

# ***LINKAGES AMONG THE JAPANESE ELECTRICITY COSTS BY FOSSIL FUEL SOURCES AFTER THE FUKUSHIMA DISASTER***

Kentaka Aruga, Saitama University,  
Phone: +81-048-858-3336,  
E-mail: kentaka.aruga@gmail.com

## **Overview**

Just after the Great East Japan Earthquake occurred in March 2011, the Fukushima Daiichi Nuclear Power Plant (FDNPP) suffered a huge tsunami leading to a nuclear meltdown. This accident urged Japan to transform its nuclear-reliant energy policy to a less reliant one. Before the Fukushima disaster, nearly 30% of electricity in Japan was generated by nuclear power. However, after the accident, nuclear power plants in Japan were gradually shutdown, and in May 2012, Japan halted all its nuclear power generation. Hence, after the nuclear accident, Japan increased the use of fossil fuels to compensate the electricity loss from shutting its nuclear power plant. As of 2016, only less than 2% of electricity supplied in Japan is generated from nuclear power (FEPC, 2017), and the electricity shortage from stopping the nuclear power plant is mostly filled by increased crude oil, natural gas, and coal use. Comparing the percentages of electricity generated from crude oil, natural gas, and coal between 2011 and 2012, all the percentages of these three major fossil fuel sources expanded from 2011 to 2012.

It is likely that such change in the energy mix of electricity generation after the Fukushima disaster has affected the linkages among the cost of electricity by fuel sources. Many studies have investigated how the Japanese energy mix should change (Huenteler, Schmidt, and Kanie 2012; Hayashi and Hughes 2013; Hong, Bradshaw, and Brook 2013) or have analysed the Japanese people's preferences toward energy mix after the disaster (Murakami et al. 2015; Rehdanz et al. 2017). However, until now, only few studies exist on how electricity price or cost of electricity generation by fuel sources altered after the Fukushima disaster.

To bridge this gap, the objective of this study is to examine how linkages among the electricity generation costs by crude oil, natural gas, and coal shifted before and after the Fukushima accident. We believe the study is a valuable case study to help understand how phasing out from nuclear power influences the linkages among the electricity generation cost by energy sources. The study will provide precious information to any other countries striving to perform an effective energy policy to secure their energy after phasing out from nuclear power.

## **Methods**

The effects of the Fukushima accident on the electricity cost relationships among the crude oil, natural gas, and coal are analyzed with the Markov regime switching model (MRSM) and the Johansen and Bierens-Martins (BM) cointegration tests. MRSM is applied to rate of change (ROC) in the log cost ratio between the two of the crude oil, natural gas, and coal based electricity costs. Using this model, we test if the relationships among these three fossil fuel costs became unstable before and after March 2011, the date when the Fukushima accident occurred. We set the Markov regime to two.

The Johansen test and its recursive cointegration tests are conducted to identify if the cointegration relationships among the three major fossil fuel costs changed before and after March 2011. Before performing the Johansen test, the ADF, PP, and KPSS stationarity tests are executed on the three fossil fuel costs. To consider the effects of structural breaks in the stationarity tests, we also applied the innovational outlier (IO) unit root test (Perron, 1997). When the Johansen test suggested that the cost series are cointegrated, we conduct the BM test to see if the cointegration relationship was time varying.

The data for the electricity generation costs by crude oil, natural gas, and coal is obtained from pps-net.org. The unit of the costs obtained was in yen per kilowatt hour (kWh), but for our research purpose, we converted them to natural logarithm.

## **Results**

Figure 1 shows the results of the MRSM estimation. The figure demonstrates that in all three cost ratios regime 1 is capturing sudden shocks in the fossil fuel cost ratio. Meanwhile, regime 2 is seizing stable states before the global financial crisis of 2008 and the Fukushima disaster. In all three cost ratios, it is noticeable that switching from one regime to another became more frequent after the Fukushima accident. This indicates that the cost spreads became unstable after the accident.

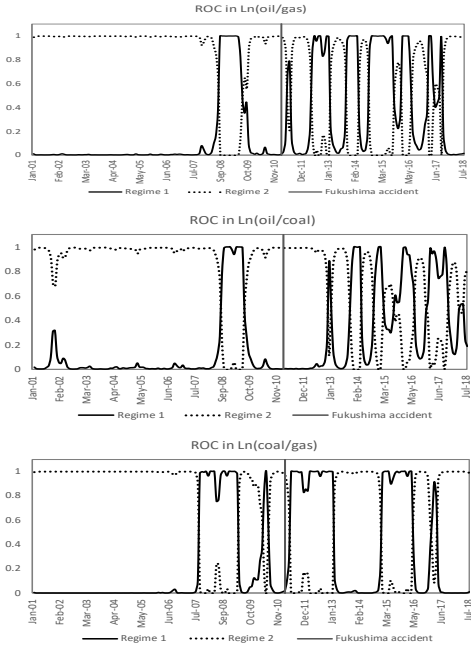
The stationarity tests confirmed that all the fossil fuel costs are integrated at order one. Table 1 depicts the results of the Johansen test. It is discernible from the table that all the binary cointegration relationships received

