A study on the Policy of Stepped Electricity Price Policy in Guangdong Province, China

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Abstract. Conducting a social survey on the electricity usage patterns of residents in various regions within Guangdong province prior to the introduction of the tiered pricing policy, this study aims to evaluate the impact of implementing step-based pricing for households. The investigation focuses on two aspects: analyzing changes in monthly electricity consumption and conducting empirical analysis using a state space model. The study further develops a computational model to comprehensively evaluate the impact of policies on various aspects including economic growth, international trade (imports and exports), commodity prices, energy consumption, and environmental consequences. This analysis aims to identify the most optimal approach for future adjustments in price policies.

Keywords: Tiered electricity pricing; Guangdong province; State space model; CGE model

1 Introduction

China has implemented a residential ladder electricity price policy since 2012, aiming to accurately reflect the electricity consumption cost of residential users, reduce cross-subsidization from industrial and commercial sectors to residential sector, encourage widespread participation in energy conservation and emission reduction efforts, and enhance the efficiency of electricity resource allocation while ensuring that basic electricity consumption of low-income families remains unaffected or minimally affected. Under this policy, have there been any changes in residential electricity consumption habits? Has awareness about energy conservation increased? Have there been any actual changes in electricity consumption?

Previous studies on step tariffs in China and other countries have primarily focused on qualitative investigations and the design of influencing factors [1-7]. However, there is a lack of research on the actual implementation effects of these policies, with most existing studies relying on theoretical simulations. For instance, literature [8-12] has examined the energy-saving and welfare effects of step tariffs using utility functions and quadratic almost ideal demand system models. While these studies offer valuable insights for designing and evaluating step tariffs, they place greater emphasis on constructing theoretical models rather than empirically testing policy effectiveness. Given that energy conservation is one of the key objectives of step tariff policies, assessing electricity consumers' behavior not only evaluates

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policy implementation but also provides a theoretical foundation for refining related energy and economic policies.

In summary, significant progress has been made by both domestic and international scholars in the research of residential electricity tariff policies. However, further investigation is still required to assess the implementation effectiveness of this policy, particularly its impact on residential electricity consumption behavior. Taking Guangdong Province in China as a case study, this paper aims to evaluate the implementation effects of residential electricity tariff policies through statistical analysis of residents' electricity consumption and intensity across different regions within the province, as well as conducting interviews and surveys with representatives of the residents.

2 Patterns of electricity use

The survey encompasses a total of 2,938 residential users in Guangdong, who are geographically dispersed across nine prefectures and cities within four regions: Pearl River Delta (Foshan City, Huizhou City, Jiangmen City), East Guangdong (Shantou City, Shanwei City), West Guangdong (Zhanjiang City, Yangjiang City), and North Guangdong (Shaoguan City, Meizhou City).

The survey employed a combination of field survey and computer-assisted telephone interview (CATI). The sampling method utilized stratified multi-stage random sampling. A total of 2,579 valid questionnaires were collected, comprising 1,799 samples from non-agricultural areas and 960 samples from rural regions. This achievement demonstrates an impressive rate of recovery stands at 93.9%. Furthermore, the survey results obtained a certainty level of 95%, with a minimal sampling error of only 3%.

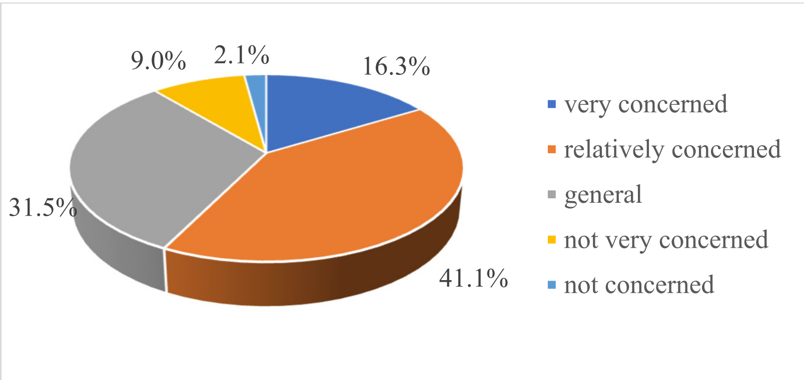

Fig 1 The willingness to save energy after implementing ladder electricity prices

