null for 8.33% of the countries at the 5% level or better. In addition, the KPSS tests cannot reject the null hypothesis of stationarity for 42.86% of the countries at the 5% level. The result of the different tests are mixed and conflicting. A possible reason for the failure of these tests is their low power due to the short time span of the data.

Tables 3–7 provide the results of the Panel SURADF tests and the critical values. We report the results for five different regional panels (East Asia, South Asia and the Pacific; the Americas and the Caribbean; the Middle East and North Africa; Europe and Central Asia; and Sub-Saharan Africa). Our main finding is that we are unable to reject the null hypothesis of non-stationarity at the 1% level, as seen in Table 3, for East Asia, South Asia and the Pacific, except for Brunei. We are also unable to reject the null hypothesis of non-stationarity at the 1% level, as seen in Table 5, for the Middle East and North

Table 8
List of selected countries by different regions

Region	No. of countries	No. of stationary (10% level) countries	Countries
East, South Asia and Pacific	18	1	Brunei
Americas and Caribbean	18	3	Cuba, Ecuador, Mexico
Middle East and North Africa	15	6	Algeria, Egypt, Arab Rep., Iraq, Libya, Saudi Arabia, United Arab Emirates
Europe and Central Asia	18	3	Germany, Denmark, Sweden
Sub-Saharan Africa	15	0	–

Africa, except for Algeria, Egypt, Libya, Saudi Arabia, and the United Arab Emirates. In addition, as can be seen in Table 5, we are able to reject the null hypothesis of non-stationarity at the 10% level in Iraq. At the 10% level, as seen in Tables 4 and 6, we are unable to reject the null hypothesis of non-stationarity for the Americas and the Caribbean, Europe and Central Asia, except for Cuba, Ecuador, Mexico, Denmark, Germany, and Sweden. Note, however, that the null hypothesis of non-stationarity cannot be rejected for Sub-Saharan Africa at the 10% significance level as shown in Table 7. A more detailed understanding of those relationships can be gained from Table 8.

We find that different reasons for stationarity exist between regions. Table 8 presents the numbers of countries which are stationary. The empirical results provide four views which could explain why energy consumption is or is not stationary. First, in regions with an abundance of energy resources it is easier to be stationary. For example, the Middle East and North Africa and America and the Caribbean are respectively first and second in the world in terms of energy resources. Thus, there are six countries and three countries, respectively, whose energy consumption is stationary in these regions. Second, less energy consumption seems to be closely connected to stationarity. Brunei in the East Asia, South Asia and the Pacific region in Table 3 is in last place in terms of consuming the least energy. In other words, those countries that are exporters or producers of energy are often able to maintain stability during periods of economic or political turbulence. Third, as can be seen in the Europe and Central Asia region of Table 6, the introduction of new environmental laws by governments, which has helped Germany and Denmark lead the way in renewable energy laws (REL), has contributed towards stationarity. Fourth, of the six significant countries, five belong to the middle income level and exhibit evidence of stationarity (see Table 5, the Middle East and North Africa region).

In order to check the robustness of our results, it is worthwhile providing some insights on the likely reasons in our paper. This study implements an alternative version categorized by different income levels.[13] Tables B1 to B3 in Appendix B provide the results of the Panel SURADF tests and critical values among three different income levels, namely, the high-, middle-, and low-income levels that are classified according to World Bank estimates of 2004 Gross National Income (GNI) per capita. Remarkably, in the three cases, our results are robustly supported by taking income levels into account. This means that the stationarity of energy consumption will be affected by different regions or income levels during the 1971–2003 period.

5. Conclusions

This paper employs data on 84 countries in five regions from 1971 to 2003 to re-examine the stationarity properties of energy consumption by applying the Panel SURADF test proposed by Breuer et al. (2001). Our results provide new findings for the current literature. The main conclusion is that the stationarity of energy consumption will be affected by regions. The results also reveal that conventional panel unit root tests can lead to misleading inferences in that they will be biased towards stationarity even if only one series in the panel is strongly stationary. Similar results are obtained when we divide the sample into income groups based on the classification criteria of the World Bank.

