A Comparison of Electricity-Pricing Schemes: Equity, Cost Recovery, and Economic Efficiency

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Abstract

Electricity pricing is the main economic instrument used to charge for residential electricity and to manage its consumption. A regulated price in general cannot reflect the true value of electricity. However, a market-based electricity-pricing scheme for residential electricity is efficient while it is also criticized due to its unaffordability to the poor. This article empirically compares four electricity-pricing schemes, namely, increasing-block pricing (IBP), floating increasing-block pricing (FIBP), free market pricing (FMP), and a price-cum-trade incentive system (PTS), in terms of the aspects of efficiency, equity, and cost recovery by using electricity-related data for Taiwan. The research results show that IBP and FIBP suffer from the same problem in that it is hard to be cost-neutral, and FMP is economically efficient while preferring utility to the households. PTS performs the best, in that it can be economically efficient, as well as cost-neutral, and it can also improve income distribution.

Keywords: residential electricity, efficiency, affordability, cost recovery, consumer's surplus, floating increasing-block pricing.

JEL classification: Q41; Q48

1. Introduction

Since the 1880s, both the demand for and supply of electricity have been constantly increasing because electricity is essential to modern life. In practical terms, the electricity industry has been characterized by economies of scale and has been treated as a regulatory industry (Smith, 1996). To prevent the abuse of private market power and achieve a stable and adequate electricity supply, the electricity industry has mainly been state-owned and operates under the government's supervision (Bacon, 1995; Holburn and Spiller, 2002). There are several fundamental pricing schemes. One is *average cost* (AC) pricing which guarantees cost recovery, but results in a deadweight loss of social welfare (SW), and another is *long-run marginal cost* (LRMC) pricing which guarantees economic efficiency, but results in positive (negative) profits for a regulated industry when the average cost curve is increasing (decreasing) in the demand domain (Posner, 1974). More recently, a popular alternative scheme has been increasing-block pricing (IBP hereafter), which charges a lower price for an initial consumption block and increasing prices for higher consumption blocks (Herriges and King, 1994; Borenstein, 2012). In general, the goals of pricing schemes such as economic efficiency, equity, and cost recovery are hardly designed compatibly (see, e.g., Schoengold and Zilberman, 2014).

Because a regulated monopoly firm may produce inefficiently and a regulated price may neither be economically efficient nor reflect the real value of electricity, economists in the 1980s started to reconsider the issue of the privatization and deregulation of the utility industries (Kahn, 1988; Nagayama, 2009; Willis and Philipson, 2014). However, while liberalization has gradually permeated the generation, distribution, and retail stages of the electricity industry, equity and affordability are still two critical concerns under a free market because electricity is usually viewed as a life necessity, although competition can improve economic efficiency.

In this article, we empirically compare four electricity-pricing schemes with each other, i.e., IBP, floating increasing-block pricing (FIBP), free market pricing (FMP), and a price-cum-trade incentive system (PTS), in terms of the indicators of efficiency, equity and cost recovery by using electricity-related data for Taiwan households. Taiwan is an electricity-deregulating economy in which energy is scarce and is heavily dependent on importing fossil-fuel derivatives. A regulated IBP scheme, which considers seasonality, has long been applied to set the price to be charged for electricity. In recent years, due to the volatile price of international crude oil, the regulated electricity price cannot correctly signal the value of electricity and is unable to reflect the production cost. The regulated electricity utility as a consequence has suffered huge losses. Recently, the electricity price has finally been allowed to float with fuel costs, i.e., FIBP has been applied. However, because IBP *per se* is found to be beset by the problems of being inefficient, having a limited capacity to address the equity issue, and hardly being cost-neutral (see, e.g., Ito, 2014; Schoengold and Zilberman, 2014; Griffin and Mjelde, 2011; Boland and Whittington, 2000; Hanemann, 1998), it is interesting to know the empirical performance of the floating version in a circumstance where demand and supply change. By the same criterion, the performance of FMP and a newly-designed pricing scheme, PTS, are also examined in this article.

The PTS, proposed by Hung and Chie (2013), combines the pricing and cap-and-trade systems. The allocation of initial rights to individuals is used to take equity into account while efficiency is achieved through trades. This scheme embodies the implication of the second fundamental theorem of welfare economics that we can achieve a Pareto optimal allocation as a market-based equilibrium using an appropriate lump-sum distribution. There are few studies that explore the performance of FIBP and PTS, although comparisons among some other pricing schemes such as IBP, a uniform rate, a two-part tariff, and means-tested tariffs have been examined (see, e.g., Schoengold and Zilberman, 2014; Barde and Lehmann, 2014; Griffin and Mjelde, 2011; García-Valiñas, 2005; Wodon et al., 2003; Castro-Rodríguez et al., 2002; Boland and Whittington, 2000; Hanemann, 1998). In addition, these existing comparisons are basically performed under a regulated scenario. In this article, we vary many different demand and supply scenarios to see in detail how the two alternatives, FIBP and PTS, will perform in comparison with IBP and FMP.

The empirical findings show that: (1) the problems of IBP mentioned above are verified again by this article, (2) FIBP faces the same problems as IBP although the rate structure can be adjusted with the variation in production costs, (3) FMP is economically efficient while it may worsen the income distribution, and (4) PTS is also economically efficient while it could improve the income distribution.

The remainder of this paper is organized as follows. In Section 2, we specify the environment for the analysis and briefly outline the individual pricing schemes. In Section 3, the relevant data in Taiwan are described and the electricity demand function is estimated. Section 4 presents our empirical findings based on three aspects of efficiency, equity, and cost recovery. Lastly, Section 5 provides conclusions.

2. The background setting: Electricity industry and pricing schemes

From production to consumption, there are four stages for the electricity industry, i.e., generation, transmission, distribution, and retail. Since the 1980s, over 70 countries, including the U.K., the U.S., Australia, New Zealand, Norway, Sweden, Chile, Nepal, Ireland, New Zealand and Taiwan, have gradually liberalized the generation and/or distribution of electricity to enhance market competition (see Lai, 2001; Bacon, 1999; Steiner, 2001; Nepal, 2013). If we take no account of the high fixed-cost transmission stage, the electricity utility industry does not have the characteristics of economies of scale and a natural monopoly. Therefore, as Figure 1 indicates, a marginal cost pricing utility will earn a positive profit (area $P_{\mathrm{MC}}\mathrm{EB}P_0$).

