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Evaluation of Increasing-Block Pricing for Residential Electricity: A Case Study of Iran

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Original Article

Abstract. In Iran, residential electricity prices are determined by the Increasing Block Pricing (IBP). In this approach, electricity prices increase with consumption as it moves from one block to a higher block. To assess the effectiveness of this policy and analyse the price elasticity of residential electricity demand in Iran, this study utilises data from the 31 provinces of Iran to estimate two models of electricity demand based on average price and marginal price from 2015:3 to 2020:2. For this purpose, this study uses the Dynamic Common Correlated Effects (DCCE) approach. The results show that electricity is inelastic. Moreover, the comparison of coefficients of average price and marginal price shows that the consumer's response to changes in the average price is greater than the marginal price. Therefore, the IBP policy has not performed well regarding electricity demand management.

Keywords: *Residential Electricity Demand; Increasing-Block Pricing; Average Price; Marginal Price; Iran.*

1. INTRODUCTION

Increasing Block Pricing (IBP) is a form of nonlinear pricing, commonly implemented by public utilities. IBP structure is a method of tiered pricing where different levels or blocks of electricity consumption are associated with different rates. In IBP, all consumers receive the initial services at a bottommost marginal price. Then, with the increase in electricity consumption, the marginal price also rises. Therefore, consumers who use more than a given level have a stronger incentive to reduce their monthly electricity consumption compared to consumers who use less. In addition, IBP relieves low-income households, who are assumed to use relatively less electricity, from the additional financial burden associated with increased marginal prices.

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This approach is often implemented to promote energy efficiency and conservation, as it encourages consumers to be mindful of their electricity usage. Because of these advantages, IBP has been widely used in many research studies. Borenstein (2009), Chen and Yang (2009), Ito (2014), Hung and Hung (2015); Lin and Jiang (2012), Liu and Lin (2020), Lin and Zhu (2021), Kim (2019), Jia et al. (2021), Ayertey et al. (2024) used the IBP structure in their research.

The responsiveness of electricity consumption to price changes plays a pivotal role in shaping future energy policies and ensuring a sustainable and efficient energy infrastructure. Understanding how consumers alter their electricity consumption patterns in response to price changes is essential for developing effective energy policies. This information helps policymakers and energy planners make informed decisions about pricing strategies, subsidies, and taxation measures to encourage energy efficiency and sustainability. Therefore, the price and income elasticity of household electricity demand are both key factors in determining welfare changes as a result of changes in energy and environmental policies (Zhai et al., 2023). Various studies investigated price elasticity and income elasticity of household electricity demand in the world, such as the United States (Alberini and Filippini, 2011; Burke and Abayasekara, 2018; Li et al.; 2021), European countries (Csereklyei, 2020; Schulte and Heindl, 2017; Filippini, 1999), other countries (Jia et al., 2021; Ayertey et al., 2023; Ayertey et al., 2023; Balarama et al., 2020; Uhr et al., 2019; Halicioglu, 2007; Filippini and Pachauri, 2004), and Iran (Varahrami and Movahedian, 2017; Pourazarm and Cooray, 2013; Jalaee et al., 2013; Morovat et al., 2019; Kiani et al., 2017; Sadeghi et al., 2011). Considering the importance of estimating the elasticity of residential electricity demand in evaluating the effectiveness of energy policies, this study estimates the residential electricity demand function of Iran's provinces from March 2013 to February 2019. In Iran, the price structure of residential electricity consumption is determined by the IBP, which means that the price of electricity increases with the increase in electricity consumption and moving from one block to a higher block. IBP is a pricing structure in which the marginal price varies based on monthly electricity consumption. This structure helps to prevent high consumption and reduces the financial burden on low-income households.

