energies

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Are Shocks to Wood Fuel Production Permanent? Evidence from the EU

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Received: 31 August 2015 ; Accepted: 1 November 2015 ; Published: 11 November 2015
Academic Editor: Thomas E. Amidon

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Abstract: This paper investigates whether shocks (economic effects) to wood fuel production for 18 countries of the European Union (EU) over the period 1961–2012 are temporary or persistent. A variety of time-series and panel data unit root tests are employed. The presence of structural breaks is taken into account when performing those tests. Wood production in approximately 78% of the countries is found to follow a non-stationary process supported by the result that most of the panel unit root tests also point towards a non-stationary process. This indicates that the economic effect will tend to be persistent and suggests that policies affecting wood fuel production, implicitly or explicitly, will have enduring effects. For instance, forest conservation policies will persistently reduce the wood fuel production level.

Keywords: wood fuel production; cross-sectional dependence; structural breaks; unit root tests

1. Introduction

Wood is the oldest source of fuel and remains to date vital for cooking and heating in many societies. The EU has specific energy policies and wood fuel has a critical role to play [1]. According to the 2009 Renewables Directive, the EU will have to reach a 20% share of energy from renewable sources by 2020. Indeed, wood-based fuel pellet production had an increasing trend in the EU between 2001 and 2009 [2]. According to the unified bioenergy terminology wood fuel is defined as all types of biofuels derived directly or indirectly from woody biomass [3]. For instance, wood fuel includes biomass derived from silvicultural activities (such as thinning and pruning) and harvesting and logging (such as tops, roots and branches), as well as industrial by-products derived from primary and secondary forest industries that are used as fuel.

From a policy viewpoint, it is essential to assess whether economic effects of policies, such as a forest conservation policy (FCP), will have a temporary or persistent effect on wood fuel availability. FCP mainly aims at creating long-term sustainable growth of the forest and forestry. FCP should ensure that wood production has no deforestation footprint. Furthermore, policies or regulations that restrict access to a specific category of resource (e.g., logging bans) can adversely impact wood fuel supplies [4]. To address these issues, a study of the unit root properties of wood fuel production can improve our understanding of long-term policy effects. Unit root is basically a feature of underlying processes affecting the production level that evolve through time. This process can either be stationary (*i.e.*, deviations from the long-term trend are stationary) or non-stationary (*i.e.*, deviations from the long-term trend are non-stationary). If wood fuel production is found to be non-stationary, then the policy effect will tend to be persistent. That is, wood fuel production will not return to its previously long-run trend, instead a new trend is established. On the contrary, if wood fuel production is found to be stationary, then the policy effect is temporary and the wood fuel production will eventually return to its long term level.

There are various implications that can be derived from this. First, the wood-pellet industry supplies refined wood fuels, such as wood-pellets, to various sectors (e.g., CHP and households) and demands wood from the forestry sector. If policy effects are temporary, the sectors that use refined wood fuels will not be affected in the long-run. That is the policy effect will not be passed on to other sectors in the long-run. However, if policy effects are persistent the effects will be transmitted across connected sectors. This can influence studies relating to the cointegrating link between wood fuel production and other economic variables. Second, in forecasting wood fuel supply, it is important to understand if the effects will be temporary or persistent. For instance, if the effects are temporary past behavior of wood fuel production can be used to forecast future wood fuel production. These forecasts could be of particular interest to the forestry sector in order to effectively handle changes in demand. They can also help to assess the risks and costs involved in the production process. On the other hand, if the effects are persistent then historical movements cannot be used to produce robust forecasts. Finally, if the effects are temporary, then any energy efficiency policies which are related to the use of wood fuel will only be short-termed. Wood fuel production will consequently reverts back to its previous equilibrium value after being effected by such policies. Thus, policies with long-term objectives will not be effective. Contrary, if the effects are persistent, then the policies will be more effective.