On the supply side, we assume that competition is introduced at the generation stage. The government auctions the total amount of electricity and the lower production-cost firms win the electricity auctions. The government further sets a price cap equal to the average cost of producing the total amount of electricity such that firms cannot charge more than this cap price. The average-cost price cap can ensure that firms are cost-neutral and do not earn an extra profit or suffer a loss. In this article, because data for Taiwan are used to perform the analysis and IBP pricing is the status quo scheme applied in Taiwan, we make an assumption that the status quo aggregate rate structure (IBP_0) is cost-neutral to simplify the comparison and analysis. That is, we assume that IBP_0 fits the LRMC curve well. Based on this assumption, we compare the empirical effects of IBP, FIBP, FMP, and PTS.

On the demand side, the influences of pricing schemes on efficiency, equity, and cost recovery are examined. These pricing schemes are outlined as follows:

(1) Increasing-block pricing, IBP

IBP charges a lower price for an initial consumption block and increasing prices for higher consumption blocks. In general, the lower-price block is designed to take care of the poor, while the higher-pricing blocks are designed to recover production costs (through cross-subsidizing) and to reduce resource waste.

(2) Floating increasing-block pricing, FIBP

Under FIBP, the existing IBP rate structure can float with the electricity-generation costs. For example, if the fuel costs rise (decrease) by two percent, the price for each electricity consumption block of the existing IBP will correspondingly rise (decrease) by the same percentage. However, if the electricity-generation costs do not change, the price under FIBP is the same as that for the status quo IBP.

(3) Free market pricing, FMP

Under this scheme, the electricity price is determined freely by the market. Each electricity user faces the market equilibrium price.

(4) Price-cum-trade incentive system, PTS

Under PTS, the total amount of electricity is allocated to each electricity user as a usufructuary electricity right ($\overline{q}$). Individual users should pay for the electricity to which they are entitled by the usufructuary rights. In this article, we set the price as the cost-neutral average cost (P_{AC}). Users can use this amount of electricity by themselves or trade with others at the market equilibrium price (P^*). Therefore, a user who sells his usufructuary quantity can earn a unit profit at the price spread of ($P^* - P_{AC}$) and a user can pay at the market equilibrium price (P^*) to buy more electricity than the amount that he is entitled to use.[1]

3. Methodology and Data

In this section, we first describe the data applied. We then discuss the methodology of how to compare the issues of economic efficiency, cost recovery, and equity among pricing schemes. Meanwhile, in order to obtain the market equilibrium price and explore the welfare effect, the household electricity demand function is estimated.

3.1 Data description

Our data set consists of the original sampling data from the “Report on the Family Income and Expenditure Survey” in Taiwan. This survey is conducted nationwide and annually and contains data on family income, various expenditures including electricity bills, and household characteristics. The main advantages of this

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[1] The interested reader can refer to Hung and Chie (2013) for the details on the PTS. In addition, we apply the ex-post market mechanism proposed in Hung and Chie (2013) to avoid the occurrence of high transaction costs when all households trade in a centralized market.

data set are that it contains many household observations which provide sufficient variation and the data are reliable and complete.

There are two points regarding the data processing and application that should be mentioned. First, we choose data for the year 2007 for our analysis because a policy, the Power Tariff Discount on Energy Conservation Incentive Measures, was applied from the year 2008. This policy might distort the relationship between the electricity tariff and its consumption, which cannot be dealt with by a cross-sectional data set. Therefore, in order to have a correct estimate of the price effect, the data set for the year 2007 is applied. However, we have also applied the latest 2013 data set in our analysis. The 2013 results confirm the robustness of the 2007 findings.[2]

Second, the data set directly provides data on annual household electricity expenditure instead of monthly household electricity consumption. To obtain the latter figure, we therefore require data such as the household monthly percentages for annual electricity expenditure and the corresponding rate structure in order to perform the calculation.[3] To be specific, we first divide the total electricity consumption of each month in the residential sector (reported by the Bureau of Energy, Taiwan) by the number of household users (reported by Taiwan Power Company) to obtain the

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[2] The 2013 results can be obtained from the authors upon request.

[3] In 2007, the rate structures for the residential sector were as follows: (1) The summer rates (NT$/kWh, monthly) were 2.1, 2.73, 3.64 and 3.74 for electricity consumption blocks of 1-110, 111-330, 331-500 and 501+ kWhs, respectively. (2) The non-summer rates were 2.1, 2.415 and 2.9 for electricity consumption blocks of 1-110, 111-330 and 331+ kWh, respectively. In addition, summer months included June, July, August and September. The other months were categorized as non-summer months.

monthly electricity consumption of an average household. We then calculate the monthly electricity expenditures of this average household by matching the monthly electricity consumption with the corresponding electricity tariffs. Next, the electricity-expenditure percentages for each month are calculated. We use these monthly percentages to spread the annual electricity expenditure of individual households reported in the data set to monthly electricity expenditures. In Taiwan, because the monthly temperatures and the tariffs in the summer and non-summer months are different, the above-mentioned method is better than directly dividing the annual electricity expenditure by twelve to obtain the monthly electricity expenditure. Finally, by using the corresponding tariffs, the monthly electricity consumption can be derived from the monthly electricity expenditures.

The data set contains 13,741 households after removing missing data and outliers. Table 1 presents the descriptive statistics of the variables. Except for annual-fixed variables (family size, house size, and the number of air conditioners), variables such as electricity expenditures, electricity consumption, household disposable income and the average electricity price are distinguished according to whether they relate to summer or non-summer months. As expected, electricity expenditures, electricity consumption and the average electricity price are higher in the summer months than in the non-summer months.

