Research Article

Estimating the Short-term Price Elasticity of Residential Electricity Demand in Iran

Anise Rouhani,1 Habib Rajabi Mashhadi,1,2 and Mehdi Feizi3

1Department of Electrical Engineering, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran
2Center of Excellence in Soft Computing and Intelligent Information Processing (SCIIP), Ferdowsi University of Mashhad, Mashhad, Iran
3Department of Economics, Faculty of Economics and Administrative Sciences, Ferdowsi University of Mashhad, Mashhad, Iran

Correspondence should be addressed to Habib Rajabi Mashhadi; h_mashhadi@um.ac.ir

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Excessive electricity consumption causes severe problems in the electricity sector and consequently in load curtailment. This paper estimates the short-term price elasticity of electricity demand for the Iranian household sector by monthly panel dataset. The estimated short-term price elasticity of electricity demand was −0.048. We use abrupt change in electricity price due to targeting subsidy on December 18th, 2010. The results show significant heterogeneity in electricity price elasticity between the various levels of consumption. Due to the heterogeneity of consumers’ electricity price elasticity, we can categorize residential consumers into four groups. Hence, policymakers are suggested to manage peak loads in the electricity network by estimating consumer responsiveness and reforming electricity pricing considering equality issues and tariff design.

1. Introduction

Economic development, improving living standards, and population growth rate raise electricity peak demand. Due to the imbalance between electricity demand and supply in Iran, power generation investment needs to build different types of power plants. Supplying Iran’s peak demand in a power system operation during critical peak hours, which occurs in summer, is a critical problem that increases electricity system operating costs and risks to supply security.

The household sector has a high share of electricity consumption in Iran. This sector accounted for 32% of consumption and was the second-largest consumer of electricity in the country in 2019; while the industrial sector with a share of 36% and the agricultural sector with a share of 14% were in the first and third ranks [1]. Therefore, strategies to reduce electricity consumption can be found by studying the behavior of residential consumers.

Aalami et al. express residential consumers usually change their normal consumption patterns related to electricity price variations [2]. So, it is necessary to estimate consumers’ reactions to these price changes to evaluate peak demand reduction in different pricing programs. According to the well-known demand law in economics, the demand for electricity like any other commodity decreases with increasing price, provided all other factors are kept constant. The sensitivity of consumer’s demand to price changes is measured by calculating the coefficient of price elasticity of demand. In fact, price elasticity is a relative measure of the rate of consumer response.

Numerous studies have been performed to calculate the price elasticity of electricity demand in different sectors of electricity consumption in several countries. For instance, Filipino estimated the own-price and cross-price elasticity of residential electricity demand during peak periods and off-peak periods in Switzerland [3]. Some existing studies obtained the price elasticity of household electricity in India [4–7]. Filipino et al. estimated the price elasticity of household electricity demand using disaggregate level survey data in India and showed that income and price elasticity of electricity demand are lower than one [8].
Chindarkar et al. indicate that setting a price is not appropriate for all different electricity consumption groups because the price elasticity of household electricity demand varies considerably in different states, different urban and rural residential consumers, and different income groups [9]. Using an Indian household-level panel data, Balarama et al. studied the price elasticity of electricity demand for different urban households in Bangladesh and showed inequity among consumers due to price elasticity policies [10].

In addition, Vesterberg uses hourly power consumption data to compute the income elasticity of electricity demand for a Swedish region [11]. He finds that income elasticity has the highest value during peak hours for lighting and kitchen use, but an insignificant value for space heating. Zhou et al. defined demand as a function of income, price, and lifestyle, and calculated the short-term price and income elasticity in the urban area of China [12]. The results show that income plays a small role in electricity consumption, but changes in electricity prices have almost the same effect on different income levels. The study by Filippini estimates the electricity demand function of residential consumers during peak and off-peak periods using several economic models in Switzerland [13]. He found that the short-term electricity of demand is less than one, and of long-term elasticity is more than one. He also stated that electricity demand could shift to the off-peak period due to rising electricity prices during the peak period.

