Welfare Effects of Nonlinear Electricity Pricing*

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Abstract

Residential electricity pricing in Korea follows a complicated block pricing system. The pricing structure consists of six blocks, each of which has a variable usage fee and a fixed fee. The largest usage fee is at least eleven times greater than the smallest usage fee. Since consumers complain about their electricity bills being unpredictable from the large difference in price between blocks, policy makers and NGOs suggest that an alternative pricing with less blocks with lower block price difference be used.

In this article, we analyze the impact of alternative electricity pricing systems on the welfare of consumers. To do this, we first establish a theoretical model to compute each household's welfare-change under alternative pricing systems. Then, we estimate the residential electricity demand function and compute every household's electricity consumption and expenses under alternative pricing systems. Finally, we compute every household's welfare-change and social welfare to draw policy implications.

Keywords: Blocking pricing; Electricity demand estimation; Welfare change; Equivalent variation; Price regulation.

JEL Classification L94; L32; L51; L53; H42; I38.

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1 Introduction

Electricity in South Korea is provided by a monopolistic state-owned entity, Korea Electric Power Corporation. This market is heavily regulated: electricity prices are set by agreement between the entity and the government. Particularly, residential electricity pricing in Korea follows a complex block pricing system.[1] The pricing structure consists of six blocks, each with its own usage fee and fixed fee. The amount of electricity a household consumes determines the block it is put in, and both usage fee and fixed fee increase for higher electricity usage blocks. Prices also depend on whether a household resides in a single-family home supplied with low-voltage or in an apartment with high-voltage. The block pricing system generates a non-convex budget set due to different fixed fees for blocks, and the ratio of the largest usage fee to the smallest usage fee (hereafter, progressivity) is at least eleven times. The original purpose of implementing this complicated block pricing was to encourage energy conservation and to redistribute income, therefore, to increase welfare.[2] However, consumers complain about the block pricing system since the large difference in price between blocks makes their electricity bills unpredictable. They experience drastic increase in their electricity bill even when their electricity consumption increases very little. To solve this situation, policy makers and NGOs suggest reducing the number of blocks and the progressivity between blocks. However, there is no research that helps assess the impact of possible changes in the electricity pricing system on consumers.

In this article, we analyze the impact of alternative pricing systems on residential electricity demand, expense, and welfare of consumers by performing scenario analysis. To do this, we first establish a theoretical model to compute each household's welfare-change due to alternative pricing systems when it faces a non-convex budget set. Our measurement of welfare-change is equivalent variation. Hausman (1981) shows how to compute equivalent variation and compensating variation when a Marshallian market demand curve is known and a budget curve is linear. We modify Hausman (1981)'s method to construct the formula of equivalent variation for the case of non-convex electricity pricing in Korea. We

[1] Baseline in Table 5 describes the current pricing system in Korea. For example, if a household using low-voltage consumes 180 kWh in a month, it is in the 2nd block. The household pays a fixed fee of 840 won, a usage fee of 14,908 won (56.2 won/kWh for its first 100 kWh consumption and 116.1 won/kWh for the next 80 kWh) and additional taxes.

[2] Block pricing is commonly adopted to protect low-usage households who are usually poorer and to discourage usage through higher marginal price for some consumers (Borenstein, 2009). It is widespread among electricity and water utilities.

estimate the Marshallian demand function of residential electricity in Korea and predict every household's electricity consumptions and expenses under different scenarios.[3] The estimated demand function and consumption levels under alternative scenarios are used to compute every household's equivalent variation. We then use these equivalent variations to calculate social welfare according to Atkinson's inequality aversion indices.

Our results say that the current pricing system prevents consumers from having greater consumer welfare. Additionally, its large price difference between the first block and the last block suppresses demand increase. All income groups significantly increase their electricity demand and welfare under alternative pricing systems. When a society desires to protect low-income households, three-tier systems with progressitivity value of three achieve greater social welfare than six-tier pricing systems or flat charges. This suggests that a tier system should be maintained to protect low-income households, but that the number of blocks and the price difference between blocks should be decreased from the current level.

Only a few studies estimate individual household welfare-change based on the practice of block pricing. Our analysis is closest to Ruijs (2009) and Reiss and White (2006). Ruijs (2009) analyzes the consumer welfare effect of water pricing system under possible price changes. His analysis adopts equivalent variation computation as we do here. Ruijs (2009) applies to the case of convex budget set for his welfare analysis. We, however, focus on analyzing the welfare effect of electricity pricing system when consumers face non-convex budget sets. Our method is directly applicable to the case of convex budget set. Reiss and White (2006) evaluate welfare-change under nonlinear prices applied to wireless phone service.[4] However, their metric to measure welfare-change is compensating variation which

[3] Few studies have been done on the residential electricity demand in Korea. Using a survey data of households in Seoul, the capital of Korea, Yoo et al. (2007) use the cross-sectional data to estimate the residential electricity demand function.

[4] From a survey of over 1000 households in Medellin, Colombia, Maddock and Castano (1991) compute compensating variation to evaluate redistribution impact of block pricing in electricity when flat charge is removed.

may not result in correct ranking of multiple pricing systems.[5] In addition, Reiss and White (2006) perform a Monte Carlo integration to overcome the lack of micro-level data. They randomly sample individual preference parameters and incomes after they estimate distribution of these parameters with aggregate data. On the other hand, our analysis uses both aggregate and micro-level household data.

Related works compute residential electricity demand and bill changes when switching from a block pricing to the flat rate. Borenstein (2012) computes consumer surplus for each income bracket when a five-tier block pricing system changes to the flat rate. His alternative price is computed to maintain profit neutrality for a utility, given the range of elasticity and marginal cost of production. Using a representative sample of Barbadian households, Carter et al. (2009) perform simulation exercises to examine the impact of a proposed electricity pricing system on residential electricity demand and expenses.[6] In regard to the existing literature, our work demonstrates a concrete welfare-analysis of a complicated non-convex block pricing system.

The paper proceeds as follows. Section 2 explains how to compute equivalent variation under a non-convex block pricing system and introduces our measure of social welfare. Section 3 estimates the residential electricity demand function for South Korea and explains how to compute price elasticity of demand in case of block pricing. Section 4 performs scenario analysis, providing household electricity consumption, expense, welfare-change and social welfare-changes under alternative pricing systems. The section draws policy implications for the various pricing systems discussed. Finally, Section 5 lists our conclusions.

[5] Compensating variation (CV) does not necessarily ranks prices correctly (Mas-Colell et al., 1995). For example, consider L-shaped indifference curves whose kinks occur at vectors (1,1), (4,2) and (5,3). Let the level of utility from consuming $(1,1)$ be $u(1,1) = 1$ and let a demand correspondance $x(p,w)$ where p is a price vector and w is income. We denote an indirect utility function by $V(p,w)$ and expenditure function by $e(p,u)$. Let $p^0 = (1,1), p^1 = (1/2,0), p^2 = (0,2/3)$ and $w = 2$. Then $x(p^0,w) \ni (1,1)$, $x(p^1,w) \ni (4,2)$, $x(p^2,w) \ni (5,3)$, implying $V(p^2,w) > V(p^1,w)$. However, $\mathrm{CV}(p^0,p^1,w) = w - e(p^1,1) = 2 - 1/2 = 3/2$ and $\mathrm{CV}(p^0,p^2,w) = 2 - e(p^2,1) = 2 - 2/3 = 4/3$ concluding that $\mathrm{CV}(p^0,p^1,w) > \mathrm{CV}(p^0,p^2,w)$.

