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The Reason for Price Spikes in Wholesale Electricity Market:

An Empirical Study on Japan's Electricity Spot Market

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Abstract:
We examine the main factors affecting the spot prices on the Japan Electric Power Exchange during price spikes using a threshold model for time-series analysis. Our findings indicate that price spikes occur only in response to supply shortages in spot markets. Moreover, renewable energy plays an important role in Japan's energy structure. Both solar and wind power can help reduce spot prices when capacity shortages occur. Further, solar power can reduce spot prices when fossil fuel energy prices remain high.

Keywords: Electricity Market; Spot Price; Price Spikes; Renewable Power; Japan Electric Power Exchange

JEL code: G13, Q41, Q21

1. Introduction

An upsurge in wholesale electricity prices was first observed in the day-ahead spot market price of the Japan Electric Power Exchange (JEPX) in December 2020 and lasted for almost three weeks, until January 2021. The spot price temporarily soared to a record high of 251 yen/kWh on January 15, 2021, which was more than ten times the average daily price in the previous year. Simultaneously, during the price spike period, electricity was sold out continuously on the JEPX. Such long-term "sold out" and price surges have rarely been seen on the electricity markets of other countries before that. Yasuda (2021) suggested that the price spike was mainly due to rapidly diminishing sell offers in the market and increasing prices of fossil fuels.

Regional electricity utilities have manipulated Japan's electricity market for many years. Since the full liberalization of electricity retail sales in April 2016, small-scale power retailers (i.e., power producers and suppliers, PPS) have steadily entered the market. However, as most of these PPSs do not have their own power generation plants, most new entrants to the retail sector procure the necessary electricity from trading markets, which makes them largely affected by the price spikes on the JEPX (Kanegae et al., 2022). As a result, 195 of approximately 706 PPSs collapsed or suspended their electricity retailing businesses as of March 2023 (TDB, 2023). The market share of regional utilities with market power increased again, making the situation run counter to the purpose of liberalizing the retail electricity market.

Previous empirical studies on electricity price spikes mainly focused on price forecasting in competitive markets (Herrera and Gonzàlez, 2014; Stathakis et al., 2021). However, the effect of abnormal bid behavior on spot prices in an imperfectly competitive market has rarely been discussed. Therefore, this study focuses on the factors that may lead to an increase in spot prices in the JEPX during price spikes. We also concentrate on how the electricity supply–demand balance and liquid natural gas (LNG) prices contribute to increasing spot prices.

2. Methodology and Data

A threshold model was used for time-series analysis to estimate the reasons driving spot prices upward. The likelihood ratio tests—FPE, AIC, and HQIC—select models with four lags. The null hypothesis was rejected using the ADF unit root test for all variables, indicating that the series was stationary. The spot price was set as the threshold variable to investigate how the balance of electricity supply and demand and LNG prices affect spot prices during price spikes. The numbers and values of the thresholds are determined by minimizing the information criterion for the residual:

$$P_t = \alpha + \delta lag\, P_t + \beta_1 Indicator_t(P_t \leq \theta) + \beta_2 Indicator_t(P_t > \theta) + \gamma Control_t + \zeta_t + \varepsilon_t, \quad (1)$$

where P_t is the electricity spot price on day t. $Indicator_t$ represents the indicators adopted to measure the reasons for price spikes, including market balancing ($Balance_t$), the utilization rate of power equipment ($Utilization_t$), and the price of LNG (LNG_t). In particular, $Balance_t$ is calculated as the sum of the buy offers divided by the sell offers on day t ($Balance_t = BuyOffer_t / SellOffer_t$). Thus, a $Balance_t$ lower than, equal to, or greater than 1 represents oversupply, equilibrium, or supply shortage of electricity in the spot market, respectively. $Utilization_t$ is defined as the capacity utilization rate of power equipment. LNG_t represents LNG prices. $Control_t$ indicates the control variables including the share of renewable generation in the total electricity supply ($RenewShare_t$) and the share of total electricity demand traded in the spot market ($SpotShare_t$). ζ_t indicates the yearly, monthly, and weekly time trends.