The questionnaire was designed to inquire about the impact of ladder electricity pricing on energy-saving behavior, specifically whether respondents paid attention to saving electricity by turning off lights and unplugging appliances when not in use. Respondents were asked to rate their level of concern on a scale from 1 (very concerned) to 5 (not concerned). Results showed that 88.9% of respondents paid attention to saving electricity, with 16.3% being very concerned, 41.1% relatively concerned, and 31.5% generally concerned; only 11.1% did not pay attention at all. Fig 1 illustrates that policy implementation had a significant positive impact on improving residents' willingness to save energy.

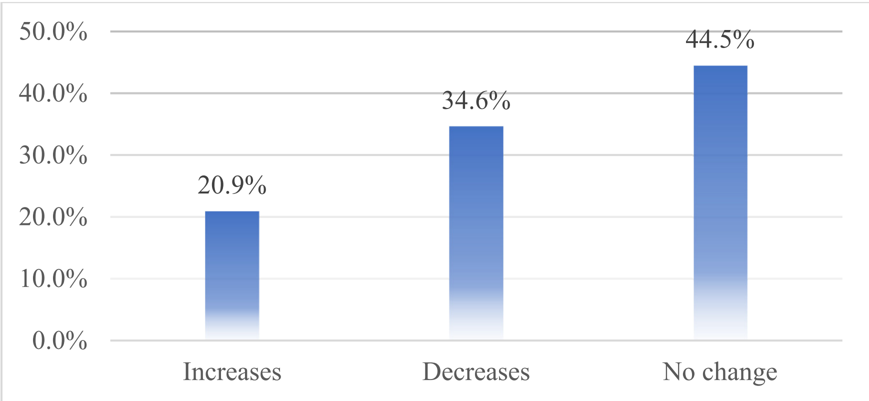

Fig 2 Changes in monthly electricity usage following the ladder electricity prices

The inquiry uncovered that the monthly household electricity consumption underwent various modifications following the execution of the tiered pricing policy. In Fig.2, it can be observed that after the policy was enforced, there was an increase in household electricity consumption for 20.9% of the respondents, a decrease for 34.6% of them, while 44.5% reported their monthly household electricity consumption remained unchanged.

3 Empirical investigation based on electricity usage

The methodology employed in this study involved constructing an model based on state space employing the Kalman filter to analyze pre-policy implementation data sequences. Subsequently, extrapolation forecasting was conducted for post-implementation data series. Additionally, the policy's impact on electricity usage was assessed by comparing the model-derived estimated value with empirical data, thereby evaluating its actual effect of conserving energy.

3.1 Processing of data and construction of models

The data in this paper are from the monthly electricity consumption of urban and rural residents in Guangdong cities. The time range of the data is from 2004 to the first half of 2013. The state space model was constructed using electricity data spanning from 2004 to the first half of 2011.

The state space model is built upon $\mathrm{ARIMA}(p,d,q)$. Hence, it is crucial to identify and determine the order of the ARIMA model beforehand. In order to establish the ARIMA model, a stationary time series is necessary. To address non-stationarity and heteroscedasticity in the electricity usage data (Y_t), we transform it using the natural log form as $\mathrm{Ln}Y_t$.

By taking the first difference form of $\mathrm{LnY_t}$, we obtain a new series $\Delta\mathrm{LnY_t}$. The results from conducting stationary tests in Table 1 indicate that $\Delta\mathrm{LnY_t}$ is indicative of a series that has been integrated at the first order, designated as $\Delta\mathrm{LnY_t} \sim \mathrm{I}(1)$. Consequently, we construct the ARIMA model based on this transformed series of $\Delta\mathrm{LnY_t}$.

Table 1. Non-stationarity Test

Test method / Series		LnY	△LnY
ADF test	no trend	5.64	-2.85☆
	with trend	-0.66	-10.34★
PP test	no trend	1.30	-11.28★
	with trend	-3.32*	-14.23★

Note:1. The critical values of the Augmented Dickey-Fuller test at a 5% significance level, accounting for both constant and trend terms, are -2.89 (-3.46). At a 1% significance level, they become -3.51 (-4.06). 2.The p-value for the Phillips-Perron test with a constant (and trend) is -2.89 (-2.89) at a 5% significance level and -3.50 (-3.50) at a 1% significance level.3. ★,☆,and * respectively represent significance at 1%, 5%, 10%.