[6] Residential electricity demand and bill changes when switching from a block pricing to the flat rate are also studied in the following works: Borenstein (2009, 2011), Maddock and Castano (1991), Olmstead et al. (2007), Pashardes and Hajispyrou (2002), Rietveld et al. (2000), Whittington (1992), Ziv et al. (2006).

2 Block Pricing System and Equivalent Variation

Applied works usually employ consumer surplus to measure welfare effects of price changes. However, Hicks' *equivalent variation* is the correct measure to evaluate welfare effects of price changes.[7] Equivalent variation (EV) measures the amount the consumer would be indifferent to accept in lieu of the price change (Mas-Colell et al., 1995). Hausman (1981) shows how to compute EV when Marshallian demand function is known.

We first compute EV when an economy allows only a flat charge for each commodity. In this case, we can easily apply Hausman (1981)'s method. Consider a two-good economy that only produces electricity and an aggregate commodity as a numeraire. In this section, we indicate the initial pricing system and new pricing system with superscripts 0 and 1, respectively. A subscript indicates the block number. Bold face type indicates a vector. The price vector is $\mathbf{p} = (p, 1)$ where the economy adopts only a flat rate, p, for electricity. A consumer faces the initial price of $\mathbf{p}^0 = (p^0, 1)$ and his income is y^0. If the price of electricity decreases to p^1, his budget line will become flatter as Figure 1 shows. Facing new price p^1, the consumer will achieve utility level u^1 at point A from consuming x^1 units of electricity. Now suppose that the price of electricity stays the same at p^0, but the consumer still achieves the utility level u^1 with his income increased. Choosing consumption point B where he consumes x^e units of electricity, the consumer achieves utility u^1. The hypothetical consumption x^e is called *virtual consumption*. Achieving utility u^1 under the initial price will require income increase to support the consumption point B. *Virtual income* y^e is the income the consumer would need, in order to be as well-off as he would be after the price change. Equivalent variation (EV) is defined as the difference between the virtual income and the initial income, that is, $\mathrm{EV}(p^0, p^1, y^0) = y^e - y^0$. The problem is that we do not observe indifference curves or virtual income. However, once we know the Marshallian demand function, we are able to compute the EV.

[7] Footnote 5 explains compensating variation may not rank prices correctly.

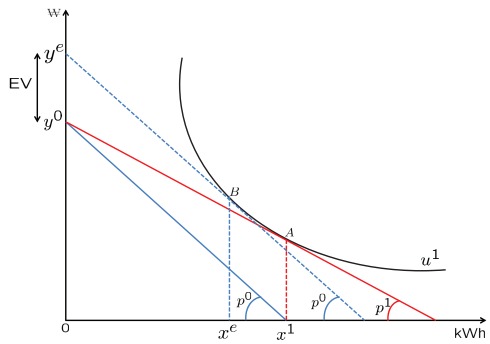

Figure 1: Equivalent Variation

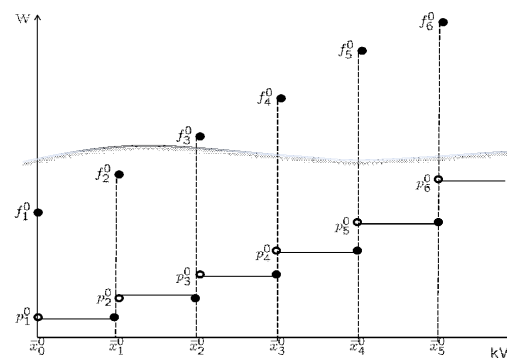

Figure 2: Baseline Pricing System

Given a Marshallian demand function, EV can be calculated easily for the case of a flat rate. Suppose Marshallian market demand function is linear as:

$$x(p, y) = \alpha p + \beta y + \gamma z \tag{1}$$

with coefficients α, β, γ and price p, income y and a vector of covariates z. An indirect utility function is defined as:

$$V(p, y) = \max_x \{u(x) | \mathbf{p} \cdot x \leq y\}$$

where u is a utility function. The expenditure function at utility u_0 and electricity price p is denoted by:

$$e(p, u^0) = \min_x \{\mathbf{p} \cdot x | u(x) \geq u^0\}.$$

Given the Marshallian demand function, we derive an indirect utility function from Roy's identity:

$$x(p, y) = -\frac{\partial V(p, y)/\partial p}{\partial V(p, y)/\partial y}.$$

The indirect utility function is increasing in income and the expenditure function is also increasing in utility. Thus, the inversion of the indirect utility function gives an expenditure function. For the demand function (1), the indirect utility function has the following form:

$$V(p, y) = \exp(-\beta p)\left[y + \frac{1}{\beta}\left(\alpha p + \frac{\alpha}{\beta} + \gamma z\right)\right]. \tag{2}$$

Replacing y with $e(p,u)$ and $V(p,y)$ with u in equation (2), the expenditure function is derived as:

$$e(p,u) = u\exp(\beta p) - \frac{1}{\beta}\left(\alpha p + \frac{\alpha}{\beta} + \gamma z\right). \tag{3}$$

When the price of electricity changes from p^0 to p^1, EV is written as:

$$\mathrm{EV}(p^0, p^1, y^0) = e(p^0, u^1) - e(p^1, u^1) = e(p^0, u^1) - y^0.$$

Plugging p^0 and u^1 to equation (3), we can write expenditure function as

$$e(p^0, u^1) = u^1 \exp(\beta p^0) - \frac{1}{\beta}\left(\alpha p^0 + \frac{\alpha}{\beta} + \gamma z\right)$$

with an unobserved value u^1. Since $u^1 = V(p^1, y^0)$ holds by definition, we have

$$u^1 = \exp(-\beta p^1)\left[y^0 + \frac{1}{\beta}\left(\alpha p^1 + \frac{\alpha}{\beta} + \gamma z\right)\right].$$

Therefore, EV is written only in known variables as follows

$$\mathrm{EV}(p^0, p^1, y^0) = \exp(\beta(p^0 - p^1))\left[y^0 + \frac{1}{\beta}\left(\alpha p^1 + \frac{\alpha}{\beta} + \gamma z\right)\right] - \frac{1}{\beta}\left(\alpha p^0 + \frac{\alpha}{\beta} + \gamma z\right) - y^0.$$

Now we compute EV for the case of nonlinear pricing system which generates a non-convex budget curve. Our argument is also applicable to the case of a convex budget curve. Our example, the electricity pricing system in Korea, is shown in Figure 2. Its fixed fee is increasing at each threshold and usage fee is increasing in block. To derive the equation of EV, we introduce the following notations. Let the current (initial) n-tier block pricing system consist of a vector of thresholds $\bar{\mathbf{x}}^0 = (\bar{x}_0^0, \cdots, \bar{x}_n^0)$ where $\bar{x}_0^0 = 0$ and $\bar{x}_n^0 = \infty$, a vector of usage fees $\mathbf{p}^0 = (p_1^0, \cdots, p_n^0)$, and a vector of fixed fees $\mathbf{f}^0 = (f_1^0, \cdots, f_n^0)$. Let an alternative m-tier block pricing system consist of a vector of thresholds $\bar{\mathbf{x}}^1 = (\bar{x}_0^1, \cdots, \bar{x}_m^1)$ where $\bar{x}_0^1 = 0, \bar{x}_m^1 = \infty$, a vector of usage fees $\mathbf{p}^1 = (p_1^1, \cdots, p_m^1)$, a vector of fixed fees $\mathbf{f}^1 = (f_1^1, \cdots, f_m^1)$.

