Effects of fossil fuel prices on the Japanese electricity market during crises

Kentaka Aruga[1,*], Md Monirul Islam[2] and Arifa Jannat[3]

1 Graduate School of Humanities and Social Sciences, Saitama University, 255 Shimo-Okubo, Sakura-ku, Saitama 338-8570, Japan

2 Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

3 Institute of Agribusiness and Development Studies, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

*Correspondence: aruga@mail.saitama-u.ac.jp

Abstract

The COVID-19 pandemic and the Russia-Ukraine war have struck the world's energy markets. The study analyzed how the recent unstable fossil fuel markets impacted the three types of Japanese electricity contracts: extra-high, high, and low-voltage contracts. Multiple structural break test was conveyed to endogenously determine breaks affecting electricity prices during 2019:1 - 2022:11. By incorporating the effects of these breaks in the autoregressive distributed lag (ARDL) model, the study analyzed the effects of natural gas, coal, and crude oil prices on the types of electricity contract prices. The results of the analyses indicated that there was a surge in electricity prices for low and high-voltage contracts driven by an increase in natural gas. The results imply the importance of providing proper financial support to mitigate the effects of soaring electricity prices and contriving policies to diversify the electricity generation mix in Japan.

Keywords: electricity price; natural gas; coal; crude oil; COVID-19; Russia-Ukraine war

Proceedings of the 18th IAEE European conference. Global Energy Transition Toward Decarbonization. Milan, 24-27 July 2023, Bocconi University

1. Introduction

Japan heavily relies on fossil fuel energy to generate electricity. More than 75% of the Japanese electricity supply depends on fossil fuels in 2020 [1]; natural gas, coal, and crude oil consisted of 39%, 31%, and 6%, respectively. Under this situation, the spread of COVID-19 after 2019 and the Russia-Ukraine war since 2022 are causing drastic movements in the global fossil fuel market. Currently, these crises are posing a major obstacle for Japan to stabilize its electricity prices. In general, the electricity market is closely related to the fossil fuel market because fossil fuel energy has been the primary source for generating electricity in many countries, and it is known that fossil fuel prices tend to have a significant impact on the electricity price [2]. Thus, understanding the connection between electricity prices and fossil fuel prices is now becoming more important than ever for the Japanese government to devise an energy policy to stabilize its electricity market.

In Japan, electricity is supplied to consumers under three types of contracts: extra-high, high, and low-voltage contracts [3]. The extra-high voltage contract is for consumers whose maximum monthly electricity demand exceeds 2000 kilowatt (kW) and is often provided for customers such as large factories and railway companies. The high voltage contract is made between the power company and customers such as companies and small to medium-sized factories whose maximum monthly electricity demand is between 50 kW and 2000 kW. Finally, the low voltage contract is for customers whose demand is less than 50 kW, such as normal households, small shops, and so on.

Although there is a strand of literature exploring the linkage between electricity and fossil fuel markets [2,4,5] not much has been investigated on whether there is a distinction among the types of electricity contracts regarding their effects from the fossil fuel market. Since electricity consumers of extra-high voltage are high users of electricity, such as factories and train companies, it is less likely to change their energy consumption even when a rise in fossil fuel prices is leading electricity prices to surge. On the other hand, consumers of the low-voltage contract, which are mainly regular residential households, are more likely to reduce their electricity use, so it could be that the electricity price of the low-voltage contract will be affected differently from the extra-high voltage contract. To shed light on this issue, the current study examines the impact of the recent unstable fossil fuel market on the three different types of electricity contracts in Japan.

The study also statistically tests whether there are structural breaks in the Japanese electricity prices during 2019 - 2022 and seeks to identify the timing of events such as the COVID-19 pandemic and the Russia-Ukraine war in the electricity prices.

The study is one of the first studies to quantitatively test how the Japanese electricity market is affected by fossil fuel prices during times of distress, when fossil fuel prices are severely affected by the COVID-19 pandemic and the Russia-Ukraine war. The result will provide valuable information for policymakers and stakeholders in the electricity market to understand what impact might occur on the electricity market from the fossil fuel market when crises are impacting the fossil fuel market at a level rarely seen in history. The study also helps understand which fossil fuel sources contribute to electricity prices when they are surging due to a pandemic and war.