Based on the above stationarity test of sequence $\Delta\mathrm{LnY_t}$, we determine that d in the model should be set as 1. Upon analysis, the autocorrelation coefficient of the series $\Delta\mathrm{LnY_t}$ shows a positive metaphysical wave decay, which exhibits trailing; and the autocorrelation coefficient and partial autocorrelation coefficient of the sample are significantly non-zero at lag k = 12 periods, suggesting that there is a seasonal effect of series $\Delta\mathrm{LnY_t}$. By applying the first-order seasonal difference, we effectively mitigate the impact of seasonality, and at the same time, the sample autocorrelation and partial autocorrelation coefficients do not exhibit statistical insignificance, indicating that D=1, P=Q=1, s=12.

Further, through the autocorrelation-partial autocorrelation function graph combined with AIC criterion, p=q=1 is identified. The X-12 method for seasonal adjustment is employed after conducting assessments of the autocorrelation coefficient and partial autocorrelation coefficient,

$$(1 + 0.56\mathrm{L})\big((1 - \mathrm{L})\Delta\mathrm{LnY_t} - 0.021\big) = (1 + 0.89\mathrm{L})\vartheta_t \quad (1)$$

where L is the lag operator, then $\Delta\mathrm{LnY_t}$ is submitted to the following state space model:

$$\mathrm{Y_t} = (1 \quad 0 \quad 1)\begin{pmatrix} \mathrm{TC_t} \\ \mathrm{b_t} \\ \mathrm{I_t} \end{pmatrix} \quad (2)$$

$$\begin{pmatrix} \mathrm{TC_t} \\ \mathrm{b_t} \\ \mathrm{I_t} \end{pmatrix} = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -0.56 \end{pmatrix}\begin{pmatrix} \mathrm{TC_{t-1}} \\ \mathrm{b_{t-1}} \\ \mathrm{I_{t-1}} \end{pmatrix} + \begin{pmatrix} \omega_t \\ 0 \\ \vartheta_t \end{pmatrix} \quad (3)$$

where $\mathrm{TC_t}$ represents a factor of tendency-cycle, $\mathrm{I_t}$ undergoes the process of $\mathrm{AR}(1)$,ω_t and ϑ_t are disturbance terms. The stability of random walk is represented by $\mathrm{b_t} = \mathrm{b_{t-1}} = \cdots \mathrm{b_0} = 0.021$, which exhibits fluctuation.

3.2 Modeling results

The Kalman filter-based state space model was utilized to approximate the electricity consumption from July 2011 to June 2012. In Figure 3, the monthly electricity usage is visually represented by the red line, while the estimated consumption is depicted by the green line. The calculated root mean square error (RMSE) is 1.53, indicating an average estimation error of 1.53% over the course of twelve months (July 2011 to June 2012). The estimation demonstrated a high level of accuracy.

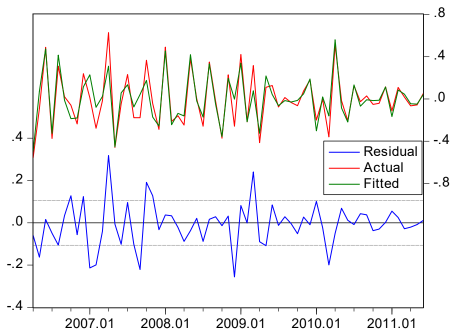

Fig.3. State-space model fitting results

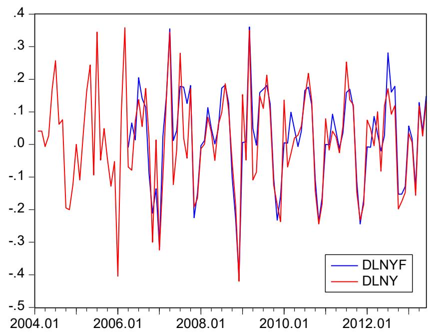

Fig.4. Prediction results of state-space model

In the same vein, an estimation was made for the electricity usage on a monthly basis from July 2012 to June 2013. Fig.4 illustrates that the estimated data during this period surpassed the actual figures, indicating a positive impact of implementing a step tariff on energy conservation, which aligns with the findings of the aforementioned social survey. Specifically, there was a significant disparity between the actual and estimated series from July to October 2012; however, subsequent to October, this discrepancy gradually diminished. This trend could be attributed to residents initially exhibiting proactive behavior in conserving electricity due to psychological pressure but later experiencing reduced effectiveness of the policy as their inflexible demand for electricity persisted over time.