Moreover, previous studies have confirmed that renewable power plays an important role in reducing electricity spot prices (Ma et al., 2019; Suliman and Farzaneh, 2022) because the marginal generation cost of renewable power is considered to be lower than that of fossil fuel energy resources. Therefore, in this study, we focus on whether the price-reducing effects of renewable power change depending on the supply demand balances of electricity and LNG prices. The indicator variables described above were set as threshold variables in Equation (2):

$$P_t = \alpha + \delta lagP_t + \beta_1 Renew_t(Indicator_t \leq \theta) + \beta_2 Renew_t(Indicator_t > \theta) + +\gamma Control_t + \zeta_t + \varepsilon_t, \quad (2)$$

where the $Renew_t$ represents the share of the different types of renewable power generation in the total electricity supply, including solar ($SolarShare_t$), wind ($WindShare_t$), and biomass ($BiomassShare_t$).

System spot prices, sell offers, and buy offers data for Japan were obtained from the JEPX homepage (JEPX, n.d.). All data on the spot market include market information, which is divided into 48 products traded in 30-min time intervals within a day, and the electricity contract is delivered the following day. Therefore, the daily spot price (P_t) is calculated as the mean of 48 values in one day, while the daily sell offer ($SellOffer_t$) and buy offer ($BuyOffer_t$) are calculated as the sum of the 48 values in one day. The utilization rate of the power generation facilities ($Utilization_t$) is calculated by dividing the electricity generation capacity during operation by the total installed capacity. The data used to calculate the utilization rate and forecast electricity demand were obtained from the Organization for the Cross-Regional Coordination of Transmission Operators (OCCTO, n.d.). Daily generation data for renewable power plants were acquired from nine general electricity companies in Japan and daily LNG prices were acquired from the CME Group (n.d.). We use LNG Japan/Korea Market (Platts) futures (JKM) to indicate LNG spot prices (LNG_t). JKM is the LNG price indicator for Northeast Asia published by S&P Global.

The descriptive statistics are shown in Table 1. Our sample covers all trading hours from April 2020 to March 2022, and includes 730 observations for each variable. The daily average of the spot price is 12.33 yen/kWh during the study period, while the highest average price increased to 154.6 yen/kWh on January 13, 2021. The average market balance is approximately 0.999, while the values suddenly increase to 1.509 in January 2021 (Figure 1), indicating a supply shortage in the spot market. The average utilization rate is 84.53%. Utilization values higher than 90% were mainly observed during the winter of 2020 and 2021, suggesting a higher risk of capacity shortage during these periods (Figure 2). The average price is 10.37 USD/MMBtu. LNG prices increased continuously since 2021, and price spikes were observed in January 2021 and 2022 (Figure 3). The average shares of different types of renewable power generation in the total electricity supply during the study period were 8.963% ($SolarShare_t$), 1.039% ($WindShare_t$), and 1.579% ($BiomassShare_t$).

Table 1: Descriptive statistics

Variables	Unit	N	Mean	Std. dev.	Min	Max
P_t	yen/kWh	730	12.33	15.76	2.613	154.6
$SellOffer_t$	GWh	730	1,072	101.4	801.2	1,328
$BuyOffer_t$	GWh	730	1,064	146.7	623.5	1,627
$Balance_t$	-	730	0.999	0.156	0.566	1.588
$Utilization_t$	%	730	84.53	3.130	72.90	93.80
LNG_t	USD/MMBtu	730	10.37	6.846	4.450	36.86
$RenewShare_t$	%	730	20.14	5.560	7.847	39.38
$SolarShare_t$	%	730	8.963	3.640	1.179	19.80
$WindShare_t$	%	730	1.039	0.568	0.092	2.925
$BiomassShare_t$	%	730	1.579	0.203	1.169	2.306
$SpotShare_t$	%	730	37.07	3.147	26.75	51.56

