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The substitutability of nuclear capital for thermal capital and the shadow price in the Korean electric power industry

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HIGHLIGHTS

- ▸ This paper estimates an input distance function for the Korean power generating sector.
- ▸ Nuclear capital is readily substituted for thermal capital, relatively, not vice versa.
- ▸ The shadow price ratio of nuclear capital to thermal capital shows an upward trend.

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ABSTRACT

As part of ongoing efforts to reduce CO_2 emissions by increasing the proportion of the energy mix relying on nuclear power, it may be useful to substitute nuclear power for thermal power wherever possible, thereby substantially reducing the need to use fossil fuels. In order to evaluate the contribution of nuclear power to potential CO_2 reduction, this study examines the substitutability of thermal capital and nuclear capital in the Korean electric power industry by utilizing the input distance function. Additionally, the unit costs of thermal capital and nuclear capital are compared in terms of their shadow prices, which are defined as the opportunity costs inherent to one additional unit of capital increase deriving from a reduction in labor. The empirical results presented herein indicate that nuclear capital is readily substituted for thermal capital, but the substitutability of thermal capital for nuclear capital is relatively low. The shadow price ratio of nuclear capital to thermal capital is estimated to be 15.9, on average, showing an upward trend over the years from 1982 to 2010.

1. Introduction

In its quest to achieve and perpetuate rapid economic growth since the 1970s, Korea has supported policies designed to enhance the competitiveness of relatively high value-added industries with inter-industrial linkage effects, such as the electronics, automobile, and shipbuilding sectors and by promoting materials industries such as the steel and chemical sectors. In particular, price subsidies for industrial fuel and power have made a significant contribution toward attaining a comparative advantage in the prices of domestic goods over foreign goods in international markets. However, this policy has induced a high level of dependence on energy and permanence of energy-intensive industrial structures. The government has lacked the will to improve energy consumption structures; as a result, there has been little motivation for firms to make investments in energy efficiency.

With growing awareness of the seriousness of global climate change since the mid-1990s, the world's nations have been forced to discuss the objective of greenhouse gas reduction and the measures needed for its realization in international treaties. The initial adoption of the Kyoto Protocol took place in 1997. However, the member nations then failed to agree on post-Kyoto protocols at the 17th COP (Conference of Parties) in Durban in 2011. This was due to a conflict of interest that arose between developed and developing countries that involved issues such as whether or not to impose a mandatory greenhouse gas emissions reduction protocol on developing countries. However, regardless of these conflicts, all of the members came to a consensus regarding the need to abate greenhouse gas emissions.

At the 15th Copenhagen climate conference, the Korean government announced its mid-term mitigation goal to reduce greenhouse gas emissions by 4% below the 2005 levels by 2020. However, industrial groups are somewhat skeptical about achieving this objective, because energy efficiency is quite low globally, largely as a result of relatively energy-intensive industrial structures. Fossil fuels account for more than 80% of the nation's primary energy use, and Korea's average annual growth rate of

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energy consumption was 3% in 2007, ranking ninth in the world (BP, 2008); additionally, CO_2 emissions increased by 113% above the 1990 levels in 2007, thereby placing Korea first in average annual growth rate and sixth in total amounts of CO_2 emissions among the OECD member nations (IEA, 2009). In order to attain the goal of greenhouse gas reduction, it can be suggested that the government, in the short-run, reduce energy consumption by improving energy efficiency in equipment, apparatuses, etc., along with the abolition of energy price subsidies. In the long-run, it is recommended that both the use of renewable energy sources, such as sunlight and wind power, and the dependence upon nuclear power be increased.

Comparing nuclear power to other energy sources in terms of their economic impact and effectiveness, nuclear power not only generates a mere 1% of the CO_2 emissions that thermal power does, but also produces electricity at a cost of 3.2 US cents per kW h, which is a lower than that for thermal (coal) power (at 5.9 US cents/kW h) and photovoltaic power (at 12.8 US cents/kW h) (based on unit price of settlement of Korea Power Exchange, as of 9/2011). As new renewable energy sources can take a comparably large amount of time to become commercially viable, considering the current level of technology and production costs in Korea, nuclear power has been proposed as a viable alternative. Korea imports 96.5% of its total energy consumption; energy imports account for 28.6% of total imports (KEEI, 2011). Therefore, an expansion of nuclear power will help bring about a gradual increase in energy self-reliance, and induce a secondary effect of substantial reductions in SO_x and NO_x generated from burning fossil fuels. However, attendant problems associated with nuclear power have not been satisfactorily solved, such as the issues of nuclear waste site security and radiation safety, as was recently observed in the case of the Fukushima nuclear disaster. With the first nuclear power plant export to the UAE in 2009 as an impetus, the Korean government plans to supply R&D funds amounting to approximately 400 million dollars for the promotion of nuclear power as a leading export industry in the next seven years.

