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# Market value for thermal energy of cogeneration: using shadow price estimation applied to cogeneration systems in Korea

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### Abstract

This study empirically analyzes the appropriateness of the current tariffs for district heating in Korea. For this purpose, we adopt the duality concept applied to the output distance function, and estimate the shadow price of heat produced from cogeneration. In addition, the analytical model takes account for the inputs of labor and capital as well as fuel as input outlays of cogeneration. The empirical results show that the current heat tariff determined by the public energy policy might be undervalued by about 15–53%. This implies that the retail price of district heating in Korea might be distorted at least in the sense of economics.  $\bigcirc$  2004 Elsevier Ltd. All rights reserved.

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## 1. Introduction

Cogeneration is the sequential generation of two different forms of useful energy from a single primary energy source. The two different forms of energy may be electrical energy and thermal energy or mechanical energy and thermal energy. The sequences of generation can be any combination of different forms of useful energy. Cogeneration is widely known to be an energy efficient technology (Kwon and Yun, 2003).<sup>1</sup> While providing the same quantity of two different required forms of energy, it has the advantage of reducing the primary energy cost.

Since 1987, the cogeneration systems have been introduced to provide district heating in Korea. In the early stage, they have provided residential heating, expanding to industrial steam production nowadays. All of five cogeneration power plants in the Seoul metropolitan area were used to be owned and operated by the Korea Electric Power Corporation (KEPCO).<sup>2</sup> The Korea District Heating Corporation (KDHC) has been purchasing the heat produced and supplying it to the final consumers through its own heat transmitting facilities.

So far, regarding to the wholesale tariff of heat produced from the cogeneration power plants, there have been a few disputes between the KEPCO as a heat producer and the KDHC as a heat demander and supplier to final customers. Both companies are government-owned, and thus the tariff disputes were arbitrated by the Ministry of Commerce, Industry and Energy (MOCIE). By the revision of the Electric Business Law in December 2000, however, the Korean electric power industry is currently under the process of restructuring and privatization. Therefore, the issue of wholesale tariff is facing a new era, and the

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<sup>&</sup>lt;sup>1</sup>Cogeneration is sometimes defined as the combined generation of heat and power (electrical or mechanical). Based on the sequence of energy use, cogeneration systems can be classified as topping cycle and bottoming cycle. The former refers to power generation first, and then utilization of thermal energy. The latter is defined as utilization of thermal energy first, and then power generation.

<sup>&</sup>lt;sup>2</sup> In 2000, LG Power, a private-owned utility company has bought out two cogeneration power plants located in Anyang and Puchon.

KEPCO is asking for a drastic revision of current tariff structure.<sup>3</sup>

The purpose of this study is empirically analyzing the appropriateness of the current tariffs for district heating in Korea. For this purpose, we check whether the actual retail tariff for district heating correctly reflects the shadow price of heat production. We describe the theoretical model to derive the shadow price of outputs, estimate the shadow price of heat produced from cogeneration, and make conclusions about the appropriateness of heat tariff in the sense of economics based on the empirical results. More specifically, the empirical estimation of the shadow price is based on the duality concept applied to the output distance function. In addition, the analytical model adopted in this study takes account for labor and capital as well as fuel as input outlays of cogeneration.

The paper is organized as follows: the next section describes the theoretical model to derive shadow price; the third section explains the empirical model and estimation procedure; and the final section summarizes the empirical results and makes conclusions.

#### 2. Theoretical model for shadow price derivation

Before we describe our theoretical model, it would be necessary to mention the approaches for the analysis of large-scale combined heat and power (CHP) for district heating. There would be three approaches: bottom-up approach; top-down approach; and the joint of these two approaches. Bottom-up approach using engineering models contains very detailed descriptions of the alternative technologies that can be combined to produce a desired service or product. This approach often uses linear programming methodology for deciding which technologies it is most economical to use. On the other hand, top-down approach based on economic models is often fairly aggregated, and focused on capturing the effects of policies that affect the whole economy, not just one of its subsectors. In these models, production technologies are thus aggregative, and estimated using flexible functional forms to capture the substitution of some factors of production for others.

There has been a lot of attention toward the differences between these two approaches. For example, the two approaches have often brought about different

magnitudes in predicting the costs and benefits of climate policies. It is quite natural that different approaches might yield different results. Generally speaking, bottom-up approach would produce more accurate results regarding the energy system. In contrast, top-down approach can be expected to incorporate economic interdependencies that engineering models cannot. Nevertheless, the apparent discrepancies may have more to do with the difference between partial equilibrium and general equilibrium analysis than with some inherent conflict between the approaches. And often, it is more the magnitude of effects that differs, not the qualitative result (Forsström and Honkatukia, 2002).

There would be several ways to measure the shadow price of the thermal energy or heat produced from cogeneration power plants. One of them is to estimate the marginal cost of heat production, and to consider it as a shadow price. This is equivalent to determining the additional cost required to produce one more unit of heat from cogeneration power plants.

Suppose that a cogeneration producer is assumed to employ the *N*-dimension input vector  $x \in \mathbb{R}_{+}^{N}$  to produce the *M*-dimension output vector  $y \in \mathbb{R}_{+}^{M}$ . For the case of cogeneration, the input vector is the regular inputs employed in the production process including labor, capital and fuel as a primary energy. The output vector consists of heat  $(y_{H})$  and electrical power  $(y_{E})$ . Denoting an input price vector by  $w \in \mathbb{R}_{+}^{N}$ , the cost function can be defined as the following function, which possibly describes the minimal costs to produce the output combinations given w:

$$c = c(w, y_H, y_E). \tag{1}$$

The cost function denoted in Eq. (1) is assumed to preserve all the usual properties of the cost function.

The marginal (production) cost for producing one more unit of heat is represented as follows:

$$MC|_{y_H, y_E} = \frac{\partial c(w, y_H, y_E)}{\partial y_H}.$$
(2)

This marginal cost would be a reasonable candidate for the shadow price of heat produced in that the balance of cogeneration power plants would not deteriorate if the price of heat sold were above the marginal cost for heat production. However, it is difficult to estimate the cost function directly in our case because the data at hand are not reliable for the purpose of estimation. That is, in order to estimate the cost function above, the input price vector should be derived, and there should be statistically reliable observations for it. Unfortunately, no variations in input prices are observed since all the power plants have been operated by the same company. Moreover, the data for only a limited number of power plants are available for estimation, and we can hardly obtain a statistically reliable estimated cost function.

<sup>&</sup>lt;sup>3</sup>In Korea tariffs, demand and energy charges have been calculated based on the heat discount method. With this method all the benefits of cost reduction through the joint production of cogeneration are supposed to go to the heating supplier. In the early stage of district heating business, it is a common practice for the government and local authorities to arbitrarily lower the tariff for the introduction and promotion of district heating. That is, there has been arising a kind of cross subsidy problem from electric to heating business in the case of cogeneration.

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