

Li, Yumin; Jiang, Yan; Dong, Changgui

Working Paper

Electricity cross-subsidies in the People's Republic of China: Equity, reverse Ramsey pricing, and welfare analysis

ADB Working Paper Series, No. 1188

Provided in Cooperation with:

Asian Development Bank Institute (ADBI), Tokyo

Suggested Citation: Li, Yumin; Jiang, Yan; Dong, Changgui (2020) : Electricity cross-subsidies in the People's Republic of China: Equity, reverse Ramsey pricing, and welfare analysis, ADB Working Paper Series, No. 1188, Asian Development Bank Institute (ADBI), Tokyo

This Version is available at:

<https://hdl.handle.net/10419/238545>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/3.0/igo/>



ADB Working Paper Series

ELECTRICITY CROSS-SUBSIDIES IN THE PEOPLE'S REPUBLIC OF CHINA: EQUITY, REVERSE RAMSEY PRICING, AND WELFARE ANALYSIS

Yumin Li, Yan Jiang,
and Changgui Dong

No. 1188
September 2020

Asian Development Bank Institute

Yumin Li is an assistant professor at the SHU-UTS SILC Business School of Shanghai University, Shanghai, People's Republic of China (PRC). Yan Jiang is a graduate student at the SHU-UTS SILC Business School of Shanghai University, Shanghai. Changgui Dong is an assistant professor at the School of Public Administration and Policy of Renmin University of China, Beijing, PRC.

The views expressed in this paper are the views of the author and do not necessarily reflect the views or policies of ADBI, ADB, its Board of Directors, or the governments they represent. ADBI does not guarantee the accuracy of the data included in this paper and accepts no responsibility for any consequences of their use. Terminology used may not necessarily be consistent with ADB official terms.

Working papers are subject to formal revision and correction before they are finalized and considered published.

The Working Paper series is a continuation of the formerly named Discussion Paper series; the numbering of the papers continued without interruption or change. ADBI's working papers reflect initial ideas on a topic and are posted online for discussion. Some working papers may develop into other forms of publication.

The Asian Development Bank refers to "China" as the People's Republic of China.

Suggested citation:

Li, Y., Y. Jiang, and C. Dong. 2020. Electricity Cross-Subsidies in the People's Republic of China: Equity, Reverse Ramsey Pricing, and Welfare Analysis. ADBI Working Paper 1188. Tokyo: Asian Development Bank Institute. Available: <https://www.adb.org/publications/electricity-cross-subsidies-prc>

Please contact the authors for information about this paper.

Email: liyumin418@gmail.com, yuminli@shu.edu.cn

Asian Development Bank Institute
Kasumigaseki Building, 8th Floor
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

© 2020 Asian Development Bank Institute

Abstract

The Chinese government has implemented reverse Ramsey pricing in the People's Republic of China's (PRC) electricity market, i.e., the residential electricity price has been lower than the industrial electricity price for decades, and the claimed rationale for this reverse Ramsey pricing is equity (i.e., low residential prices ensure that low-income households enjoy basic living conditions). Many have argued that the PRC's government should have adopted Ramsey pricing in the electricity industry to achieve efficient outcomes, which implies that the residential electricity price should be higher than the industrial electricity price based on their price elasticities. This paper presents one explanation of the phenomenon of reverse Ramsey pricing in the Chinese power market. In this paper, based on a modified Ramsey model, we assume the government has different weights on residential and industrial consumer surplus and derive a reverse Ramsey pricing rule. To numerically demonstrate that the reverse Ramsey pricing rule is reasonable under some circumstances, we calibrate the model and simulate social welfare under different scenarios. We find that the reverse Ramsey pricing rule is optimal if we introduce equity considerations, and the greater the weight of the residential sector, the lower the residential electricity prices. Our social welfare simulation results under different scenarios provide useful guidance for policy makers in future energy reform.