Some policy implications do emerge from our results. First, we are able to reject the null hypothesis of a unit root which might have to do with a government environmental policy. Our findings imply that, without considering the influence of new environmental laws, energy

[13] We would like to thank an anonymous referee for the suggestion that we apply an alternative classification method based on the level of development.

consumption will not be inherited if there is a shock to energy consumption in respect of the Panel SURADF test. In addition, our results suggest that non-stationarity may arise for different reasons, such as less energy consumption, the lack of an environmental policy, or the scarcity of energy resources.

Finally, it is particularly worth noting that our study has opened up several directions for future research on energy consumption. First, one avenue of inquiry would be to examine the commonality of structural breaks by conducting Panel SURADF tests. Second, future studies could conduct Panel SURADF tests on other environmental or macroeconomic variables, such as carbon dioxide emissions and aggregate output.

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Appendix A. Univariate unit root tests

Table A1
Univariate unit root tests

Country	ADF	DF-GLS	P–P	KPSS	NP
East, South Asia and Pacific					
Australia	−3.253 (0)	−2.858 (0)	−3.220 (3)	0.070 (3)	−9.091
Brunei	−3.202 (0)	−2.004 (0)	−5.076 (10)***	0.165 (4)**	−3.225
China	−3.871 (2)**	−3.223 (1)**	−2.566 (3)	0.112 (3)	−26.510***
India	−0.774 (0)	−1.079 (0)	−0.986 (2)	0.121 (4)	−2.999
Indonesia	−1.388 (0)	−1.614 (0)	−1.388 (0)	0.082 (4)	−5.395
Japan	−1.975 (0)	−2.011 (0)	−2.183 (2)	0.086 (4)	−6.544
North Korea	−1.965 (1)	−1.662 (1)	−1.575 (3)	0.183 (4)**	−5.231
South Korea	−0.738 (0)	−1.126 (0)	−0.813 (2)	0.105 (4)	−3.345
Malaysia	−2.668 (0)	−2.767 (0)	−2.716 (1)	0.080 (3)	−10.421
Myanmar	−2.136 (0)	−2.187 (0)	−2.136 (0)	0.111 (4)	−7.408
Nepal	−1.829 (0)	−1.909 (0)	−1.881 (1)	0.141 (4)	−6.138
New Zealand	−1.671 (0)	−1.754 (0)	−2.146 (3)	0.081 (4)	−5.455
Pakistan	0.028 (0)	−0.528 (0)	−0.106 (1)	0.151 (4)**	−1.358
Philippines	−1.914(0)	−1.964 (0)	−2.033 (3)	0.132 (4)	−6.266
Singapore	−1.212 (0)	−1.501 (0)	−1.461 (3)	0.085 (4)	−5.014
Sri Lanka	−2.263 (0)	−2.318 (0)	−2.113 (2)	0.141 (4)	−8.013
Thailand	−1.910 (1)	−1.924 (1)	−1.727 (3)	0.108 (4)	−7.686
Vietnam	−1.708 (0)	−1.809 (2)	−1.742 (7)	0.192 (4)**	−13.457
Americas and Caribbean					
Argentina	−2.457 (0)	−2.585 (0)	−2.604 (2)	0.073 (2)	−9.620
Bolivia	−3.157 (2)	−2.857 (2)	−1.857 (3)	0.095 (4)	−47.658***
Brazil	−3.849 (1)**	−2.808 (1)	−3.254 (0)	0.101 (3)	−14.248
Canada	−3.794 (1)**	−3.111 (1)	−4.260 (7)**	0.081 (2)	−15.604
Chile	−2.366 (0)	−1.576 (0)	−2.354 (1)	0.181 (4)**	−2.107

(continued on next page)

Table A1 (*continued*)