One of the questions that arise concerning IBP is whether consumers respond to changes in the marginal price under IBP or not. This is an important question because the basic assumption of IBP is that consumers adjust their electricity consumption based on marginal prices. If consumers tend to respond to other factors, IBP is not useful in achieving the policymaker's goal of modifying consumption patterns (Ito, 2014). To assess IBP policy effectively, it is essential to understand the sensitivity of consumers to block-pricing. In other words, policymakers and analysts need to have insights into how consumers respond to changes in the pricing structure in blocks. Therefore, in this paper, the electricity demand function is estimated and compared without considering the block system (average price) and considering the block pricing system (marginal price). For this purpose, the DCCE panel approach has been used. This method is used when there is a cross-sectional correlation between the data and the usual methods cannot be used to estimate the coefficients.

The paper is organised as follows: Theoretical framework and literature review are presented in sections 2 and 3, respectively. The electricity market in Iran is introduced in section 4. Section 5 describes model estimates, and the results are shown in section 6. Finally, section 7 discusses the conclusions.

2. THEORETICAL FRAMEWORK

Block pricing (BP)is a nonlinear price system that considers a kind of price discrimination for different consumption patterns. In this pricing structure, the price changes when consumption exceeds a threshold. Therefore, compared to other goods and services that have a fixed price for all consumption amounts, the consumer is faced with several prices and each price will correspond to various consumption amounts. In general, there are two types of BPs, Increasing and decreasing. In the increasing block pricing (IBP) system, the price of each unit of consumer goods increases with the increase in consumption levels, while in the decreasing block pricing (DBP) system, the price of each unit of consumer goods decreases with the increase in consumption levels. IBP is often used in electricity markets to prevent high demand without increasing the financial burden on low-income households. Since the social marginal costs of electricity are higher than the marginal costs due to the potential negative side effects of electricity generation, utilities and governments are looking for ways to charge marginal prices as much as the social marginal costs. However, a sharp increase in electricity prices to equalise prices with social marginal costs can create a large financial burden on low-income households. BPs can solve this issue by applying different marginal prices to different consumption blocks (Kim, 2019). Figure 1 shows the IBP system. Consumption up to the level of Q1 is calculated at the price of P1, but for the values between Q1 and Q2, the price will be equal to P2. Under BPs, the marginal price changes depending on consumption.

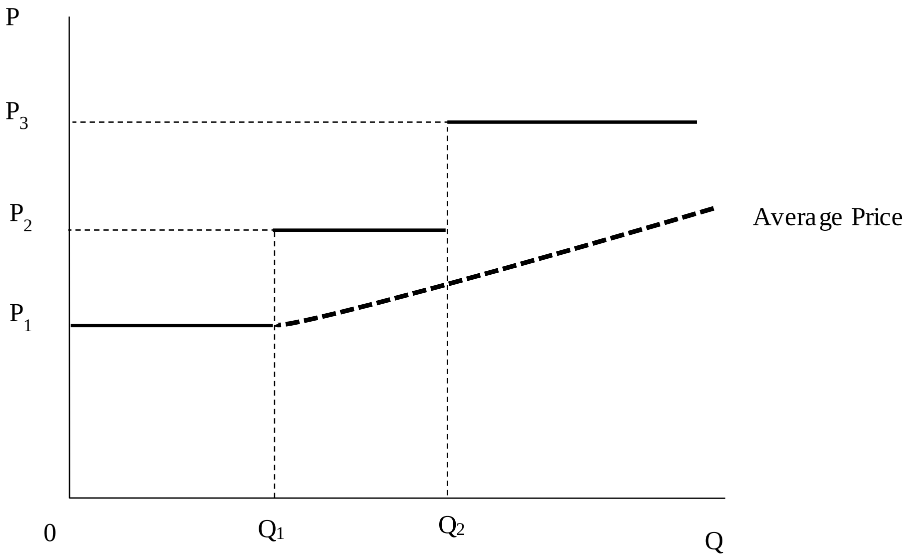

Figure 1. The IBP system

In Figure 1, the marginal price of the lower block is P1, the middle block is P2, and the higher block is P3. Therefore, if the electricity consumption is less than Q1, the total electricity bill per unit of consumption will be calculated at the price of P1. But if the electricity consumption exceeds Q1, the consumer must pay the price of P2 for each kilowatt-hour of consumption more than Q1. Every kilowatt-hour of consumption more than Q2 will be calculated at P3 price. Therefore, the average price for consumption levels higher than Q1 is smaller than the marginal price and increases at a lower rate than the marginal price.