So far, little research on the stochastic properties of renewable energy production has been done. However, there is a large bulk of literature devoted to the study of stochastic properties of other economic variables, which started with the seminal work of Nelson and Plosser [5]. Narayan *et al.*, provided a review of the method applied in this study with respect to economic and energy variables [6]. With the development of the methods, studies addressing the stochastic properties of energy data have contributed to the advancement of the literature. For example, Smyth provided a recent review of this literature and argued that the sensitivity of results depends on the methodology used and type of energy studied [7]. In this context, there are a few energy studies that report temporary effects, *i.e.*, stationary processes, for energy variables [8–10]. From the energy production perspective, the contextual literature remains relatively small. For instance, Narayan *et al.*, examined the unit root properties of crude oil production for 60 countries employing a range of panel data unit root tests for the period 1971 to 2003 [6]. Their results suggest that crude oil and natural gas liquids (NGL) production are stationary, indicating that policy effects are temporary. Barros *et al.*, examined the properties of oil production for 13 OPEC countries within a fractional integration modelling framework incorporating the potential for structural breaks and outliers [11]. They use monthly data from January 1973 to October 2008 and their results indicate that there is non-stationarity in the oil production, with structural breaks identified in ten countries. Thus, policy effects affecting the structure of OPEC oil production will be persistent in the long run. From the forest products perspective, Jaunky and Lundmark investigated whether the effects to pulp for paper production in 17 OECD countries over the period 1980–2012 are temporary or persistent [12]. They apply a variety of time-series and panel data unit root tests and conclude that approximately two-thirds of the countries are found to follow a non-stationary process which is also the case for the overall data panel. Hence, effects to the pulp for paper production are permanent. This paper intends to bridge this gap by studying the implications of policy effects on wood fuel production in a sample of EU countries.

2. Methodology

The data for wood fuel production are compiled from the online forestry database provided by the Food and Agriculture Organization of the United Nations (FAO). Specifically, 18 EU countries are chosen over the period 1961–2012. The sample selection is based on the availability of data. As a starting point, the mean and standard deviation of the wood fuel production data can be examined when searching for a unit root. Countries with a high standard deviation are logically more likely to exhibit a lack of mean reversion since countries with high variation in the production levels deviation from the long-run equilibrium path [6]. As a consequence, economic effects are likely to be larger and the departures from the long-term path will tend to be permanent [11]. As presented in Table 1, various countries, as well as the entire panel, exhibit relatively high standard deviations of wood fuel production, where The Netherlands has the highest value.

Table 1. Mean and standard deviation of wood fuel production.

Countries	Mean	Standard deviation	Countries	Mean	Standard deviation
Austria	14.572	0.542	Italy	15.332	0.225
Bulgaria	14.196	0.382	Netherlands	11.297	1.043
Cyprus	9.355	0.644	Poland	14.633	0.382
Denmark	12.777	0.830	Portugal	13.443	0.519
Finland	15.446	0.415	Romania	15.162	0.422
France	16.631	0.502	Spain	14.876	0.661
Germany	15.294	0.360	Sweden	15.259	0.265
Greece	14.281	0.362	UK	12.463	0.649
Hungary	14.718	0.151			
Ireland	10.648	0.806	Panel	13.910	1.932

To study the stochastic properties of wood fuel production, several time-series and panel unit root tests are applied since no single test is devoid from statistical limitations in terms of size and power. To conduct the tests, two different regressions are considered. One regression includes a constant term only, while the other contains both a constant term and a time trend. Generally, economic data tend to have a time trend thus it is more fitting to consider the regression with both a constant term and a time trend. Nevertheless, and for the sake of comparison, both approaches are employed.

Most of the panel unit root tests are based on an augmented Dickey-Fuller (ADF) test type which can be algebraically denoted by:

$$\Delta F_{it} = \mu_i + \beta_{it} + \rho_i F_{it-1} + \alpha_{im} \sum_{m=1}^{k_i} \Delta F_{i,t-m} + e_{it} \tag{1}$$

where, F_{it} denotes the natural logarithm of wood fuel production over the period t and for country i, $\Delta F_{it} = F_{it} - \Delta F_{it-1}$, k is the lag length, and ρ_i is a mean-reverting coefficient and e_{it} is the idiosyncratic disturbance assumed to be *identically and independently distributed*. The null hypothesis that the series contains a unit root is tested.