Country	ADF	DF-GLS	P–P	KPSS	NP
Colombia	0.473 (1)	−2.065 (3)	−0.202 (3)	0.166 (4)**	−1092.840***
Costa Rica	−2.307 (0)	−2.418 (0)	−2.303 (1)	0.169 (4)**	−8.776
Americas and Caribbean					
Cuba	−3.071 (1)	−2.418 (1)	−2.091 (1)	0.160 (4)**	−8.117
Dominican Republic	−2.129 (0)	−2.128 (0)	−2.233 (3)	0.138 (4)	−6.854
Ecuador	−2.166 (0)	−1.513 (0)	−2.166 (0)	0.155 (4)**	−2.172
El Salvador	−1.685 (0)	−1.610 (0)	−1.915 (3)	0.109 (4)	−4.151
Haiti	−1.720 (0)	−1.784 (0)	−1.720 (0)	0.123 (4)	−5.520
Mexico	−2.414 (0)	−1.310 (2)	−2.414 (0)	0.185 (4)**	−5.554
Netherlands Antilles	−0.922 (0)	−1.226 (0)	−1.148 (2)	0.142 (4)	−3.756
Nicaragua	−3.651 (1)**	−2.867 (0)	−2.919 (3)	0.088 (0)	−10.521
Panama	−1.477 (0)	−1.510 (0)	−1.339 (7)	0.186 (4)**	−4.051
Peru	−1.896 (0)	−1.775 (0)	−2.030 (1)	0.094 (4)	−4.707
United States	−2.722 (1)	−2.848 (1)	−2.154 (1)	0.127 (4)	−14.667
Middle East and North Africa					
Algeria	−1.776 (0)	−1.371 (3)	−1.766 (1)	0.197 (4)**	−9.714
Bahrain	−5.148 (2)***	−1.214 (3)	−4.115 (4)**	0.160 (4)**	−2.154
Egypt, Arab Rep.	−0.891 (0)	−0.895 (0)	−0.867 (1)	0.187 (4)**	−1.488
Iran, Islamic Rep.	−3.325 (0)	−2.857 (0)	−3.214 (4)	0.144 (3)	−8.886
Iraq	−1.143 (0)	−1.213 (0)	−0.209 (14)	0.191 (4)**	−2.783
Israel	−1.745 (1)	−3.282 (0)**	−3.216 (2)	0.145 (4)	−12.012
Kuwait	−3.701 (1)**	−3.788 (1)***	−2.644 (6)	0.086 (2)	−24.521***
Libya	−2.159 (1)	−1.520 (0)	−2.964 (2)	0.199 (4)**	−1.475
Malta	−1.370 (1)	−1.523 (1)	−2.492 (1)	0.143 (4)	−4.858
Morocco	−3.154 (0)	−1.791 (0)	−3.147 (1)	0.129 (4)	−2.219
Qatar	−1.548 (2)	−1.419 (2)	−1.985 (7)	0.178 (4)**	−5.829
Saudi Arabia	−1.880 (1)	−1.723 (1)	−1.089 (2)	0.180 (4)**	−6.568
Tunisia	−2.225 (0)	−1.767 (0)	−2.169 (9)	0.177 (4)**	−3.746
United Arab Emirates	−1.060 (0)	−1.569 (2)	−0.977 (6)	0.195 (4)**	−7.720
Yemen, Rep.	−4.582 (0)***	−4.560 (0)***	−4.703 (3)***	0.129 (4)	−15.185
Europe and Central Asia					
Austria	−2.775 (0)	−2.855 (0)	−2.775 (0)	0.166 (2)**	−11.048
Belgium	−2.056 (0)	−2.082 (0)	−2.338 (2)	0.136 (4)	−6.748
Cyprus	−4.628 (1)***	−4.228 (1)***	−2.367 (10)	0.111 (1)	−18.337**
Denmark	−2.899 (0)	−2.998 (0)	−2.979 (3)	0.148 (0)**	−11.174
Finland	−3.589 (0)**	−3.286 (0)**	−3.499 (4)	0.176 (0)**	−11.300
France	−3.640 (0)**	−3.692 (0)**	−3.668 (3)**	0.089 (1)	−13.389
Germany	−3.087 (0)	−2.438 (0)	−3.087 (3)	0.166 (3)**	−6.412
Iceland	−2.715 (0)	−2.584 (0)	−2.677 (1)	0.102 (4)	−8.595
Ireland	−2.508 (0)	−2.356 (0)	−2.484 (1)	0.161 (4)**	−7.447
Italy	−2.164 (0)	−2.227 (0)	−2.281 (3)	0.143 (4)	−7.697
Luxembourg	−1.032 (0)	−1.229 (0)	−1.196 (3)	0.155 (4)**	−3.376
Poland	−2.296 (0)	−1.956 (1)	−2.295 (4)	0.174 (4)**	−6.090
Portugal	−2.045 (0)	−2.301 (0)	−2.114 (2)	0.087 (3)	−9.058
Romania	−2.518 (1)	−1.926 (1)	−2.138 (2)	0.187 (4)**	−6.293
Spain	−3.008 (0)	−2.289 (0)	−3.109 (3)	0.073 (3)	−5.548
Sweden	−3.036 (0)	−3.020 (0)	−3.007 (2)	0.124 (3)	−10.924
Turkey	−3.056 (0)	−2.539 (0)	−3.099 (1)	0.095 (2)	−7.326
United Kingdom	−2.094 (0)	−2.010 (0)	−2.060 (2)	0.159 (4)**	−5.968