3.2 Economic efficiency, cost recovery, and equity

As for the aspect of economic efficiency, we take social welfare, which is composed of the consumer's surplus (CS) and the utility's profit, as the criterion for comparison among schemes. As mentioned above, the status quo IBP is assumed to be cost-neutral. When production cost does not change, FIBP is the same as the status quo IBP. When production cost changes, FIBP can reflect this change while IBP cannot. The magnitudes of profit under IBP and FIBP depend on the analyzed scenarios. Under PTS, because the utility charges the cost-neutral average cost, the utility's profit is always zero. Under FMP, the utility can make a profit if the market equilibrium price is higher than the average cost.

The magnitude of CS is illustrated in Figure 2, which is a simple two-tier IBP case with two households considered. The curve IBP_0 is the aggregation of the individual IBP rate structure faced by households (IBP_i) and IBP_0 is assumed to fit the LRMC well. Suppose that the curve TD represents the aggregate electricity demand and the total electricity supply is currently TQ. Under IBP, the area above IBP_0 and under the demand curve is CS, which is the sum of the dark and light gray areas (CS_1 and CS_2). Under FMP, the market equilibrium price (P^*) and quantity (Q^*) are determined by IBP_0 (LRMC) and TD. The consumer's surplus is therefore simply the dark gray area, CS_1. Under PTS, a user can buy more electricity than the usufructuary amount he is entitled to or sell his usufructuary quantity at the market equilibrium price (P^*). A basic part of the consumer's surplus is CS_1. Moreover, because a user might earn a profit at the price spread of ($P^* - P_{AC}$), this profit is also treated as a part of the consumer's surplus. In theory, the social welfare under FMP is the largest. We conduct an empirical analysis under various scenarios to understand the magnitudes of social welfare, the consumer's surplus, and the utility's profit under different pricing schemes.

The utility's profit and a cost recovery ratio (CRR) are used to examine the issue of cost recovery. CRR is defined as the ratio of the utility's total revenue to the utility's total cost. Under the different scenarios, the utility may either recover its cost or not.

As for equity, we first sort the data set by the level of household disposable income per capita (DIPC) from low to high, and separate the data into five groups where each group basically has an equal number of observations. We then define a new variable, DIPC_after (which is the household DIPC after deducting the electricity expenditure per capita), to see the differences in income distribution under different pricing schemes.

3.3 Estimation of household electricity demand

Because electricity is generally recognized as a necessity of modern life, it is reasonable to assume that there is a minimum or subsistence level of household electricity consumption which is incurred irrespective of the electricity price. To estimate this subsistence consumption level, the setting of a demand function derived from the Stone-Geary utility function is frequently used, and is specified as follows:[4]

$$q = \delta + \beta \frac{I}{p}, \tag{1}$$

where q is the quantity of electricity consumption, I is disposable income, and p denotes the electricity price. The parameter β is the ratio of electricity expenditure to disposable income and $\delta = (1-\beta)\gamma$, where γ represents the subsistence consumption level. Therefore, the estimated subsistence level ($\hat{\gamma}$) can be obtained by $\hat{\gamma} = \hat{\delta}/(1-\hat{\beta})$, where $\hat{\delta}$ and $\hat{\beta}$ are the estimates of δ and β, respectively. In addition, the estimated price elasticity (η_p) and income elasticity (η_I) can be derived by $\eta_p = -\eta_I = -\hat{\beta}(\bar{I}/\overline{pq})$. Here, $\bar{I}$, $\bar{p}$, and $\bar{q}$ are the means of I, p, and q, respectively.

In order to capture the diversity of household electricity consumption, we sort the data set by the level of household electricity consumption from low to high and

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[4] For the details regarding the function's derivation, the reader can refer to Gaudin et al. (2001), Martínez-Espiñeira and Nauges (2004), Dharmaratna and Harris (2012), and Hung and Chie (2013). In addition, there are a few studies that estimate the electricity demand function for the case of Taiwan. Holtedahl and Joutz (2004) used annual time-series data for the period 1955-1995 to perform the estimation and Hung and Huang (2015) employed a monthly panel data set, composed of 19 counties and spanning the period from 2007 to 2013, to do so. Their estimated results are, however, not suitable for being applied in this paper due to the characterisics of the data, time and functional form.

separate the data into five groups with each having equal observations in principle in order to estimate five different household electricity demand functions. Furthermore, we argue that if we estimate the household demand function directly by defining a household as a unit, the variable family size not only influences the dependent variable of household electricity consumption, but also the independent variables such as the purchasing power (represented by the disposable income). For example, with the same household income, the purchasing power of a household with one member or ten members is very different. To avoid estimation bias, we estimate the per capita electricity demand function for each group. We then sum the per capita electricity demand functions according to the family size of the individual household to derive the individual household electricity demand function.

To be specific, we first develop the estimate of per capita electricity demand for each group as

$$q_i = \delta + \beta \frac{I_i}{p} + \alpha X_i + \varepsilon_i , \tag{2}$$

where the subscript i refers to an average individual in household i, q_i is the quantity of electricity consumption per capita, I_i is disposable income per capita, X_i contains control variables to represent the idiosyncratic properties of individuals, α is the corresponding vector of estimation parameters, and ε is the regression residual. The control variables (X_i) in this article are house size per capita (*HSPC*) and the number of air-conditioners owned per capita (*ACPC*).

We then obtain the electricity demand of household *i* by multiplying q_i by n_i, the family size of household *i*. That is,

$$n_i q_i = n_i(\delta + \beta \frac{I_i}{p} + \alpha X_i + \varepsilon_i) \qquad (3)$$

It should be mentioned that our estimation uses the average price faced by the individual to represent the *p*. The average price is defined by dividing the household electricity expenditure by the quantity of household electricity consumption. The reason we did not consider marginal price is that the rate structure applied in Taiwan is very complicated and it is too expensive for households to monitor the real-time marginal price in reality (Ito, 2014).

