THE ECONOMIC IMPACT OF NUCLEAR POWER PLANT SHUTDOWNS

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Overview

This paper analyzes the economic and welfare consequences of electricity shortages and power shutdowns in South Korea, which followed the shutdown of multiple nuclear power plants from June 2013 to January 2014. Nuclear power plants are base load power sources to consistently meet minimum electricity demand. As many countries including South Korea consider an option of increasing nuclear power generation, this paper will show what might be market and welfare impacts when base load power plants suddenly stop generation. The exogenous supply side shock from shutdowns is expected to amplify or de-amplify the price differences and cross-subsidizations among sectoral retail electricity prices. To see their impacts in depth, we estimate the changes in sectoral retail prices, changes in sectoral consumer surpluses, and the green house gas emission increase when nuclear power plant shutdowns lead to fossil fuel power plants generation. Since the substation cost and the amount of cross-subsidizations from the residential sector to industrial sector are often hidden to the public, we recover these costs using the state space model and find a systematic change among the sectors due to nuclear power plant shutdowns.

Methods

Our state-space model describes how sectorial electricity prices are determined not only by unobserved production costs but also by cross subsidization between sectors. First, the following measurement equations explain how sectoral electricity prices are determined by common cost factor and individual sectoral cost factors. Let

$$\begin{pmatrix} y_{1t} \\ y_{2y} \\ y_{3t} \end{pmatrix} = \begin{pmatrix} z_1 w_{0t} + w_{1t} \\ z_2 w_{0t} + w_{2t} \\ z_3 w_{0t} + w_{3t} \end{pmatrix} + \begin{pmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{pmatrix}, \tag{1}$$

where y_{it} is percentage change (divided by 100) of the ith sector electricity price (seasonally adjusted), w_{0t} is the unobserved common factor, and w_{it} for $i = 1,2,3$ is the unobserved ith sector idiosyncratic factor, where $i = 1,2,3$ represent residential, commercial and industrial sectors, respectively, and t is the monthly time index.

For the idiosyncratic factors w_{it} for $i = 1,2,3$, we impose a company-wise budget constraint so that the weighted idiosyncratic factors add up to zero, i.e, we have

$$k_1 w_{1t} + k_2 w_{2t} + k_3 w_{3t} = 0$$

for all $t > 0$, where k_i for $i = 1,2,3$ is the sectoral sales weight given by k_i =(ith sector electricity sales)/(total electricity sales). These weights are obtained as $k_1 = 0.19$, $k_2 = 0.23$ and $k_3 = 0.58$. This budget constraint implies that the total revenue and total cost for all electricity production are equivalent. That is, it means break-even profit for the public enterprise.

For the common and idiosyncratic factors of the model that are not observed but we recover through the model, we define them such that

$$\begin{pmatrix} w_{0t} \\ w_{1t} \\ w_{2t} \\ w_{3t} \end{pmatrix} = \begin{pmatrix} u_0 \\ u_1 \\ u_2 \\ u_3 \end{pmatrix} + \begin{pmatrix} b_{00} & 0 & 0 & 0 \\ 0 & b_{11} & 0 & 0 \\ 0 & 0 & b_{22} & 0 \\ 0 & 0 & 0 & b_{33} \end{pmatrix} \begin{pmatrix} w_{0t-1} \\ w_{1t-1} \\ w_{2t-1} \\ w_{3t-1} \end{pmatrix} \tag{2}$$

$$+ \begin{pmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & c_{27} & c_{28} & c_{29} & c_{210} \\ 0 & 0 & 0 & 0 & 0 & 0 & c_{37} & c_{38} & c_{39} & c_{310} \\ 0 & 0 & 0 & 0 & 0 & 0 & c_{47} & c_{48} & c_{49} & c_{410} \end{pmatrix} x_t + \begin{pmatrix} v_{0t} \\ v_{1t} \\ v_{2t} \\ v_{3t} \end{pmatrix},$$

where x_t is a vector of the

- percentage change of the average wage,
- percentage change of the uranium price,
- percentage change of the coal price,

- (percentage change of the oil price)/(electricity power reserve rate),
- (percentage change of the LNG price)/(electricity power reserve rate),
- (changes in nuclear power plant failure rate)/(electricity power reserve rate),
- percentage change of the IAIP (index of all industry production),
- percentage change of the producer price index,
- percentage change of the Dallor/Won exchange rate,
- percentage change of the unemployment rate.