Some studies, e.g., [14], examined the short-term and long-term relationship between electricity demand and the factors affecting it. The values of price and income elasticity of residential electricity demand are also calculated in Sri Lanka. Athukorala et al. found that long-run electricity tariff reformation can play an important role in managing electricity demand. Fan et al. achieved the annual price elasticity for flat rate programs in South Australia [15]; they considered the demand function dependence on population, GSP (Gross State Production) temperature, and lagged price variables. Moreover, they determined how the price elasticity changes at different times in a day or in different seasons.

The authors in [16, 17] show clearly that long-run electricity demand is sensitive to changes in prices and household revenues. They believe that electricity prices can be used as a tool to reduce electricity consumption. Bose et al. obtained the electricity demand function for different sectors in India [7]. The results indicated that the income elasticity of electricity demand for large industrial and commercial sectors is more than one, and for residential, agricultural, and small industrial sectors is less than one. Habibollah et al. extracted the mathematical models according to the price elasticity coefficient of demand in Iran [18]. Using the mentioned models and evaluating different scenarios on the country’s daily load curve, they calculated new consumption curves, the amount of energy consumed and the percentage of peak reduction. Likewise, Aalami et al. developed an economic model for demand response programs using the concept of price elasticity of demand and customer benefit function [19]. Furthermore, they used the proposed model to investigate its effects on the energy market of Iran.

The electricity price in Iran is subsidized. The subsidy is transfer payments by governments that can be done directly or indirectly to increase the consumers’ actual purchasing power, the producers’ sale power, and greater equitable income distribution. In addition, economic stability and compensation for the effects of governmental policies enhance the general well-being. The Iranian Parliament passed the Iranian targeted subsidy plan or the subsidy reform plan on January 05, 2010. The governments have defined the subsidy plan as the “largest surgery” to the nation’s financial system in half of a century and “one of the maximum essential undertakings in Iran’s current monetary history” [20].

Due to the absence of smart meters in Iran, access to more frequent data on electricity consumption is still a challenge. However, in developed countries, with an estimation of price elasticity of electricity demand, price-based electricity demand response programs are designed by the widespread application of smart meters to estimate the demand curve conveniently [21].

The purpose of this paper is to determine the short-term price elasticity of electricity demand of residential consumers in Mashhad, the second-largest city of Iran, by monthly panel dataset, which corresponds to targeting subsidies time in Iran, and is one of the most important and visible parts of the economic transformation plan that was carried out, which leads to an abrupt change in the electricity price. For the first time, we focused on this period and calculated the price elasticity of electricity demand in Iran. Furthermore, this paper categorized the residential consumers into four groups based on the price elasticity of electricity demand.

Generally, the price elasticity of demand will vary according to the price of electricity and consumer behavior, and it can be used for demand response programs to reduce the peak load.

2. Background

The electricity prices of residential consumers in 30 countries are shown in Figure 1. As can be seen, the price of electricity for residential consumers in Iran is much lower than in other countries and is ranked the last among 32 countries. Countries such as Iran, Qatar, Russia, and Saudi Arabia, due to their great crude oil and natural gas production output, have the lowest price of electricity in the world. In contrast, countries heavily dependent on fossil fuel imports for electricity generation are more vulnerable to market price fluctuations [22]. In fact, the cost of energy production in Iran is much higher than what is paid by consumers. The prices paid by the consumers are very different from the actual prices due to government subsidies.

According to Figure 2, residential consumers account for 32.4% of the consumption share among the six sections of the total consumers [1]; due to the high volume of consumption of residential consumers and their significant impact on the amount of peak electricity demand in Iran, studying the behavior of residential consumers is of great importance.
2.1. Definition of Price Elasticity of Demand. Price elasticity of demand is the percentage of change in the amount of demand in proportion to the percentage of change in price, which is shown in the following equation:

\[
elasticity = \frac{\Delta Q}{\Delta P} \times \frac{P}{Q}.
\]

In this formula, \(\Delta Q\) is the change in electricity demand, and \(\Delta P\) is the change in electricity price. If the price of electricity increases, the amount of electricity demand decreases, and vice versa; as a result, the amount of price elasticity of demand will be negative.

