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AVRUPA PİYASALARINDA TOPTAN ELEKTRİK FİYATLARININ YAKINSAMASI: HENÜZ VARMADIK MI?[1]

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Öz

Avrupa elektrik piyasası entegrasyonu, özellikle iç piyasayı hedefleyen üçüncü elektrik direktifinden sonra, araştırmaların odak noktası olmuştur. Elektrik piyasaları, benzersiz fiyat dinamiklerine yol açan depolama ve iletim ağı kısıtları ve anlık tüketim ile karakterize edilir. Avrupa piyasalarındaki fiyat yakınsaması, piyasa entegrasyonunu destekleyerek rekabetçi fiyatlandırmaya yol açabilir. Bu araştırma, Avrupa toptan spot elektrik fiyatlarının yakınsayıp yakınsamadığını incelemektedir. Önceki literatür, fiyat yakınsamasını test etmek için sigma ve beta yakınsamasını kullanmaktadır. Bu araştırma, 2013-2021 yılları arasında 19 Avrupa ülkesinde fiyatların stokastik yakınsamasını aylık veriler ve RALS regresyonuna dayalı trend kırılmalı LM testleri kullanarak incelemektedir. RALS-LM testleri, yapısal kırılmalar ve normal olmayan hatalar mevcut olduğunda, doğrusal testlerden daha güçlüdür. İki trend kırılmalı LM ve RALS-LM birim kök testleri tüm ülkeler için birim kök hipotezini reddetmekte ve nispi toptan elektrik fiyatlarının durağan olduğunu göstermektedir. Dolayısıyla, nispi fiyatlara gelen şoklar geçicidir ve toptan elektrik piyasaları düzeyinde fiyat yakınsamasını desteklemektedir. Bu sonuç, perakende elektrik fiyatlarını beta-sigma- ve kulüp yakınsaması kullanarak inceleyen son literatürdeki sonuçlarla çeliştiği için dikkatle değerlendirilmelidir. Bu bulgunun politika çıkarımları, uyumlu ve entegre bir Avrupa elektrik piyasasını teşvik eden politikaların oluşturulması için bir temel sağlayabilir.

Anahtar Kelimeler

Avrupa Elektrik Piyasaları
Piyasa Entegrasyonu
Stokastik Yakınsama
RALS- LM

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CONVERGENCE OF WHOLESALE ELECTRICITY PRICES ACROSS EUROPEAN MARKETS: ARE WE THERE YET?

Abstract

European electricity market integration has been a research focus, especially after the third electricity directive emphasizing the internal market. Electricity markets are characterized by immediate consumption with storage and transmission constraints, leading to unique price dynamics. Price convergence in European markets can lead to competitive pricing, advocating market integration. This research examines whether European wholesale spot electricity prices converge. Prior literature uses sigma and beta-convergence to test price convergence. We have examined the stochastic convergence of prices across 19 European nations from 2013 to 2021 utilizing monthly data. For this analysis, we employed LM tests incorporating trend breaks grounded on the RALS regression framework. RALS-LM tests are more powerful than linear tests when structural breaks and nonnormal errors are present. LM and RALS-LM unit root tests with two trend breaks resulted in rejection of the unit root hypothesis for all countries, suggesting relative wholesale prices are stationary. Thus, shocks to relative prices are transient, supporting price convergence at the wholesale level. This result should be considered carefully as it contradicts the results from recent literature that examines retail electricity prices using beta- sigma- and club convergence. The policy implications of this finding can provide a foundation for establishing policies that promote a harmonized and integrated European electricity market.