The regression results of the per capita demand function for five groups (sorted by household electricity consumption from low to high) are shown in Tables 2 and 3, where Table 2 presents the estimation for the summer period, and Table 3 that for the non-summer period. The results of the demand patterns are consistent in both periods. It is shown that the house size per capita (*HSPC*) and the number of air-conditioners owned per capita (*ACPC*) have significantly positive influences on the electricity consumption per capita. However, the price and income elasticities are all very small. This means that the electricity demand per capita is inelastic. The estimated subsistence levels ($\hat{\gamma}$) for each group are shown in the last row, which exhibits a

U-shaped pattern as the household consumption level increases. Interestingly, the empirical findings of these heterogeneous behaviors might foster the transaction motivation between electricity consumers when trades are allowed.

4. Empirical Analysis

This section empirically analyzes the performance of the four pricing schemes, namely, IBP, FIBP, FMP and PTS, on economic efficiency, income equity, and production cost recovery. The status quo IBP is assumed to be cost-neutral and the aggregate rate structure, IBP_0, represents the LRMC curve. In the following, the status quo and the other six different scenarios for changes in supply and demand conditions are set and discussed. Note that the unit of all monetary variables is the New Taiwan dollar (NT$), and the quantity of electricity is measured in kWh.

4.1 Status quo scenario

The status quo situation in terms of the demand for and supply of residential electricity is the basic analytical environment. Under this scenario, the monthly total electricity consumption is 7,180,539 kWh for the summer months and 5,372,284 kWh for the non-summer months. It should be noted that these quantities of electricity consumption are not efficient allocations from the viewpoint of society. This could be illustrated by Figure 2. In Figure 2, households consume quantities Q_1 and Q_2 when they face the IBP rate structure (IBP_i) and total electricity consumption $TQ = Q_1 + Q_2$. However, according to the optimal condition for resource use, the equality of LRMC (IBP_0) and marginal benefit (*TD*), the efficient allocation is Q^* and the optimal electricity price is P^*. Therefore, household 1 over-consumes electricity ($Q_1 > Q_1^*$) because it faces a price which is lower than the efficient price. This results in a deadweight loss, depicted by the triangle ABC. Under IBP, most households do not face the real price of resources (e.g., household 1 in Figure 2). Resources are inefficiently used and a deadweight loss is caused. This is one of the IBP's problems that is usually criticized. FIBP faces the same problem because it is also tiered-pricing. Under FMP and PTS, however, free trades lead to the optimal allocation of price and quantity (P^* and Q^*).

Under the status quo scenario, the situations of income distribution, electricity expenditure, CS, the utility's profit, and SW for different pricing schemes are shown in Table 4. Remember that if the electricity production cost does not change, FIBP is the same as IBP. As for the utility's profit, since the status quo IBP is assumed to be cost-neutral and the utility charges a cost-neutral average cost under PTS, the utility's profit under IBP/FIBP and PTS is zero and CRR is equal to 100%. However, since P^* (NT$ 3.74 and NT$ 2.9 for the summer and non-summer periods, respectively) is equal to the highest-tier price under IBP, which is higher than the average cost, the utility makes a profit under FMP.

From the aspect of electricity expenditure and income distribution, no matter which scheme or which time period is involved, the richer the households are, the higher the monthly electricity expenditure they incur. However, PTS (FMP) improves (degrades) the income distribution situation in comparison to the status quo IBP. The differences among schemes are clearly shown in Table 5, where the status quo IBP is taken as the baseline. It can be seen that the figures of “DIPC_after difference” between FMP and IBP are negative which means that the electricity expenditures of households under FMP are higher than those under IBP because the electricity price is higher under FMP. Under PTS, households pay a cost-neutral price for their usufructuary rights. The poorer households also have the incentive to save electricity in order to sell it. Therefore, the electricity expenditures of poorer households are lower than those under IBP. In addition, although P^* is high, it causes different results in terms of the CS under FMP and PTS. The figures for the “CS difference” between FMP and IBP are all negative, which indicates that the CS decreases significantly for households in every income quintile under FMP. However, under PTS, the poorer (richer) households obtain a higher increase (decrease) in the CS compared to IBP. This is because the poorer households can save their usufructuary rights to sell and earn the price spread, while the richer households pay P^* to buy more electricity than the amount they are entitled to use.

Overall, the SW under FMP and PTS is the same and is higher than that under IBP/FIBP in the status quo scenario. However, most of the SW is obtained by households under PTS (particularly by the poor households), while most of the SW is obtained by the utility under FMP.

In what follows, six other scenarios are studied. Because the results for the non-summer period are similar to those for the summer period, we suppress the presentation of the non-summer results.

4.2 Scenario with 5% less electricity supply

Assume that for some reason, e.g., a natural disaster has occurred, the capacities of electricity production are destroyed such that the status quo electricity supply (TQ) is reduced by 5%. We further assume that the marginal cost curve does not change (the case of a cost change will be discussed later).

Under IBP, the reduction in supply results in an excess demand for electricity. The utility should therefore ration out electricity or rotationally stop supplying electricity in different areas. Let us suppose that the electricity consumption of each household is reduced by 5%. This reduction in electricity consumption makes the aggregation curve of the individual IBP rate structure become shorter and higher than the LRMC (see IBP_1 in Figure 3 for an illustration).[5] We found that the utility now makes a profit under IBP. The situation under FIBP is the same as that under IBP because the production cost is assumed to be unchanged. Under FMP, because of the reduction in supply, the market equilibrium price increases significantly (NT$ 6.22). This as well as the corresponding decrease in marginal cost for producing less electricity lead the utility to earn a very high profit which doubles the CRR index (212%). Under PTS, however, the utility makes no extra profit because the cost-neutral average cost is charged.