Supplementary time-series unit root tests (KPSS), as proposed by Kwiatkowski *et al.*, and Narayan *et al.*, are consequently applied [13,14]. The KPSS test statistics is the score statistics for testing $\sigma^2_{e_{it}} = 0$ against the alternative $\sigma^2_{e_{it}} > 0$ and is given by:

$$KPSS = \left(T^{-2} \sum_{t=1}^{T} \hat{S}_t^2 \right) / \hat{\lambda}^2 \tag{2}$$

where $\hat{S}_t$ is the sum of residuals of the regression and $\hat{\lambda}^2$ is a consistent estimate of the long-run variance of the residual. The unit root test the H_0 of non-stationarity [15–21] (e.g., ADF and Narayan-Popp tests) is supplemented with a test of the H_0 of stationarity [22,23] (e.g.,KPSS test). This joint testing, usually coined as confirmatory analysis, adds significant power to the testing framework. Yet, the test could produce unreliable results if too few observations over an adequately long time period are used. As suggested by Toda, even 100 observations may not guarantee satisfactory performance [24]. One solution is to apply panel data techniques which allow for a substantial increase in the number of observations and therefore testing power. The KPSS test is a more powerful test than the ADF test. For instance, it can clearly distinguish between a series which appears to be stationary and non-stationary in case the data are not sufficient to conclude about the order of integration. The ADF and KPSS time series unit root tests fail to capture the presence of structural breaks in the data and this can potentially lead to a fall in power of the test to reject a unit root even if the trend holds [25]. Breaks can occur as a result of economic effects which can be climatic, economical, or technological in nature. Philips and Perron were amongst the first to account for a break in the unit root testing [26]. However, they assume that the break is exogenous and this can lead to the invalidation of the sampling distribution theory underlying conventional time-series unit root tests [27]. In contrast, Zivot and Andrews recommended a test which allows for one break to be endogenously determined from the time-series [28], but when two or more breaks occur, the Zivot-Andrews test tends to lose power. The Narayan-Popp test allows for the presence of two endogenous breaks.

In addition to the three time series test are outlined above (ADF, KPSS and Narayan-Popp), 1st, 2nd and 3rd generations of panel unit root tests are outlined. The 1st generation panel unit root tests are based on the individual lags computed from the ADF tests. The LLC test relies on the assumption of homogeneity in the ADF specifications [15]. It also ignores the presence of structural breaks and assumes cross-sectional independence. Thus, the LLC test tends to be problematic in the presence of cross-sectional dependence [29]. The IPS test controls for heterogeneity and also cross-sectional dependence by employing demeaned data [16]. Demeaned data is basically the exclusion of the means from the time series. The IPS test is more powerful than the LLC test but it tends to have low power in panels with few time periods [30]. The Maddala-Wu test is a non-parametric test and has a tendency to be more powerful than the LLC and IPS tests [17]. It controls for heterogeneity across countries and does not require a balanced panel. The test is suitable to use when a mixture of stationary and non-stationary series is included. It has relatively higher power in differentiating the null from the alternative hypothesis. The H_0 of non-stationarity of all the series within a specific panel is tested against the alternative of at least one stationary series. The Maddala-Wu test employs the Fisher approach to derive test statistics which combine the p-values from individual unit root tests such as the ADF test in each cross-sectional unit [31]. The last of the 1st generation panel unit root tests is the Hadri test. It is based on the KPSS approach and tests the H_0 of stationarity. In contrast to the LLC or IPS test, the Hadri test performs comparatively well in panel data with few time periods [32]. It is also robust to serial correlation and heteroskedasticity. The test, which includes a time trend, will be employed for inferences.

