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Optimal Share of Natural Gas in the Electric Power Generation of South Korea: A Note

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Abstract: Natural gas (NG) not only emits fewer greenhouse gases and air pollutants than coal but also plays the role of a peak power source that can respond immediately to the variability of increasing renewables. Although the share of NG generation worldwide is increasing, it is difficult for South Korea to increase its NG generation significantly in terms of fuel supply security, since it depends on imports for all of the NG used for power generation. Therefore, the optimal share of NG generation in electric power generation is a serious concern. This note attempts to estimate the optimal share by modelling the plausible relationship between NG generation and national output in the Cobb–Douglas production function setting and then deriving the output-maximizing share of NG generation. The production function is statistically significantly estimated using annual data from 1990 to 2016, allowing for the first-order serial correlation. The optimal share is computed to be 20.3%. Therefore, it is recommended that South Korea increases the share of NG generation slightly and makes efforts to secure a stable NG supply, given that, according to the national plan, the share will be 18.8% in 2030.

Keywords: natural gas; optimal share; electric power generation; economic growth

1. Introduction

Natural gas (NG) is one of the essential inputs for economic activities that are widely used in power generation, industry, transportation, commerce, housing, and so on [1]. In particular, the use of NG in electricity generation not only emits fewer greenhouse gases and air pollutants than coal but also enables us to respond immediately to the variability of increasing renewables [2,3]. According to the Greenhouse Gas Inventory and Research Center of Korea Ministry of Environment, the amounts of fuel use per power generation of coal and NG are 0.232 and 0.122 TOE per kWh, respectively. In addition, the greenhouse gas (GHG) emission coefficients per fuel use for coal and NG are 3.766 and 2.123 CO_2 tons per TOE, respectively. Thus, the coefficients of the GHG emissions per power generation of coal and NG in South Korea are 0.874 and 0.270 CO_2 tons per kWh, respectively. The former is about 3.2 times as large as the latter. In other words, GHG emissions from the NG-fired generation are only 0.31 times higher than those from coal-fired generation. Consequently, NG acts as an eco-friendly fuel and a peak power source. Moreover, NG is expected to play the role of bridge energy as a practical means to cope with the intermittent and uncertain nature of renewable energy such as wind and solar power in an era of the energy transition [4], even though, of course, the flexible energy storage solutions are also an important “green” alternative to the solar photovoltaic and wind energy integration [5]. The share of NG generation in the total electricity generation will increase from 17.8% in 2017 to 22.4% in 2040 [6].

Although the share of NG generation worldwide is increasing, it is difficult for South Korea to increase its NG generation significantly in terms of fuel supply security, since it depends on imports for all of the NG used for power generation [7]. Moreover, the NG consumed in the country is more expensive than other fuels, such as coal and uranium because it is imported in the form of liquefied NG (LNG) due to its convenience for transportation from abroad. Therefore, the optimal share of NG generation in electric power generation is a serious concern [8]. Comparing the optimal share with the actual share will give some suggestions on whether to increase or decrease the share of NG generation in the medium to long term.

This note attempts to estimate the optimal share by modelling the plausible relationship between NG generation and national output in a simple Cobb–Douglas production function setting and then deriving the output-maximizing share of NG generation. The production function is estimated using annual data from 1990 to 2016, allowing for first-order serial correlation. The rest of the note consists of three sections. The second section explains the model and data employed in the note. The third section describes the estimation method and results and the implications of the results. The conclusions are reported in the final section.

2. Model and Data

2.1. Model

In the case of a simple production function, the input factors are usually labor and capital. This study aims to consider electricity as an additional input. Thus, there are three inputs in the economy at time t: the total labor input (L_t), the aggregate capital input (K_t), and the total electricity consumption (E_t). These three inputs are used to produce the national output (Q_t). Meanwhile, the total amount of electricity consumed ($E_t.$) can be decomposed into electric power generated from NG (S_t) and electric power generated from non-NG (N_t).

A seminal work of Berndt and Wood [9] viewed energy including electricity as an additional input and applied the so-called KLEM model consisting of four inputs of capital, labor, energy, and intermediate goods using the data for the United States manufacturing industry over the period 1947–1971. Moreover, Griffin and Gregory [10] estimated three-input model of capital, labor, and energy combining manufacturing data from nine developed countries. Energy was also reflected as an additional input factor in Berndt and Wood [9] and Field and Grebenstein [11]. Of course, there are works that consider electricity itself as an additional input along with labor and capital in the literature [12–14]. Therefore, judging from the literatures on applied energy economics and policy, energy or electricity, along with labor and capital, can be considered as one of the important inputs. The aggregate production function adopted in this study can be formulated as follows:

$$Q_t = f(L_t, K_t, E_t) = f(L_t, K_t, S_t, N_t) \tag{1}$$

More specifically, we employ the Cobb–Douglas production function here. In fact, economic theory does not indicate the form of a production function. In other words, it is not possible to determine the specific form of a production function directly from economic theory, and researchers should establish an appropriate form of function based on literature. In this regard, Cobb–Douglas production functions are adapted for three main reasons in this study. First, the Cobb–Douglas production function is relatively simple in its form, but its usefulness has already been demonstrated since it has been the most widely, standard, and long-used production function in the literature of applied economics [15]. For example, Cobb–Douglas production functions have been applied for nearly one century [12].