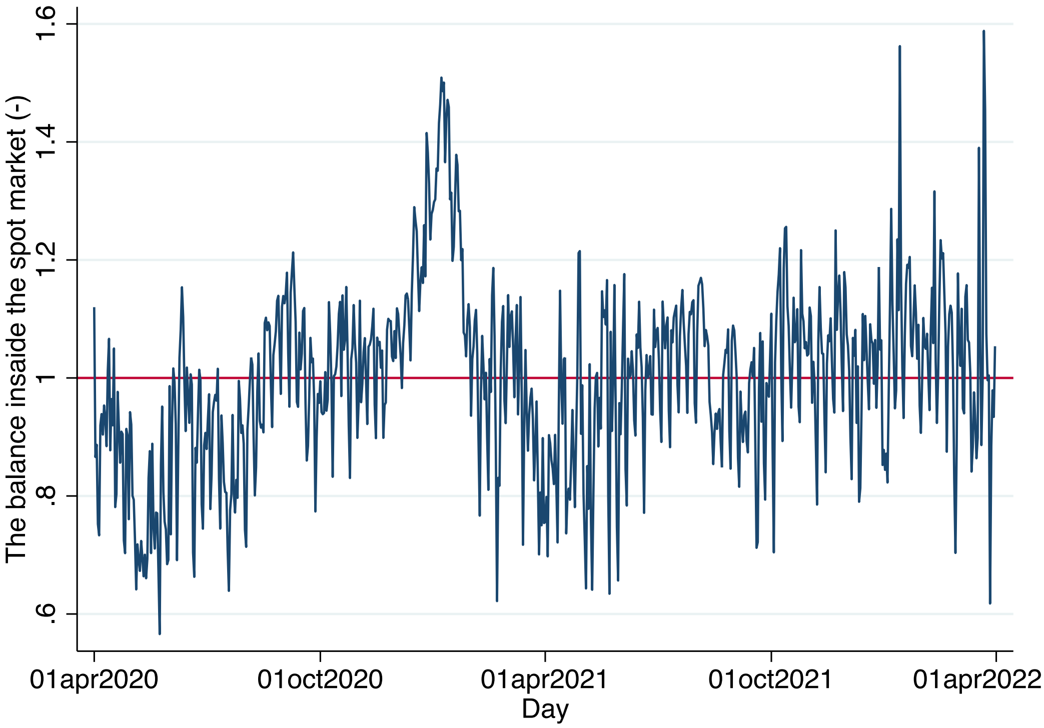

Figure 1: Trends in daily market balancing (FY2020–FY2021)

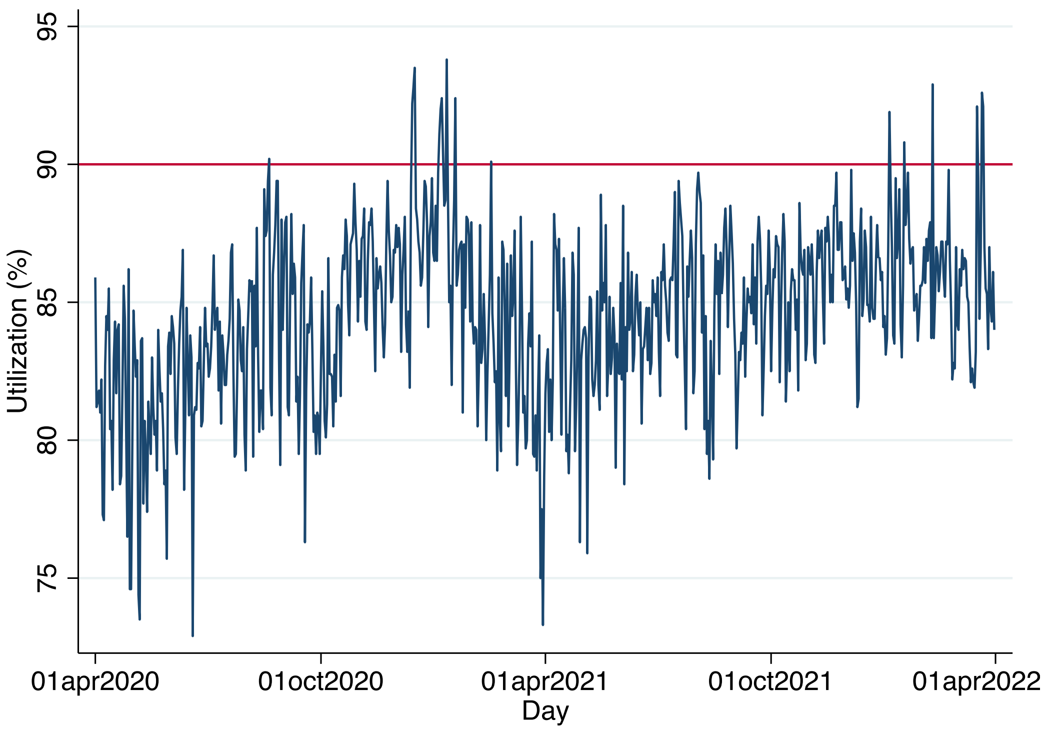

Figure 2: Trends in daily utilization rate (FY2020-–FY2021)