The four 1st generation tests are likely to suffer from low power and size distortions in the presence of contemporaneous cross-dependence. To mitigate such effects, the 1st generation tests utilize demeaned data. This approach assumes the existence of a common factor with similar effect on all individual wood fuel series but this is unlikely to hold in practice. The demeaning of data may not adequately tackle the size problems produced by the magnitude and variation of cross-sectional dependence [33]. The 2nd generation of panel unit root test relaxes the assumption of cross-sectional independency and allows for the presence of cross-sectional dependence in a more general pattern. Taylor and Sarno developed the multivariate ADF (MADF) test which is based on the seemingly unrelated regressions (SUR) panel framework [18]. Pesaran suggests an alternative 2nd generation panel unit root test [19]. The conventional ADF regression models are augmented with the cross-section averages of lagged levels and first-differences of the individual wood series. The Pesaran test is based on the averages of the individual cross-sectionally augmented ADF (CADF) statistics. The test has good size and power properties even with a low number of cross-sections and time periods. Comparable to the time series unit root tests, panel unit root tests can be biased if structural breaks are ignored. Im *et al.*, suggested a new LM based test which allows for heterogeneous breaks in both the intercept and slope of each cross-sectional unit [20]. They extend their LM test to control for cross-sectional dependence by employing the CADF procedure and derive a cross-sectionally augmented LM (CALM) test statistic. Panel unit root tests which allow for breaks are found to depend critically on nuisance parameters specifying the size and break locations. These tests can be subject to serious size distortions. To tackle this problem, a method was designed which renders the asymptotic properties of their test invariant to these nuisance parameters [20]. They derive these asymptotic properties and examine the finite-sample properties of their tests. As another confirmatory test, the Hadri-Kurozumi test is conducted testing the H_0 of stationarity. This test is an extension of the Hadri test and it allows the LM test to control for cross-sectional dependence. The regression is augmented by cross-sectional average of the observations, in same way as the Pesaran test which augments the conventional ADF regression.

Finally, the 3rd generation of panel unit root tests addresses that cross-sectional cointegration can undermine the results accruing from the 1st and 2nd generation tests. A 3rd generation test which can account for both short- and long-run co-movements across units is accordingly required [34]. The incidence of cross-sectional cointegration has been recently applied by e.g., Jaunky [35]. Long-run dependence arises when two or more units share a common stochastic trend and this can cause biased panel unit root test statistics, leading to erroneous inferences [36]. Several recent studies which analyze the impact of economic effects ignore the implications of structural breaks and cross-sectional cointegration, e.g., [8–10]. Chang and Song put forward a panel unit root test which employs a set of orthogonal functions as instrument generating function (IGF) to tackle any forms of dependence [21].

3. Results and Discussion

The test results based on the methods described above are reported in Table 2. According to the ADF tests with a constant and trend, 12 series are found to be non-stationary while six series are stationary. Nonetheless, the ADF test tends to have low power against stationary alternatives which are closer to being non-stationary. Also, when both a constant and trend tends is included the ADF test have less power relative to the test with a constant only. For the KPSS test with a trend, 17 series are found to be non-stationary and one stationary. Yet, the KPSS test tends to have extreme size distortions when the H_0 of a stationary series is close to the alternative of a unit root [37]. Hence, the test may reject H_0 even if the true series is stationary. As shown in Table 1, two Narayan-Popp tests are considered (M1 and M2). The first test allows for two structural breaks in the level while the second tests accounts for breaks in the level and slope. These tests are found to have suitable power. In the first Narayan-Popp test, 12 series are non-stationary and six are stationary. In the second Narayan-Popp test, 14 series are non-stationary and four are stationary. Indeed, the second tests reveal to be non-stationary and stationary respectively. In other words, approximately 78% of the series tend to be non-stationary according to the Narayan-Popp tests. Furthermore, the breaks coincide with several economic crises. Demand shocks could be explained by the excessive hike in oil price following the 1979 Iranian revolution and the 1980–1981 Iran-Iraq war. The second break coincides with another spike in oil price, mainly due to the 1990 Gulf war and to the 1997 Kyoto protocol.