2. Literature review

Recently, studies have drawn attention to the rapidly developing nexus between natural gas and electricity markets [6-9]. These studies analyze the mechanisms where natural gas prices could affect the formation of electricity prices and the clearing of markets. Binder and Mjelde [10] observe long-run relationships between coal inventories and coal, natural gas, and electricity prices. They find cointegrating relationships for the aggregate United States (US) market but suggest that deregulation is a likely source of parameter instability, encouraging further research on the impact of regulatory policy changes. Chuliá et al. [11] examine the extent and evolution of the links between energy markets using a broad data set consisting of seventeen series of prices for commodities such as electricity, natural gas, coal, oil, and carbon. Additionally, some recent studies examine the relationship between natural gas and electricity prices in abnormally distressed periods. For example, Scarcioffolo and Etienne [12] and Uribe et al. [13] provide evidence of spillovers between natural gas and electricity returns (among other energy commodities) under different market conditions, especially at moderate and high return quantiles of energy prices. Uribe et al. [14] investigated the transmission of natural gas shocks to electricity prices under different scenarios of electricity generation for 21 European markets in times of distress where electricity prices were surging dramatically during 2021 and 2022.

Moreover, in recent times, pandemics and war conflicts have significantly impacted energy supply chains and market prices due to economic stagnation across the world [15,16]. In some studies, the effects of the COVID-19 pandemic have been examined for the energy markets [17,18] and electricity markets [19,20]. Similar concerns have also followed the Russia-Ukraine turmoil, adding to global energy market uncertainty [21,22].

Since our study focuses on the relationship between the Japanese electricity and fossil fuel markets under crisis events, here we only covered studies that investigate such relationships along with the recent global crisis events. It is also important to note that most of the studies applied conditional quantile regression [14], the Granger-causality test [2,7], time series forecasting models [15], multi-fractal detrended cross-correlation analysis (MF-DCCA) [21], and so on.

None of the above-mentioned studies investigated the effects of natural gas and coal prices on the Japanese electricity market during the crisis by applying an auto-regressive distributed lag (ARDL) model by incorporating breaks in the time series data tested. One of the contributions of the present study to the existing literature is that it examines the effects of the recent unstable fossil fuel market on the three different types of electricity contracts in Japan. Although the study conducted by Uribe et al. [14] is conceptually similar to ours, they focused on European markets through conditional quantile regression and considered weather-related variables, including wind speed, temperature, precipitation, and irradiance. The current study is different from this study since it focuses on the relationship between electricity and fossil fuel prices and compares differences in the relationships among different types of electricity contracts.

3. Methods

The theoretical background of the econometric model analyzed in this study is based on the electricity and fossil fuel price model developed by Mohammandi [2]. In this study, this model has been modified to consider the seasonality effects, the COVID-19 pandemic, and the Russia-Ukraine war impacts by including the effects of break points in the time series data after statistically identifying them.

First, the multiple structural break test was conducted to identify structural breaks in the price series following Bai and Perron [23]. There exist methods for identifying structural breaks in time series data when breaks are unknown, such as Andrews [24] and Andrews and Ploberger [25], but these methods have weaknesses when the series are nonstationary. The Bai-Perron test is known to overcome these issues and has the advantage of finding multiple unknown breaks in the series [26].

The Bai-Perron test is performed under the following m-partitioned regression model:

$$Y_t = Z_t'\delta_j + \varepsilon_t \;\; (j = 1, \ldots, m+1) \tag{1}$$

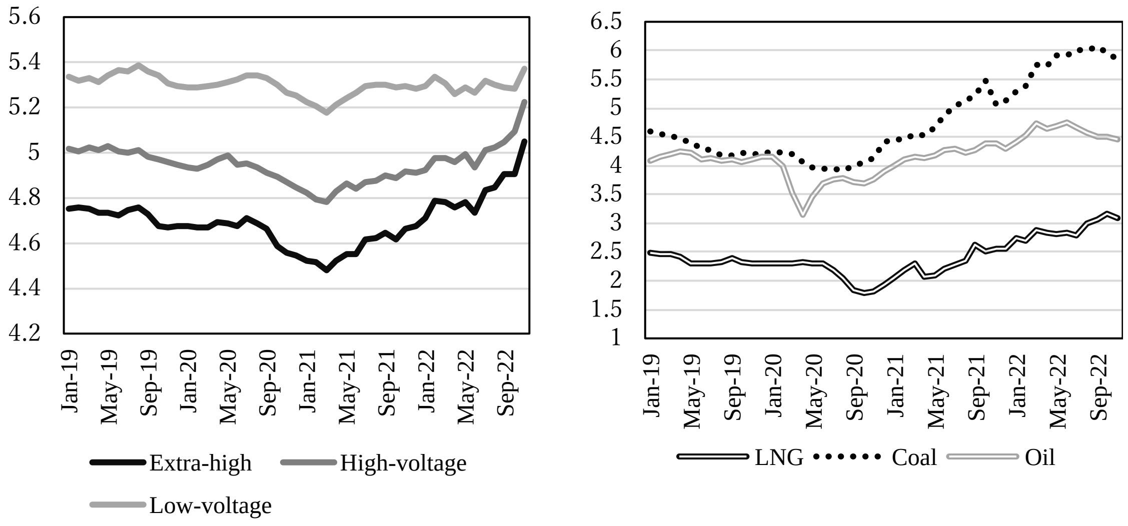
where Y_t is the electricity price for the types of electricity contracts at time *t*, Z_t is a vector of independent variables including an intercept that is regime specific, δ_j is the corresponding vector of coefficients, *m* is the number of breaks, and ε_t is the disturbance term. In this study, Equation (1) is analyzed by including the lag of the electricity price to estimate the model with a simple autoregressive model (AR(1)), and liquefied natural gas (LNG), coal, and oil prices to consider their effects on the electricity price. The maximum number of breaks is set to three in this study.