Keywords

European Electricity Markets
Market Integration
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INTRODUCTION

European electricity market integration has been a research focus, especially after the third electricity directive emphasizing the internal market. An overview of the literature reveals that the law of one price (LOP) constitutes a theoretical framework in market integration studies, while cointegration techniques are the most used methodology on the empirical side. However, there are limitations. Cointegration techniques are useful to determine the long-term common trends but not sufficiently flexible to capture the dynamic nature of integration- that is likely to be observed in the financial markets. Besides, cointegration methodologies are more appropriate for low-frequency data and long sample periods as they produce long-term estimations and do not fit well with high-frequency data and relatively short sample periods (Evans and McMillan, 2009, p. 217). Karatepe (2017) provides a comprehensive framework to test the European market integration with a study structured into two segments. The first segment focuses on the market dynamics employing Dynamic Conditional Correlation (DCC) methodology to high-frequency data. Whereas the second segment places its emphasis on long-term common trends using cointegrated VAR methodology that allows structural breaks in the model building process. The results derived from DCC indicate significant regional connectivity. In contrast, results from CVAR provide evidence in favor of integration at regional and pan-European levels in the presence of structural breaks.

The degree of integration in financial markets changes over time due to the macroeconomic and financial conditions occurring in an interrelated environment. Deregulated electricity markets have similar characteristics to financial markets regarding the market mechanism. However, a distinguishing feature of electricity is that it needs to be consumed immediately once produced, as there's limited scope for significant storage. This leads to unique price dynamics exclusive to electricity markets. Given that electricity market deregulation aims for supply and demand determined by market forces, it's reasonable to expect a market structure that's interconnected and competitive yet bound by storage and transmission limitations. Consequently, if prices in European electricity markets gravitate towards a balanced value, it underscores market integration and can pave the way for more affordable electricity due to heightened competition. Empirical integration and price convergence findings differ based on the methodology, period, and region examined. However, the results have some common indications. The most common empirical evidence in the literature indicates that the level of integration is not complete but partial. Among those, findings of regional integration or price convergence in the Nord Pool and Central-Western Europe regions are noteworthy (Balaguer, 2011; Bower, 2002; de Jonghe, et al., 2008; de Menezes and Houllier, 2016; Pellini, 2014; Zachmann, 2008).

The evidence of integration or price convergence, to some extent, is found to be related to factors of tradability, such as geographical proximity and an increase in interconnection capacity (de Jonghe, et al., 2008; Higgs, 2009; Nepal and Jamasb, 2012; Pellini, 2014) and with the introduction of market coupling or electricity directives (de Jonghe, et al., 2008; Nitsch, et al., 2010; Pinho and Madaleno, 2011; Zachmann, 2008). On the other hand, factors such as resource composition in local electricity markets, differences in generation technology mix and costs, market structure, and the stage of the liberalization process are listed as barriers to full integration (Amundsen and Bergman, 2007; Bosco, et al., 2010). Beyond that, more recent studies highlight the impact of the promotion of renewables on market integration. There is evidence of weakening integration as RES-E increases (Gianfreda, et al., 2016; Menezes, et al., 2016), especially if the adaptation of transmission lines to renewables was not made (Saez, et al., 2019).

The convergence hypothesis was investigated by testing beta- sigma- and club-convergence in several other markets. At the same time, a limited number of studies use these methodologies in (European) electricity markets. Zachman (2008), Telatar and Yaşar (2020), and Cassetta et al. (2022a, 2022b), among others, concluded that there is not a strong indication of convergence. On the contrary, another study by Robinson (2008) analyzed retail prices from 1978 to 2003 using a similar methodology and reported evidence of convergence.

Recent studies have addressed the price convergence of electricity in European countries. Telatar and Yaşar (2020) examined annual data spanning 2003 to 2017 for 12 European nations. Their findings suggest that during the period under observation, both beta and sigma convergence were absent. On the other hand, Cassetta et al. (2022a, 2022b) focused on the price convergence within the retail electricity and natural gas sectors among the EU-28 Member States from 2008 to 2018. They employed beta, sigma, and club convergence methodologies at the EU and cluster levels. Their analysis indicated a lack of convergence in electricity and natural gas prices across the EU-28 member states throughout the evaluated period.

Despite the extensive research, the results of the empirical literature still need to be revised. A deeper understanding of electricity price convergence is of the essence since the European Commission promotes the European single electricity market to reach the potential gains in affordability, security of supply, and environmental conservation.