The basic assumption in a nonlinear pricing system is that consumers will respond to the marginal price. However, consumers may neither realise the complex pricing structure nor have the information needed to adjust their consumption according to the marginal price. Therefore, rational consumers may respond to the expected marginal price or the average price as an approximation of the marginal price (Ito, 2014).

3. LITERATURE REVIEW

Ayertey et al. (2024) studied the causal effect of the IBP policy schedules on electricity consumption using the monthly electricity billing data from the urban residential consumers of the Electricity Company of Ghana. They used a Regression Kink (RK) design. they found that the IBP policy has no causal effect on electricity consumption at the 50 KWh lower block threshold.

Based on the 2017 micro-survey data of residents from first-tier cities in China, Lin and Zhu (2021) investigated the impact of the IBP policy cognition on electricity consumption. For this purpose, they used endogenous switching regression (ESR). Their results showed that policy cognition can reduce electricity consumption.

Jia et al. (2021) calculated price and income elasticity by instrumental variables. They used a dataset from the Chinese Residential Energy Consumption Survey, 2014. This study revealed that the residential demand for electricity is an essential commodity in the short run.

Lin and Chen (2018) investigated the effectiveness of IBEPs in regulating residents' electricity demand in the Sichuan Province of China in 2014. They used the Synthetic control method (SCM). The paper revealed that the IBEPs policy significantly reduces urban and rural residential electricity consumption.

Hung and Huang (2015) estimated the dynamic demand for residential electricity in Taiwan from 2007:01 to 2013:12, using panel data. For this purpose, they considered the IBP. Results showed seasonal differences in electricity demand between summer and other seasons. Moreover, they found that the adjustment speed and Price Elasticity of Demand are lower during summer.

Ito (2014) investigated the consumers' response to changes in average prices and marginal prices from 1999 to 2007, using the American household-level panel data. He found that there is a stronger response to changes in average prices than marginal prices.

A review of the research literature shows that no research has been conducted in Iran investigating the effectiveness of the IBP policy using electricity demand elasticity.

4. RESIDENTIAL ELECTRICITY IN IRAN

Household electricity bills in Iran have been adjusted in an ascending step form since the early 1960s. However, the number and rates of consumption steps were changed several times after that. Regarding the most important changes, in 2011, the first stage of the Iranian targeted subsidy plan was implemented, electricity tariffs were revised, and electricity consumption was controlled. However, electricity consumption began to increase again in the following years as a result of non-implementation of the next stages of this plan, consumer growth, high inflation, and exchange rate changes. Figure 2 shows the trend of electricity consumption in the household sector in Iran and the average increase in the price of electricity in the household sector from 2000 to 2019.