If any breaks were determined by the Bai-Perron test, a dummy variable, break, is created to capture the effect of the breaks in the price series. Using this dummy variable, the electricity and fossil fuel price relationships are tested under the following autoregressive distributed lag (ARDL) model:

$$\begin{gathered}\Delta electricity_t = a + b_1 electricity_{t-1} + b_2 LNG_{t-1} + b_3 coal_{t-1} + b_4 oil_{t-1} + \sum_{i=1}^{p} b_{5i}\Delta electricity_{t-i} + \\ \sum_{i=0}^{q} b_{6i}\Delta LNG_{t-i} + \sum_{i=0}^{r} b_{7i}\Delta coal_{t-i} + \sum_{i=0}^{s} b_{8i}\Delta oil_{t-i} + b_9 summer + b_{10} winter + \\ \sum_{j=1}^{n} b_{11j} break + \varepsilon_t\end{gathered} \tag{2}$$

where electricity is the type of electricity (extra-high, high, and low voltage). LNG is the cost, insurance and freight (CIF) price of imported LNG price for Japan. Coal and oil are the Australian imported coal price and the Dubai Fateh crude oil price. These prices are one of the major indicators of imported coal and crude oil prices in Japan. All price series are monthly data. Finally, *summer* and *winter* are dummy variables capturing seasonality effects, where *summer* contains months from June to September and *winter* includes months from December to March.

The period covered in this study is from January 2019 to November 2022. All the price variables are obtained from the homepage administered by the Energy Information Center, a general incorporated association located in Tokyo, Japan [27]. Since the electricity price was provided in Japanese Yen (JPY) while the fossil fuel prices were in United States Dollar (USD), the electricity prices are converted to JPY using the monthly exchange rate provided by Investing.com. Then, all the price data used in the study is transformed into a natural log form. Figure 1 illustrates the plots of log prices investigated in the study. It is evident from the figure that both electricity and fossil fuel prices are stagnant until 2020, but they start to have an increasing trend after 2021. The drop in electricity and fossil fuel prices in 2020 is likely related to the effect of restrictions on human mobility due to the spread of COVID-19. Aruga [20] reveals that an increase in the number of hours spent at home in 2020 had a negative impact on electricity demand during the COVID-19 pandemic in Tokyo. The increase in price after 2021 is perhaps connected to the recovery from the effects of the pandemic since economic activities began to normalize after 2021.



(a) Electricity prices

(b) Fossil fuel prices

Figure 1. Three types of electricity contracts and energy prices during the study period

Since the ARDL model requires the test variables to be either integrated of order zero or one, three types of unit roots were preliminary conducted on the test variables. For this purpose, the Augmented Dickey–Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests were conducted with intercept and trend. In addition, the Zivot-Andrews (ZA) with a trend break was performed to consider the effect of a structural break in the series.

Finally, to capture the dynamic causal effects between electricity and fossil fuel prices, we estimated the cumulative dynamic multipliers under the ARDL model.

The robustness of the models is tested by performing serial correlation, heteroskedasticity, and stability tests. The serial correlation was tested with the Breusch–Godfrey (BG) test and the heteroskedasticity of errors was examined with the Breusch-Pagan-Godfrey (BPG) test. The stability of the coefficients is assessed with the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests. These results are provided in Table 6 and Figure 3 in Appendix A. Since the low-voltage contract model had heteroskedasticity and autocorrelation, the ARDL models were estimated with the Newey-west heteroskedasticity and autocorrelation consistent (HAC) estimator.

4. Results and discussions

The Bai-Perron test suggested that in all three electricity contracts, three breaks were the statistically optimal number of breaks (Table 1). According to the sequential SupF test [23], three was the statistically optimal number of breaks.