4 Impacts of Stepped Electricity Price on the macroeconomy

The government's primary concern lies in the impact of step tariffs on inflation and economic growth. In order to assess the policy's effects on the macroeconomy, we utilized a CGE model to simulate its influence on commodity prices and overall economic growth.

The model known as CGE is a tool that finds extensive application in the analysis of the impacts caused by domestic and international price policies. The fundamental concept behind the CGE model is that the determination of the ideal quantity of goods by producers is driven by the goal of maximizing profits, while consumers optimize their utility by considering budget constraints to determine the desired quantity of each commodity. When the economy reaches a state of equilibrium where the supply and demand are perfectly balanced, it attains its highest level of stability. Consequently, a set of equilibrium prices can be derived from this balance between supply and demand.

In order to perform an extensive evaluation of the macroeconomic impacts of step tariffs, various aspects were incorporated into the extended CGE model. These factors included the expansion of the economy, international trade in goods, fluctuations in prices of commodities, levels of energy usage, and emissions impacting the environment.See Figure 5 for details.

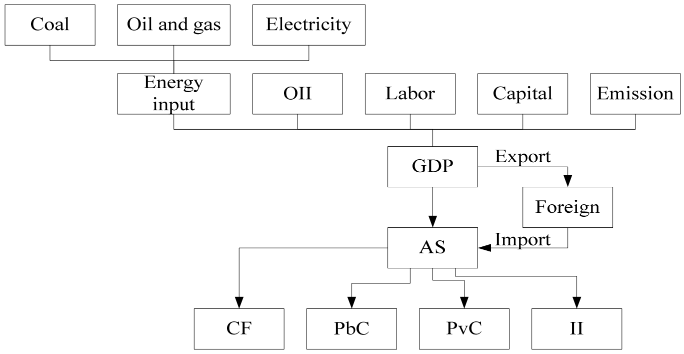

Fig.5. Structural design of the model

Note: In the Fig 5, OII represents other intermediate inputs; AS stands for the supply of Amington; CF denotes the process of creating and accumulating capital; PvC stands for personal expenditure; PbC represents the utilization of resources for the benefit of society as a whole; II stands for inputs at an intermediate stage.

4.1 Consequences on the Expansion of the Economy

To conduct CGE analysis, the initial step involves compiling a matrix for social accounting, which is derived from a table for input and output. Since power price is considered as a holistic variable in the model and cannot be segmented, the influence of the cost of electricity for households on the rate of economic expansion is represented through a consecutive series pertaining to the cost of electricity for households- average retail electricity pricing- overall electric power pricing. In simpler words, the average electricity price in society is directly impacted by any modifications made to residential electricity rates. Following this concept, an analysis was conducted to examine the impact of power prices on Guangdong province's economy through the simulation of five different scenarios. These situations entailed adjustments in residential electricity prices resulting in a respective rise of 10%, 20%, 40%, 75%, and 100% in the average selling price of electricity.

The findings depicted in Fig 6 indicate that an increase in electricity prices has a detrimental impact on the economy. A modest negative effect of -0.43% is observed when there is a 10% price hike, but as the prices continue to rise, it leads to more significant economic strain. Notably, if the price surges by 100%, it results in a GDP loss of approximately 4.20%.