Table A1 (*continued*)

Country	ADF	DF-GLS	P–P	KPSS	NP
Sub-Saharan Africa					
Angola	−1.930 (0)	−2.036 (0)	−1.464 (5)	0.144 (3)	−6.956
Benin	−4.458 (3)***	−3.307 (0)**	−3.197 (0)	0.073 (1)	−12.345
Cameroon	−0.851 (0)	−0.897 (0)	−0.851 (0)	0.183 (4)**	−1.602
Congo, Dem. Rep.	−2.023 (0)	−2.143 (0)	−2.023 (0)	0.175 (4)**	−7.497
Congo, Rep.	−1.898 (0)	−1.788 (0)	−1.986 (3)	0.149 (4)**	−4.839
Ethiopia	−3.758 (1)**	−3.823 (1)***	−2.534 (7)	0.073 (1)	−26.196***
Gabon	−1.561 (2)	−1.516 (2)	−3.246 (4)	0.124 (2)	−3.154
Ghana	−2.126 (0)	−2.204 (0)	−2.126 (0)	0.154 (4)**	−7.529
Kenya	−2.963 (1)	−2.993 (1)	−2.467 (2)	0.135 (3)	−19.070**
Mozambique	0.863 (0)	−1.214 (1)	0.451 (2)	0.127 (3)	−9.699
Senegal	−2.459 (0)	−2.236 (0)	−2.482 (3)	0.102 (4)	−6.842
South Africa	−1.234 (0)	−1.115 (0)	−1.258 (2)	0.184 (4)**	−1.954
Sudan	−2.378 (0)	−2.491 (0)	−2.067 (8)	0.174 (2)**	−9.176
Zambia	−2.261 (2)	−1.446 (2)	−4.590 (4)***	0.164 (4)**	−3.741
Zimbabwe	−0.149 (0)	−0.669 (0)	−0.365 (1)	0.136 (4)	−1.814

Notes: ** and *** indicate significance at the 5% and 1% levels, respectively. DF-GLS and NP are unit root tests proposed by Elliott et al. (1996) and Ng and Perron (2001), respectively. The numbers in parentheses are the lag orders in the ADF and DF-GLS tests. The lag parameters are selected on the basis of MAIC. The truncation lags are for the Newey-West correction of the P–P and NP tests in parentheses. The NP test is based on the MZa statistic.