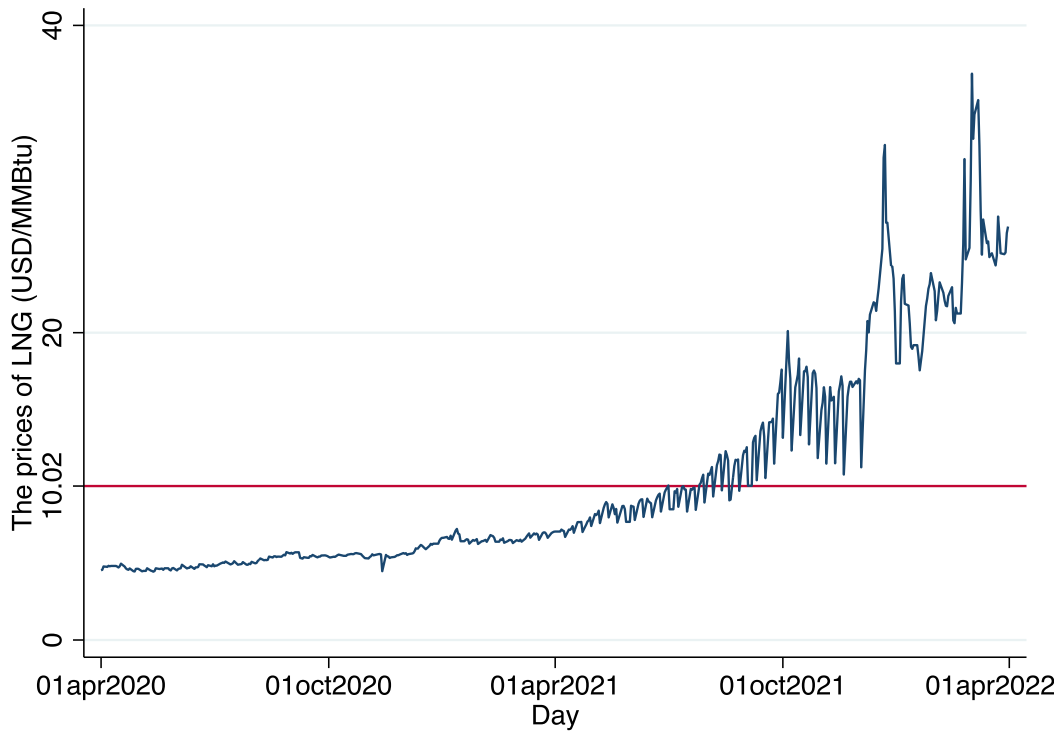

Figure 3: Trends in daily LNG price (FY2020–-FY2021)

3. Results

3.1. Effects of LNG price and Demand-Supply Balance on Spot Price

Table 2 indicates that the supply demand balances of both electricity and LNG prices have significant effects on spot prices in the JEPX. However, the major reasons for the increase in spot prices differ at each price level. A total of two threshold values (12.11 yen/kWh and 18.14 yen/kWh) are estimated in the model, separating electricity spot price into three price regions: low, normal, and price spike (Figure 4). The coefficients on $Balance_t$ in region 3 are approximately 1.7 - 3 times higher than those in regions 1 and 2, suggesting that the shortage of sell offers in the JEPX has a stronger effect on increasing spot prices when price spikes occur. The coefficient on $Utilization_t$ is statistically insignificant in region 3, which suggests that an insufficient power supply leads to an increase in spot prices, although it is not the main reason for price spikes. The positive and statistically significant coefficients on LNG_t in region 1 indicate that increasing gas prices lead to a significant increase in spot prices when spot prices are lower than 12.11 yen/kWh, whereas the effect vanishes when spot prices are higher.