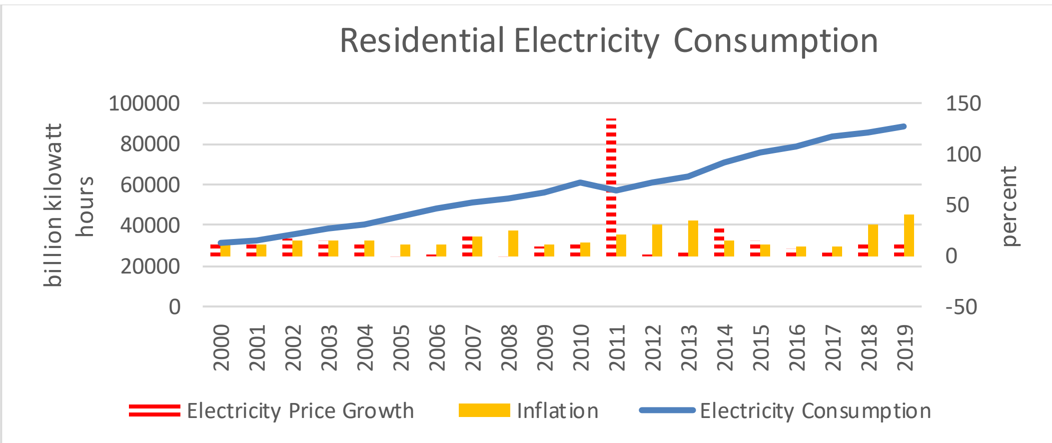

Figure 2. Residential Electricity Consumption

Figure 2 shows that in 2011, household electricity consumption decreased following an increase (135%) in the average price. Other years, however, saw an upward trend in electricity consumption. It should be noted that most of the time, the inflation rate exceeded the growth rate of the average price of household electricity.

Electricity tariffs for households are determined based on consumption patterns in the household sector, as per the resolution of the Board of Ministers on 27/09/2009. Based on the climate diversity of Iran, the country is divided into five climatic regions, which include four tropical regions, and the regions that are not among these four are considered normal regions. Each year, the Ministry of Energy announces new tariffs, and until 2018, they considered the same percentage increase for all consumption levels, not differentiating between high- and low-consumption subscribers. Table 1 shows residential electricity tariffs in Iran in 2018.

Table 1. Residential Electricity Tariffs in Iran in 2018

Levels of Consumption (Kilowatt hours of monthly)	**Other Regions (Rials per kilowatt hour)**	**Tropical Regions 4 (Rials per kilowatt hour)**	**Levels of Consumption (Kilowatt hours of monthly)**	**Tropical Regions 3 (Rials per kilowatt hour)**	**Tropical Regions 2 (Rials per kilowatt hour)**	**Tropical Regions 1 (Rials per kilowatt hour)**
0-100	490	393	0-1000	408	360	164
100-200	571	458	1000-1500	1063	816	181
200-300	1224	816	1500-2000	1878	1388	196
300-400	2203	1305	2000-3500	2042	1714	816
400-500	2531	1878	3500-4500	2203	2042	1470
500-600	3184	2449	4500-6000	2368	2203	1878
More than 600	3511	2939	More than 6000	2531	2368	2203

(Tavanir, 2018)

5. MODEL

According to the theoretical foundations and research of Reiss and White (2005), the block electricity demand function for the residential sector is introduced. In this research, Eq. 1 has been used to estimate the average residential electricity price model (Model 1):

$$\ln q_{it} = \alpha_0 + \beta_1 \ln aph_{it} + \beta_2 \ln pg_{it} + \beta_3 \ln HDD_{it} + \beta_4 \ln CDD_{it} + \beta_5 \ln income_{it} + \varepsilon_{it} \quad (1)$$

In the notation, i = 2, 3 ... 31 denotes the provinces, and t stands for time. $\ln q_{it}$ is the logarithm of residential electricity consumption per capita. Per capita electricity consumption is calculated by dividing residential electricity consumption by the number of electricity subscribers. $\ln aph_{it}$ is the logarithm of the average residential electricity price. The average price of electricity is calculated by dividing the income from the sale of electricity to the residential sector by the amount of electricity consumed by this sector (sold electricity). $\ln income_{it}$ is the logarithm of per capita household income, which is obtained by dividing the gross domestic product by the number of households. $\ln HDD_{it}$ and $\ln CDD_{it}$ represent the logarithm of heating-degree days and cooling-degree days, respectively. $\ln pg_{it}$ is the logarithm of the price of electricity substitute goods. In this research, the logarithm of the price of natural gas is used to calculate the price of the substitute product.