In the light of the background mentioned above, this study extends the literature by implementing transformed LM tests with trend breaks based on Residual Augmented Least Squares (RALS) regression to examine the stochastic conditional convergence of electricity prices in 19 EU countries from 2013 to 2021. More specifically, this research uses a recent and robust time-series approach to enhance the existing literature by investigating the propensity for wholesale electricity prices in European nations to converge, especially when considering the impact of structural breaks. Since the sampling period includes the COVID-19 era, a period of significant economic shifts, carefully determining structural breaks while examining the stochastic properties of the observed series is crucial. This study examines the stochastic conditional convergence of electricity prices among EU, focusing on identifying the stationarity of the observed series by utilizing testing procedures that consider the structural breaks already apparent in the data.

The literature on unit root tests reveals the importance of allowing for structural breaks clearly in terms of tests' power and size properties. Linear unit root tests lose power due to nonlinearities caused by structural breaks. This issue has been mostly ignored in the existing literature on integration/ price convergence in European electricity markets. Although Telatar and Yaşar (2020) utilize nonlinear unit root tests to account for the nonlinearities due to structural breaks, Lee et al. (2011) reveal that nonlinear unit root tests also lose power in the presence of non-normal errors or misspecified functional forms of nonlinearity (Lee et al., 2011, p. 1189).

The unit root test statistic depends on the nuisance parameter, which indicates the location of breaks, and according to Meng et al. (2014), unit root testing procedures eliminate this dependency by assuming no breaks under the null hypothesis (p. 349). However, this leads to several other problems, such as size distortions and spurious rejections under the null hypothesis. The transformed RALS-LM test statistic is independent of the nuisance parameter and allows for structural breaks under the null hypothesis. RALS regression uses the information of non-normal errors to capture the nonlinearity indirectly and hence does not require assuming a particular functional form of nonlinearity. Therefore, when using the transformed RALS-LM tests, there is an increased testing power in scenarios with structural breaks and non-normal errors. This superiority is evident when compared to both linear and nonlinear testing methods (Meng et al. 2014, p. 354). For a deeper exploration of this topic, we refer to the comprehensive discussions in Im and Schmidt (2008), Meng et al. (2014), and Meng et al. (2016).

In the context of unit root testing, in the case of relative electricity prices following a stationary process, the impact of shocks will only have a transitory effect. Thus, the empirical finding of stationarity in a given series would provide evidence supporting the notion of convergence of prices. This is the first empirical study that examines the stochastic convergence of wholesale prices in European electricity markets using the transformed RALS-LM procedure to the best of my knowledge.

The remainder of this paper is organized as follows. This chapter outlines the motivation of the study with a brief discussion of the related literature. Section 1 presents the data and explains the implementation of the empirical methodology. Section 2 presents the results, and section 3 discusses the policy implications and concludes.

1. Data and Methodology

The data set consists of wholesale spot electricity prices from national exchanges for 19 European countries. These countries are Belgium, Czech, Denmark, Estonia, Finland, France, Germany, Hungary, Italy, Latvia, Lithuania, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. The price series were obtained either directly from the electricity exchange itself or using the Bloomberg data terminal and measured in euro currency. The data set includes daily spot prices for each country from 01/01/2013 to 21/04/2021. All data were transformed into monthly averages prior to the analyses.

For each national market i, the natural logarithm of the ratio of electricity price (P) relative to the average across all markets at time t, is as follows:

$$y_{it} = ln(P_{it}/averageP_t) \qquad (1)$$

If the relative price defined in Eq. (1) follows a stationary process, the impact of shocks will only have a transitory effect- that is supporting the notion of convergence of prices. To examine the stationarity of the relative price series the transformed LM tests by Lee et al. (2012) and transformed RALS-LM tests by Meng et al. (2014, 2016) were employed. Throughout the analysis, models at most two level and trend shifts with a maximum of eight lags were considered.