Due to the high market price, the burden of electricity expenditure on households in each quintile increases significantly under FMP. Row I in Table 6 shows the differences in DIPC_after and CS among schemes under this supply-decreased scenario. In comparison to IBP, both DIPC_after and CS under FMP become worse for all households. However, the income distribution improves under PTS. Both DIPC_after and CS of the poorer (richer) households get better (worse). This is because, on the one hand, the charged average cost of producing less electricity

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[5] As in the case of Figure 2, Figure 3 is a simple two-tier IBP case with two households considered. The curve IBP_0 is the aggregation of individual IBP rate structures faced by households (IBP_i) and IBP_0 is the LRMC curve. When demand decreases (Q_1 to Q_1' and Q_2 to Q_2'), the aggregation of IBP_i becomes IBP_1 (this is the rate structure that the utility charges for consumption quantity $Q_1' + Q_2'$). It can be seen that IBP_1 is shorter and higher than IBP_0. The utility charges part of Q_2' at a price that is higher than its production cost. Therefore, the utility makes an extra profit.

decreases and, on the other hand, the poorer households have a higher incentive to save electricity that they can sell when facing a higher market equilibrium price.

Overall, the SW under PTS is as high as that under FMP. However, as in the previous status quo scenario, most of the SW is obtained by households under PTS, while most of the SW is obtained by the utility under FMP.

4.3 Electricity cost increased or decreased by 10%

In recent years, the price of oil has exhibited volatility, which has led to large variations in the cost of producing electricity. In order for utilities to avoid recording either losses or extra profits, FIBP has been proposed to flexibly reflect the variations in production cost. However, the performance of FIBP has rarely been empirically studied. In this subsection, two scenarios depicting 10% upward or downward shifts in LRMC (IBP_0) are established to compare the effects of different pricing schemes.

First, we implement the analysis for the scenario where the cost has increased by 10%. Under IBP, the utility suffers a loss because the rate structure is such that the price charged is now lower than the real production cost. It then needs to be asked whether FIBP, which shifts the rate structure upwards by 10%, can maintain the utility’s cost-neutrality. The answer is unfortunately no. The reason is that the design of FIBP ignores the change in the user’s demand. When the electricity price increases, the households' demand decreases. This decrease in demand will result in the aggregate rate structure curve being shorter than the new LRMC curve (e.g., IBP_1 in Figure 3). The utility therefore makes a profit in the cost-increase case under FIBP. Under FMP, the utility makes an even higher profit because the upward shift in the supply curve causes P^* to be higher (NT$ 4.11). As before, however, the utility is cost-neutral under PTS because it charges a cost-neutral average cost under this scheme.

Row II in Table 6 shows the differences among the schemes. Compared to IBP, the electricity expenditures of households under the other three schemes all increase because the electricity price has increased. The increase in electricity expenditures causes DIPC_after to decrease. However, the increase is lower (higher) for the poorer (richer) households. Moreover, the impact of the increase in expenditure on DIPC is the lowest under PTS. In regard to the "CS difference", all households, with the exception of the two poorest quintiles under PTS, experience a reduction in CS when the cost increases. As mentioned above, poorer households can save their usufructuary rights to sell which increases their CS. Overall, the SW under FMP and PTS is the highest, followed by that under FIBP. Due to the utility's loss, the SW under IBP is the lowest.

Second, we implement the analysis for the scenario where the cost decreases by

10%. Contrary to the above scenario, the utility's profit is now positive under IBP. Under FIBP, however, the utility suffers a loss. This result seems to counter the intuition. The reason is that when the price decreases under FIBP, the electricity demand of the households increases. This demand increase results in the aggregate rate structure curve being longer and lower than the new LRMC curve (see IBP_2 for example in Figure 3). The utility therefore suffers a loss in the cost-decrease case under FIBP. On the other hand, the utility still makes a profit and breaks even, respectively, under FMP and PTS.

In comparison with IBP, Row III in Table 6 shows that DIPC_after is higher (lower) under FIBP and PTS (FMP). In particular, the CS under PTS increases (decreases) more for the poorer (richer) households and PTS improves the income distribution. Overall, the SW under FMP and PTS is the highest, followed by that under IBP. Under FIBP, although the increase in electricity consumption increases the CS, the utility's loss decreases the SW.

4.4 Increase in cap of the first low-price block and cross-subsidy

In this subsection, we will examine the situation for changes in the design of the IBP rate structure. The first change is to increase the cap of the first low-price block (from 110 to 120 kWh), which is usually designed to take more care of the poorer households.[6] It should be noted that because the cap increase does not change the production cost and market equilibrium price, the results under FMP and PTS are not different from those under the status quo scenario. In addition, the result under FIBP is the same as that under IBP.

Under IBP, the increase in the first-block cap will reduce the electricity expenditure of some households and the utility's profit when compared to the status quo IBP (Table 4). However, as shown in Row IV of Table 6, the magnitudes of these differences in DIPC_after and the CS are small (see line "$\mathrm{IBP} - IBP_0$"). In particular, the poorer households do not gain more than the richer households.

In addition to the increase in the first-block cap, the second change we discuss is that of adding a new highest-price block (701 kWh and above for the summer months as well as 501 kWh and above for the non-summer months) to the IBP structure to cross-subsidize and solve the problem of the utility's loss. We let the price of this new tier be as high as that which makes the utility just break even. The results of both changes included are shown in Row V of Table 6. Compared to the IBP case with only the first-block cap change (denoted as IBP_C in Row V), as expected the burden of electricity expenditure is increased more for the richer households. That is, the utility's loss is solved through the implementation of a cross-subsidy. However, it

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[6] Increasing the cap of the first low-price block from 110 kWh to 120 kWh and the later discussed measure of a cross-subsidy are policy measures applied in Taiwan.

should be noted that since the price is increased, the consumption is decreased, which reduces the CS of households in each quintile. In addition, in comparison with the status quo IBP (see line "$\text{IBP} - IBP_0$" in Row V), the DIPC_after and CS decrease in each household quintile (as does the overall SW). The results show that the measure of the increase in the first-block cap with the cross-subsidy may not really increase the welfare of poorer households and should be well-considered.[7]

4.5 Growth of households

This scenario represents a case of demand growth for electricity, which is also a persistent situation in Taiwan. To form a bigger sample, we randomly replicate one percent of households in each quintile. The estimated results for each pricing scheme are interesting.

First, although the production costs do not change, the utility suffers a loss under IBP/FIBP. This happens because there are now more households consuming more electricity. They pay for part of their consumption at the lower-tier price while their increased consumption further increases the LRMC.[8] This situation could be illustrated by the curve IBP_2 in Figure 3, where we replicate household 1 and the

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[7] We do not mention the results of FMP and PTS because the results for them are similar to those in the previous scenarios.