The calculation of EV depends on whether virtual consumption x^e belongs to the interior of any i-th block or coincides with any threshold $\bar{x}_i^0$ of the initial n-tier block pricing system. We explain this point with a simple example in which the initial price system has three blocks and the new price system has two blocks as Figures 3 and 4 where their thresholds hold a relation such as $\bar{x}_1^0 < \bar{x}_1^1 < \bar{x}_2^0$. Suppose new consumption x^1 occurs

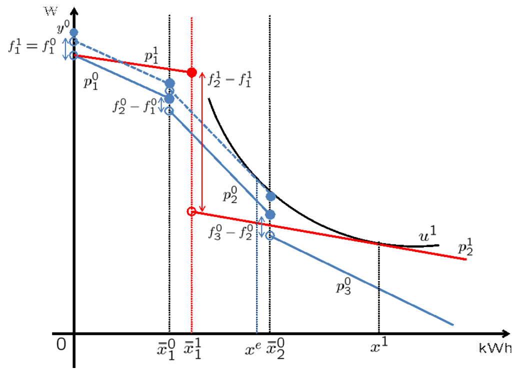

Figure 3: x^e lies in $(\bar{x}_1^0, \bar{x}_2^0)$

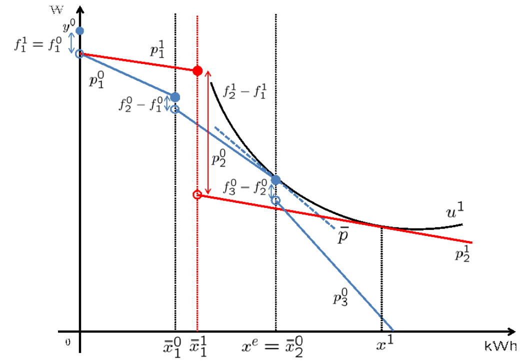

Figure 4: x^e meets a threshold $\bar{x}_2^0$

in the 2nd block of the new price system, that is, $\bar{x}_1^1 < x^1 \leq \bar{x}_2^1$, as in Figure 3. Then, the utility level from consuming x^1 is

$$u^1 = V(p_2^1, y^0 - f_2^1 + (p_2^1 - p_1^1)\bar{x}_1^1). \tag{4}$$

When a consumer demands x^1 in the 2nd block, he has to pay the corresponding fixed fee f_2^1. Then, his net income decreases to $y^0 - f_2^1$. In addition, the demand $\bar{x}_1^1$ out of x^1 is charged at p_1^1 instead of p_2^1. Thus, to demand x^1, he saves $(p_2^1 - p_1^1)\bar{x}_1^1$. Neither thresholds nor prices of the initial pricing system enter to equation (4).

Now consider a case in which virtual consumption x^e belongs to the interior of the 2nd block of the initial pricing system, that is, $x^e \in (\bar{x}_1^0, \bar{x}_2^0)$ as in Figure 3. A virtual income y^e supporting the virtual consumption x^e is

$$y^e = e(p_2^0, u^1) + f_2^0 - (p_2^0 - p_1^0)\bar{x}_1^1.$$

The expenditure $e(p_2^0, u^1)$ is the amount of money that a consumer needs to achieve utility level u^1 when the pricing system adopts only flat rate p_2^0. However, for the first $\bar{x}_1^1$ units of electricity, he actually needs to pay p_1^0 per unit. Thus, the third term in the above equation adjusts this price difference between blocks. In addition, he needs f_2^0 amount of money to pay the fixed fee as x^e belongs to the 2nd block. Thus, equivalent variation in this case is written as

$$\mathrm{EV}(\mathbf{p}^0, \mathbf{p}^1, y^0) = e(p_2^0, u^1) + f_2^0 - (p_2^0 - p_1^0)\bar{x}_1^1 - y^0. \tag{5}$$

Note that equation (5) only includes prices and thresholds of the initial pricing system. We can generalize this argument. Let optimal consumption x^1 after price change belong to the

l-th block of the new pricing system, that is, $\bar{x}^1_{l-1} < x^1 \leq \bar{x}^1_l$. Let virtual consumption x^e occur in the interior of the i-th block of the initial pricing system. For convenience, we define $\sum_{j=a}^{b} = 0$ if $a > b$ in this paper. The utility level after price change is

$$u^1 = V(p^1_l, y^0 - f^1_l + \sum_{j=1}^{l-1}(p^1_{j+1} - p^1_j)\bar{x}^1_j), \tag{6}$$

and the virtual income is

$$y^e = e(p^0_i, u^1) + f^0_i - \sum_{j=1}^{i-1}(p^0_{j+1} - p^0_j)\bar{x}^0_j,$$

therefore, the equivalent variation is written as

$$\mathrm{EV}(\mathbf{p}^0, \mathbf{p}^1, y^0) = e(p^0_i, u^1) + f^0_i - \sum_{j=1}^{i-1}(p^0_{j+1} - p^0_j)\bar{x}^0_j - y^0. \tag{7}$$

Now we consider the other case in which virtual consumption x^e occurs at an initial threshold $\bar{x}^0_2$ as in Figure 4. Any of the initial block prices p^0_1, p^0_2, p^0_3 does not make a tangent to the indifference curve achieving utility u^1. We have to define virtual price $\bar{p}$ and virtual income $\bar{y}$ which enables the virtual consumption x^e satisfying

$$u^1 = V(\bar{p}, \bar{y}). \tag{8}$$

From the Marshallian demand function, we have

$$x^1 = \alpha p^1_2 + \beta(y^0 - f^1_2 + (p^1_2 - p^1_1)\bar{x}^1_1) + \gamma z \tag{9}$$

and

$$\bar{x}^0_2 = \alpha\bar{p} + \beta\bar{y} + \gamma z. \tag{10}$$

Arranging equations (4), (8), (9), (10), we can write virtual price as

$$\bar{p} = p^1_2 + \frac{1}{\beta}\ln\left(\frac{\bar{x}^0_2 + \frac{\alpha}{\beta}}{x^1 + \frac{\alpha}{\beta}}\right). \tag{11}$$

The virtual income is derived from equation (10) as

$$\bar{y} = \frac{\bar{x}^0_2 - \alpha\bar{p} - \gamma z}{\beta} = \frac{1}{\beta}\bar{x}^0_2 - \frac{\alpha}{\beta}\left(p^1_2 + \frac{1}{\beta}\ln\left(\frac{\bar{x}^0_2 + \frac{\alpha}{\beta}}{x^1 + \frac{\alpha}{\beta}}\right)\right) - \frac{\gamma}{\beta}z.$$