Table 2: The effects of indicators on spot prices

Main		Threshold	Region 1 (0, 12.11]	Region 2 (12.11, 18.14]	Region 3 (18.14, ∞]
P_{t-1}	0.350***	$Balance_t$	0.788***	0.427***	1.355***
	(0.047)		(0.086)	(0.099)	(0.211)
P_{t-2}	0.037	$Utilization_t$	0.044***	0.012***	0.010
	(0.045)		(0.002)	(0.004)	(0.008)
P_{t-3}	0.032	LNG_t	0.281***	0.041	-0.042
	(0.043)		(0.048)	(0.037)	(0.053)
P_{t-4}	0.095***	$Constant$	-0.460***	0.067	-0.389
	(0.035)		(0.205)	(0.403)	(0.801)
$SpotShare_t$	-0.007***				
	(0.002)				
$Renewshare_t$	-0.006***				
	(0.002)				
N=726;	Threshold orders: 12.11, 18.14				

Notes: Standard errors are between parentheses. ∗ $p < 0.1$, ∗∗ $p < 0.05$, ∗∗∗ $p < 0.01$. Year, month, and week dummy variables are used for all models.

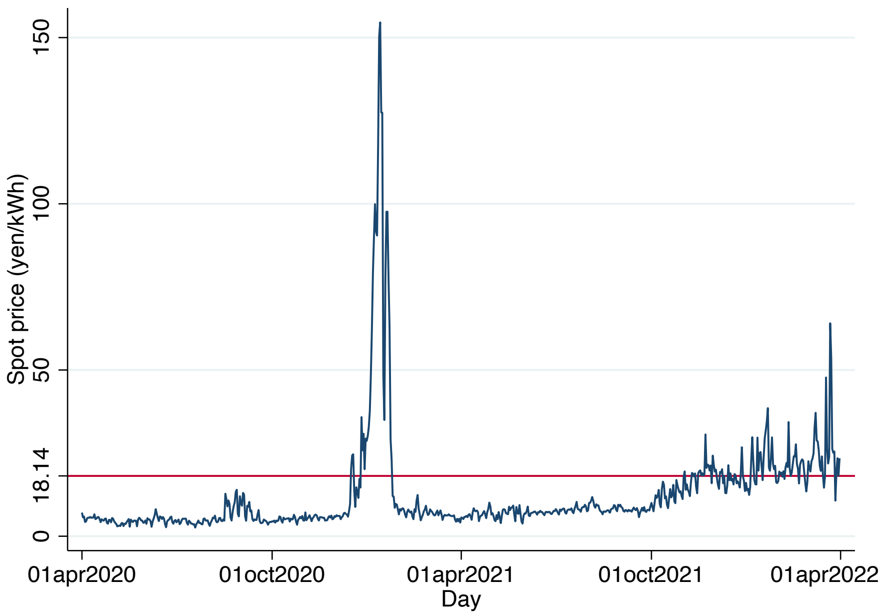

Figure 4: Trends in daily spot price (FY2020—FY2021)

3.2 Effects of renewable power penetration on spot price

The estimation results of how the indicators influence the price-reducing effects of renewable power in the spot market are presented in Table 3 in the Appendix. Panel A shows how the price-reducing effects of renewables change according to the supply-demand balance in the spot market. Two threshold values (0.948 and 1.027 yen/kWh) are estimated for the model. The coefficients on $SolorShare_t$ are negative and statistically significant in regions 1 and 2, indicating that increasing the generation share of solar power only reduces the electricity spot price when oversupply occurs. Based on the merit order principle, baseload and mid-range energy resources can lead to an increase in electricity spot prices because of their higher marginal costs compared with renewable energy (Antweiler and Muesgens, 2021). Therefore, when increasing demand leads to a supply shortage in the market, the clearing price is determined by the baseload energies with higher generation costs.

Panel B shows how the price-reducing effects of renewables change according to capacity utilization. Only one threshold value for the capacity utilization rate (88.00%) was estimated in the model. Capacity shortage occurs when capacity utilization is higher than 89%–92%, which means that the reserve power supply capacity ratio is lower than 8%–11% (OCCTO, 2019). Therefore, our estimation results can be used to discuss the price-reduction effect of renewables when a shortage in reserve power capacity occurs. Both $SolarShare_t$ and $WindShare_t$ are negative and statistically significant in region 2, suggesting that an increasing share of renewable power generation can help reduce electricity spot prices for a higher risk of insufficient reserve capacity.