First, consider the data generating process (DGP) based on the unobserved component representation as follows:

$$y_t = \delta' Z_t + e_t, e_t = \beta e_{t-1} + \epsilon_t \tag{2}$$

Where Z_t incorporates exogenous variables. The null hypothesis of unit root is $\beta = 1$, with a rejection indicating stationarity of the data. For $Z_t = [1, t]'$ the testing procedure parallels with the LM test without breaks by Schmidt and Phillips (1992). If we adopt the level-shift model, Z_t is characterized as $Z_t = [1, t, D_t]'$ with $D_t = 1$ for instances $t \geq T_B + 1$ and zero otherwise; here, and T_B marks the break's occurence. Alternatively, the trend-break model describes Z_t as $Z_t = [1, t, DT_t^*]'$, where $DT_t^* = t - T_B$ when $t \geq T_B + 1$ and is zero in other cases.

If we assume at most two breaks are present in the data, then using additional dummy variables, the Z matrix can be described as:

$$Z_t = [1, t, D_{1t}, D_{2t}, DT_{1t}^*, DT_{2t}^*]' \tag{3}$$

Initially, by setting a foundational restriction where $\beta = 1$ and focus to the subsequent regression delineated in differences:

$$\Delta y_t = \delta' \Delta Z_t + u_t \tag{4}$$

Where $\delta = \left[\delta_1, \delta_{2,} \delta_{3i}', \delta_{4i}'\right]'$, $i = 1,2$.

Then by using the following regression, the unit root test statistic is obtained.

$$\Delta y_t = \delta' \Delta Z_t + u_t + \phi \tilde{S}_{t-1} + e_t \tag{5}$$

where $\tilde{S_t}$ is the de-trended series

$$\tilde{S_t} = y_t - \tilde{\mathbf{\Psi}} - Z_t \tilde{\delta} \tag{6}$$

Given that the parameters are de-trended and represented in differences, any nuisance parameters in models with level shifts remain unaffected by the location of breaks. In addressing a model with trend-shifts, to negate the effects of the nuisance parameter, one can adopt a transformation as suggested by Lee et al. (2012, p. 86).

$$\tilde{S}_t^* = \begin{cases} \frac{T}{T_{B_1}} \tilde{S_t} & for \quad t \leq T_{B1} \\ \frac{T}{T_{B_2} - T_{B_1}} \tilde{S_t} & for \quad T_{B1} \leq t \leq T_{B2} \end{cases} \tag{7}$$

By using this transformation, the test equation in (4) can be modified as:

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}_{t-1}^* + \sum_{j=1}^{k} d_j \Delta \tilde{S}_{t-j} + e_t \tag{8}$$

Let the t-statistic for the null hypothesis of unit root $\phi = 0$ from equation (5) be $\tilde{\tau}^*$, and from equation (8) be $\tilde{\tau}_{LM}^*$. By applying the aformantioned transformation, the asymptotic distribution of both become immune to the infulence of the nuisance parameter. Instead they solely rely on the number of breaks (R). The simulation for new critical values is not necessary since the distribution of the nuisance parameter is the same for both untransformed and transformed tests.

Incase of nonnormal errors, Meng at al. (2016) proposed the RALS method to improve the power of the LM statistic $\tilde{\tau}^*_{LM}$.

To implement the RALS method, equation (8) is rearranged with the introduction of the augmented term $\hat{w}_t$ as:

$$\Delta y_t = \delta' \Delta Z_t + \phi \tilde{S}^*_{t-1} + \sum_{j=1}^{p} d_j \Delta \tilde{S}_{t-j} + \hat{w}'_t \gamma + e_t \quad (9)$$

where $\hat{w}_t = h(\hat{e}_t) - \hat{K} - \hat{e}_t \hat{D}_2$

and $h(\hat{e}_t) = [\hat{e}_t^2 \quad \hat{e}_t^3]'$, $\hat{K} = \frac{1}{T}\sum_{t=1}^{T} h(\hat{e}_t)$, $\hat{D}_2 = \frac{1}{T}\sum_{t=1}^{T} h'(\hat{e}_t)$ (10)

The RALS procedure captures the information on nonnormal errors by using the second and third moments of $\hat{e}_t$ in $h(\hat{e}_t) = [\hat{e}_t^2 \quad \hat{e}_t^3]'$. By letting $\hat{m}_j = \frac{1}{T}\sum_{t=1}^{T} \hat{e}_t^j$, the augmented term can be given as:

$$\hat{w}_t = [\hat{e}_t^2 - \hat{m}_2, \quad \hat{e}_t^3 - \hat{m}_3 - 3\hat{m}_2 \hat{e}_t]' \quad (11)$$