Analogously to equation (5), we can write equivalent variation as

$$\mathrm{EV}(\mathbf{p}^0,\mathbf{p}^1,y^0)=e(\bar{p},u^1)+f_2^0-(\bar{p}-p_2^0)\bar{x}_2^0-(p_2^0-p_1^0)\bar{x}_1^1-y^0. \tag{12}$$

Having $e(\bar{p},u^1)=\bar{y}$ by definition, the individual welfare-change is written as

$$\begin{aligned}\mathrm{EV}(\mathbf{p}^0,\mathbf{p}^1,y^0)=&\frac{1}{\beta}\bar{x}_2^0-\frac{\alpha}{\beta}\left(p_2^1+\frac{1}{\beta}\ln\left(\frac{\bar{x}_2^0+\frac{\alpha}{\beta}}{x^1+\frac{\alpha}{\beta}}\right)\right)-\frac{\gamma}{\beta}z+f_2^0\\&-\left(p_2^1+\frac{1}{\beta}\ln\left(\frac{\bar{x}_2^0+\frac{\alpha}{\beta}}{x^1+\frac{\alpha}{\beta}}\right)-p_2^0\right)\bar{x}_2^0-(p_2^0-p_1^0)\bar{x}_1^1-y^0.\end{aligned}$$

Rearranging equation (9) to $\gamma z=x^1-\alpha p_2^1-\beta(y^0-f_2^1+(p_2^1-p_1^1)\bar{x}_1^1)$, we rewrite the equivalent variation as

$$\begin{aligned}\mathrm{EV}(\mathbf{p}^0,\mathbf{p}^1,y^0)=&-\frac{1}{\beta}\left(\bar{x}_2^0+\frac{\alpha}{\beta}\right)\ln\left(\frac{\bar{x}_2^0+\frac{\alpha}{\beta}}{x^1+\frac{\alpha}{\beta}}\right)+f_2^0+(p_2^1-p_1^1)\bar{x}_1^1\\&-(p_2^0-p_1^0)\bar{x}_1^1+(p_2^0-p_2^1)\bar{x}_2^0+\frac{1}{\beta}(\bar{x}_2^0-x^1).\end{aligned}$$

We generalize the above argument when virtual consumption x^e occurs at an initial threshold $\bar{x}_i^0$. The Marshallian demand function gives

$$x^1=\alpha p_l^1+\beta(y^0-f_l^1+\sum_{j=1}^{l-1}(p_{j+1}^1-p_j^1)\bar{x}_j^1)+\gamma z \tag{13}$$

and

$$\bar{x}_i^0=\alpha\bar{p}+\beta\bar{y}+\gamma z. \tag{14}$$

Using (6), (8), (13) and (14), we can write virtual price as

$$\bar{p}=p_l^1+\frac{1}{\beta}\ln\left(\frac{\bar{x}_i^0+\frac{\alpha}{\beta}}{x^1+\frac{\alpha}{\beta}}\right). \tag{15}$$

The virtual income is written as

$$\bar{y}=\frac{1}{\beta}\bar{x}_i^0-\frac{\alpha}{\beta}\left(p_l^1+\frac{1}{\beta}\ln\left(\frac{\bar{x}_i^0+\frac{\alpha}{\beta}}{x^1+\frac{\alpha}{\beta}}\right)\right)-\frac{\gamma}{\beta}z. \tag{16}$$

The welfare-change is

$$\begin{aligned}\mathrm{EV}(\mathbf{p}^0,\mathbf{p}^1,y^0)=&e(\bar{p},u^1)+f_i^0-(\bar{p}-p_i^0)\bar{x}_i^0-\sum_{j=1}^{i-1}(p_{j+1}^0-p_j^0)\bar{x}_j^0-y^0\quad\text{for } i\geq 1, \qquad (17)\\=&e(\bar{p},u^1)-y^0\quad\text{for } i=0.\end{aligned}$$

Rearranging equation (13) to $\gamma z = x^1 - \alpha p_l^1 - \beta(y^0 - f_l^1 + \sum_{j=1}^{l-1}(p_{j+1}^1 - p_j^1)\bar{x}_j^1)$, we write equivalent variation when $x^e = \bar{x}_i^0$ as

$$\begin{aligned} \mathrm{EV}(\mathbf{p}^0, \mathbf{p}^1, y^0) = & -\frac{1}{\beta}\left(\bar{x}_i^0 + \frac{\alpha}{\beta}\right) \ln\left(\frac{\bar{x}_i^0 + \frac{\alpha}{\beta}}{x^1 + \frac{\alpha}{\beta}}\right) + f_i^0 + \sum_{j=1}^{l-1}(p_{j+1}^1 - p_j^1)\bar{x}_j^1 \\ & - \sum_{j=1}^{i-1}(p_{j+1}^0 - p_j^0)\bar{x}_j^0 + (p_i^0 - p_l^1)\bar{x}_i^0 + \frac{1}{\beta}(\bar{x}_i^0 - x^1) \quad \text{for } i \geq 1, \\ = & -\frac{\alpha}{\beta^2} \ln\left(\frac{\frac{\alpha}{\beta}}{x^1 + \frac{\alpha}{\beta}}\right) + \sum_{j=1}^{l-1}(p_{j+1}^1 - p_j^1)\bar{x}_j^1 - \frac{1}{\beta}x^1 \quad \text{for } i = 0. \end{aligned} \tag{18}$$

So far we have assumed that the location of virtual consumption x^e is known. However, a tricky part of computing EV is actually to locate the virtual consumption x^e. First we assume that virtual consumption x^e belongs to the interior of the i-th block of the initial pricing system. Under the new pricing system, the utility level after price change satisfies equation (6). The virtual income y^e supporting x^e satisfies

$$u^1 = V(p_i^0, y^e). \tag{19}$$

Equating (6) and (19), we rewrite y^e in observable variables. We can compute the associated virtual consumption from demand function $x^e = \alpha p_i^0 + \beta y^e + \gamma z$. If the computed x^e indeed belongs to the interior of the i-th block, we conclude that x^e belongs to the i-th block. If not, we assume that x^e belongs to other blocks and repeat the same procedure until we have no contradiction.

If we still have a contradiction for the interiors of all blocks, x^e occurs at some threshold $\bar{x}_i^0$. In this case, equation (15) gives virtual price $\bar{p}$ written in observed or estimated variables. We derive virtual income $\bar{y}$ from equations (6) and (8). Then, we plug them into $x^e = \alpha\bar{p} + \beta\bar{y} + \gamma z$. We can compute virtual consumption x^e from

$$x^e = \left(\frac{\beta\bar{x}_i^0 + \alpha}{\beta x^1 + \alpha}\right)\left[y^0 - f_l^1 + \sum_{j=1}^{l-1}(p_{j+1}^1 - p_j^1)\bar{x}_j^1 + \frac{1}{\beta}\left(\alpha p_l^1 + \frac{\alpha}{\beta} + \gamma z\right)\right] - \frac{\alpha}{\beta}.$$

We check whether the derived x^e equals the assumed level $\bar{x}_i^0$. If $x^e = \bar{x}_i^0$ holds, we conclude that x^e occurs at $\bar{x}_i^0$. Otherwise, we repeat the procedure with other thresholds.