Keywords: multi-objective regulation, reverse Ramsey pricing, social welfare

JEL Classification: Q41, Q48

Contents

1.	INTRODUCTION	1
2.	THEORETICAL MODEL.....	2
2.1	The Classical Ramsey Problem.....	2
2.2	The Ramsey Problem with Equity Consideration.....	3
3.	CALIBRATION.....	5
4.	SIMULATION RESULTS	6
5.	ROBUSTNESS CHECK	8
6.	CONCLUSION.....	8
	REFERENCES	10
	APPENDIX	12

1. INTRODUCTION

In the PRC, the retail electricity sector is operated by two wide area synchronous grids, the State Grid and the China Southern Power Grid Corporation. As in many countries, this sector can be considered a monopoly as in most cases households and firms can only buy electricity from one of them and the government sets the prices for different areas (see Lin, Jiang, and Lin 2009; Li, Dong, and Xie 2011).¹ Although marginal-cost pricing is believed to be the most efficient pricing mechanism, it may not be financially feasible for the operators because of huge fixed costs and economies of scale. For a natural monopoly, under the constraint that the revenue should compensate for the cost, regulators can use the Ramsey rule to set the prices to maximize social welfare (Ramsey 1927). Ramsey pricing is also known as the “inverse-elasticity pricing rule,” which aims to set high prices for consumers with low price demand elasticity and low prices for consumers with high price elasticity.

However, electricity prices in the PRC are inconsistent with Ramsey’s pricing rules. For decades, the residential electricity prices have been lower than the industrial prices. In contrast, most countries in the world have adopted Ramsey pricing in the electricity industry. For example, in 2016, the average selling prices of industrial and residential electricity in Australia were 0.109 and 0.219 \$/kWh, while in the PRC, the average prices were 0.112 and 0.084 \$/kWh, respectively.

In most countries, the residential electricity price is much higher than the industrial electricity price, which is consistent with the Ramsey pricing rule. The PRC’s reverse Ramsey pricing in the electricity industry has been hotly debated for years. Many researchers argue that the PRC should reform the electricity pricing mechanism as the distortion of price structure creates huge deadweight loss (Lin 2004; Qi et al. 2008; Qi et al. 2010; Liu et al. 2020). The PRC started a new round of electricity reform in 2015, which continues today. One of the key aims of this new round of reform is to form a new market-based pricing mechanism and reduce the cross-subsidies from the industrial sector to the residential sector. In the PRC’s 2018 Report on the Work of the Government, the government requested a 10% reduction of the industrial electricity prices. In 2019, the government requested a further 10% reduction of the industrial electricity prices. Currently, the residential electricity prices are still lower than the industrial ones.

Many believed that the original rationale of the reverse Ramsey pricing rule was to promote equity and ensure a minimum standard of living for low-income households by keeping residential electricity prices low or even below the real marginal cost (Lin 2004; Li, Dong, and Xie 2011; Liu, Yao, and Ye 2015; Ye et al. 2017). Zheng and Fu (2015) argued in a media piece-article that the cross-subsidies in the Chinese power sector can be seen as an environmental tax, which delivers double dividends, as the industrial sector has been the major source of environmental pollution in the PRC and the subsidies enhance residential consumers’ welfare. However, few articles explain the reason for, and mechanism of, reverse Ramsey pricing rigorously. This paper attempts to rationalize reverse Ramsey pricing and demonstrate that it could be the optimal pricing mechanism in some circumstances.

¹ Before the separation of transmission and distribution, the prices of electricity were determined by the price department of the State Council. Since the separation of transmission and distribution, the prices have been determined by the provincial government. The provincial NDRC would submit the prices to the price department of the State Council for approval.

Traditional Ramsey pricing was established to maximize social welfare under the constraint of operator profit. However, the optimal pricing rule could be different if the objective of regulators were different from the traditional social welfare maximization or the regulators had other constraints. Feldstein (1972) argued that the total social surplus should reflect the distribution of social benefits when setting optimal prices. Since the demand elasticity of low-income residents is relatively low, to achieve social equity, regulators should give them a higher weight. Therefore, regulators might consider equity in the optimization problem in addition to the profit constraint.