Let the t-statistic for $\phi = 0$ from equation (8) be $\tau^*_{RALS-LM}$. The asymptotic distribution of $\tau^*_{RALS-LM}$ is:

$$\tau^*_{RALS-LM} \rightarrow \rho \tilde{\tau}^*_{LM} + \sqrt{1-\rho^2}\, Z \quad (12)$$

where ρ signifies the proportional relationship between the variances of the two error terms. Similar to the transformed LM test statistic, the transformed RALS-LM test statistic is independent of the nuisance parameter. The critical values of the TR-RALS-LM statistic depend only on ϱ, given R and T, and are provided by Meng et al. (2016).

2. Empirical Results

The descriptive statistics for monthly averages of wholesale electricity prices of each country are reported in Table 1. On the wholesale level, the prices are highest in UK and Italy and lowest in Norway.

Table 1. Descriptive Statistics of Wholesale Electricity Prices

Country	Mean	St. Dev.	Min.	Max.
Belgium	42.97	12.00	14.72	41.92
Czech	36.94	8.73	18.08	59.43
Denmark	33.61	8.97	13.72	56.26
Estonia	38.54	7.85	23.70	59.15
Finland	36.80	8.24	19.46	57.13
France	40.53	11.97	13.45	78.00
Germany	35.37	8.20	17.09	56.68
Hungary	44.17	10.68	23.59	81.25
Italy	53.44	10.64	21.78	76.32
Latvia	43.15	8.86	23.31	64.20
Lithuania	42.92	8.93	23.52	64.20
Netherlands	41.74	9.35	17.51	63.34
Norway	29.74	11.65	2.01	53.83
Portugal	45.98	12.02	15.38	71.52

Table 1 (Continued). Descriptive Statistics of Wholesale Electricity Prices

Country	Mean	St. Dev.	Min.	Max.
Slovakia	38.31	9.42	18.27	61.85
Spain	46.03	11.75	17.11	71.49
Sweden	32.24	9.98	8.25	54.46
Switzerland	42.30	12.11	16.92	76.87
United Kingdom	53.54	10.48	25.05	89.18

Note: Sample consists of monthly observations for 19 countries over the period 2013/01 – 2021/04.

Table 2 presents the results of the two-break TR-LM and TR-RALS-LM unit root tests. For all the relative prices, the unit root null hypothesis is rejected. This outcome indicates that these relative prices are stationary, implying that any impact from shocks would be transitory in nature. When contrasting the results from the two-break tests with those from the one-break tests and no-break tests, the significance of accommodating structural breaks in unit root tests becomes evident. The findings consistently suggest that not allowing for these breaks might lead to the false non-rejection of the null hypothesis due to reduced test power. This is particularly noticeable in the cases of the Netherlands and Switzerland: the unit root null hypothesis failed to be rejected when using the 1-break tests but is clearly rejected under the 2-break tests. It's also important to note the results of no-break tests: For TR-LM test, Denmark, Finland, Sweden, Switzerland, and the UK; while for the TR-RALS-LM test, only Finland and the UK were identified as non-converging with the nonrejection of null hypothesis (Table 3 and 4).