Once we measure the welfare-change of an individual household, we are able to measure an aggregate welfare-change of consumers from the change in pricing system. The aggregate welfare of all households is called the social-welfare. The most popular measure of social-welfare is the Atkinson measure. The Atkinson measure allows us to adjust the degree of inequality aversion. Given income level y_i of household i, $i = 1, \cdots, N$, social-welfare is defined as

$$W = \frac{1}{N} \sum_{i=1}^{N} u(y_i)$$

where $u(y_i)$ is household i's utility with income y_i. We denote by ρ the degree of inequality aversion. The individual utility function u is $u(y_i) = \frac{y_i^{1-\rho}}{1-\rho}$ for $\rho \neq 1$ and otherwise, $u(y_i) = \ln y_i$. Without loss of generality, for $\rho \neq 1$, it is assumed that $\frac{\partial W}{\partial y_i} = \frac{y_i^{-\rho}}{N} > 0$ and $\frac{\partial^2 W}{\partial y_i^2} = -\rho \frac{y_i^{-\rho-1}}{N} < 0$. This implies that the more a society averts inequality, the more it cares about the poor. For example, utilitarian social-welfare function is associated with the degree of inequality aversion $\rho = 0$, which is the average of all individual utilities. Rawlsian maximin social-welfare function follows from the infinite inequality aversion with $\rho = \infty$. Usually the degree of inequality aversion ρ is chosen between 0 and 2.

3 Electricity Demand and Individual Price Elasticity

In this section, we estimate the Marshallian demand function of residential electricity and compute price elasticity. This will allow us to compute a change of each household's electricity consumption under an alternative pricing system. Our household data is not panel-data but yearly survey-data for the year 2011 from Statistics Korea (KOSTAT). The household data has very limited price variation. There is no regional variation in the pricing system because electricity in Korea is supplied by the monopolistic state-owned entity, Korea Electric Power Corporation (KEPCO). Any price change occurs only once a year. Due to the limitation of the household data, we use aggregate data to estimate the demand function. When we compute each household's price elasticity and consumption levels under alternative scenarios, however, we use its consumption and marginal price from household data.[8]

[8] Ruijs (2009) applies the estimates in Ruijs et al. (2008) to welfare analysis for income quantiles. Ruijs et al. (2008) estimate water demand function using aggregate data for the Brazilian Metropolitan Region of São Paulo. The micro-level data was not available for their analysis. They assume that price elasticity of demand is the same for every household. They compute consumption change plugging household income to demand function.

Our aggregate data is annually reported by KEPCO. KEPCO announces its total sales value, the number of households as its customers, and the total usage for each year. Adjusting for inflation, we calculate average price as the total sales value divided by total usage.[9] The annual data covers the period 1980 through 2011. To estimate the demand function, we use real GDP per capita as a proxy to average income. Table 1 shows descriptive statistics of the aggregate data from 1980 through 2011. On average, a household consumes 269 kWh per month for average price of 153 won per kWh. During the sample period, the average real GDP per capita is approximately 10 million won and reaches 25 million won at the end of sample period. As weather is a significant factor for the consumption of electricity, we use heating degree days (HDD) and cooling degree days (CDD) as explanatory variables as well.

Table 1: Descriptive statistics: aggregate data

Variable	Average	Standard deviation	Minimum	Maximum
Usage(kWh)	269	145	80	499
Price(Won/kWh)	153	48	101	253
GDP per capita (Real,10,000 won)	1,024	755	101	2,492
Heating degree days (HDD)	722	102	451	946
Cooling degree days (CDD)	2,723	210	2,323	3,103

We will estimate a linear demand equation as follows:

$$x_t = \alpha p_t + \beta y_t + \gamma z_t + e_t \tag{20}$$

where $E[e_t|\Xi_t] = 0$ and Ξ_t represents the explanatory variables in (20). We denote household usage by x_t, price by p_t, household income by y_t at time t.[10] Additional covariates are denoted by a vector z_t. Since we find that x_t, p_t, y_t are unit-root time series and they are not cointegrated, we estimate with differenced series as follows:

$$\Delta x_t = \alpha \Delta p_t + \beta \Delta y_t + \gamma \Delta z_t + \epsilon_t. \tag{21}$$

[9] Using residential bill data from Southern California Edison, Borenstein (2009) examines the change in consumption in response to change in actual price schedule. He tests what concept of price consumers respond to. He finds both average price and marginal price are highly significant in the regressions of the elasticity of demand.

[10] When estimating aggregate demand (20) with average price, however, we do not include virtual compensation (Ruijs et al., 2008).

Choi et al. (2008) use the same procedure as this article and call it GLS corrected estimation.[11] They prove that coefficients in a spurious regression can be consistently estimated by taking the full first difference and the estimators are asymptotically normal. Regressing Δx_t on differenced explanatory variables generates consistent estimators for α and β.

Since the electricity price is set by the Korean government, we expect that endogeneity between price and consumption is not significant in our model. The endogeneity tests on price Δp_t support this observation, thus we can run OLS to estimate (21). For the endogeneity tests, we use one-period and two-period lagged average prices as instruments. Since the Cragg-Donald Wald F statistic is 10.278, there is little concern about weak instruments. The instruments are valid because the Sargan test statistic is 1.834 with a p-value of 0.1757. The Hausman test statistic is 1.05 and the p-value is 0.5906, which implies that we cannot reject the null hypothesis of no endogeneity between price and consumption.

We conduct two OLS regressions of models with different specifications, one with only price and income variables and the other also including weather variables. The results of the regressions are described in Table 2. In Model 1, the price coefficient is -0.494 and the income coefficient is 0.134. Model 2 shows that the estimated price coefficient is -0.582 and the estimated income coefficient is 0.125. Though both models show statistically-significant estimates of price and income coefficients, the coefficient estimates of CDD and HDD in Model 2 are not significant. EV computation requires the coefficient estimates to be as precise as possible. Therefore, we will use the estimates from Model 1 to calculate price elasticity later on.