Panel C presents the estimation results of how the price-reducing effects of renewable energy change with LNG prices. Two threshold values (6.500 and 10.02 USD/MMBtu) are estimated in the model. The coefficient on $SolarShare_t$ is negative and statistically significant in region 3, suggesting that a 1% increase in the share of solar power leads to a 0.009% reduction in the spot price when the LNG price is higher than 10.02 USD/MMBtu. This result implies that solar power plays an important role in Japan's energy structure, as it can help mitigate the upward pressure on electricity prices caused by an increase in fossil fuel prices. The results emphasize the importance of renewable energy as an energy source whose prices are not affected by the global situation regarding the prices of fossil fuels.

Table 3: Effects of renewable power Penetration on spot price

Panel A		Threshold	Region 1	Region 2	Region 3
Threshold Variable: $Balance_t$			(0, 0.948]	(0.948, 1.027]	(1.027,∞]
$Balance_t$	1.570***	$SolarShare_t$	-0.009***	-0.007**	-0.005
	(0.147)		(0.016)	(0.003)	(0.004)
$Utilization_t$	0.005**	$WindShare_t$	-0.027	-0.012	-0.007
	(0.002)		(0.062)	(0.018)	(0.019)
LNG_t	0.202***	$BiomassShare_t$	0.108*	-0.034	-0.068
	(0.037)		(0.178)	(0.056)	(0.075)
$SpotShare_t$	-0.018***	$Constant$	-1.134***	-1.196***	-1.176***
	(0.003)		(0.359)	(0.236)	(0.250)
N=726;	Threshold orders: 0.948, 1.027				
Panel B		Threshold	Region 1	Region 2	
Threshold Variable: $Utilization_t$			(0, 88.00]	(88.00,∞]	
$Balance_t$	0.929***	$SolarShare_t$	-0.005***	-0.035***	
	(0.102)		(0.002)	(0.002)	
$Utilization_t$	0.001	$WindShare_t$	-0.001	-0.081*	
	(0.002)		(0.012)	(0.045)	
LNG_t	0.193***	$BiomassShare_t$	0.516*	-0.112	
	(0.003)		(0.262)	(0.135)	
$SpotShare_t$	-0.012***	$Constant$	-1.134***	-0.202	
	(0.105)		(0.359)	(0.276)	
N=726;	Threshold Orders: 88.00				
Panel C		Threshold	Region 1	Region 2	Region 3
Threshold Variable: LNG_t			(0, 6.500]	(6.500, 10.02]	(10.02,∞]
$Balance_t$	1.136***	$SolarShare_t$	-0.003	-0.005	-0.009**
	(0.105)		(0.003)	(0.003)	(0.004)
$Utilization_t$	0.005**	$WindShare_t$	-0.025	-0.013	0.000
	(0.002)		(0.017)	(0.027)	(0.018)
LNG_t	0.107**	$BiomassShare_t$	0.009	0.100	0.408***
	(0.047)		(0.057)	(0.072)	(0.075)
$SpotShare_t$	-0.022***	$Constant$	-0.347***	-0.354	-0.645***
	(0.003)		(0.266)	(0.256)	(0.247)
N=726;	Threshold orders: 6.500, 10.02				

Notes: Standard errors are between parentheses. ∗ $p < 0.1$, ∗∗ $p < 0.05$, ∗∗∗ $p < 0.01$. We omit the results for the lag prices from the table. Year, month, and week dummy variables are used for all models.

3.3 Robustness Check

We also conduct a robustness check using indicator $TradeOfferRate_t$ to replace $Balance_t$ in equation (1). This indicator is calculated as the daily traded volume divided by the daily sell offers in the spot market. A higher rate implies a shortage of sell offers in the spot market. As Figure 5 shows, the sell offers were sold almost entirely ($TradeOdderRate_t$ = 100%) when a price spike occurred.