Appendix B. Results for Alternative Classification Method

Table B1

Panel SURADF tests and critical values (high income level)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Australia	−1.506	−4.660	−4.012	−3.632
Austria	0.358	−5.628	−4.967	−4.597
Belgium	−1.424	−5.951	−5.243	−4.808
Canada	−2.485	−4.821	−4.169	−3.788
Denmark	−6.172***	−5.688	−5.020	−4.625
Finland	0.065	−4.534	−3.859	−3.536
France	−0.487	−5.164	−4.479	−4.112
Germany	−6.070***	−5.305	−4.658	−4.261
Ireland	−0.797	−4.743	−4.052	−3.708
Italy	−0.545	−4.668	−3.997	−3.673
Japan	−2.077	−5.421	−4.658	−4.275
Korea, Rep.	−3.230	−4.615	−3.987	−3.637
New Zealand	−2.025	−4.579	−3.869	−3.521
Portugal	−1.618	−4.189	−3.565	−3.214
Spain	−0.228	−4.979	−4.306	−3.954
Sweden	−2.096	−4.378	−3.783	−3.445
United Kingdom	−3.019	−5.390	−4.739	−4.366
United States	−0.892	−4.902	−4.234	−3.843

Notes: Classified according to World Bank estimates of 2004 GNI per capita. *** indicates significance at the 1% level. Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

Table B2
Panel SURADF tests and critical values (middle income level)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Algeria	−4.175***	−3.806	−3.227	−2.912
Angola	2.078	−4.318	−3.677	−3.339
Argentina	−1.349	−4.214	−3.544	−3.224
Bolivia	−2.895	−4.142	−3.530	−3.206
Brazil	−1.960	−4.272	−3.648	−3.325
China	0.365	−3.967	−3.388	−3.054
Colombia	−2.056	−4.510	−3.841	−3.480
Cuba	−3.361	−4.469	−3.860	−3.503
Ecuador	−3.629**	−4.062	−3.452	−3.108
Egypt, Arab Rep.	−1.677	−4.570	−3.920	−3.567
Indonesia	−1.387	−4.247	−3.647	−3.330
Iran, Islamic Rep.	−3.104	−4.553	−3.889	−3.525
Libya	−5.927***	−4.359	−3.673	−3.352
Mexico	−5.714***	−4.178	−3.539	−3.202
Philippines	0.308	−4.301	−3.651	−3.304
Romania	−3.322	−4.602	−3.912	−3.575
South Africa	−2.739	−3.960	−3.408	−3.085
Thailand	−0.459	−4.525	−3.818	−3.462

Notes: Classified according to World Bank estimates of 2004 GNI per capita. ** and *** indicate significance at the 5% and 1% levels, respectively. Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

Table B3
Panel SURADF tests and critical values (low income level) (*) and triple-asterisk (***)

Country panel label	Panel SURADF	Critical values		
		0.01	0.05	0.1
Benin	−0.961	−4.237	−3.612	−3.297
Cameroon	−2.554	−4.325	−3.671	−3.339
Congo, Dem. Rep.	−0.991	−4.268	−3.681	−3.340
Congo, Rep.	−2.366	−4.328	−3.720	−3.378
Ethiopia	0.418	−4.093	−3.499	−3.178
Ghana	−0.478	−4.288	−3.692	−3.309
Haiti	−4.579**	−4.649	−4.039	−3.677
India	−0.502	−4.219	−3.569	−3.237
Kenya	−0.894	−4.648	−4.062	−3.686
Korea, Dem. Rep.	−3.563	−4.748	−4.028	−3.654
Mozambique	−1.744	−4.969	−4.267	−3.890
Myanmar	−0.686	−4.363	−3.709	−3.372
Nepal	−1.468	−3.863	−3.268	−2.952
Nicaragua	−0.893	−3.702	−3.174	−2.848
Pakistan	−1.902	−4.266	−3.656	−3.301
Senegal	−1.414	−5.036	−4.359	−3.995
Sudan	−0.230	−4.539	−3.850	−3.501
Vietnam	2.342	−4.315	−3.672	−3.310

Notes: Classified according to World Bank estimates of 2004 GNI per capita. ** indicates significance at the 5% level. Critical values are calculated using the Monte Carlo simulation with 10,000 draws, tailored to the present sample size. (For details of this simulation, see Breuer et al., 2001.)

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