Second, a form of Cobb–Douglas production function is good to derive elasticities of output. The Cobb–Douglas production function combines several exponential functions, but natural logarithms on both sides can transform the Cobb–Douglas production function into a simple double-log form, making it easy to estimate and intuitive to use the results because the estimated coefficients can be interpreted as elasticities of output. In addition, the optimal quantity or share of an input can be derived analytically and easily when the Cobb–Douglas production function is used.

Third, the Cobb–Douglas production functions have almost always been applied in applied works that derive a level or share of a particular input that maximizes the economic output. For example, the Cobb–Douglas production functions were always employed in Grossman [16] to derive the optimal government size, Scully [17] to determine the optimal tax size, and Ferris [18] to decide the optimal government and debt sizes. The production function is:

$$Q_t = C(L_t)^{\alpha}(K_t)^{\beta}(S_t)^{\gamma}(N_t)^{\delta} \tag{2}$$

When homogeneity of degree one is not imposed on the function, α, β, γ, and δ are all larger than zero and smaller than one. Taking the logarithm of Equation (2) and omitting subscript t for simplicity, we obtain:

$$\ln Q = \ln C + \alpha \ln L + \beta \ln K + \gamma \ln S + \delta \ln N \tag{3}$$

Differentiating Q with respect to S yields:

$$\frac{\partial Q}{\partial S} = \gamma \frac{Q}{S} > 0 \tag{4}$$

$$\frac{\partial^2 Q}{\partial S^2} = -\gamma \frac{Q}{S^2} < 0 \tag{5}$$

Clearly, the effect of an increase in NG generation on the output is positive but at a diminishing rate. Let the share of NG generation in the total power generation be λ. Rewriting Equation (3) by using $S = \lambda E$ and $N = (1-\lambda)E$ gives us:

$$\ln Q = \ln C + \alpha \ln L + \beta \ln K + \gamma \ln \lambda E + \delta \ln[(1-\lambda)E] \tag{6}$$

The output-maximizing λ (λ^*) can be obtained by differentiating Equation (2) with respect to λ, setting the result to zero and solving for λ^*. For simplicity, we can deal with Equation (6) rather than Equation (2). Differentiating Q with respect to λ yields:

$$\frac{\partial Q}{\partial \lambda} = Q\left(\frac{\gamma}{\lambda} - \frac{\delta}{1-\lambda}\right) \tag{7}$$

To obtain the value for λ^*, setting Equations (4) and (5) to zero and solving this equation produces:

$$\lambda^* = \frac{\gamma}{\delta + \gamma} \tag{8}$$

Interestingly, a formula for λ^* is available in a simple closed form. The following equation can be obtained by adding an error term, μ_t, to Equation (6).

$$\ln Q_t = a + \alpha \ln L_t + \beta \ln K_t + \gamma \ln \lambda E_t + \delta \ln[(1-\lambda)E_t] + \mu_t \tag{9}$$

where $a(= \ln C)$ is a constant term.

2.2. Data

The prime objective of this note is to estimate the value of λ^* and to confirm its statistical significance. To achieve this objective, the use of annually-comparable and reliable data is obviously critical. The real gross domestic product (GDP), which is taken from Statistics Korea [19], is regarded as a proxy for the national output (Q_t). Statistics Korea [19] also provides the data on L_t, which is defined as the labor force. Data on fixed capital formation in 2015 constant values, which are obtained from Statistics Kores [19], are used for K_t. It appears that these three sets of time series data can serve as reasonably good proxies for the theoretical variables.

The Korea Electric Power Corporation, which is a monopolistic public utility, transmits and distributes the electric power produced in South Korea. The data on E_t, S_t, and N_t come from the Korea Energy Economics Institute [20]. South Korea's NG generation began in 1986 and reliable data on NG generation have been available since 1990. Therefore, the period for this study is the 27 years from 1990 to 2016. The variables employed in this note are explained in Table 1.

Table 1. Description of variables in the model.

Variables	Definitions	Value in 1990	Value in 2016
Q	Real gross domestic product in 2010 constant price (unit: billion Korean won) [1]	419,518	1,508,265
L	Labor force (unit: thousand persons) [1]	18,085	26,409
K	Fixed capital formation in 2015 constant value (unit: billion Korean won) [1]	166,803	458,931
S	Amount of electric power generation from natural gas (NG) (unit: Giga watt hours) [2]	9604	120,852
N	Amount of electric power generation from non-NG (unit: Giga watt hours) [2]	98,066	419,589

[1] The source is Statistics Korea [19]. [2] The Source is Korea Energy Economics Institute [20].

3. Estimation Method and Results

3.1. Estimation Method

The results of estimating Equation (9) using the conventional least squares estimation method are reported in the second column of Table 2. When analyzing time series data such as those used in this study, it is important to consider the treatment of serial correlation [21]. In addition, contrary to the authors' expectation, the estimated coefficient for the capital term has a negative sign and is distinguishable from zero at the 1% level. It is not reasonable to say that the capital negatively contributes to the output.