The 1st generation panel root tests are conducted using the individual lags computed from the ADF tests. The results of the tests are presented Table 3. The wood fuel production is found to be stationary at conventional levels in the LLC test whilst the Madalla-Wu test, which includes a time trend, provides supporting evidence that at least one of the wood fuel production series follows a stationary process. The degree of cross-sectional dependence can be evaluated by computing the pair-wise correlations of the first-differences in two series [38]. For instance, the pair-wise correlation coefficients of ΔF_t between two series are mostly positive and range from -0.322 to 0.449. These results indicate the existence of cross-sectional dependence, which can lead to bias panel data unit root tests [36]. As shown in Table 3, for both raw and demeaned data, the IPS test statistics with trend illustrate a non-stationary process for wood fuel production. Finally, the Hadri test reports a non-stationary process for the wood fuel production.

Table 2. Time series unit root test results of wood fuel production.

Country	ADF		KPSS		Narayan-Popp					
					$M1_{B,L}$			$M2_{B,L}$		
	without Trend	with Trend	without Trend	with Trend	*t*-Value	T_{B1}	T_{B2}	*t*-Value	T_{B1}	T_{B2}
Austria	−0.052(0)	−2.734(0)	1.800(2) *	0.215(2) $^{+}$	−2.195(0)	1978	1984	−2.566(0)	1978	1984
Bulgaria	−1.894(0)	−3.295(0) ‡	1.060(2) *	0.230(2) *	−3.516(0)	1986	1993	−3.111(4)	1980	1988
Cyprus	−1.872(0)	−4.469(0) *	1.570(2) *	0.265(2) *	−5.708(0) *	1973	1999	−6.056(0) *	1973	1999
Denmark	−0.903(1)	−3.100(2)	1.340(2) *	0.199(2) $^{+}$	−4.704(1) $^{+}$	1978	2000	−7.615(0) *	1977	1998
Finland	−2.373(0)	−1.351(0)	1.020(2) *	0.499(2) *	−0.961(0)	1988	1992	−2.111(0)	1988	1992
France	−1.466(0)	−1.942(0)	1.450(2) *	0.187(2) $^{+}$	−6.397(0) *	1971	1987	−7.635(4) *	1972	1987
Germany	−0.491(0)	−0.904(0)	0.497(2) $^{+}$	0.255(2) *	−3.327(0)	1994	2001	−3.160(0)	1994	2001
Greece	−0.525(1)	−3.720(0)$^{+}$	1.780(2) *	0.234(2) *	−4.594(0)$^{+}$	1982	1988	−4.734(0)	1982	1988
Hungary	−2.305(0)	−2.357(0)	0.461(2) ‡	0.157(2) $^{+}$	−2.253(0)	1984	1998	−4.430(0)	1989	1998
Ireland	−2.919(4)	−3.447(4) $^{+}$	0.370(2) ‡	0.111(2)	−4.378(4)	1972	2000	−2.302(2)	1973	1977
Italy	−1.549(0)	−3.349(0) ‡	0.724(2) *	0.254(2) *	−3.768(0)	1971	1998	−3.930(0)	1979	1998
Netherlands	−1.090(2)	−1.891(3)	1.770(2) *	0.131(2) ‡	−5.202(0) $^{+}$	1973	1975	−2.594(1)	1971	1974
Poland	−1.554(1)	−2.257(1)	0.717(2)$^{+}$	0.127(2) ‡	−1.406(0)	1980	1994	−3.272(0)	1980	1994
Portugal	−4.537(2) *	−4.209(4) *	0.926(2) *	0.410(2) *	−3.131(0)	1975	1977	−4.751(0)	1971	1975
Romania	−1.834(1)	−1.245(1)	1.190(2) *	0.370(2) *	−2.897(4)	1988	1992	−6.423(3) *	1988	1992
Spain	−2.458(2)	−1.677(2)	0.865(2) *	0.384(2) *	−2.545(1)	1973	1997	−4.479(0)	1982	1997
Sweden	−1.137(1)	−3.111(1)	1.200(2) *	0.181(2) $^{+}$	−4.434(0)‡	1977	1997	−3.921(0)	1977	1997
UK	−1.587(2)	−1.668(2)	0.502(2) $^{+}$	0.398(2) *	−1.019(0)	1972	1974	−2.540(2)	1972	1976

