Research on the Disadvantages and Countermeasures of Cross-subsidy for Sales Electricity Price

Jiaqi Zhang*
School of Economics and Management, North China Electric Power University, Beijing, China
*Corresponding author e-mail: mergeret@163.com

Abstract. In the context of deepening the reform of the power system and advancing the marketization of power, how to advance the price reform in an orderly manner has become an important issue in the reform process. Due to excessive consideration of economic structural adjustment and subsidies for agricultural residents' electricity, the deviation between China's sales price and electricity costs is very common, causing serious cross-subsidy problems. This paper applied Ramsey pricing theory, social welfare net loss theory, and cross subsidy application conditions to analyze the problems caused by cross subsidy of electricity price in China, and proposed several ideas and solutions to cross electricity subsidy.

1. Introduction

1.1. Connotation of cross-subsidy
Generally speaking, cross-subsidy refers to the deviation between the price paid by a customer for a certain product or service and the cost incurred by the manufacturer to obtain the product or provide the service, which is a way between different products or different services of the same enterprise to transfer economic profits.

As for the power industry in China, there are three types of cross subsidies. The first category is the subsidies from users in developed areas of provinces (autonomous regions and municipalities) to the users in less developed areas; the second category is subsidies from high voltage users to low-voltage users; The third category is subsidies from large industrial, general industrial and commercial users to residents and agricultural users.

1.2. Current status of cross-subsidy for electricity price in China
The way to judge whether there is cross subsidy is to compare if the electricity price matches the electricity cost. It is known that due to the low voltage level, the long power supply chain, and the use of many service resources, the peak power consumption is mainly concentrated, and its power supply cost is significantly higher than that of general industrial and large commercial industrial power users. However, the actual level of residential electricity prices in China is lower than most other categories, about 80% of industrial electricity prices. The electricity price of residents in most countries in the world is the highest among all kinds of electricity prices. The electricity price of residents is usually 1.5-2 times that of industries. Table 1 shows the comparative data of electricity prices.
### Table 1. Comparison data of industrial electricity prices and residential electricity prices in 2018.

| Country       | Average electricity price | Industrial electricity price | Residential electricity price | Residential electricity prices/Industrial electricity prices |
|---------------|---------------------------|------------------------------|-------------------------------|-----------------------------------------------------------|
| United States | 0.099                     | 0.069                        | 0.129                         | 1.870                                                      |
| United Kingdom| 0.164                     | 0.125                        | 0.202                         | 1.616                                                      |
| France        | 0.150                     | 0.111                        | 0.189                         | 1.703                                                      |
| Germany       | 0.244                     | 0.143                        | 0.344                         | 2.406                                                      |
| China         | 0.091                     | 0.107                        | 0.084                         | 0.785                                                      |
| Spain         | 0.205                     | 0.116                        | 0.293                         | 2.526                                                      |
| South Korea   | 0.095                     | 0.099                        | 0.09                          | 0.909                                                      |
| Greece        | 0.154                     | 0.107                        | 0.2                            | 1.869                                                      |
| Chile         | 0.170                     | 0.14                         | 0.199                         | 1.421                                                      |

1.3. Achievements of domestic cross-subsidy measures

Cross-subsidy reflects the relationship between income and costs attributed to a commodity. As the reform of the energy system continues to advance, more and more scholars at home and abroad have begun to pay attention to and study the problems of cross subsidies for electricity prices. Faulhaber [1] first proposed the concept of cross-subsidization. He pointed out that the essence of cross-subsidization in the pricing of utility goods is price distortion, which has an adverse effect on public goods and other commodities. Kuo Guanghui [2] analyzed the current situation of severe cross-subsidies of industrial, commercial electricity prices and residential electricity prices in China by comparing with the situation in many countries. Zeng Ming [3] explained that under the new model of large user direct purchase, large users entering the market to purchase electricity should bear the corresponding “outside price” social responsibility. Lin Boqiang [4] stated that today's household electricity prices should have the function of restraining unreasonable demand and encouraging savings in the increasingly serious energy supply and environmental problems. In short, scholars at home and abroad already have a certain understanding of the issue of cross-subsidization of electricity prices, but the measurement and treatment of cross-subsidization is still in the theoretical research stage. I will explain the problems caused by the existence of cross-subsidization based on the status of the electricity reform phase.