[8] It should be mentioned that, in the simulation, we assume that the highest marginal cost is equal to the highest-tier price under IBP. It could be inferred that the loss will be bigger if the marginal cost further increases as the quantity increases.

consumption increase of this new household causes the aggregate rate structure curve, IBP_2, to be longer and lower than the LRMC curve (IBP_0). A loss for the utility therefore results. Again, this indicates that it is hard for IBP to be cost-neutral. Under FMP, the utility makes a profit because the demand increase forces a higher market price. Under PTS, the utility breaks even.

Second, Row VI of Table 6 provides a comparison among schemes. Compared to IBP, households pay more for electricity and encounter a decrease in DIPC_after and the CS under FMP. However, under PTS, the income distribution improves. The poorer households enjoy a higher DIPC_after and CS. Overall, trades under FMP and PTS improve the economic efficiency of electricity use. The SWs under these two schemes are the same and are the highest.

5. Conclusion

This article empirically compares four electricity-pricing schemes. We found that under IBP, it is hard for the utility to be cost-neutral. When the electricity demand or supply situation changes, the utility either becomes profitable or suffers a loss. The poorer households face a lower burden of electricity expenditure than the richer households. However, their CSs are lower too. As indicated by theoretical research, IBP is not economically efficient. Its SW is lower than that of FMP. Under FIBP, although the variation of production cost can be flexibly considered, it is still hard to be cost-neutral. This is because FIBP does not consider the demand variation resulting from rate variation. In addition, FIBP has the same problems as IBP in regard to economic efficiency and income distribution.

As for FMP and PTS, the market mechanism makes them both economically efficient. However, the high SW is mainly composed of the utility's profit under FMP, and the CS under PTS. The burden of electricity expenditure on households is highest under FMP, yet PTS improves the income distribution situation. This is because PTS embodies the implication of the second fundamental theorem of welfare economics. As indicated by Zivin and Novan (2016), residential energy efficiency programs have become a major component of U.S. energy policy. However, they count heavily on subsidized efficiency upgrades to low-income households and are substantially costly. Since PTS could induce the poor households to reduce their energy use in order to earn extra profits, it is a low-cost option for reducing energy use. PTS is also cost-neutral since the utility is engaged in AC pricing.

From this research, it is again shown (in addition to the existing theoretical literature) that the popular IBP is not an ideal pricing scheme, neither is its flexible version, FIBP. The market mechanism can enhance the economic efficiency of electricity usage while income distribution can also be improved if an appropriate lump-sum distribution of resources can be dealt with. Trades, of course, might result in transaction costs. However, the growing computing power, information and communications technology (ICT), the application of smart meters, and cell phone application tools and so on may greatly reduce transaction costs. We believe the concept of PTS would be much easier to apply in many respects in the current electricity market to enhance both the market's efficiency and equity.

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Table 1. Descriptive statistics of variables

Variable	Description	Unit	Mean	SD	Min.	Max.
EXP	Household monthly electricity expenditure	NT$	1552.422^{S} 956.573^{NS}	855.805^{S} 526.982^{NS}	67.998^{S} 42.000^{NS}	29153.515^{S} 17960.634^{NS}
Q	Household monthly electricity consumption	kWh	522.563^{S} 390.968^{NS}	234.147^{S} 187.817^{NS}	32.380^{S} 20.000^{NS}	7907.250^{S} 6260.460^{NS}
P	Monthly average price of electricity ($=EXP/Q$)	NT$/ kWh	2.869^{S} 2.391^{NS}	0.265^{S} 0.132^{NS}	2.100^{S} 2.100^{NS}	3.687^{S} 2.869^{NS}
I	Monthly household disposable income	NT$	77300.534^{S} 77312.131^{NS}	53005.643^{S} 53013.594^{NS}	2585.575^{S} 2585.963^{NS}	1037454.161^{S} 1037609.795^{NS}
FS	Family size	Person	3.361	1.529	1.000	17.000
HS	House size	Ping	43.791	23.835	2.000	305.000
AC	Number of air conditioners owned per household	One	1.968	1.352	0.000	10.000

Notes: 1. ^{S}, and ^{NS} denote figures for summer months (June, July, August, and September) and non-summer months (other remaining months), respectively.

2. For the unit of house size (HS), one ping = 3.3058 square meters.

3. In 2007, 32.842 NTD = 1 USD.

Table 2. Regression of summer demand per capita

Variable	Lowest 20%	Fourth 20%	Third 20%	Second 20%	Highest 20%
δ	97.47***	74.35***	67.69***	71.19***	96.45***
	(2.42)	(2.33)	(2.22)	(2.34)	(4.80)
$\frac{I_i}{p}$	0.0016***	0.0013***	0.0013***	0.0024***	0.0024***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0004)
HSPC	1.81***	2.85***	3.25***	3.35***	3.56***
	(0.08)	(0.10)	(0.12)	(0.13)	(0.31)
ACPC	24.58***	51.45***	55.07***	53.50***	74.14***
	(1.96)	(2.42)	(2.45)	(2.82)	(5.72)
Obs.	2748	2748	2748	2748	2749
R^2	0.31	0.46	0.49	0.48	0.23
$\eta_p(=-\eta_I)$	-0.088	-0.010	-0.008	-0.011	-0.008
$\hat{\gamma}$	97.62	74.45	67.79	71.37	96.68

Note: p-value<0.1, * p-value <0.05, ** p-value <0.01, ***, Standard Errors in parentheses.