2.2. Price Slab System in Iran. The electricity pricing system in Iran is nonlinear. The basic philosophy of this electricity tariff is to protect low-income consumers. It is concerning how this pricing will impact the most vulnerable consumers. Consequently, with tiered pricing, customers pay a lower rate up to particular usage and pay more for the additional electricity exceeding that threshold.

The day is broken into three periods of time. In the autumn, midpeak hours are typically around 5:00 am to 5:00 pm. Midpeak is also known as the intermediate peak. Peak hours are between 5:00 pm and 9:00 pm. The off-peak time band runs from 9:00 pm to 5:00 am. These periods are the same all weekdays, weekends, and public holidays. Prior to targeting subsidies, electricity prices were set for different consumption levels (11 steps) in midpeak, off-peak, and peak periods. According to the pricing mechanism, the first step was considered from 0 to 80 kWh every month. In the peak period, there was an overpayment for different consumption levels.

Table 1 shows the price per different consumption levels in the midpeak, off-peak, and peak period in the pricing system before the targeting subsidies, where \(c\) corresponds to the total consumption per month [23].

Table 2 shows the overpayment for peak and midpeak periods before targeting subsidies, but no overpayment is taken into account in the off-peak and first steps [23].

Iran’s Rial exchange rate against USD averaged 10365 (IRR/USD) in December 2010, the maximum average electricity price per kilowatt-hour for the components of peak, midpeak, and off-peak periods was 773 Rials (7.46 cents), and the minimum monthly electricity price was 3398 Rials (32.78 cents). After the Iranian targeted subsidy plan, seven different consumption
overpayment is considered in the peak period, and a discount is applied on marginal prices. According to this pricing mechanism, an average overpayment of 124.3 Rial/kWh (3.09 cent/kWh) is applied on the peak period. In the next steps, consumers will face higher overpayment, 202.35 Rial/kWh (5.67 cent/kWh) in the mid-peak period and 0 Rial/kWh (0 cent/kWh) in the off-peak period. The steps have been considered (see Table 3). The first step is 0–100 kWh monthly with 270 Rial/kWh (2.60 cent/kWh), and the second step is 100–200 kWh per month with 320 Rial/kWh (3.09 cent/kWh). In the next steps, consumers will face higher overpayment of 601–800 kWh with 456.16 Rial/kWh (12.4 cent/kWh) and 801–966 kWh with 514.8 Rial/kWh (15.5 cent/kWh). Table 2 illustrates the overpayment in the mid-peak, peak, and off-peak periods.

2.3. Electricity Bill Structure. A typical household electricity bill includes the following information:

1. Consumer Information: name and family, postal code, address, the number of households, being single-phase or three-phase, and the amperes value.

2. Consumption information: information measured in peak, midpeak, and off-peak periods in the previous and the current month, consumption steps and prices in each step, and the formula to calculate the consumption cost, overpayment peak, and off-peak discount.

3. Consumption history: 60-day consumption information of the last year and current year.

Table 1: Price and percentage of changes in marginal price before targeting subsidies.