2. Analysis of the Disadvantages of Cross-subsidies

2.1. Low price elasticity of residential electricity demand

According to the Ramsey pricing principle of sub-optimal pricing, the degree of price deviation from marginal cost should be inversely proportional to its elasticity of demand [5]. The use of cross subsidies requires the subsidized party to have sufficient demand price sensitivity, so that the increase in profits because of the growth of power consumption caused by the discounted price can make up for the loss caused by the price reduction of another product. In the cross-subsidization of electricity, the subsidized party is represented by residential users. The following will calculate the elasticity of demand of large industrial users and residential electricity users to determine whether the conditions for cross-subsidy are met.

2.1.1. Modeling. I considered the many factors that affect user’s power consumption, and established a multivariate non-linear regression model based on the national electricity consumption data and related economic data from 2009 to 2019, and calculated the power demand price elasticity of large industrial users and residential users respectively [6]. The electricity prices for residents and large
industrial users were obtained by weighting the ladder electricity prices and electricity consumption. In order to study the relationship between changes in variables, in this model I used a log-linear model to build a power demand model. The industrial power demand model was:

\[
\ln Q_i = \alpha_0 + \alpha_1 \ln P_i + \alpha_2 \ln GI_i + \alpha_3 \ln MI_i + \mu_i
\]  

Among them, the explanatory variable \(Q_i\) was the industrial electricity consumption, the explanatory variable \(P_i\) was the industrial electricity price, \(GI_i\) and \(MI_i\) respectively represented the growth rate of industrial output value and the number of industrial enterprises above designated size. To exclude the effects of inflation, taking 2009 as the base year, the purchase price index of fuel and power industrial producers was used to deflate the values of \(P_i, GI_i,\) and \(MI_i\). The variables were all annual data. The total unit of industrial power consumption was 100 million kilowatt hours, the unit of finished products of industrial enterprises was 100 million yuan, the number of industrial enterprises above designated size was 1 unit, and the unit of large industrial electricity price was 1 yuan per kilowatt hour.

Similarly, we can get the residential electricity demand model:

\[
\ln Q_i = \beta_0 + \beta_1 \ln P_i + \beta_2 \ln C_i + \beta_3 \ln N_i + \mu_i
\]  

Among them, the explanatory variable \(Q_i\) was the total power consumption of domestic consumption, the explanatory variable \(P_i\) was the residential electricity price, and \(C_i\) and \(N_i\) represented the disposable income of residents and the total population at the end of the year. To ensure that the data excludes the effects of price level changes, I took 2009 as the base year, and used the consumer price index and the purchase price index of fuel and power industrial producers to deflate \(C_i\) and \(P_i\). The variables were all annual data. The unit of total electricity consumption for domestic consumption was 100 million kilowatt-hours, the unit of residential electricity price was yuan per kilowatt-hour, the unit of disposable income of residents was yuan, and the unit of total population at the end of the year was one.

2.1.2. Empirical analysis. The data came from the databases of the National Energy Administration, the International Power Network, the International Energy Agency, and the National Bureau of Statistics. After the collected sample values were properly processed, the SPSS software was used to analyze the industrial power demand model and the residential power demand model and obtain the coefficients and significance of each variable. The regression model passed the F test, believed that the overall variable could explain the change in the dependent variable; the number of industrial enterprises above the size in the variable did not pass the t test. After removing the variable and re-regressing, the results could pass statistical tests and econometric tests. Finally, the formula model of industrial user demand was obtained:

\[
\ln Q_i = -0.643 - 0.863 \ln P_i + 1.038 \ln GI_i
\]  