The marginal price function in the Model (2) is written as Eq. 2 (Nordin, 1976):

$$\ln q_{it} = \alpha_0 + \beta_1 \ln mph_{it} + \beta_2 \ln pg_{it} + \beta_3 \ln HDD_{it} + \beta_4 \ln CDD_{it} + \beta_5 \ln income_{it} + \beta_6 dif_{it} + \varepsilon_{it} \quad (2)$$

$\ln mph_{it}$ shows the logarithm of the marginal price of residential electricity in province I, in period t. In this research, the marginal price of residential electricity is determined based on electricity consumption. In this way, the price of the last price block is determined according to the per capita consumption of the household. Therefore, the price in that block is considered as the marginal price. The amount of electricity consumed by the subscribers in each month and each province was placed in each of the municipal electricity tariff blocks. The price calculated in that block is considered the marginal price. To equalise the data in the provinces that had several consumption patterns in the tariffs, the average price calculated in several tariff patterns will be considered as the marginal price. dif indicates difference parameters, which is the difference between the actual consumer's payment and the consumer's payment if the marginal price is considered (Ruijs, 2009). In other words, this variable shows the penalty that consumers pay due to their higher consumption. The difference parameter is considered as Eq. 3:

$$d_\tau = \left(p_1 q_1 + p_2(q_2 - q_1) + p_3(q_\tau - q_2)\right) - p_3 q_\tau \tag{3}$$

q_1 and q_2 show the highest amount of consumption in blocks 1 and 2. For example, if the third block is a consumption block, then the marginal price is the price of the third block. To calculate the cooling-degree days and heating-degree days, Eq. 4 and Eq. 5 are used:

$$CDD = \sum (T - \theta_2) \quad \theta_2 = 21^{\circ C} \tag{4}$$

$$HDD = \sum (\theta_1 - T) \quad \theta_1 = 18^{\circ C} \tag{5}$$

In which CDD is cooling-degree days, T is the average daily temperature in degrees, θ_1, and θ_2 are temperature thresholds, and HDD indicates heating-degree days. The cooling and heating degree days are defined as the sum of the daily average temperature differences from a certain threshold in a certain period of the year. Threshold temperatures can have different numbers based on the condition, but in general, the numbers 18 to 28 are recommended (Jalali et al., 2012). According to previous studies, the threshold temperature for cooling is 21°C, and the threshold temperature for heating is 18°C.[2]

6. RESULTS AND DISCUSSION

This paper aims to investigate the effectiveness of the IBP policy in the provinces of Iran. We use a balanced monthly panel dataset covering all Iranian provinces from March 2015 to February 2020 (Table 2).[3]

Table 1. Descriptive statistics

Variables	Mean	Max	Min	S. E	Obs
Electricity consumption per capita	254	1700	93	262	1860
The average price of electricity	510	1051	101	159	1860
Marginal price of electricity	941	2017	435	241	1860
CDD	77	581	0	118	1860
HDD	137	14103	0	360	1860
Substitute price	2229	3053	1308	565	1860
Per capita income	19563	51091	10230	5404	1860

In a block price system, the average price and the marginal price are different. Nordin (1976) demonstrated that using marginal price and a difference parameter shows the income effect. The

[2] All price and income variables in this research have been considered as real variables using the monthly consumer price index in the base year of 2015 in each province

[3] The authors acknowledge the importance of estimating the electricity demand function and calculating the average and marginal price using micro-level household information. However, the lack of access to this information has led to the use of aggregated data in this study, like the studies of Ruijs et al. (2008) and Hung & Huang (2015). Although important information is lost when using aggregated data, we still believe that the current analysis provides insight into the distributional aspects of electricity pricing policies, an issue that has not received much attention so far.

difference parameters show the difference between the consumer's actual bill and the consumer's expenses if the total consumption is calculated with the marginal price.