[11] Choi et al. (2008) assume serial uncorrelatedness between the innovations of Ξ_t and e_t. However, even with a weaker condition such that $E[\Delta\Xi_t \Delta e_t] = 0$, coefficients in (21) can be consistently estimated. For example, the following model satisfies the condition $E[\Delta\Xi_t \Delta e_t] = 0$: we can write $p_t = p_{t-1} + u_{1,t}$, $y_t = y_{t-1} + u_{2,t}$ and $e_t = \psi e_{t-1} + \eta_t$ where $u_{1,t}, u_{2,t}$ and η_t are mean-zero stationary processes with $E[u_{1,t}\eta_t] = 0$ and $E[u_{2,t}\eta_t] = 0$. The explained and explanatory variables are cointegrated only if $|\psi| < 1$. We would like to check the validity of regressing equation (21). Differencing equation (20) and repeating equation (21) let us write the following two equalities and the last equality, respectively.

$$\begin{aligned}\Delta x_t &= \alpha\Delta p_t + \beta\Delta y_t + \gamma\Delta z_t + (e_t - e_{t-1}) = \alpha\Delta p_t + \beta\Delta y_t + \gamma\Delta z_t + (\psi - 1)e_{t-1} + \eta_t \\ &= \alpha\Delta p_t + \beta\Delta y_t + \gamma\Delta z_t + \epsilon_t.\end{aligned}$$

If $\psi = 1$ holds, then $E[\Delta p_t \epsilon_t] = E[u_{1,t}\eta_t] = 0$ and $E[\Delta y_t \epsilon_t] = E[u_{2,t}\eta_t] = 0$. As $e_t = e_0 + \sum_{i=0}^{t} \eta_i$ with $E[\eta_t] = 0$, we can rather assume $E[e_0] = 0$ instead of $E[e_t] = 0$. It's hard to tell what is the mean of nonstationary process.

Table 2: Regression results

Variables	Model 1	Model 2
Price	-0.494**	-0.582**
	(0.204)	(0.246)
Real GDP per capita	0.134***	0.125***
	(0.035)	(0.037)
CDD		0.032
		(0.024)
HDD		0.001
		(0.008)

Note : 1) *, **, *** represent significance at the 10%, 5% and 1% level, respectively.
2) Standard errors are in parentheses.

Our micro-level data from Family Budget Survey (FBS) shows household's income and expenses during a representative month of the year 2011. FBS is conducted by KOSTAT and it is nationally representative.[12] The data includes 10,543 households surveyed, but the sample we use in our scenario analysis includes 10,504 households. Since KEPCO charges every household a minimum fee of 1,000 won and taxes of 130 won per month, we omit households whose incomes are lower than 1,130 won. Factors that affect electricity consumption, such as the size and composition of a household, its residence type, and the ownership of electrical appliances are not considered in our analysis. Table 3 shows household electricity consumption and expense averaged for each income group under the current pricing system as of July 2011. Not surprisingly, higher income households have higher usage of electricity and pay more than lower income households. However, electricity expense as percentage of income decreases with the level of household income. This suggests that economic burden from paying for electricity consumption is greater among low-income households.

The computation of price elasticity is more involved for the case of nonlinear pricing systems (Reiss and White, 2005). Let an electricity pricing system consist of block usage fees $\mathbf{p} = (p_1, \cdots, p_n)$ and fixed fees $\mathbf{f} = (f_1, \cdots, f_n)$. Thresholds for blocks are denoted by

[12] KOSTAT surveys households on monthly basis and it announces monthly data, quarterly data and yearly data. We recover each household's electricity usage from its electricity bill at prices as of July 2011.

Table 3: Descriptive statistics: monthly household data

Income deciles	Income (won)	Electricity demand (kWh per month)	Electricity bill (won per month)	Electricity bill as % of income
1st	468,056	231	29,730	6.3
2nd	1,084,807	264	36,159	3.3
3rd	1,668,489	281	39,438	2.4
4th	2,205,302	292	41,478	1.9
5th	2,730,061	308	45,079	1.6
6th	3,242,167	322	48,012	1.5
7th	3,800,280	329	49,789	1.3
8th	4,475,195	337	51,556	1.2
9th	5,463,410	348	55,131	1.0
10th	8,288,155	372	60,694	0.7
Average	3,346,285	308	45,705	1.4

Note: The price schedule applied is as of July 2011.

$\bar{\mathbf{x}} = (\bar{x}_0, \bar{x}_1, \cdots, \bar{x}_n)$ where $\bar{x}_0 = 0$ and $\bar{x}_n = \infty$. A household's income is denoted by y^0. Let x^* be the household's optimal consumption level under the pricing system. We denote by p^* the household's equilibrium marginal willingness-to-pay (*mwtp*, which may differ from the marginal price if x^* occurs at a threshold). Let y^* be the household's income level that would induce x^* at price p^*. Let the household consume x^* units of electricity in the l-th block, i.e., $\bar{x}_{l-1} < x^* \leq \bar{x}_l$ for $1 \leq l \leq n$. The consumption x^* can be written from equation (20) as follows:

$$x^* = \alpha p^* + \beta y^* + \gamma z \tag{22}$$

where $y^* = y^0 - f_l + \sum_{j=1}^{l-1}(p^* - p_j)(\bar{x}_j - \bar{x}_{j-1})$. When the household's consumption x^* does not occur at threshold $\bar{x}_l$, marginal price p_l is the same as the household's *mwtp* for the last unit consumed. If x^* occurs at $\bar{x}_l$ where the price rises from p_l to p_{l+1}, the marginal price (*mp*) may differ from *mwtp*.

Denoting the price elasticity as $\xi = \frac{(mp)}{x^*}\frac{dx^*}{d(mp)}$, the total change in consumption can be written as

$$\frac{dx^*}{d(mp)} = \left[\frac{\partial x^*}{\partial(mwtp)} + \frac{\partial x^*}{\partial y} \cdot \frac{d\Delta y}{d(mwtp)}\right]\frac{d(mwtp)}{d(mp)} \tag{23}$$

where $\Delta y = -f_l + \sum_{j=1}^{l-1}(p^* - p_j)(\bar{x}_j - \bar{x}_{j-1})$. Note that the first term in the brackets, $\frac{\partial x^*}{\partial(mwtp)}$, is the slope of demand. The ratio $\frac{\partial x^*}{\partial y}$ is marginal income effect and $\frac{d\Delta y}{d(mwtp)}$ is the change in intra-marginal expenditure. The term outside the brackets satisfies $\frac{d(mwtp)}{d(mp)} = 0$ if $x^* = \bar{x}_l$ and $\frac{d(mwtp)}{d(mp)} = 1$ otherwise. We can arrange (23) to the following equation:

$$\frac{dx^*}{d(mp)} = \big(\alpha + \beta\bar{x}_{l-1}\big) \cdot \mathbf{1}\{\bar{x}_{l-1} < x^* < \bar{x}_l\}$$

where $\mathbf{1}\{\cdot\}$ is the indicator function. Finally, we write price elasticity at consumption level x^* with marginal price p_l as follows:

$$\xi = \frac{p_l}{x^*} \cdot \big(\alpha + \beta\bar{x}_{l-1}\big) \cdot \mathbf{1}\{\bar{x}_{l-1} < x^* < \bar{x}_l\}.$$

Table 4: Price elasticities (average: -0.297)

Income deciles	1	2	3	4	5	6	7	8	9	10
Price elasticity	-0.337	-0.315	-0.303	-0.301	-0.287	-0.289	-0.283	-0.287	-0.286	-0.283

Table 4 presents average price elasticities for each income decile. The price elasticity averaged for all households is -0.297, which implies inelastic demand. The absolute value of price elasticity decreases as a household income increases. The average price elasticity estimated in Yoo et al.(2007) is -0.2463, which is consistent with our price elasticity estimate.