In order to produce a tangible reduction of CO_2 emissions by increasing the reliance on nuclear power, nuclear power should be substituted for thermal power wherever possible, thereby resulting in a substantial reduction in the use of fossil fuels. If thermal power plants can be widely substituted by nuclear power plants, the effect on CO_2 reduction is expected to be greater than otherwise. In order to assess the contribution of nuclear power to potential CO_2 reduction, this study first measures the substitutability between thermal capital and nuclear capital in the Korean electric power industry. Numerous previous works have estimated the elasticities of substitution between input factors in the electric generation sector; these studies mostly, however, examined either the inter-inputs (capital, labor, and fuel) or inter-fuel (coal, oil, and gas) relationship (Christensen and Greene (1976) and Atkinson and Halvorsen (1976) are pioneers in this research). Additionally, the unit costs of thermal capital and nuclear capital are compared in terms of shadow price, which is defined as the opportunity cost of increasing an additional unit of capital as the result of a reduction in labor.

The use of the cost function dual to the production function makes it much easier to study the structure of production for specific industries, and particularly to derive the input demand equations and formulas for the elasticities of demand and substitution (Halvorsen and Smith, 1986). However, estimation of the cost function requires a relatively large quantity of data regarding input prices. For instance, the Christensen–Jorgenson formula, which has been preferentially used to measure the price of capital, consists of a variety of specific items, including the Handy–Whitman price index of electric utility, the rates of return on common equity and long-term debt, the capitalization ratio of equity, etc (Christensen and Jorgenson, 1969). In this study, where the total capital stock is divided into nuclear power plants and thermal power plants, it is almost impossible to calculate each capital price separately, because data regarding items by capital type are seldom obtainable. For certain industries, even data on some input prices are not available.[1]

In an effort to deal with the limited data problem, this study employs Shephard's input distance function, which has an advantage over the cost function in terms of the quantity of data required for estimation (Shephard, 1970). The use of the input distance function, which is a function of the inputs and outputs, enables us to avoid additional work in calculating the input prices; consequently, less data need to be acquired. In addition, defining the distance function is not premised on the specific optimal firm's behavior (for instance, profit-maximization or cost-minimization), whereas the cost function is derived by imposing cost-minimization as a maintained hypothesis (Grosskopf et al., 1995, p278). In fact, cost-minimization is not guaranteed for firms that are faced with restricted environments, including imperfect markets, strikes, and government regulations (Atkinson and Halvorsen, 1984).

This paper is organized as follows: The changing trends in generating electricity over time are compared across energy sources in the following section. The elasticities of substitution between inputs and their shadow prices are calculated in Section 3 and the empirical results are discussed in Section 4. Korea's nuclear energy policy is described in Section 5. Section 6 presents conclusions.

2. Electricity generation by energy sources in Korea

Korea has relied on three main energy sources to generate electricity: hydro power, thermal power, and nuclear power. In 1961, thermal power and hydro power accounted for 63.2% and 36.8% of total electricity generation, respectively. Afterwards, thermal power continued to increase its share to 94.5% in 1977, when the first nuclear power plant started operating. Since 1978, the nuclear power share has been on a rising trend, exceeding 10% in 1983, and reaching a peak of 43.1% in 1999, as can be seen in Fig. 1. Thermal power underwent a decreasing share (ranging between 86.6 and 39.6%) over the period 1982–1987 and a rising share up to 63.2% over the period 1991–1997, and subsequently fell to 55.5% in 1998; the share of thermal power displayed an upward trend and that of nuclear power a downward trend from 2000 through 2010. The contribution of hydro power has continuously diminished, falling to 1–2% in the 2000s, and alternative power (such as wind, photovoltaic power, and cogeneration) has been of little importance so far.

The overall pattern of change in generating facilities' capacity by energy source over time is analogous to the time trend for electricity generation by energy sources, but there are discrepancies in the shares of individual energy sources, due to the base-load technology. Fig. 2 compares the changing trends in facility capacity across energy sources from 1982 through 2010. Accounting for 8.5% of total generating facility capacity in 1978, nuclear power thereafter rapidly increased its share to 12.3% in 1982, 26.4% in 1986, and 36.3% in 1989. The share of nuclear power steadily declined after that, however, dropping to 25.1% in 1997,

[1] In order to circumvent the problem of unpriced inputs, Halvorsen and Smith (1986), Halvorsen and Smith (1986), Lee and Ma (2001), and Lee (2008) used the theory of restricted cost (profit) function, in which the quantities of those inputs are assumed to be set equal to the optimum levels in the short-run. In particular, Lee (2008) treated abatement capital as a quasi-fixed input due to a lack of relevant data required to compute its price in his study of the structure of production under environmental regulations.