| Consumption steps | Electricity price in mid-peak period (Rial/kWh) | Electricity price in peak period (Rial/kWh) | Electricity price in off-peak period (Rial/kWh) |
|-------------------|-----------------------------------------------|------------------------------------------|-----------------------------------------------|
| 0–80              | 0                                             | 0                                        | 0                                             |
| 81–150            | 80.94                                         | 202.35                                   | 20.24                                         |
| 151–200           | 93.74 – (1276.30/c) + (133245.2/c^2)          | 234.35 – (3190.75/c) + (33313.0/c^2)     | 23.44 – (319.08/c) + (33313.0/c^2)           |
| 201–250           | 112.75 – (3331.13/c) + (559676.7/c^2)         | 281.88 – (8327.83/c) + (1399191.8/c^2)   | 25.63 – (757.08/c) + (1399191.8/c^2)        |
| 251–300           | 124.3 – (6218.63/c) + (25252175.3/c^2)       | 310.75 – (15546.58/c) + (30546986.3/c^2)| 28.25 – (1413.33/c) + (30546986.3/c^2)     |
| 301–400           | 375.1 – (81458.63/c) + (1392438.3/c^2)       | 937.75 – (203646.58/c) + (30546986.3/c^2)| 85.25 – (18513.33/c) + (30546986.3/c^2)    |
| 401–500           | 375.1 – (81458.63/c) + (1392438.3/c^2)       | 937.75 – (203646.58/c) + (30546986.3/c^2)| 85.25 – (18513.33/c) + (30546986.3/c^2)    |
| 501–600           | 375.1 – (81458.63/c) + (1392438.3/c^2)       | 937.75 – (203646.58/c) + (30546986.3/c^2)| 85.25 – (18513.33/c) + (30546986.3/c^2)    |
| 601–800           | 965.8 – (435878.63/c) + (1089696.58/c)       | 2414.5 – (1089696.58/c) + (30546986.3/c^2)| 219.5 – (99063.33/c) + (30546986.3/c^2) |
| 801–966           | 965.8 – (435878.63/c) + (1089696.58/c)       | 2414.5 – (1089696.58/c) + (30546986.3/c^2)| 219.5 – (99063.33/c) + (30546986.3/c^2) |
| >966              | 514.80                                        | 1287.00                                  | 117.00                                       |

Table 2: Overpayment for different periods before targeting subsidies.

| Consumption steps | Overpayment in midpeak period (Rial/kWh) | Overpayment in peak period (Rial/kWh) | Electricity price in off-peak period (Rial/kWh) |
|-------------------|------------------------------------------|---------------------------------------|-----------------------------------------------|
| 0–80              | —                                        | —                                     | —                                             |
| 81–150            | —                                        | —                                     | —                                             |
| 151–200           | 22.55 – (5176.23/c) + (133245.2/c^2)     | 56.38 – (12940.57/c) + (33313.0/c^2)  | —                                             |
| 201–250           | 49.72 – (13674.45/c) + (559676.7/c^2)   | 124.30 – (34186.13/c) + (1399191.8/c^2)| —                                             |
| 251–300           | 225.06 – 105140.18/c + 12218794.5/c^2   | 562.65 – 262850.45/c + 30546986.3/c^2 | —                                             |
| 301–400           | 375.10 – (197739.63/c) + (25252175.3/c^2)| 937.75 – (494349.08/c) + (6310438.3/c^2)| —                                             |
| 401–500           | 562.65 – (332243.95/c) + (4561683.2/c^2) | 1406.63 – (830609.86/c) + (114042082.0/c^2)| —                                             |
| 501–600           | 1448.7 – 1194665.95/c + 244092032.8/c^2 | 3621.75 – (2986664.66/c) + (610230082.0/c^2)| —                                             |
| 601–800           | 1931.60 – (1798925.26/c) + (418443484.8/c^2) | 4829.0 – (4497313.15/c) + (1046108712.0/c^2) | —                                             |
| 801–966           | 1029.60 – (494208.00/c)                   | 2574.00 – (1235520.00/c)              | —                                             |
| >966              | —                                        | —                                     | —                                             |

Table 3: Price and percentage of changes in marginal price after targeting subsidies.