The first step in this analysis is to explore the potential existence of cross-section dependence in the data. Cross-section dependence can emerge from different factors, including common shocks, unobserved factors, or spatial dependence. To assess cross-section dependence, this paper utilises the Pesaran (2015) test for weak cross-section dependence. The results of this test are presented in Table 3. According to Table 3, the null hypothesis, stating no dependence between sections, is rejected. Conversely, the alternative hypothesis, indicating cross-sectional dependence among the research data, is confirmed. Hence, the utilisation of common panel methods for examining relationships between variables is not feasible.

Table 2. Pesaran (2015) test for weak Cross-sectional Dependence (CD) and unit root test (Cross-Sectionally Augmented IPS (CIPS))

Variables	CD-Statistic	Cross-Sectionally Augmented IPS (CIPS)	
		Levels	First Difference
Ln electricity consumption per capita	112.6^{***}	-4.06^{***}	-
Ln average price of electricity	103.6^{***}	-5.36^{***}	-
Ln marginal price of electricity	148.4^{***}	-4.1^{***}	-
Ln CDD	144.5^{***}	-4.04^{***}	-
Ln HDD	145.8^{***}	-4.5^{***}	-
Ln substitute price	166.6^{***}	-1.8	-5.9^{***}
Ln per capita income	107.8^{***}	-1.7	-5.2^{***}
Dif	9.3^{***}	-4.3^{***}	-

*** denote Significance at the 1% level

The unit root test used in this research is Cross-Sectionally Augmented IPS (CIPS)

To identify the utilised panel method, it is crucial to first examine the stationarity of the variables. In this study, the CIPS (Cross-Sectionally Augmented IPS) method will be employed to evaluate the stationarity of the research variables, considering the presence of cross-sectional dependence. The results of this test are presented in Table 3. Therefore, except for the variables of the logarithm of per capita income and the logarithm of the price of substitute goods, which are stationary at the first difference, other research variables are stationary in levels. Despite the presence of cross-sectional dependence and the fact that all variables show stationarity in levels or first differences, Pesaran (2015) recommends using the DCCE (Dynamic Common Correlated Effects) method for estimating panel data under such circumstances.

The results of the dynamic panel data estimation using the DCCE (Dynamic Common Correlated Effects) method are presented in Table 4. In Model (1), the average price, and in Model (2), the marginal price has been employed to formulate the electricity demand function in the provinces of Iran. The research results demonstrate that the lag of the logarithm of electricity consumption (lag of the dependent variable) has a positive and significant impact on the logarithm of electricity consumption per capita in both Models (1) and (2). The value of the above coefficient for Models (1) and (2) is 0.199 and 0.245, respectively. These values are statistically significant at the 99% confidence level. This coefficient indicates that an increase in the amount of electricity consumption per capita in the previous years is associated with a higher level of electricity consumption per capita in the current year. This result indicates that per capita electricity consumption exhibits rigidity. In other words, the sign and coefficient of this variable show that the amount of electricity consumption per capita in both models has not fluctuated during the period under review and has gone through an upward trend. However, since this coefficient has a smaller value than one, it does not have an explosive state and converges towards an equilibrium value. These results are in line with the studies conducted by Mohammadi and Karouki (2014), and Varahrami and Mohedian (2015).

In both models, the coefficient for the logarithm of per capita income is 0.1974 and 0.2045, respectively, and is statistically significant at the 10% confidence level. This coefficient, representing the elasticity of income, reveals that electricity is an essential commodity. In other words, a one percent increase in per capita income leads to a 0.1974% increase in per capita electricity consumption in Model (1) and a 0.2045% increase in Model (2). These values indicate that the increase in income does not have a significant effect on the amount of residential electricity consumption. Mohammadi and Karuki (2014), and Varahrami and Mohdian (2016) showed that electricity is a necessary commodity and its income elasticity is less than one.