The maximum lag is computed following $k_{\max} = \text{int}(4(T/100))^{1/4} \approx 4$, where int denotes integer and $T = 52$. $k_{\max}$ is rounded up to next lowest integer while excluding the decimal portion of the value. ADF critical values (CV) without and with a time trend are −3.60, −2.94 and −2.60; and −4.18, −3.51 and −3.19 at 1%, 5% and 10% significance levels respectively. The optimal lag is chosen as per the Akaike Information Criterion. KPSS one-sided CV without a trend at 1%, 5% and 10% levels are 0.739, 0.463 and 0.347 and with a trend, these are 0.216, 0.146 and 0.119 respectively. To yield the optimal bandwidth for the KPSS statistics, the quadratic spectral kernel is applied. T_{B1} and T_{B2} are the dates of the structural breaks. The one-sided critical values are −5.259, −4.514 and −4.143 respectively for model $M1_{B,L}$ and −5.949, −5.181 and −4.789 at 1%, 5% and 10% level of significance ($T = 50$) for model $M2_{B,L}$. The optimal lag is in parentheses. *, $^{+}$ and ‡ denote 1%, 5% and 10% levels respectively.

Table 3. 1st generation panel unit root test result statistics.

Test								
	Without Trend	With Trend						
LLC [16] [1]	−1.649 (0.049)	−2.048 (0.020)						
Madalla-Wu [18] [2]	46.230 (0.118)	48.46 (0.080)						
IPS [17] [3]	**Raw Data**		**Demeaned Data**					
	Without Trend	With Trend	Without Trend	With Trend				
	−0.683 (0.247)	−2.155 (0.016)	−1.133 (0.129)	−1.220 (0.111)				
Hadri [36] [4]	**Serial Correlation**				**Heteroskedasticity**			
	Raw Data		**Demeaned Data**		**Raw Data**		**Demeaned Data**	
	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend	Without Trend	With Trend
	15.079 (0.000)	10.145 (0.000)	16.528 (0.000)	9.153 (0.000)	67.985 (0.000)	50.436 (0.000)	63.904 (0.000)	46.912 (0.000)

[1] The lag lengths for the panel test are based on those employed in the univariate ADF test in Table 1. Assuming no cross-country correlation and T is the same for all countries, the normalized t^* test statistic is computed by using the t-value statistics. The H_0 of non-stationarity is tested. It is then compared to the 1%, 5% and 10% significance levels with the one-sided critical values of −2.326, −1.645 and −1.282 correspondingly. The p-values are in square brackets; [2] The lag lengths are chosen according to the Bartlett kernel. Based on the p-values of individual unit root tests, the Fisher test assumes that all series are non-stationary under the H_0 against the alternative that at least one series in the panel is stationary. The test has a χ^2 distribution with $2N$ degrees of freedom, where N is the number of cross-sectional units or countries. The test is based on the ADF test; [3] The lag lengths for the panel test are based on those employed in the univariate ADF test in Table 1. The IPS test statistics are computed as the average ADF statistics across the sample. These statistics are distributed as standard normal as both N and T grow large. Assuming no cross-country correlation and T is the same for all countries, the Ψ_t test statistics for H_0 of joint non-stationarity are compared to the 1%, 5% and 10% significance levels with critical values of −2.330, −1.645 and −1.282 correspondingly; [4] The Z test is based on the Lagrange Multiplier (LM) tests are based on the average of the N country-specific KPSS LM-statistics under which the H_0 of stationarity is tested. The Bartlett kernel is equal to 4. The KPSStest statistics are compared to the 1%, 5% and 10% significance levels with the one-sided critical values of 2.326, 1.645 and 1.282 respectively. The test statistics are robust to serial correlation and heteroskedasticity.