Table 1. Bai-Perron multiple breakpoints test

	Extra-high voltage		**High voltage**		**Low voltage**		
Break test	Scaled F-stat.		Scaled F-stat.		Scaled F-stat.		Critical Value
0 vs. 1	230.73	**	540.77	**	1331.09	**	18.23
1 vs. 2	33.16	**	159.19	**	37.96	**	19.91
2 vs. 3	34.75	**	120.62	**	269.87	**	20.99
Identified breaks	Oct. 2020, Jul. 2021, May. 2022		Oct. 2019, Apr. 2021, May 2022		Oct. 2019, Apr. 2021, May 2022		

Note: ** denotes significance at the 5% level.

The first break was found in Oct. 2020 for the extra-high voltage contract, and it was in Oct. 2019 for the high- and low-voltage contracts. In all contracts, the second break occurred in 2021, when the COVID-19 pandemic relatively calmed down in Japan. Thus, it could be conjectured that the period between the first and second breaks is affected by the COVID-19 pandemic. Finally, in all contracts, the third break was identified in May 2022, which is likely related to the effects of the Russian invasion of Ukraine in February 2022. Dummy variables to capture the breaks were created using the breakpoints determined in the electricity price series. *B1* denotes the first break, which is the period before Oct. 2020 for extra-high voltage contact and before Oct. 2019 for the high and low voltage contracts. *B2* is the second break, which represents the period between Oct. 2020 and Jul. 2021 for the extra-high contract and between Oct. 2019 and Apr. 2021 for the high and low contracts. *B3* signifies the third structural break, containing the period after May 2022 in all contracts.

To confirm the validity of applying the ARDL model to the test series, the Augmented-Dickey-Fuller, Zivot–Andrews, and Kwiatkowski–Phillips–Schmidt–Shin tests were conducted. As seen in Table 2, at least the Zivot-Andrew test indicated that all price variables were either I(0) or I(1), supporting the use of the ARDL model for analyzing the price series (Table 2).

Table 2. Unit root tests

Variables	**Levels**					**First differences**					
	ADF	ZA		KPSS		ADF		ZA		KPSS	
Extra-high voltage	0.945	-2.821		0.211	**	-3.245	*	-7.199	***	0.160	**
High voltage	1.362	-1.788		0.211	**	-2.999		-8.294	***	0.157	**
Low voltage	-1.592	-2.786		0.139	*	-5.314	***	-5.990	***	0.067	
LNG	-1.679	-4.803	**	0.217	***	-2.495		-6.297	***	0.086	
Coal	-2.030	-4.793	**	0.214	**	-6.295	***	-7.558	***	0.125	*
Crude oil	-1.710	-4.782	**	0.173	**	-5.757	***	-6.117	***	0.098	

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. All unit root tests are performed with intercept and trend. ADF, ZA, and KPSS represent the Augmented-Dickey–Fuller, Zivot–Andrews, and Kwiatkowski–Phillips–Schmidt–Shin test statistics.

Next, the ARDL bound test was performed to examine the cointegrating relationship between electricity and fossil fuel prices. The results in Table 3 suggest that there is a cointegration relationship in all three electricity contracts.

However, the long-run coefficient estimation presented in Table 4 reveals that the long-run relationship was not held by the fossil fuel price for the extra-high contract. Meanwhile, the low-voltage and high-voltage contract models demonstrated that the long-run relationship was led by the natural gas price with a negative impact on the electricity contract prices. For the low-voltage contract, coal and crude oil prices had a negative impact on the electricity price. The reason for the negative impacts of coal and oil models might be due to their substitute nature. It can be argued that coal and oil are substitutes for natural gas (LNG), and their prices are indicators of the general energy price. Rising coal and oil prices reflect the condition where energy prices are increasing in general, resulting in consumers saving energy costs by reducing their electricity consumption, which negatively affects the electricity price. A price increase in LNG, however, is likely to have a direct impact on increase in the electricity generation cost since LNG is the major source of generating power in Japan, accounting for over 30% of the whole electricity generation in Japan during 2019-2021 [27].

Table 3. ARDL bound test

	Extra-high voltage	**High voltage**	**Low voltage**
F-statistic	6.73***	7.33***	5.23**
I(0)		4.27, 3.08	
I(1)		5.41, 4.02	

Note: *** and ** denote significance at the 1% and 5% levels, respectively. Critical values for the I(0) and I(1) denote those at the 1% and 5% significance levels, respectively.