Table 3. Regression of non-summer demand per capita

Variable	Lowest 20%	Fourth 20%	Third 20%	Second 20%	Highest 20%
δ	66.64***	54.21***	50.75***	53.93***	73.48***
	(1.69)	(1.70)	(1.67)	(1.78)	(3.76)
$\frac{I_i}{p}$	0.0011***	0.0008***	0.0008***	0.0015***	0.0016***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)
HSPC	1.23***	2.06***	2.43***	2.54***	2.74***
	(0.06)	(0.07)	(0.09)	(0.10)	(0.24)
ACPC	17.15***	37.58***	41.33***	40.51***	56.65***
	(1.37)	(1.76)	(1.84)	(2.14)	(4.49)
Obs.	2748	2748	2748	2748	2749
R^2	0.31	0.46	0.49	0.48	0.23
$\eta_p(=-\eta_I)$	-0.095	-0.012	-0.010	-0.014	-0.054
$\hat{\gamma}$	66.71	54.25	50.79	54.01	73.60

Note: p-value<0.1, * p-value <0.05, ** p-value <0.01, ***, Standard Errors in parentheses.

Table 4. Status quo scenario

DIPC quintile	Lowest 20%	Fourth 20%	Third 20%	Second 20%	Highest 20%		
Summer							
DIPC	10,746	15,707	20,349	27,225	49,263		
	Electricity expenditure per capita					Profit	TQ/Q^*
IBP/FIBP	349	426	476	635	2,275	0	7,180,539
FMP	448	528	585	748	2,398	5,523,386	7,040,911
PTS	328	408	466	629	2,278	0	7,040,911
	DIPC_after					CRR	P^*
IBP/FIBP	10,397	15,281	19,873	26,590	46,988	100.00%	NA
FMP	10,298	15,179	19,764	26,477	46,866	126.54%	3.74
PTS	10,418	15,299	19,883	26,597	46,985	100.00%	3.74
	Household CS					SW	
IBP/FIBP	7,533	8,325	8,418	8,704	8,666	114,452,247	
FMP	7,143	7,927	8,018	8,304	8,268	114,516,456	
PTS	7,947	8,525	8,426	8,544	8,228	114,516,456	
Non-summer							
DIPC	10,748	15,709	20,352	27,229	49,271		
	Electricity expenditure per capita					Profit	TQ/Q^*
IBP/FIBP	214	267	300	438	2,038	0	5,372,284
FMP	257	312	348	488	2,052	2,435,349	5,291,083
PTS	204	259	295	435	2,040	0	5,291,083
	DIPC_after					CRR	P^*
IBP/FIBP	10,534	15,442	20,053	26,791	47,232	100.00%	NA
FMP	10,491	15,397	20,004	26,741	47,219	118.87%	2.9
PTS	10,544	15,450	20,057	26,794	47,231	100.00%	2.9
	Household CS					SW	
IBP/FIBP	5,713	6,387	6,461	6,702	6,664	87,741,427	
FMP	5,544	6,210	6,283	6,524	6,486	87,762,355	
PTS	5,973	6,504	6,465	6,600	6,393	87,762,355	

Table 5. Comparison of schemes: Status quo scenario

DIPC quintile	Lowest 20%	Fourth 20%	Third 20%	Second 20%	Highest 20%
Summer					
	DIPC_after difference				
FMP – IBP	-99	-102	-109	-113	-122
PTS – IBP	21	18	10	7	-3
	CS difference				
FMP – IBP	-390	-398	-400	-400	-398
PTS – IBP	414	200	8	-160	-438
Non-summer					
	DIPC_after difference				
FMP – IBP	-43	-45	-49	-50	-13
PTS – IBP	10	8	4	3	-1
	CS difference				
FMP – IBP	-169	-177	-178	-178	-178
PTS – IBP	260	117	4	-102	-271

Table 6. Comparison of schemes in different scenarios (summer)

Row	Scenario	Comparison	DIPC quintile	Lowest 20%	Fourth 20%	Third 20%	Second 20%	Highest 20%
I	Supply 5% less	DIPC_after difference	FMP – IBP	-403	-445	-484	-519	-582
			PTS – IBP	84	41	2	-33	-95
		CS difference	FMP – IBP	-1410	-1565	-1606	-1673	-1711
			PTS – IBP	736	360	38	-246	-682
II	Electricity cost increased by 10%	DIPC_after difference	FIBP – IBP	-41	-51	-58	-67	-78
			FMP – IBP	-142	-150	-162	-170	-187
			PTS – IBP	-10	-19	-31	-39	-55
		CS difference	FIBP – IBP	-136	-160	-165	-181	-136
			FMP – IBP	-534	-551	-549	-549	-549
			PTS – IBP	343	101	-101	-283	-581
III	Electricity cost decreased by 10%	DIPC_after difference	FIBP – IBP	40	49	56	64	77
			FMP – IBP	-56	-53	-56	-56	-58
			PTS – IBP	52	54	51	52	50
		CS difference	FIBP – IBP	133	156	160	175	185
			FMP – IBP	-245	-244	-250	-247	-247
			PTS – IBP	487	298	119	-34	-294
IV	Increase in cap of the first block	DIPC_after difference	IBP – IBP_0	2	2	2	2	3
			FMP – IBP	-101	-104	-111	-115	-125
			PTS – IBP	19	16	8	5	-6
		CS difference	IBP – IBP_0	6	7	6	6	7
			FMP – IBP	-396	-405	-406	-406	-405
			PTS – IBP	408	193	2	-166	-445
V	Increase in cap of the first block and cross-subsidy (IBP profit=0)	DIPC_after difference	IBP – IBP_C	-2	-4	-5	-7	-9
			IBP – IBP_0	0	-2	-3	-5	-6
			FMP – IBP	-113	-116	-124	-127	-138
			PTS – IBP	23	20	12	8	-3
		CS difference	IBP – IBP_C	-9	-12	-13	-15	-14
			IBP – IBP_0	-3	-5	-7	-9	-7
			FMP – IBP	-441	-451	-452	-449	-447
			PTS – IBP	422	203	9	-161	-444
VI	Growth of households	DIPC_after difference	FMP – IBP	-98	-101	-109	-113	-125
			PTS – IBP	16	13	5	1	-11
		CS difference	FMP – IBP	-386	-396	-399	-399	-398
			PTS – IBP	403	181	-2	-180	-465