| Consumption steps | Electricity price (Rial/kWh) | Percentage of changes in marginal price |
|-------------------|-----------------------------|----------------------------------------|
| 0–100             | 270                         | —                                      |
| More than 100 to 200 | 320                         | 18.51%                                 |
| More than 200 to 300 | 720                         | 125%                                   |
| More than 300 to 400 | 1300                        | 80.55%                                 |
| More than 400 to 500 | 1500                        | 15.38%                                 |
| More than 500 to 600 | 1900                        | 26.66%                                 |
| More than 600      | 2100                        | 10.52%                                 |
2.4. The Final Electricity Bill. The final monthly electricity bill, $Bill_i$, paid by household $i$ in month $t$, is calculated. In the final bill calculated for each household, the amounts of the peak period penalty and off-peak period discount are considered. The average price charged to household $i$ in month $t$ is calculated through the following formula:

$$P_{it} = \frac{Bill_{it}}{q_{it}}$$

(2)

According to the above formula, $q_{it}$ (kWh) is the total consumption of household $i$ in month $t$ and $P_{it}$ (Rial/kWh) is the average electricity price charged to household $i$ in month $t$.

It is noteworthy that after changing the tariff, the average electricity price charged to households is calculated during peak and off-peak periods by considering overpayment and discounted in these periods.

2.5. Regression Price Elasticity. Using the data panel, we applied the fixed effect regression model to estimate the price elasticity of residential electricity demand to avoid omitted variable bias, remove the effect of those time-invariant household characteristics, and control unobserved heterogeneity in the Equation as follows:

$$\ln q_{it} = \alpha_i + \beta \ln p_{it} + \varepsilon_{it}$$

(3)

In the above equation, $q_{it}$ is the monthly consumption of household $i$ in period $t$ and $p_{it}$ is the average electricity price charged to household $i$ in period $t$, and $\alpha_i$ will be the fixed effects in the model. We employed the log-log model, so the coefficient $\beta$ will also be the average price elasticity of residential electricity demand. $\varepsilon_{it}$ is the error term and the term $a_i$ represents the unobserved time-invariant individual effect. We estimated the short-run price elasticity by assuming that climatic conditions, household size, and household income do not vary over the study period.

3. Data and Methodology

We collected the dataset from one of the largest cities in Iran, Mashhad. The electricity tariff was changed by the Iranian targeted subsidy plan in Iran on December 18th, 2010. We studied how this tariff change affected the electricity consumption of residential consumers. We used the data panel of 2,651 consumers living in Mashhad. According to the Iranian targeted subsidy plan data, we used the consumption information for December and January to estimate the short-term price elasticity of residential electricity demand. In December and January, the autumn months in Iran, temperatures are low, and electricity consumption is low due to the lack of air conditioning. Because these consumers have three-rate electricity meters, consumption information was used in the off-peak, mid-peak, and peak periods to estimate the price elasticity of electricity demand.

Tables 4 and 5 summarize the descriptive statistics of the key variables. In peak periods, the average electricity consumption in December and January is 42.08 kWh and 40.81 kWh, respectively. The maximum values of monthly electricity consumption in December and January in peak periods are 335.09 kWh. In peak periods, the average electricity prices charged to households in December and January are 240.69 Rial/kWh and 662.77 Rial/kWh, respectively. The maximum values of electricity prices in December and January in peak periods are 793.52 Rial/kWh and 1613.50 Rial/kWh, respectively. The minimum values of electricity prices in December and January in peak periods are 43.67 Rial/kWh and 463.42 Rial/kWh, respectively.

The comparison of the average electricity consumption values in these two months shows that the average electricity consumption values in January compared to December in all periods have decreased, while the average electricity prices in January compared to December have increased.

4. Results

The price elasticity of electricity demand is used to assess consumer behavior. As residential consumers’ load profiles vary with the price, their price elasticity of demand can be used to develop demand response programs to control and reduce peak loads in power systems. Due to the high proportion of residential consumers in Iran, it is crucial to know their consumption behavior in the face of electricity price changes because they have the significant potential to manage peak loads in the network. Unfortunately, estimating the elasticity of electricity demand in developing countries is difficult due to the lack of data and abrupt changes in electricity prices. However, we used the period of targeting subsidies on December 18th, 2010, and calculated the short-term price elasticity of residential electricity demand for the first time.