In the same way, the SPSS software was used to perform regression analysis on the residential electricity demand model. We obtained the residential electricity demand formula model:

\[
\ln Q_i = -20.587 - 0.325 \ln P_i + 1.050 \ln C_i + 1.643 \ln N_i
\]  

Table 2 shows the analysis results of the industrial power model established using SPSS software.
Table 2. Statistical results of industrial power demand models.

|                      | Regression coefficients |
|----------------------|-------------------------|
| Constant             | -0.643 (-0.269)         |
| $P_i$                | -0.863 (-2.187*)        |
| $GI_i$               | 1.038 (4.868**)         |

Sample size 11  
R-squared 0.892  
Adjusted R-squared 0.864  
F value $F(2,8)=32.891, p=0.000$  
Dependent variable: $Q_i$  
Durbin-Waston stat: 1.625

* $p<0.1$  ** $p<0.01$ The number in brackets is t-value.

2.1.3. Analysis of the Result. According to the above results, we have obtained that the elasticity of the price of industrial demand was -0.863, which meant that for every 1% increase in industrial electricity price, the demand for industrial electricity will decrease by 0.863%, less than 1%, indicating that the price of industrial electricity demand was inelastic. The output of industrial products is determined by the production department according to the market demand plan and workers’ production efficiency. Industrial enterprises may adopt methods, such as formulating production plans to avoid load peaks, to reduce electricity costs, but power demand will not change much.

The price elasticity of residential demand was -0.325, which meant that for every 1% increase in the price of residential electricity, the demand for residential electricity will decrease by 0.325, less than 1%, indicating that the price of residential electricity demand was inelastic. Most of the electricity used by residents is domestic electricity, and the basic electricity demand is relatively stable, and there will not be excessive fluctuations due to changes in residential electricity prices. The absolute value of the price elasticity of industrial demand was greater than the price elasticity of household demand, which did not meet the conditions required to adopt cross subsidies.

According to the Ramsey pricing principle, users with higher price elasticity should set higher electricity prices, and users with lower price elasticity should set lower electricity prices. Only when the residential electricity price is larger and the industrial electricity price is farther from the marginal cost can the zero-profit condition be met.

2.2. Incurring high deadweight losses
Deadweight loss refers to the social cost of a market because it has not reached its optimal operating state [7]. Because of the existence of cross subsidies, product prices are not set according to market rules, which is essentially an irrationality of pricing, which will lead to an increase in net loss of social welfare. Governments around the world attached great importance to the measurement of cross-subsidy quotas and their impact on economic operations. Cross-subsidization will affect market regulation in a macroscopic way, hinder society from optimizing the allocation of resources, and will eventually have an adverse impact on the national economy. It will again be reflected in the overall poverty and inequality of the country, contrary to the original intention of setting up cross-subsidization. On the micro level, the sales electricity price formed by cross subsidies does not meet
the market competitive pricing standards, transmitting the wrong price signals to power users, which is not conducive to the formation of energy saving ideas.

![Figure 1. Power demand curve for industrial users.](image)

Under the condition that other control variables are not changed, MATLAB software was used to obtain the functional relationship between industrial user power demand and electricity price change from known nonlinear regression models. The industrial user power demand curve and the quintic polynomial fitting curve are shown in Figure 1. Considering the particularity of power supply, only the changes in consumer surplus were discussed here.

![Figure 2. Analysis of consumer distortions due to price distortion.](image)

Figure 2 analyzes the consumer's residual losses caused by large industrial users who have lower power supply costs but sell at high prices to curb production. As the electricity price rises to be higher than the marginal cost, which suppresses the power demand of industrial users, the reduction of deadweight losses at this time can be expressed as the area shaded in the figure 2.

In the same way, we can get the functional relationship between the electricity demand of residents and the price changes under the condition that other control variables are unchanged. The image is shown in Figure 3. Due to the existence of cross-subsidies, the residential electricity price has been reduced from $P'$ to $P_0$. At this time, the increased consumer surplus is also represented by the shaded area in Figure 2.
Comparing Figure 1 and 3, it can be seen that the power demand curve of industrial users is steeper, that is, the elasticity of price demand is greater. From a qualitative perspective, the consumer surplus caused by the decline in residential electricity prices is not enough to make up for the loss.