Table 2. Estimation results of the model.

Variables [1]	Least Squares Estimation	Cochrane and Orcutt's [22] Iterative Estimation
Constant	−3.8199(−4.13) #	4.6327(2.77) #
$\ln L$	1.2156(9.00) #	0.4048(1.79) *
$\ln K$	−0.1546(−3.16) #	0.1939(3.24) #
$\ln S$	0.0759(5.32) #	0.0522(2.95) #
$\ln N$	0.5235(20.36) #	0.2054(2.21) #
ρ		0.9647(67.31) #
R^2	0.9992	0.9993
Number of observations	27	26

Notes: [1] The variables are defined in Table 1. ρ is serial correlation parameter at convergence. The dependent variable is natural logarithm of gross domestic product. The numbers in parentheses below the coefficient estimates are t-values. * and # indicate statistical significance of the estimate at the 10% and 5% levels, respectively.

The estimated production function does not conform to economic theory. According to micro-economic theory, an increase in capital should have a positive effect on output. In other words, the marginal product of capital should be positive, but this is negative when the least squares estimation is applied. Thus, the production function estimated by the use of least squares estimation method does not conform to economic theory. Therefore, as an alternative to the conventional least squares method, this study applies Cochrane and Orcutt's [22] iterative estimation method in order to deal with the first-order serial correlation in estimating the production function. In the estimation, it is assumed that the process generating the errors has a stationary first-order autoregressive structure. That is, $\mu_t = \rho\mu_{t-1} + e_t$, where ρ is the serial correlation parameter and e_t is the errors, being white noise.

3.2. Estimation Results and Their Implications

The results of estimating Equation (9) using Cochrane and Orcutt's [22] iterative estimation method are given in the third column of Table 2. All the signs of the estimated coefficients for the four inputs are positive and consistent with economic theory. Moreover, they are all statistically different from zero at the 10% level. ρ is computed to be 0.9647 and is statistically different from zero at the 1% level. The optimal share expressed as Equation (8) is computed to be 20.3% from Table 2. Its t-value is calculated to be 3.86, which indicates that the estimated optimal share (λ^*) has statistical meaningfulness at the 1% level.

South Korea's electricity demand is expected to rise 1.3% annually from 2017 (507 TWh) to 2031 (580 TWh) without stabilizing [23]. The ratio of NG in the total electricity generation was 16.9% in 2017 and is expected to be 14.5% in 2030. In response, the Government finalized and announced its "eighth basic plan for electricity supply and demand (2017–2031)" in late 2018 to increase the share of NG to 18.8% by 2030 by introducing a tax reform of power sources and reflecting the environment in determining power sources' ranking [23]. For example, the Government will lower taxes on NG for power generation, raise taxes on bituminous coal for power generation, and consider the environmental costs of each generation source when determining the power source for electricity generation.

The Government's plan to expand NG generation is exactly in line with the findings of this study and the global trend to increase the proportion of NG generation. However, its target of 18.8% (118 TWh) in 2030 is lower than the optimum percentage of NG generation, 20.3% (127 TWh), thus it is recommended that South Korea increases the share of NG generation slightly. Moreover, since most of the NG for power generation in the country depends on imports in the form of liquefied NG (LNG), efforts are required to secure a stable LNG supply such as promoting the introduction of a NG pipeline from Russia; diversifying of NG importing, which is currently limited to Qatar and Oman; and increasing import of shale gas from the United States.

4. Conclusions

This study sought to estimate the optimal share by modeling the plausible relationship between NG generation and national output in a simple Cobb–Douglas production function setting and then deriving the output-maximizing share of NG generation. The optimal share was calculated to be 20.3%, which possessed statistical significance at the 1% level. The share is larger not only than the actual share of 16.9% in 2017 but also than the national target share of 18.8% in 2030. Thus, it is recommended to enlarge the share of NG generation slightly in the future. Since the findings are specific to South Korea, if the framework of this note is applied to other East Asian countries, such as China, Japan, and Taiwan, which use LNG and then the results are compared with the results of this study, more useful implications can be obtained.

In fact, NG-fired generation not only has excellent GHG reduction effect but also has made significant contributions to enhancing the stability of power supply by performing the role of peak loads. Nuclear power generation, in particular, requires about 24 h of warming-up time to generate power, and coal power also demands more than 10 h of warming-up time. On the other hand, the NG-fired generation has the advantage of being able to generate electricity instantly when power demand arises. In particular, as renewable energies such as solar and wind power grow at a rapid pace worldwide, the expansion of variable power sources that can overcome the intermittent and uncertain nature of renewable energy should also increase. NG-fired generation is a representative variable power source, and when the supply of renewable energy is cut off, it immediately starts up and generates electricity, which will greatly increase its role. The main findings from this research not only exactly corresponds the global trend that NG-fired generation is playing an increasing role, but also provide suggestions that governments should have sufficient NG-fired generation facilities, securing NG stably, in order to increase NG-fired generation.

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