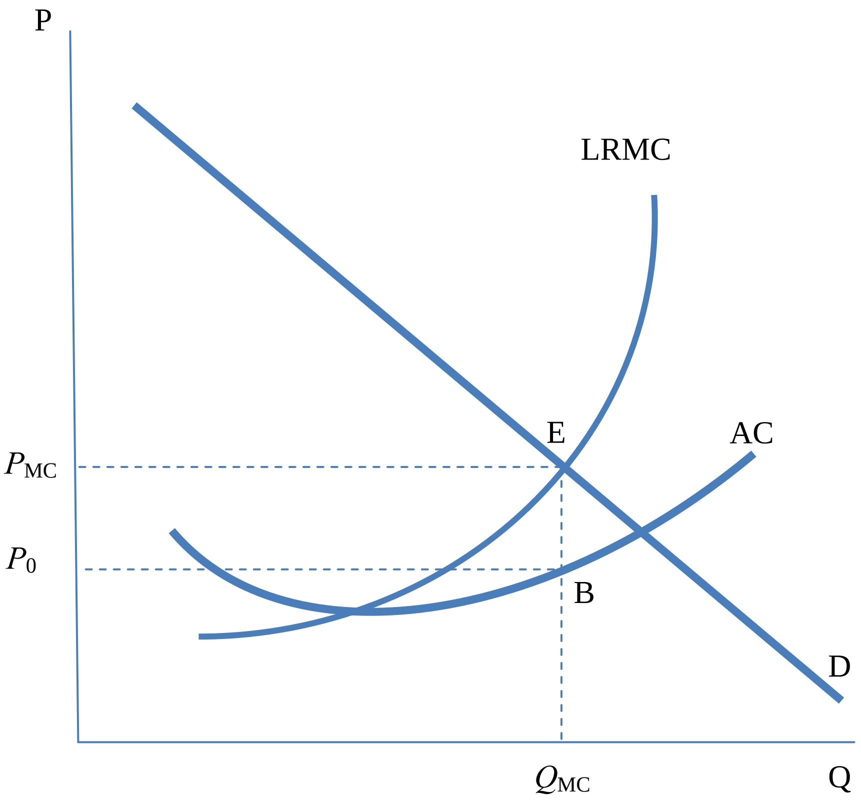

Figure 1. Marginal-cost pricing and positive profit

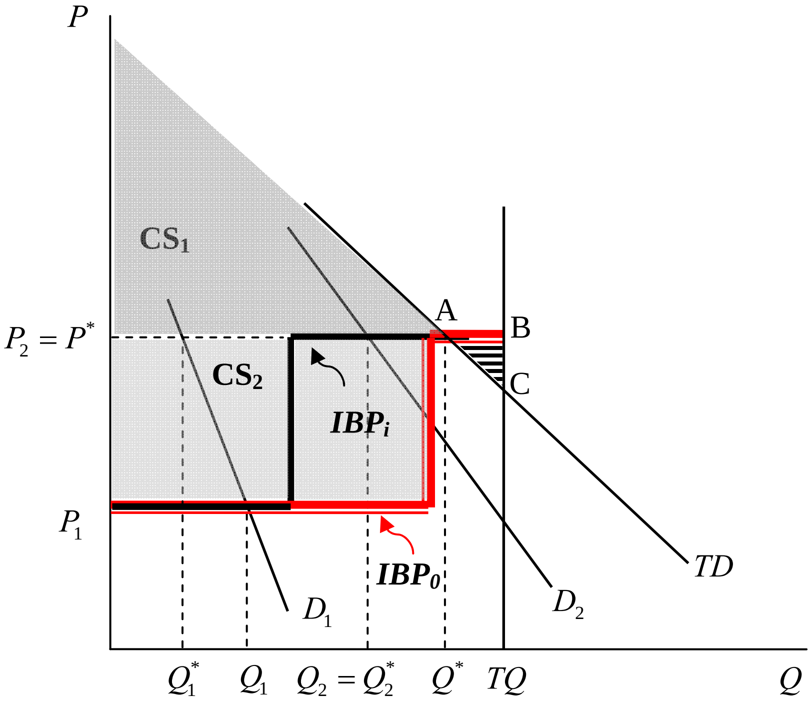

Figure 2. Illustration for CS, SW, and electricity consumption

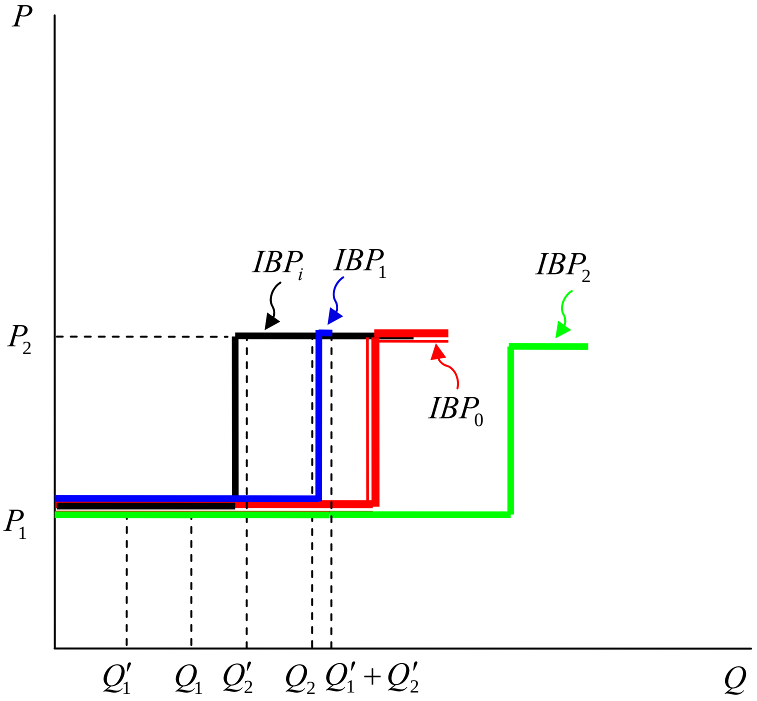

Figure 3. Changes in IBP charging when demand and supply conditions change