All values in x_{it} are the percentage changes divided by 100.

To model this two-folded impact on the green house gas, we set up the model as

$$green_t = \alpha + [\beta_0 + (\beta_1 + \beta_2 reserve_t) failure_t] q_t^o + e_t, \quad (3)$$

where $green_t$ is the change rate of green house gas emission, $reserve_t$ is the electricity reserve rate, $failure_t$ is the nuclear plant failure rate, and q_t^o is the change rate of the total electricity production without seasonal adjustment. This model is based on the idea that the usage ratio of fossil fuel will increase as the nuclear plant failure rate increases, and moreover, the impact of the nuclear plant shutdown on the usage of fossil fuel will be different depending on the current level of the electricity reserve rate.

Results

Our estimates of the coefficients in equations (1) and (2) are as follows:

$$z = \begin{pmatrix} 0.27 \\ 0.39 \\ 0.001 \end{pmatrix}, u = \begin{pmatrix} 0.0263 \\ -0.0057 \\ 0.0059 \end{pmatrix}, B = \begin{pmatrix} -0.18^* & 0 & 0 \\ 0 & -0.17^* & 0 \\ 0 & 0 & -0.33^* \end{pmatrix},$$

$$C = \begin{pmatrix} -0.017 & 0.228^* & -0.106^* & -0.736^* & 0.717^* & 0.400^* & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.114 & 0.977^* & -0.049 & 0.0001 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.001 & -0.326^* & -0.007 & 0.0004 \end{pmatrix}$$

Note: for B and C, estimates with superscript * are statistically significant.

From the estimates of z, we learn the common cost factor influences on residential and commercial electricity price positively, however, rarely on industrial price. This supports a notion that industrial sector receives the benefit of cross subsidization by not paying for its fair share of production cost. The negativite coefficients of B reveals mean reversion property of cost factors. The coefficient 0.400 in the first row of C shows that nuclear power plant failure significantly raises the production cost when the electricity reserve rate is low. The coefficient 0.717 in the first row of C implies that the marginal plants are often LNG fired, and thus the LNG price upon low power reserve rate significantly increases production cost.

For the parameters in (3), the estimation result is given by $\alpha = -0.0022$, $\beta_0 = 1.03^{**}$, $\beta_1 = 10.43^{**}$, $\beta_2 = -72.28^{**}$. Moreover, from the analysis in the previous section, the decrease in the total electricity generation due to 1%p increase of the nuclear plant failure rate is given by

$$\frac{\partial q_t^o}{\partial failure_t} = -0.014 s_1 - 0.021 s_2 - 0.00016 s_3 = -0.015 \quad (4)$$

where $s_1 = 0.19$, $s_2 = 0.58$ and $s_3 = 0.23$ are the average sectoral sales ratio, when the power reserve rate is zero. Now suppose that the power reserve rate is 0%, the nuclear plant failure rate is 0%, and the total electricity generation is at its monthly average growth rate 0.3%, for example. Then we have

$$\frac{\partial green_t}{\partial failure_t} = \frac{\partial}{\partial failure_t}(\beta_0 + \beta_1 failure_t)(0.003 - 0.00015 failure_t)$$
$$= -0.00015\beta_0 + 0.003\beta_1 = 0.031$$

at $failure_t = 0$. If this local slope remains the same for small changes of the failure rate, it implies that the additional increase of the green house gas will be $4 \times 0.031 = 0.12\%$p a month, when the nuclear plant failure rate increases from zero to 4%. From the 2014 average green house gas emission of 16.4 million metric tons a month, the additional increase amount is calculated as 19.7 thousand metric tons a month.

Conclusions

We model the relationship of sectoral prices and unobserved costs of electricity production in Korea. Our results show how nuclear power electricity generation failure and shutdowns can raise production costs, but sectoral price outcomes imply the conspiring cross subsidization from residential/commercial to industrial sectors. Especially, the corss subsidization will get more intense on the channel from commercial to industrial rather than from residential which the public is not aware of.