Table 2. Results From Two-Break TR-LM And TR-RALS-LM Unit Root Tests

	TR-LM	TR-RALS-LM				
Country	τ_{LM}	τ_{RALS}	ρ^2	Tb1	Tb2	k
Belgium	-5.088***	-4.692***	0.846	2018:10	2019:05	1
Czech	-7.796***	-7.971***	0.931	2015:11	2017:08	0
Denmark	-6.332***	-8.193***	0.722	2015:06	2016:10	1
Estonia	-7.161***	-7.616***	0.863	2014:11	2020:02	0
Finland	-6.236***	-6.182***	0.853	2014:11	2019:05	8
France	-5.785***	-5.661***	0.986	2017:11	2018:07	4
Germany	-8.358***	-8.401***	0.955	2017:09	2018:12	0
Hungary	-6.182***	-6.437***	0.936	2017:10	2019:08	0
Italy	-7.312***	-7.714***	0.918	2016:05	2018:02	1
Latvia	-6.968***	-7.209***	0.941	2016:10	2020:02	4
Lithuania	-7.037***	-7.234***	0.942	2016:10	2020:02	4
Netherlands	-6.586***	-6.528***	0.995	2017:07	2018:06	3
Norway	-5.487***	-6.196***	0.598	2019:11	2020:05	5
Portugal	-6.466***	-7.178***	0.747	2014:01	2014:06	3
Slovakia	-4.565**	-5.141***	0.902	2017:07	2018:02	2
Spain	-5.521***	-6.021***	0.764	2014:01	2014:04	3
Sweden	-4.656***	-4.701***	0.835	2015:04	2015:08	8

Table 2 (Continued). Results from Two-Break TR-LM And TR-RALS-LM Unit Root Tests

Country	TR-LM τ_{LM}	TR-RALS-LM τ_{RALS}	ρ^2	Tb1	Tb2	k
Switzerland	-8.158***	-8.477***	0.947	2015:09	2018:12	5
United Kingdom	-5.886***	-6.720***	0.867	2016:12	2017:12	3

*Notes: The TR-LM and TR-RALS-LM tests share breakpoints and optimal lags. *, **, and *** denote that the test statistic is significant at the 10%, 5%, and 1% levels, respectively.*

Table 3. Results From One-Break TR-LM And TR-RALS-LM Unit Root Tests

Country	TR-LM τ_{LM}	TR-RALS-LM τ_{RALS}	ρ^2	Tb1	k
Belgium	-3.796**	-3.602*	0.899	2017:10	6
Czechia	-5.778***	-6.090***	0.904	2019:02	0
Denmark	-3.542*	-6.761***	0.476	2016:01	8
Estonia	-5.575***	-6.019***	0.848	2020:02	0
Finland	-5.619***	-5.437***	0.880	2019:05	8
France	-5.841***	-5.580***	0.982	2017:11	4
Germany	-4.886***	-4.920***	0.988	2017:09	1
Hungary	-3.998**	-4.213**	0.978	2014:09	6
Italy	-6.014***	-6.159***	0.963	2017:11	0
Latvia	-5.141***	-5.183***	0.971	2020:02	0
Lithuania	-5.155***	-5.246***	0.984	2020:02	4
Netherlands	-3.113	-3.095	0.974	2019:09	4
Norway	-5.659***	-5.714***	0.634	2020:05	5
Portugal	-4.129**	-5.146***	0.484	2019:05	8
Slovakia	-5.812***	-6.452***	0.812	2017:11	0
Spain	-4.098**	-5.333***	0.492	2019:05	8
Sweden	-4.054**	-4.546***	0.780	2020:03	2
Switzerland	-3.132	-3.343	0.954	2018:01	7
United Kingdom	-4.673***	-5.151***	0.938	2016:10	3

*Notes: The TR-LM and TR-RALS-LM tests share breakpoints and optimal lags. *, **, and *** denote that the test statistic is significant at the 10%, 5%, and 1% levels, respectively.*

Table 4. Results From No-Break TR-LM and TR-RALS-LM Unit Root Tests

Country	TR-LM τ_{LM}	TR-RALS-LM τ_{RALS}	ρ^2	k
Belgium	-4.224***	-4.346***	0.944	6
Czechia	-6.355***	-6.372***	0.965	0
Denmark	-1.839	-3.702***	0.647	8
Estonia	-4.261***	-4.213***	0.946	0
Finland	-2.169	-2.083	0.895	8
France	-5.678***	-5.703***	0.914	4
Germany	-4.301***	-4.734***	0.867	1