Table 4. Long-run coefficient estimation

Models	**Variables**	**Coefficient**	**Std. Error**
Extra-high voltage	Const.	4.123 ***	0.082
	LNG	0.046	0.133
	Coal	0.166	0.052
	Oil	-0.065	0.368
High voltage	Const.	6.969 **	2.065
	LNG	0.485 **	0.233
	Coal	-0.217	0.226
	Oil	-0.432	0.345
Low voltage	Const.	5.818 ***	0.390
	LNG	0.208 ***	0.016
	Coal	-0.147 **	0.061
	Oil	-0.061 **	0.026

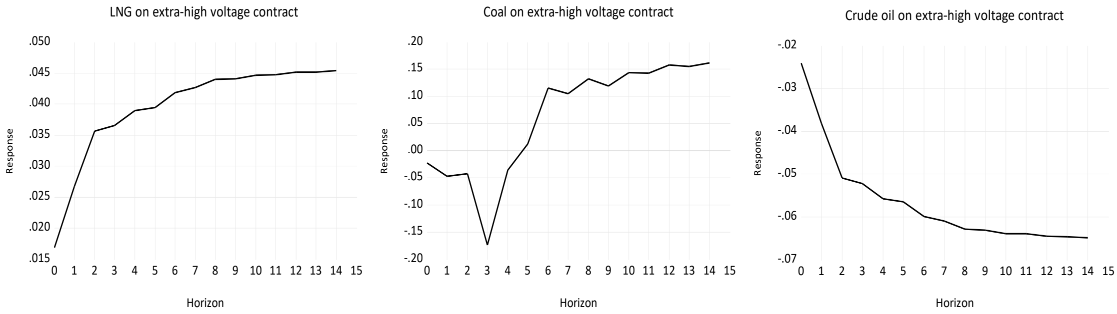
Note: *** and ** denote significance at the 1% and 5% levels, respectively.

The ARDL short-run estimation result in Table 5 reveals that natural gas did not have a short-run impact in all three contract models, but it indicates that the change in crude oil price had a negative impact in the high contract model. It also suggests that the coal price had a negative impact on the low-voltage model. This negative impact of the fossil fuel price on electricity prices in the short run might be reflecting the drop in the electricity demand when fossil fuel prices rise, leading to a temporary decrease in electricity price.

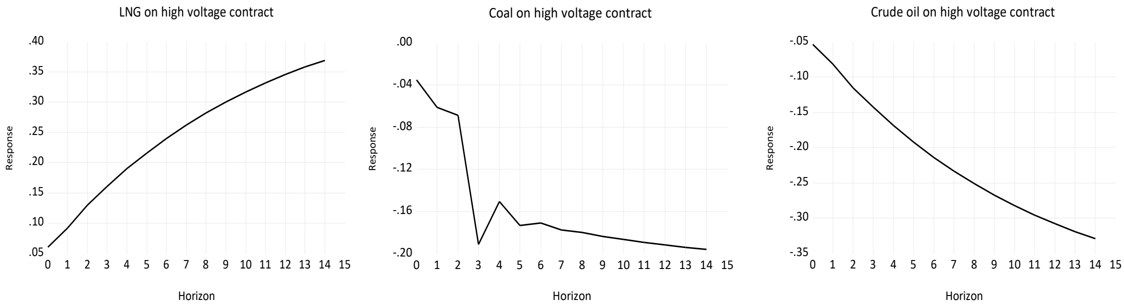
Table 5. Short-run coefficients and seasonal and break dummy variables estimation

	Extra-high voltage		**High voltage**		**Low voltage**	
Variable	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
ΔLNG	0.017	0.046	0.061 *	0.036	-0.048	0.042
Δcoal	-0.023	0.044	-0.035	0.034	-0.052 **	0.025
Δoil	-0.024	0.026	-0.054 **	0.021	-0.022	0.020
Winter	0.001	0.012	-0.001	0.011	0.013	0.010
Summer	-0.004	0.013	-0.024 ***	0.008	0.013 ***	0.009
B1	-0.004	0.029	-0.044	0.026	-0.035	0.022
B2	-0.034	0.025	-0.075 **	0.030	-0.064 **	0.024
B3	0.034	0.032	0.054 **	0.024	0.021	0.027

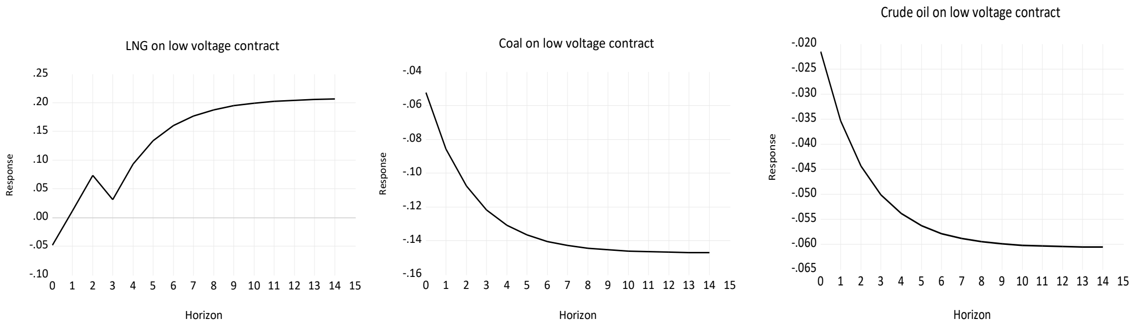
Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.