In order to accurately calculate the change in deadweight loss, the following will take the electricity price of 0.60-0.65 yuan per kilowatt-hour as an example for quantitative analysis. Integrate the power demand curve of industrial users and the power demand curve of residential users within the range of independent variables, that is, the area of the shaded part in Figure 2. According to the calculation of MATLAB, the reduction value of industrial user consumer surplus is 5.4083e-02, and the increase value of consumer user consumer surplus is 3.1589e-10, which is far less than the increase in deadweight loss caused by rising industrial electricity prices. Therefore, it can be explained that cross subsidies can cause loss of social welfare.

2.3. Power system reform makes cross-subsidy unsustainable
Since the implementation of the "Power System Reform Plan" document No. 5 of 2002, the power industry has successively carried out explorations and large-scale direct power purchase pilots has also been underway for more than a decade.

Direct electricity purchase by large customers promotes effective competition in the market through direct transactions between generators and users, reduces costs and network fees and improves resource allocation efficiency. However, while large industrial users enjoy low-cost power supply services, some of the large user revenues that SGCC has used to obtain cross subsidies will gradually disappear, while the SGCC, as a state-owned enterprise, still has the obligation to assume the responsibility of providing universal power services [8]. In order to protect people's livelihood, SGCC still need to supply power to remote areas with lower prices, lower income and engaged in agricultural production. This will inevitably cause losses for SGCC, affect their influence and leadership in the power industry, and influent the fairness of power transactions.
With the further advancement of China's electricity marketization reform, a large number of power supply companies have been established, more and more power supply companies and power users have entered into bilateral trading markets and listed trading markets for electricity trading, and eventually formed multi-buyer corresponds to multi-seller near-perfect competition in the electricity market, as shown in Figure 4. In the form of overproduction of electricity, power suppliers would reduce the reported electricity price to increase the load rate, and the electricity price gradually tends to cost pricing, and cross-subsidization of sales electricity prices will be more difficult to sustain.

3. Suggestions on Measures to Mitigate Cross-subsidies
In order to solve the disadvantages caused by cross subsidies, time-of-use electricity prices, load-rate electricity prices, and voltage-grade electricity prices should be used to design step-rate electricity prices, appropriately expand the voltage grade spread, increase the proportion of basic electricity charges, and promote the return of user electricity prices to the actual power supply costs.

The existence of cross-subsidy has its rationality. According to the "Improving the Government's Public Welfare Regulatory Service Function" as stated in Document No.9, the government price department shall follow the principles of "reasonable cost, reasonable profit and fair burden" to design transmission and distribution prices, comprehensively introduce competition mechanisms on the power supply side and the power sales side.

To implement and solve the electricity consumption problems of non-profit services such as agriculture and residents, the low-income households adopt the method that the power supply company first collects the electricity fee from the user according to the normal electricity price, and then reports the amount of cross-subsidy to the finance departments, which are distributed to low-income households in the form of electricity fee subsidies through prescribed channels. In the future, the financial department will also need to strengthen the management of funds, do a good job in investigating and verifying beforehand, issue separately established energy subsidy funds for low-income households. The preferential treatment policy is not only in line with the requirements of the Central Committee of the Communist Party of China to achieve precise poverty alleviation and guarantee the basic people's livelihood, but also to avoid affecting the overall rationality of the electricity price policy due to some minority residents [9].

4. Conclusion
Based on the basic theories of microeconomics and macroeconomics, this paper analyzed the disadvantages of cross-subsidization of sales price in view of the current situation of cross-subsidization of electricity prices in China, such as causing unnecessary loss and affecting market unfairness. However, as China's power reform has not yet been completed, the establishment of an independent transmission and distribution price mechanism is still in progress. The analysis and judgments made are time-efficient and should be continuously adjusted as the current situation of the
power industry changes. As for the negative issues, the implementation details need to be further discussed.

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