impacts from the Fukushima accident. The cost relationship between oil and gas became stronger while that for oil-coal and coal-gas became weaker after the accident. The results indicate that although coal was cointegrated with oil and gas before the Fukushima accident, these relationships disappeared after the accident. This could be implying that the strengthened oil-gas relationship after the accident have interrupted the post-Fukushima coal-oil and coal-gas relationships. The BM test revealed that the cointegration relationship between oil and gas was time variant before the accident but became time invariant after the accident. This also suggested that the oil-gas relationship strengthened after the accident.

**Table 1 Johansen cointegration tests**

All period (2001:1-2018:8)				
Variables	$H_0: \text{rank}=r$	Trace test	Max test	Lag length
Oil and Gas	$r=0$	21.746 **	17.109 **	4
	$r \leq 1$	4.637	4.637	
Oil and Coal	$r=0$	13.661	7.915	3
	$r \leq 1$	5.746	5.746	
Coal and Gas	$r=0$	4.315	3.494	6
	$r \leq 1$	0.821	0.821	
Before the accident (2001:1-2011:2)				
Variables	$H_0: \text{rank}=r$	Trace test	Max test	Lag length
Oil and Gas	$r=0$	20.262 *	15.892 *	4
	$r \leq 1$	9.165	9.165	
Oil and Coal	$r=0$	25.133 ***	21.102 ***	4
	$r \leq 1$	4.032	4.032	
Coal and Gas	$r=0$	21.932 **	17.618 **	3
	$r \leq 1$	4.314	4.314	
After the accident (2011:3-2018:8)				
Variables	$H_0: \text{rank}=r$	Trace test	Max test	Lag length
Oil and Gas	$r=0$	30.960 ***	28.582 ***	2
	$r \leq 1$	2.378	2.378	
Oil and Coal	$r=0$	8.293	6.314	3
	$r \leq 1$	1.980	1.980	
Coal and Gas	$r=0$	8.578	7.751	3
	$r \leq 1$	0.827	0.827	

\*\*\*, \*\*, \* denotes significance at 1%, 5%, and 10% respectively.



**Figure 1 MS smoothed regime probabilities**

## Conclusions

The study investigated how shutting down the nuclear power plants in Japan after the Fukushima accident affected the linkages among the electricity generation costs by crude oil, natural gas, and coal. The MRSM result suggested that the fluctuations of the fossil fuel cost spreads became more frequent after the Fukushima accident. The cointegration tests revealed that the cost relationships between coal and other fossil fuels weakened after the accident while that for the oil and gas strengthened after the the accident. These results might be reflecting the change in the Japanese energy policy after the accident to promote LNG to compensate the reduced energy supply from closing the nuclear power plants while coping to meet the requirements of Paris Agreement to reduce its CO2 emissions.

## References

- Hayashi, M., and Hughes, L. (2013) The policy responses to the Fukushima nuclear accident and their effect on Japanese energy security. *Energy Policy* 59:86-101.
- Hong, S., Bradshaw, C.J.A., and Brook B.W. (2013) Evaluating options for the future energy mix of Japan after the Fukushima nuclear crisis. *Energy Policy* 56:418-424.
- Huenteler, J., Schmidt, T.S., and Kanie, N. (2012) Japan's post-Fukushima challenge – implications from the German experience on renewable energy policy. *Energy Policy* 45: 6-11.
- Murakami, K., Ida, T., Tanaka, M., and Friedman L. (2015) Consumers' willingness to pay for renewable and nuclear energy: A comparative analysis between the US and Japan. *Energy Economics* 50:178-189.
- Perron, P. (1997) Further evidence on breaking trend functions in macroeconomic variables. *Journal of Econometrics* 80(2):355-385.
- Rehdanz, K., Schroder, C., Nanita D., and Okubo, T. (2017) Public preferences for alternative electricity mixes in post-Fukushima Japan. *Energy Economics* 65:262-270.
- The Federation of Electric Power Companies of Japan (FEPC). (2017) *FEPC Infobase 2017*. FEPC, Tokyo. <http://www.fepec.or.jp/library/data/infobase/> (accessed 4 Dec. 2018)