(a) Extra-high voltage



(b) High voltage



(c) Low voltage

Figure 2. Cumulative dynamic multiplier

The shock in Oct. 2019 detected by the Bai-Perron test showed that electricity prices declined from Oct. 2019 to April. 2021, which is a period when Japan was in the middle of the COVID-19 pandemic. This result is consistent with Aruga [20], who found a decrease in the electricity price in Tokyo, Japan, which is related to the confinement measure during the COVID-

19 pandemic. The structural shock detected after May 2022 had an increasing effect on the electricity price, indicating that the Russia-Ukraine war led to an increase in the electricity price.

Finally, the cumulative dynamic multipliers in Figure 2 suggest that the shock from natural gas had an increasing effect on all three electricity contracts, while crude oil had a decreasing impact on all contracts. Coal had a different influence among the three contracts. There was a rising shock after the third-period shock in the extra-high contract model, while high- and low-voltage contracts revealed a declining shock.

5. Conclusions

The study investigated how the severe changes in fossil fuels during the COVID-19 pandemic and the 2022 Russia-Ukraine war influenced the Japanese electricity market. The ARDL model estimation suggested that an increase in the natural gas price during the 2019-2022 period was driving the electricity price to rise in the long run for the low and high-voltage contracts. This indicates the importance of providing special subsidies or support for low and high-voltage electricity consumers when a surge in natural gas prices is soaring the electricity price. Furthermore, to mitigate the effect of the increase in the natural gas price on the electricity price, power companies in Japan need to continue their efforts to increase the use of renewable energy to diversify their electricity generation mix.

Funding: This research received no external funding.

Data Availability Statement: All price data is available at: https://pps-net.org/.

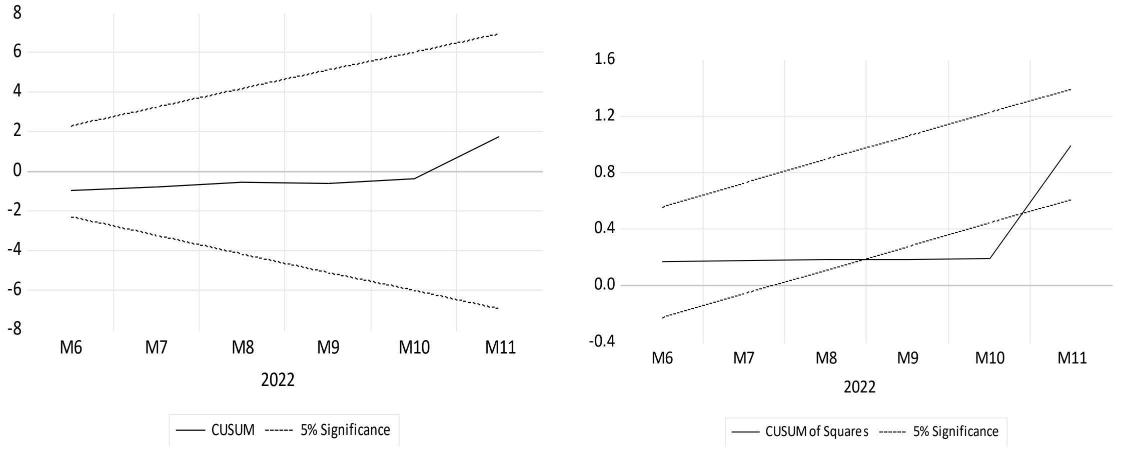
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

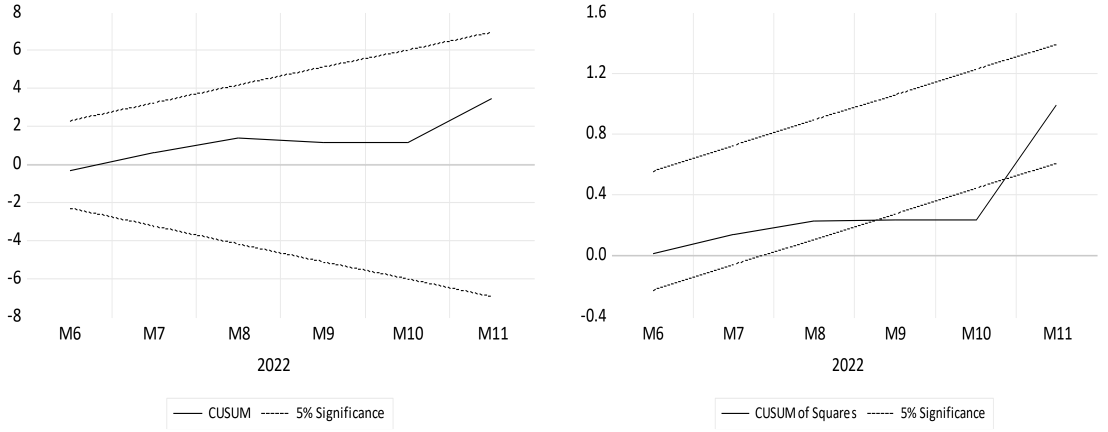
Table 6. Serial correlation and heteroskedasticity tests