The 2nd generation panel unit root tests are presented in Table 4. The MADF panel test statistics reject the H_0 of joint non-stationarity in favor of the alternative where at least one of the wood fuel production series in the panel is generated by a stationary process. Similar to the Madalla-Wu test, the rejection of the null should be interpreted with caution as they do not imply a stationary vector process for all the series in the EU panel. The CADF test, which includes a time trend, suggests a stationary process. The CALM test suggests that the wood fuel production is non-stationary process in the presence of either one or two breaks. Finally, two test statistics are calculated for the Hadri-Kurozumi test (ZA_{spc} and ZA_{la}). The statistics are the augmented panel KPSS test statistics with long-run variance corrected by the Sul *et al.*, and lag-augmented methods [39,40]. The H_0 of stationarity is rejected.

Table 4. 2nd generation panel unit root test result statistics.

Test	Statistic			
MADF [19] [1]	72.863			
	Without trend	**With trend**		
CADF [20] [2]	−1.260 (0.104)	−2.114 (0.017)		
	One break	**Two breaks**		
CALM [21] [3]	2.639	5.916		
	ZA_{spc}		ZA_{la}	
	Without trend	**With trend**	**Without trend**	**With trend**
Hadri-Kurozumi [38,39] [4]	54.175	310.292	191.580	720.705

[1] The lag length is based on to the Bartlett kernel. The H_0that all time-series in the panel are integrated of order one, I(1), processes is tested against the alternative that at least one series in the panel is stationary. Approximate 5% critical value, derived from Monte Carlo simulation, is equal to 21.578. [19] omit a linear trend in their test; [2] The lag lengths for the panel test are based on those employed in the univariate ADF test in Table 1. The Pesaran CADF test of the H_0 of non-stationarity is based on the mean of individual DF (or ADF) *t*-statistics of each unit in the panel. The Z test statistic is compared to the 1%, 5% and 10% significance levels with the one-sided critical values of −2.326, −1.645 and −1.282 correspondingly; [3] The maximum lag length is based on to the Bartlett kernel. The H_0 of non-stationarity is tested. In similar fashion to [20], cross-sectionally augmented versions of the transformed LM test statistics for trend or level shift are computed. The breaks are assumed to occur in the intercepts. We allow for time fixed-effects to mitigate cross-correlations. Critical values for the CALM panel unit root test are distributed asymptotic standard normal and are compared with the one-sided critical values −2.326, −1.645, and −1.282 at the 1%, 5%, and 10% levels, respectively; [4] The lag length is based on to the Bartlett kernel. The H_0 of stationarity is tested. The ZA_{spc} and ZA_{la} test statistics are compared to the 1%, 5% and 10% significance levels with the one-sided critical values of 2.326, 1.645 and 1.282 respectively.

Lastly, 3rd generation tests are conducted. As illustrated in Table 5, two types of panel unit root test statistics are computed. The average tests relate to the testing of the H_0 of non-stationarity for all individual EU countries whereas the minimum tests evaluate the H_0 of non-stationarity of some individual countries within the panel. In general, these tests confirm a non-stationary process for the wood fuel production. According to Karlsson and Löthgren, a rejection of a unit root may be caused by a few stationary series and the whole panel can be incorrectly modelled as stationary [30]. Homogeneity of non-stationarity or stationarity properties is inherent to the joint testing of most panel unit root tests.

Table 5. 3rd generation panel unit root test result statistics.