Table 4 (Continued). Results from No-Break TR-LM and TR-RALS-LM Unit Root Tests

	TR-LM	TR-RALS-LM		
Country	τ_{LM}	τ_{RALS}	ρ^2	k
Hungary	-3.474***	-3.472**	0.991	6
Italy	-6.428***	-6.729***	0.947	0
Latvia	-3.998***	-3.956***	0.999	0
Lithuania	-3.962***	-3.960***	0.990	4
Netherlands	-4.364***	-4.212***	0.994	4
Norway	-3.363**	-4.759***	0.511	5
Portugal	-5.392***	-7.968***	0.509	8
Slovakia	-6.670***	-6.440***	0.990	0
Spain	-5.456***	-8.025***	0.550	8
Sweden	-2.686	-3.811***	0.742	2
Switzerland	-2.632	-2.864*	0.962	7
United Kingdom	-1.482	-1.594	0.959	3

*Notes: The TR-LM and TR-RALS-LM tests share breakpoints and optimal lags. *, **, and *** denote that the test statistic is significant at the 10%, 5%, and 1% levels, respectively.*

CONCLUDING REMARKS

The European electricity market has been undergoing rapid changes with the integration of renewable energy sources, interconnection capacity expansion, and policy changes. Understanding the integration of European electricity markets requires looking at it from multiple angles. Different methodologies provide different perspectives; similarly, different datasets and timeframes capture different convergence dynamics. One important distinction between the time series approach and classic methods like sigma- and beta-convergence is that the time series approach, especially with the consideration of structural breaks, offers a dynamic understanding of price movements and shocks, while sigma- and beta-convergence methodologies have traditionally been instrumental in providing a static picture of market equilibria over time. This study tests the stochastic conditional convergence of electricity prices among EU with a particular focus on identifying the stationarity of the observed series by utilizing powerful testing procedures that consider the structural breaks that are already apparent in the data. By accounting for structural breaks, this study adds a layer of sophistication to the phenomenon.

The results of this study clearly suggest that relative prices for 19 European countries are stationary, implying that any impact from shocks would be transitory in nature, therefore providing evidence in favor of the convergence of wholesale prices. When interpreting the results, it is important to remember that the methodology implemented here treats the problem with a pure time-series approach. Convergence in a time series context (i.e., stationarity) does not necessarily imply that the countries are catching up to one another in terms of price levels or growth rates, as suggested by sigma and beta convergence. This is a limitation of the present study.

The European electricity market has feedback mechanisms (i.e., network interconnectors) that can lead to transient shocks having a short lifespan. These mechanisms are designed to react to any disturbances to help the system return to a balanced state. The transient nature of shocks in the wholesale market, as shown in this study, emphasizes the role of interconnectors and market mechanisms in balancing disparities. Wholesale spot prices reflect the immediate, short-term cost of electricity in the market and are determined by supply and demand conditions on electricity exchanges and can be quite volatile. Retail prices on the other hand, are what end-consumers pay for electricity and include not merely the cost of electricity itself but also transmission and distribution costs, taxes, etc. Retail prices are typically more stable, as they are regulated or based on long-term contracts. The divergence between the findings of this study and recent studies by Telatar and Yasar (2020) and Cassetta et al. (2022a) suggests that while market forces are pushing wholesale prices towards convergence, regulatory and policy decisions might be impacting retail prices differently. This should be questioned by policymakers considering the empirical evidence from different methodologies. Further investigation of the reasons behind this difference might provide valuable insights for policymakers to protect consumer interests. Is it due to differences in distribution costs, taxes, profit margins, or information asymmetry in the market? Policymakers can promote greater transparency in pricing mechanisms by allowing a clearer understanding of price formation at both wholesale and retail levels.

The implications of this study can provide a foundation for establishing policies that promote a harmonized and integrated European electricity market. Policymakers should be attentive to these subtleties to ensure that the benefits of a converging wholesale market aren't lost when translating to the retail side. Further research could focus on combining methodologies to address the problem in both time and space domains for both wholesale and retail levels. Nuanced, data-driven, and consumer-centric policy decisions can trigger the successful realization of the European Commission's vision of a single electricity market, promoting efficiency and sustainability.

Ethical Principles and Publication Policy

The author declares that the submitted nanuscript has been conducted in an ethical and responsible manner and that comply with the journal's publishing policies and scope.

Author Contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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APPENDIX.

Graphics of tested series and two-break TR-RALS-LM unit root test breakpoints.