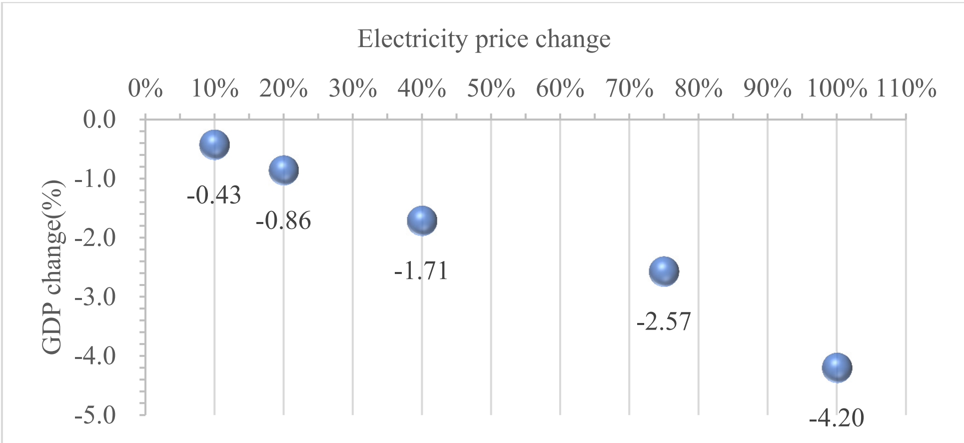

Fig.6. Impact on GDP

The simulation of policy indicates that a moderate increase in power prices has an acceptable impact on the economy, but if the increase exceeds a certain range, it will significantly affect economic growth.

4.2 Influences on general price

The CPI, also known as the Consumer Price Index, serves as an inflation gauge by capturing variations in the costs incurred by individuals when purchasing goods and services. Maintaining stable prices is crucial for the overall stability of the economy, and it is considered a primary goal by the Chinese government. The step tariff system for residential electricity directly impacts the cost of living for consumers. Consequently, there is significant interest in understanding how adjustments to electricity prices affect CPI. Table 2 presents the variations in CPI corresponding to different degrees of price adjustment. According to Table 2, an increase in electricity prices by 5%, 10%, 15%, and 20% leads to respective increases in CPI by 0.4%, 0.7%, 1.0%, and 1.2%. Additionally, there is a continuous decrease in elasticity as these adjustments occur. When electricity prices rise by 20%, the average elasticity stands at only 0.07%.

Table 2. Influences on CPI

Change ratio	5%	10%	15%	20%
CPI	0.4%	0.7%	1.0%	1.2%
Elasticity	0.08	0.07	0.07	0.06

Ensuring price stability is consistently a top priority for the Chinese government in terms of macroeconomic objectives, as it directly impacts the stability and quality of public living standards. Hence, when formulating power pricing policies, policymakers must carefully assess their potential impact on the Consumer Price Index (CPI). Generally, a moderate and acceptable increase in CPI would be within 1%. Research findings indicate that adjusting electricity prices by up to 15% leads to an increase in CPI that does not exceed 1%. However, this does not imply that a 15% increase in electricity prices is always deemed acceptable.

Considering the diverse determinants impacting CPI, including monetary policy and fiscal policy, Any modifications to the pricing of electricity ought to be implemented under appropriate circumstances with comprehensive consideration of overall pricing dynamics. The objective of this strategy is to mitigate its impact on the general cost levels and economic output.

5 Conclusions

The research examined how consumers behave when step tariffs are applied and revealed a significant correlation between willingness to conserve energy and electricity usage, based on comprehensive questionnaire data. This study aims to improve the theoretical comprehension and bridge existing knowledge gaps in the post-assessment and examination of consumer behavior during stepped electricity price policy investigations.

The social survey's fundamental findings were validated by employing the Kalman filter within a state space model. Specifically, the implementation of step tariffs initially stimulated public willingness to conserve energy and led to a reduction in actual electricity consumption compared to pre-policy levels. However, this decline in electricity usage was not sustained over an extended duration. Research indicates that psychological pressure had an evident initial impact on energy conservation upon policy implementation; however, as time progressed, inflexible electricity demand undermined the efficacy of energy-saving measures.

The rise in residential electricity prices is imperative due to the progressive enhancement of living standards of the general public and the need to address scarcity of energy and the value of the environment. Decision-makers express concerns about potential inflationary effects and impacts on economic growth during the adjustment and refinement of price policies. To address these concerns, a CGE simulation was conducted, demonstrating that while there is an impact on economic growth resulting from the rise in residential electricity prices, it remains manageable and acceptable. Therefore, as long as price adjustments are made within an appropriate range, excessive government worry regarding inflation is unnecessary.

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