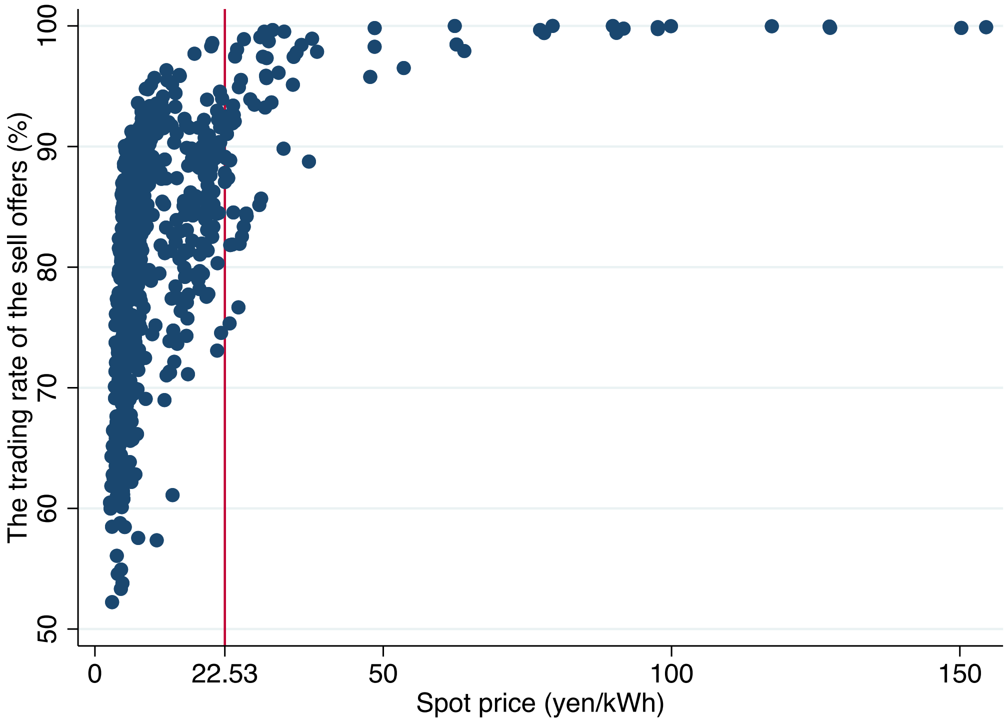

Figure 5: Relationship between the traded offer rate and spot price

The results in Table 4 indicate that the trading rate of the sell offers ($TradeOfferRate_t$) also has a significant effect on the spot prices on the JEPX. Two threshold values (12.12 yen/kWh and 22.53 yen/kWh) are estimated in the model. In this study, we define the price spike period as a price level higher than the threshold value of 22.53 yen/kWh. The coefficients on $TradeOfferRate_t$ in region 3 are approximately 2.545—4.667 times higher than those in regions 1 and 2, suggesting that the price spikes are driven by a shortage of sell offers in the spot market. Therefore, the results of the robustness check confirm our main estimated result that the abnormal supply shortage in the spot market was the major reason for price spikes.

Table 4: Robustness check on the effect of indicators on spot prices

Robustness check		Threshold	Region 1	Region 2	Region 3
			(0, 12.12]	(12.12, 22.53]	(22.53,∞]
P_{t-1}	0.407***	*$TradeOfferRate_t$*	0.011***	0.006***	0.028***
	(0.047)		(0.001)	(0.002)	(0.004)
P_{t-2}	0.044	*$Utilization_t$*	0.003	0.013**	0.025**
	(0.043)		(0.002)	(0.005)	(0.011)
P_{t-3}	0.003	*LNG_t*	0.250***	-0.015	-0.076
	(0.049)		(0.051)	(0.034)	(0.070)
P_{t-4}	0.112***	*Constant*	-0.222	0.227	-2.381*
	(0.042)		(0.213)	(0.455)	(1.220)
$SpotShare_t$	-0.013***				
	(0.002)				
$Renewshare_t$	-0.010***				
	(0.002)				
N=726;	Threshold orders: 12.12, 22.53				

Notes: Standard errors are between parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Year, month, and week dummy variables are used for all models.

4. Conclusions

Our findings confirm that the major factor affecting price spikes was a supply shortage inside the electricity spot market rather than an increase in the LNG price. Due to the significant decrease in Japan's LNG inventories and the influence of cold waves, spikes in spot gas prices have been observed since December 2020. Under fuel constraints, reductions in the power output and supply to the wholesale market are accompanied by an increasing number of "unplanned outage-generation facilities" (ANRE, 2021). Simultaneously, the Japan Fair Trade Commission (JFTC) confirmed that some regional utilities intended to reduce the competitiveness of PPSs, which depended on purchasing electricity from the wholesale market, by reducing the amount of electricity supplied to the wholesale market (JFTC, 2023). While an abnormal supply shortage occurs in the market, to avoid paying high imbalance fees, retailers may choose to bid higher than the marginal cost to fulfill demand (Rassi and Kanamura, 2023), which will result in long-lasting price spikes in the JEPX.

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