In this paper, the elasticity of electricity demand has been calculated according to the available data from the electricity consumption of 2,651 residential consumers with three-rate electricity meters in Mashhad in December and January. Data analysis was performed in a multistep process during which the collected data were processed.

As seen in Table 6, mean, mid, maximum value, minimum value, and standard deviation are listed for each of the research variables, respectively. When taking into account all customers without classifying them, we estimate the average short-term price elasticity of electricity demand to be $-0.048$. The results of the regression are shown in Table 7.

The price elasticity of electric demand can be applied to different pricing programs to decrease peak electricity demand. An appropriate electricity pricing program design requires knowing how the price elasticity of peak electricity demand...
changes between consumers. Hence, to examine the heterogeneity of price elasticities in the peak period, we classified households into seven groups based on monthly consumption to explore the heterogeneous consumption pattern.

Figure 3 shows the average elasticity during the peak period per consumption step. Results indicate that most households are willing to reduce electricity demand when they face higher average prices of electricity. However, there is significant heterogeneity in electricity price elasticity between the various consumption levels. Furthermore, the maximum average elasticity is in the sixth step, and the minimum average elasticity is in the first step. Because low-usage households are often low-income households requiring a minimum kWh for basic needs, they cannot change their consumption when the average price increases. However, the consumers in the sixth step have the highest price electricity of demand and often have a medium lifeline.

They have to significantly reduce their additional electricity consumption to maintain other needs when their average price rises. On the other hand, consumers in the last steps are affluent and do not care about the rise in average price. Additionally, the principal reason for the lower price elasticity of electricity demand in our case study is that consumers did not need to use the air conditioner due to low temperature.

Finally, in Iran, there are two categories for residential electricity consumption: low-usage consumers use less than the consumption pattern that is the monthly electricity consumption, which is determined based on climate zones and seasonal temperature changes, and high-usage consumers use more than the consumption pattern.

According to the price elasticity of electricity demand for different consumption groups in Figure 3, we find that clustering consumers into two groups (low-usage and high-
usage consumers) is incorrect. Consumers in the sixth and fifth steps have a medium lifeline with the highest responsiveness. Consumers in the first step have the lowest responsiveness to price changes. Due to the heterogeneity of consumer’s electricity price elasticity, it is better to change the classification into four groups: vulnerable consumers (with monthly consumption lower than 100 kWh), low-usage consumers (with monthly consumption between 100 and 400 kWh), medium-usage consumers (with monthly consumption between 400 and 600 kWh), and high-usage consumers (with monthly consumption more than 600 kWh).

5. Conclusion

In this study, we have investigated the residential electricity demand and examined how price changes affect electricity consumption in a household in Mashhad; one of the largest cities in Iran. Knowledge of consumer behavior is crucial, as residential consumers create a significant potential for load reduction due to the high share of their consumption among all consumers. Therefore, it is extremely important to calculate the price elasticity of electricity demand. Unfortunately, the electricity price in Iran is very different from the actual price due to government subsidies, and consumers’ reaction to price rise is slight. Therefore, electricity pricing in Iran is needed to reform.

Using the targeting subsidies shock that occurred on December 18th, 2010, we used the panel data of 2,651 residential consumers with a fixed effect regression model. The estimated short-term price elasticity of electricity demand was -0.048. We have examined the price elasticity of electricity demand of residential consumers with different consumption levels. We find significant heterogeneity in electricity price elasticity between the various levels of consumption. Low-consumption consumers are proportionately inelastic; however, medium-consumption consumers are the most responsive to price increases. Finally, the high consumption consumers are more flexible than the low consumption consumers but not as responsive as the medium-consumption consumers.

This study provides more information about the behavior of residential consumers to policymakers to reform electricity prices. Mainly, it can be used in critical peak pricing programs.
to manage peak loads. Because of different price elasticities, we need to design the tariff according to the level of consumption to decrease inequality between consumers.

Data Availability

The monthly consumption of residential consumers data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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