	Extra-high voltage		**High voltage**	**Low voltage**	
	F-stat		F-stat	F-stat	
Serial correlation	2.85	*	0.99	5.19	**
Heteroskedasticity	1.20		1.41	2.30	**

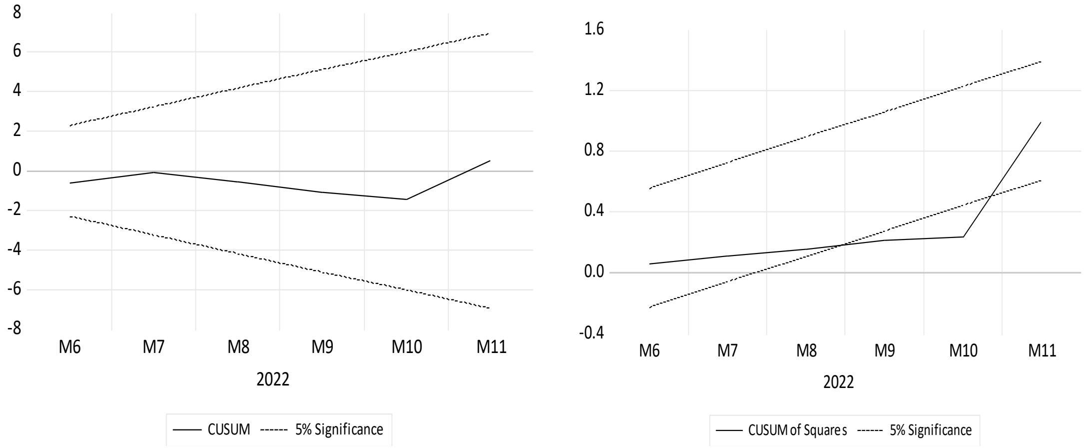
Note: ** and * denote significance at the 5% and 10% levels, respectively. The F-statistics for the serial correlation denote the BG test statistics and those for the heteroskedasticity are the BPG test statistics.



(a) Extra-high voltage



(b) High voltage



(c) Low voltage

Figure 3. CUSUM and CUSUM-square stability tests

References

1. Ministry of Economy, Trade and Industry (METI) *Energy White Paper* 2022. Available online: https://www.enecho.meti.go.jp/about/whitepaper/2022/pdf/whitepaper2022_all.pdf (accessed on 24 March 2023).
2. Mohammadi, H. Electricity prices and fuel costs: Long-run relations and short-run dynamics. *Energy Econ.* **2009**, 31(3): 503-509. https://doi.org/10.1016/j.eneco.2009.02.001.
3. Sanada, H. Ultra-high-voltage receiving equipment as seen by electric power companies. *Journal of IEIE Japan* **2009**, 29: 808-811. https://doi.org/10.14936/ieiej.29.808.
4. Nakajima, T.; Hamori, S. Testing causal relationships between wholesale electricity prices and primary energy prices. *Energy Policy* **2013**, 62: 869-877. https://doi.org/10.1016/j.enpol.2013.07.033.
5. Bernal, B.; Molero, J.C.; Perez De Gracia, F. Impact of fossil fuel prices on electricity prices in Mexico. *J. Econ. Stud.* **2019**, 46(2): 356-371. https://doi.org/10.1108/JES-07-2017-0198.
6. Alexopoulos, T.A. The growing importance of natural gas as a predictor for retail electricity prices in US. *Energy* **2017**, 137, 219-233. https://doi.org/10.1016/j.energy.2017.07.002.
7. Chae, Y.; Kim, M.; Yoo, S-H. Does natural gas fuel price cause system marginal price, vice-versa, or neither? A causality analysis. *Energy* **2012**, 47 (1): 199-204. https://doi.org/10.1016/j.energy.2012.09.047.
8. Ding, W.; Xu, Y.; Gao, F.; Wu, B.; Fu, Y. Electricity market dynamics: The influence of fuel prices and the spillover effect. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK. 615, **2020**, pp. 012079. https://doi.org/10.1088/1755-1315/615/1/012079.