Table 3. DCCE Model of Residential Electricity Under Block Rates

Variables	Model (1)	Model (2)
Lag of Ln electricity consumption per capita	0.199^{***}	0.245^{***}
Ln average price of electricity	-0.205^{**}	-
Ln marginal price of electricity	-	-0.175^{*}
Ln CDD	-0.002	0.0186^{**}
Ln HDD	0.0098	0.008
Ln substitute price	0.026	0.07
Ln per capita income	0.197^{*}	0.20^{*}
Dif	-	-0.062^{**}
C	0.14	0.98
CD Test	- 1.24(0.2161)	0.69(0.488)

Note: *, **, and * indicate significance at 1%, 5%, and 10%, respectively.**

In Model (1), the coefficient of the logarithm of average electricity price is 0.205, which is statistically significant at the 95% confidence level. This coefficient, signifying the price elasticity of residential electricity demand, is negative and less than one. In other words, electricity is a commodity with low elasticity and a one percent increase in the average price of electricity reduces the amount of residential demand by 0.205%. Mohammadi and Karuki (2016) also showed that the price elasticity of electricity in Iran is less than one.

In Model (2), the marginal price logarithm coefficient is 0.1749, which is statistically significant at the 90% confidence level. This coefficient shows that with a one percent increase in the marginal price, the per capita consumption of residential electricity decreases by 0.17%. Comparing the coefficient of the marginal price to the average price shows that the amount of residential electricity consumption per capita is more affected by the increase in the average price of electricity. The difference parameters coefficient is equal to -0.062, which is significant at the 95% confidence level. Similar to Nordin (1976), the coefficient of the difference parameters is similar to the income effect, but with the opposite sign.

In Model (2), CDD has a positive and statistically significant effect on the residential per capita electricity consumption at the 95% confidence level. So, a one percent increase in the CDD increases the amount of electricity consumed by 0.018%. At the end of the examination, the CD test shows that there is independence in the disturbance components of Models (1) and (2) and the results of the models are reliable.

CONCLUSIONS

The purpose of this study is to investigate the effectiveness of the IBP policy in Iran. This paper estimates price elasticities of residential electricity demand under increasing blocks in the 31 provinces of Iran from March 2015 to February 2020. Considering the research data has two dimensions of time and sections (provinces), the panel data approach was used to estimate the model. Since there is a cross-sectional dependence between the data based on the CIPS test, the DCCE approach has been used to estimate the electricity block demand function. Two models were used to investigate the effectiveness of the IBP policy. In Model (1), the average price and in Model (2) the marginal price of electricity were considered to estimate the price elasticity of electricity demand. The average price was calculated through the income from electricity sales divided by the amount of electricity consumption. The marginal price was obtained using different price blocks. This was accomplished in such a way that the marginal price would be equal to the last block in which the consumer is placed.

The results of Model (1) show that the variable coefficient of the logarithm of the average price of electricity is less than one and is significant at the 95% confidence level. This shows that electricity in the household sector is an inelastic commodity. The results of Model (2) show that the coefficient of the logarithm of the marginal price is less than one and is significant at the confidence level of 90%. The comparison of average and marginal price elasticity reveals that the amount of electricity consumption is more influenced by the average price of electricity. Therefore, IBP in Iran has not been able to manage electricity consumption and has not performed properly.

The purpose of IBP is to manage electricity consumption, increase justice in distribution, and improve the economy of the electricity industry. However, the results indicate that consumers adjust their consumption according to the average price as an approximation of the marginal price. This suboptimal behaviour prevents the IBP system from achieving its goals. One of the reasons for this issue can be the lack of realisation of the complex structure of pricing and the lack of access to information needed by consumers. Therefore, it is suggested that policymakers determine a mechanism to inform consumers about how to calculate their electricity prices. In addition, it is suggested to reconsider determining consumption patterns and electricity tariffs, for example, higher price steps can be increased with more leaps.

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