Test	ta_c	ta_h	ta_a	tm_c	tm_h	tm_a
Chang-Song [22] [1]	−0.485	−0.399	0.042	−1.715	−1.197	−2.656
Chang-Song limited [34] [2]	−0.287	0.108	−0.118	−1.716	−1.197	−2.655

[1] The nonlinear IV average and minimum tests are denoted by *ta* and *tm* while the subscripts *c*, *h* and *a* refer to those tests with single IGF and no covariate, with single IGF and covariate and orthogonal IGF with no covariate respectively. The tests include a constant term only. The H_0 of non-stationarity is tested. Each test statistic is compared to the 1%, 5% and 10% significance levels with the one-sided critical values of −2.326, −1.645 and −1.282 for the average test while these are −3.289, −2.799 and −2.559 for minimum test respectively. The critical values for latter (n = 20) are computed according to Chang and Song [21]; [2] Each test statistic can be compared to the 1%, 5% and 10% significance levels with the one-sided critical values of −2.326, −1.645 and −1.282 for the average test while these are −3.207, −2.705 and −2.457 for minimum test (n = 15) respectively.

To test this homogeneity assumption, the Chang-Song test has been recomputed for the entire wood fuel production series by excluding the four series (Cyprus, Denmark, France and Romania) which are found to be stationary according to the Narayan-Popp test with breaks in level and slope. Once more, the Chang-Song panel unit root test statistics fail to reject the H_0 of non-stationarity in five cases.

In summation, Table 6 presents the test results on stationarity from the performed unit root tests.

Table 6. Summary of test results.

Tests	Stochastic properties of wood fuel production
Time-series:	
ADF	Non-Stationary: Austria, Denmark, Finland, France, Germany, Hungary, Netherlands, Poland, Romania, Spain, Sweden, UK. Stationary: Bulgaria, Cyprus, Greece, Ireland, Italy, Portugal.
KPSS	Non-Stationary:Austria, Bulgaria, Cyprus, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Poland, Portugal, Romania, Spain, Sweden, UK. Stationary: Ireland.
Narayan-Popp	Non-Stationary:Austria, Bulgaria, Finland, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Spain, Sweden, UK. Stationary: Cyprus, Denmark, France, Romania.
Panel:	
1st Generation:	
LLC	Stationary.
IPS	Non-Stationary.
Madalla-Wu	At least one series is stationary.
Hadri	Non-Stationary.
2nd Generation :	
MADF	At least one series is stationary.
CADF	Stationary.
CALM	Non-Stationary.
Hadri-Kurozumi	Non-Stationary.
3rd Generation:	
Chang-Song	Non-Stationary.

Where applicable, the conclusion is based on those unit root tests which include a linear trend. Results for the $M2_{B,L}$ Narayan-Popp test are reported.

4. Conclusions

The paper investigates the stochastic properties of wood fuel production for 18 EU countries over the period 1961–2012. Several generations of time-series and panel unit root tests are applied. The importance of structural breaks in the series has significant implications for the power of the unit root tests and can affect the final outcome. To capture the effects of breaks, conventional tests together with the latest unit root tests have been applied. In connection with panel unit root tests, it is specifically important to control for cross-sectional dependence. At country levels, about 78% of the wood fuel production series have been found to follow a non-stationary process. Thus, economics effects to wood fuel production are more likely to be persistent.

The policy implications are threefold. First, since the economic effects on wood fuel production tends to be persistent, other economic sectors (e.g., electricity markets) and macroeconomic aggregates (e.g., GDP, industrial production, *etc.*) are likely to inherit the effects from specific policies aimed at wood fuel production. Further studies could be conducted to study such linkages. Second, from a modelling and forecasting perspective, the persistent nature of economic effects on wood fuel production implies that past behavior provide little information regarding predictions on future production levels. Third, forest conservation policies can have long-term effects. This can result in an increasing demand for wood fuel substitutes, like coal, whose production is less environmentally friendly.

Acknowledgments: The authors thank the Bio4Energy, a strategic research environment appointed by the Swedish government. This study was funded by Formas (dnr: 213-2014-184), Kempe Foundations and the Swedish Energy Agency.

Author Contributions: All authors participated in preparing the research by establishing research design, method, analysis and helped in the discussion and finalization of the manuscript. Vishal Chandr Jaunky did the implementation of the econometrical tests and summarization of results will Robert Lundmark provided guidance and key suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

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