9. Ohler, A.; Mohammadi, H.; Loomis, D.G. Electricity restructuring and the relationship between fuel costs and electricity prices for industrial and residential customers. *Energy Policy* **2020**, 142: 111559. https://doi.org/10.1016/j.enpol.2020.111559.
10. Binder, K.E.; Mjelde, J.W. Fuel inventory and price relationships in the U.S. electric power sector under regulatory and market change. *J. Regul. Econ.* **2017**, 51, 197–219. https://doi.org/10.1007/s11149-017-9319-9.
11. Chuliá, H.; Furió, D.; Uribe, J.M. Volatility spillovers in energy markets. *Energy J.* **2019**, 40(3). https://doi.org/10.5547/01956574.40.3.hchu.
12. Scarcioffolo, A.R.; Etienne, X. Testing directional predictability between energy prices: A quantile-based analysis. *Resour. Policy* **2021**, 74: 102258. https://doi.org/10.1016/j.resourpol.2021.102258.
13. Uribe, J.M.; Guillen, M.; Mosquera-López, S. Uncovering the nonlinear predictive causality between natural gas and electricity prices. *Energy Econ.* **2018**, 74: 904-916. https://doi.org/10.1016/j.eneco.2018.07.025.
14. Uribe, J.M.; Stephania Mosquera-López, S.; Arenas, O.J. Assessing the relationship between electricity and natural gas prices in European markets in times of distress. *Energy Policy* **2022**, 166: 113018. https://doi.org/10.1016/j.enpol.2022.113018.
15. Wu J.; Levi N.; Araujo R.; Wang Y.G. An evaluation of the impact of COVID-19 lockdowns on electricity demand. *Electr. Power Syst. Res.* **2023**, 216: 109015. https://doi.org/10.1016/j.epsr.2022.109015.
16. Cihan, P. Impact of the COVID-19 lockdowns on electricity and natural gas consumption in the different industrial zones and forecasting consumption amounts: Turkey case study. *Int. J. Electr. Power Energy Syst.* **2022**, 134. https://doi.org/10.1016/j.ijepes.2021.107369.

17. Wang, Q.; Yang, X.; Li, R. The impact of the COVID-19 pandemic on the energy market – A comparative relationship between oil and coal. *Energy Strategy Rev*. **2022**, 39: 100761. https://doi.org/10.1016/j.esr.2021.100761.
18. Cui Z.; Wu J.; Lian W.; Wang Y.G. A novel deep learning framework with a COVID-19 adjustment for electricity demand forecasting. *Energy Rep*. **2023**, 9:1887–1895. https://doi.org/10.1016/j.egyr.2023.01.019.
19. Leach, A.; Rivers, N.; Shaffer, B. Canadian Electricity markets during the COVID-19 pandemic: An initial assessment. *Can Public Policy* **2020**, 46, S145-S159, 10.3138/cpp.2020-060.
20. Aruga K. Effects of the Human-Mobility Change during the COVID-19 Pandemic on Electricity Demand. *J. Risk Financ. Manag.* **2022**, 15(10): 422. https://doi.org/10.3390/jrfm15100422.
21. Huang, M.; Shao, W.; Wang, J. Correlations between the crude oil market and capital markets under the Russia–Ukraine conflict: a perspective of crude oil importing and exporting countries. *Resour. Policy* **2023**, 80: 103233. https://doi.org/10.1016/j.resourpol.2022.103233.
22. Chen Y.; Wei Y.; Bai L.; Zhang J. Can Green Economy stocks hedge natural gas market risk? Evidence during Russia-Ukraine conflict and other crisis periods. *Finance Res. Lett.* **2023**, 53: 103632. https://doi.org/10.1016/j.frl.2023.103632.
23. Bai, J.; Perron, P. Estimating and testing linear models with multiple structural changes. *Econometrica* **1998**, 66(1): 47-78. https://doi.org/10.2307/2998540.
24. Andrews, D.W.K. Testing for parameter instability and structural change with unknown change point. *Econometrica* **1993**, 61(4): 821-56. https://doi.org/10.2307/2951764.

25. Andrews, D.W.K.; Ploberger, W. Optimal tests when a nuisance parameter is present only under the alternative. *Econometrica* **1994**, 62(6): 1383-414. https://doi.org/10.2307/2951753.
26. Aruga, K. Are the Tokyo Grain Exchange non-genetically modified organism (non-GMO) and conventional soybean futures markets integrated? *Agric. Finance Rev.* **2011**, 71(1): 84-97. https://doi.org/10.1108/00021461111128174.
27. EIC. Shin denryoku netto (new power net), Energy Information Center. 2023. Available online: https://pps-net.org/statistics (accessed on 24 March 2023).
28. ISEP. Percentage of the energy generation mix in 2021 (in Japanese), Institute for Sustainable Energy Policies. 2021. Available online: https://www.isep.or.jp/archives/library/13774 (accessed on 2 May 2023).