4 Scenario Analysis

Our scenario analysis will address the impact of alternative pricing systems on consumers. We compute bill changes, consumption changes, and welfare-changes of individual households. In addition, we measure the change in social welfare to evaluate the alternative pricing systems. Six scenarios are set up as alternative pricing systems. We design them to maintain revenue neutrality under the assumption of perfectly inelastic demand as does Borenstein (2012). The summary of our scenarios is shown in Table 5.

The baseline scenario is the pricing system in Korea as of July 2011. It is a six-tier pricing system. The residential electricity is differently priced by voltage, low and high. Moreover, fees are composed of two parts, fixed fee and usage fee for each usage block. The Korean electricity pricing system is more complicated than in other countries, since not only usage fees but also fixed fees increase by usage block. A household should pay fixed fee of the fourth usage block if its marginal price is the usage fee of the fourth usage block. As noted earlier, the baseline has very large progressivity: the usage fee of the sixth block is eleven times that of the first block.

Scenarios S2 and S3 in Table 5 examine the effect of removing tiers by using flat charges. Saenuri Party and Ministry of Trade, Industry and Energy claim the progressivity should be three. Some of them request an alternative pricing system that has three usage blocks, separated by thresholds at 260kWh and 340kWh. Scenario S4 adopts these popular requirements. Similarly, we set scenarios S5 and S6 to have three blocks with the progressivity of three on fees. They differ from S4, as S5 has thresholds at 150kWh and 300kWh, and S6 has thresholds at 100kWh and 200kWh. Scenarios S5 and S6 help us to see how sensitive our result is to the level of thresholds. Scenario S1 maintains six-tiers with the same thresholds as the baseline system, but it adopts the progressivity of three.

Table 6 shows average demand, electricity expense and equivalent variation for income deciles under different scenarios. The marginal price each income decile faces under each alternative pricing system decreases from the marginal price it faces under the baseline. This explains why all income groups increase their electricity demand in every scenario. We also observe that in every scenario, except scenario S4, the percentage change in consumption tends to increase as income increases. On the other hand, as income increases, the percentage change in electricity expense decreases in every scenario. That is, low-income households experience a sharp increase in their electricity bill for a moderate consumption increase. This implies that low-income households may be relatively disadvantaged by rate changes. The flat charge scenarios S2 and S3 bring out the most drastic change in consumption and bills. Under scenario S3, the consumption among the lowest income group increases by 6.3 percent but the bill jumps up by 30.1 percent from the baseline. On the other hand, the average consumption of the highest income group rises by 15.4 percent from the baseline while its expense decreases by 1.2 percent. Low-income households will be worse off and high-income households will be better off under flat charge system in terms of monthly bill. Also, the lowest income households experience the smallest increase in EV under flat charges while highest income households experience the largest increase in EV. This demonstrates that a tier system serves one of its original purposes, which is to protect low-income households.

The values of EV in Table 6 allow us to clearly interpret the welfare impact of electricity

Table 5: Current pricing system and scenarios

Usage block(kWh)			1 ∼ 100	101 ∼ 200	201 ∼ 300	301 ∼ 400	401 ∼ 500	501 ∼
Baseline	Low voltage	Fixed	380	840	1,460	3,490	6,540	11,990
		Usage	56.2	116.1	171.6	253.6	373.7	656.2
	High voltage	Fixed	380	680	1,170	2,890	5,470	9,970
		Usage	53.4	91.2	135.1	196.3	294.5	531.9
S1	Low voltage	Fixed	1,493	2,091	2,688	3,285	3,883	4,480
		Usage	89.9	125.8	161.8	197.7	233.7	269.6
	High voltage	Fixed	1,362	1,907	2,452	2,997	3,541	4,086
		Usage	73.3	102.6	131.9	161.2	190.5	219.8
Usage block(kWh)			Flat charge					
S2	Low voltage	Fixed	0					
		Usage	142					
	High voltage	Fixed	0					
		Usage	119.7					
S3	Low voltage	Fixed	2,933					
		Usage	131.9					
	High voltage	Fixed	2,888					
		Usage	110.9					
Usage block(kWh)			1∼ 260		261∼ 340		341∼	
S4	Low voltage	Fixed	1,582		3,163		4,745	
		Usage	103.7		207.4		311.1	
	High voltage	Fixed	1,318		2,636		3,954	
		Usage	83.3		166.6		249.9	
Usage block(kWh)			1∼ 150		151∼ 300		301∼	
S5	Low voltage	Fixed	1,249		2,499		3,748	
		Usage	81.7		163.3		245	
	High voltage	Fixed	1,110		2,220		3,330	
		Usage	65.3		130.6		195.9	
Usage block(kWh)			1 ∼100		101∼200		201∼	
S6	Low voltage	Fixed	1,047		2,094		3,142	
		Usage	66		132.1		198.1	
	High voltage	Fixed	985		1,970		2,954	
		Usage	53		105.9		158.9	

Note: Fixed (won) and Usage (won/kWh)

pricing systems on each income group and average household. The values of EV are positive for all income groups under every scenario. This implies that changing the electricity pricing system from the baseline is considered desirable. The 1st income decile has the largest EV under scenario S5, the second largest under S4, the third largest under S6, the fourth under S1, the fifth under S2 and the smallest under S3. The 2nd and 3rd income deciles have the largest EV under scenario S4, the second largest under S5, the third largest under S6, the fourth under S1, the fifth under S2 and the smallest under S3. Low-income households prefer a three-tier system with progressivity three to a six-tier system or a flat charge system. Given the information of average prices in Table 7, we note that for a household from the first three income deciles, the less its average price increases, the more its EV increases. The 4th and 5th income deciles experience the largest increase in EV under scenario S4 and the smallest increase under S2. Those median income groups favor S4 which is a three-tier system with higher threshold levels than the other three-tier systems S5 and S6. Overall, low-income households improve their welfare under S4 as the most and under S2 as the least. Households from the 6th to 10th income deciles improve their welfare under S3 as the most, then the second most under S2. Their EV increases the least under S4 and S5. The richest households from the 9th and 10th income deciles have significant EV increases in every scenario. Thus, the average household for all income deciles ranks scenarios in the same way as a household from the 9th and 10th income deciles ranks them. The average household for all income deciles have the largest EV under S3, and the second largest under S2, the third largest S6, the fourth largest under S1, the fifth largest under S5 and the smallest under S4. The households from 9th and 10th income deciles are very responsive to changes in average price, in order to enhance their welfare.

Now we want to summarize the results for multiple income groups and evaluate scenarios from the perspective of social welfare. Having each household's EV, we compute social welfare according to the Atkinson measure of social welfare. We set the degree of inequality aversion, ρ, to vary from 0 to 2. The results in Table 8 show the percentage changes compared to the social welfare of the baseline pricing system. When a society is concerned less about inequality, that is, ρ is less than 1, a flat charge with a fixed fee is the best pricing system. When a society likes to avoid inequality, with ρ greater than or equal to 1, the three-tier systems S4, S5, S6 achieve greater social welfare than the six-tier pricing system S1 or flat charges S2, S3. The first five income deciles prefer scenarios S4 and S5 to the scenario S6 whose thresholds are as small as 100kWh and 200kWh. Thus, for

Table 6: Change in demand, bill, and equivalent variation

Income deciles	Demand (kWh)	Electricity bill (Won)	EV (Won)	Income deciles	Demand (kWh)	Electricity bill (Won)	EV (Won)
S1				S2			
1st	238 (3.0)	34,949 (17.6)	12,985	1st	243 (4.4)	37,439 (25.9)	5,359
2nd	275 (4.3)	41,450 (14.6)	20,821	2nd	284 (8.1)	43,485 (20.3)	15,851
3rd	296 (5.1)	44,913 (13.9)	25,601	3rd	308 (9.5)	46,634 (18.2)	19,767
4th	307 (5.3)	46,786 (12.8)	25,063	4th	321 (9.6)	48,353 (16.6)	19,411
5th	326 (5.6)	49,973 (10.9)	18,019	5th	341(11.1)	51,085 (13.3)	17,447
6th	343 (6.5)	52,734 (9.8)	78,255	6th	360(11.9)	53,135 (10.7)	79,826
7th	351 (6.7)	54,440 (9.3)	43,064	7th	369(11.8)	54,383 (9.2)	49,519
8th	361 (7.1)	55,942 (8.5)	133,448	8th	380(12.8)	55,526 (7.7)	133,023
9th	375 (7.7)	58,684 (6.4)	111,564	9th	394(13.4)	57,196 (3.7)	134,558
10th	404 (8.7)	63,649 (4.9)	280,988	10th	426(14.4)	60,560 (-0.2)	336,303
Average	328 (6.5)	50,352 (10.2)	74,981	Average	343(11.4)	50,780 (11.1)	81,106
S3				S4			
1st	247 (6.3)	38,683 (30.1)	3,019	1st	242 (4.0)	33,875 (13.9)	17,069
2nd	289 (9.7)	44,272 (22.4)	14,776	2nd	275 (4.5)	39,663 (9.7)	25,878
3rd	312(11.0)	47,182 (19.6)	19,454	3rd	292 (4.0)	42,716 (8.3)	31,607
4th	325(11.0)	48,753 (17.5)	20,072	4th	302 (3.2)	44,224 (6.6)	29,920
5th	345(12.4)	51,270 (13.7)	18,485	5th	317 (3.4)	47,244 (4.8)	20,876
6th	364(13.2)	53,143 (10.7)	80,250	6th	333 (3.3)	50,109 (4.4)	78,373
7th	373(13.0)	54,297 (9.1)	52,114	7th	339 (2.8)	51,889 (4.2)	40,951
8th	384(14.0)	55,347 (7.4)	138,372	8th	348 (3.3)	53,482 (3.7)	130,194
9th	398(14.5)	56,877 (3.2)	139,575	9th	360 (3.5)	56,837 (3.1)	98,109
10th	429(15.4)	59,939 (-1.2)	345,630	10th	387 (3.8)	62,746 (3.4)	246,704
Average	347(12.7)	50,976 (11.5)	83,175	Average	320 (3.9)	48,279 (5.6)	71,968
S5				S6			
1st	236 (1.2)	33,036 (11.1)	17,264	1st	232 (-0.2)	32,878 (10.6)	15,062
2nd	270 (2.7)	39,611 (9.5)	24,881	2nd	269 (2.5)	39,799 (10.1)	22,148
3rd	290 (3.2)	43,205 (9.6)	28,336	3rd	291 (3.6)	43,612 (10.6)	26,927
4th	301 (2.7)	44,984 (8.5)	25,774	4th	303 (3.6)	45,749 (10.3)	23,166
5th	318 (3.9)	48,398 (7.4)	18,373	5th	322 (5.1)	49,227 (9.2)	17,517
6th	336 (4.3)	51,262 (6.8)	75,454	6th	342 (6.1)	52,016 (8.3)	77,060
7th	344 (4.3)	53,175 (6.8)	39,308	7th	350 (6.2)	53,711 (7.9)	42,424
8th	353 (4.9)	54,609 (5.9)	129,603	8th	361 (7.3)	55,289 (7.2)	134,271
9th	368 (5.7)	57,656 (4.6)	104,123	9th	376 (8.2)	57,774 (4.8)	113,319
10th	398 (6.9)	63,168 (4.1)	269,827	10th	409 (9.8)	62,560 (3.1)	296,703
Average	321 (4.2)	48,910 (7.0)	73,294	Average	326 (5.8)	49,262 (7.8)	76,860

Note: The percentage change from the baseline in both demand and bill expense is in parentheses.

Table 7: Average Price (Won)

Income deciles	S1	S2	S3	S4	S5	S6
1st	146.84	154.07	156.61	139.98	139.98	141.72
2nd	150.73	153.12	153.19	144.23	146.71	147.95
3rd	151.73	151.41	151.22	146.29	148.98	149.87
4th	152.40	150.63	150.01	146.44	149.45	150.99
5th	153.29	149.81	148.61	149.03	152.19	152.88
6th	153.74	147.60	146.00	150.48	152.57	152.09
7th	155.10	147.38	145.57	153.06	154.58	153.46
8th	154.96	146.12	144.13	153.68	154.70	153.16
9th	156.49	145.17	142.91	157.88	156.67	153.65
10th	157.55	142.16	139.72	162.13	158.71	152.96
Average	153.51	148.05	146.90	150.87	152.37	151.11

ρ greater than or equal to 1, social welfare is greater under S4 and S5 than under S6. This implies that if a society is highly concerned with inequality, it should change its pricing system to a three-tier system with progressitivity three whose first two blocks are wider than the baseline's or scenario S6's. The flat charge systems S2 and S3 generate the smallest social welfare under ρ greater than or equal to 1. Therefore, decreasing progressivity and the number of blocks to three from the current pricing system is desirable if society abhors inequality. Keeping multiple blocks serves to protect low-income households. But, if low-income households instead can be protected better by other measures, changing to a flat charge system with moderate average price would enhance social welfare.

5 Conclusions

Our work not only draws practical implications of residential electricity block pricing for policy makers, but also demonstrates a concrete welfare-analysis of a complicated non-convex block pricing. Our results imply that the current pricing system reduces consumer welfare. In addition, the large price difference between the first block and the last block suppresses demand increase. Thus, the current pricing system may function as a passive energy conservation method, but it does not function well as a redistribution method. Searching for

Table 8: Percentage changes in social welfare

	S1	S2	S3	S4	S5	S6
ρ=0	2.24333	2.42664	**2.48852**	2.15318	2.19287	2.29956
ρ=0.5	1.05569	1.07644	**1.09455**	1.05739	1.05759	1.08112
ρ=1	0.16730	0.15606	0.15669	**0.17599**	0.17482	0.17215
ρ=1.5	3.07573	2.79561	2.83238	3.24834	**3.25391**	3.13498
ρ=2	30.12964	28.79043	29.43455	30.77017	**30.85318**	30.16936

Note: Percentage changes are compared to the social welfare of the baseline pricing system. Numbers in bold indicate the largest values of social welfare.

alternative pricing systems is desirable. In conclusion, our result suggests that a tier system should be maintained to protect low-income households, but that the number of blocks and the price difference between blocks be decreased from the current level. We plan to examine whether the new higher electricity demands, arising under our scenarios, will be able to be served by the existing electric power market when access to the production cost data is attained.

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