Based on a modified Ramsey model, this paper assumes that the government regulation might have multiple objectives and solve the issue of the optimal prices for different sectors. It is difficult to fully solve the optimization problem as the solution depends on lots of parameters. We calibrate the theoretical model and numerically simulate the solution under different weighting structures. The simulation results show that reverse Ramsey pricing could be optimal if the government had high enough weight on the benefits of residential sector. We also simulate the optimal prices under other policy constraints (e.g., 5% or 10% reduction of the industrial electricity prices).

This paper is organized as follows. Section 2 establishes our theoretical model and derives the reverse Ramsey pricing rule. To numerically demonstrate that the reverse Ramsey pricing rule is optimal under some circumstances, we calibrate the theoretical model and simulate the social welfare under different scenarios. The parameters are calibrated in Section 3. The simulation results are reported in Section 4. Section 5 checks the robustness of our results and Section 6 concludes the paper.

2. THEORETICAL MODEL

In the PRC's retail electricity market, power grid enterprises act as monopolists selling power to residential and industrial users. The government, as the regulator, maximizes the social welfare under the constraint of cost compensation of power grid enterprises. The regulator is assumed to set the residential electricity price p_R and the industrial electricity price p_I to maximize the social welfare, which is a function of surplus of different sectors. We first briefly review the classical Ramsey pricing rule and then introduce the equity consideration.

2.1 The Classical Ramsey Problem

In the Ramsey problem, the residential and industrial users' power demand functions are $q_R(p_R)$ and $q_I(p_I)$, respectively. The regulator might want the power grid to make a certain profit. Assume that the marginal costs of electricity sold by the two types of users are equal, both being c .² Then the profit of the grid enterprise is given by:

$$\pi = p_R q_R + p_I q_I - c q_R - c q_I$$

The government, under the constraint of cost compensation of power grid enterprises, sets the residential price p_R and industrial price p_I to maximize the total social welfare:

$$\text{Max} \int_{p_R}^{\infty} q_R(p_R) dp_R + \int_{p_I}^{\infty} q_I(p_I) dp_I$$

² As the fixed cost as a constant does not affect our optimization results, we ignore the fixed cost here to simplify the notation.

$$\text{Subject to: } \pi = p_R q_R + p_I q_I - c q_R - c q_I \geq \pi^* \geq 0$$

It is easy to show that the optimal pricing rule is:

$$p_i = \frac{(1+\lambda)c}{(1+\lambda) - \frac{\lambda}{\varepsilon_i}} \quad (1)$$

Here $\lambda > 0$ is the Lagrange multiplier, and ε_i is the price elasticity of sector i . Equation (1) is the Ramsey pricing; it means the regulator should set lower prices for users with higher elasticity of demand, and vice versa. The electricity pricing mechanisms in most countries are consistent with this Ramsey pricing rule as the residential prices are higher than the industrial prices.

2.2 The Ramsey Problem with Equity Consideration

Now we adjust the theoretical model to introduce equity consideration. We assume that the government assigns different weights to different sectors of the electricity industry. Following Feldstein (1972), Lu and Yu (2017), the objective function is the weighted sum of the profits of power grid enterprises and the net surplus of residents and industrial users. The regulator's objective function can be expressed as:

$$SW = \beta_1 S_R + \beta_2 S_I + (1 - \beta_1 - \beta_2) \pi_0$$

where $0 < \beta_1 < 1, 0 < \beta_2 < 1, 1 - \beta_1 - \beta_2 > 0$, β_1 and β_2 are the weights of the net surplus of residential and industrial sectors, respectively.

Under the constraint of ensuring the cost compensation of power grid enterprises, the new optimization problem with a weighted social welfare function is as follows:

$$\text{Max } SW = \beta_1 \int_{p_R}^{\infty} q_R(p_R) dp_R + \beta_2 \int_{p_I}^{\infty} q_I(p_I) dp_I + (1 - \beta_1 - \beta_2)(p_R q_R + p_I q_I - c q_R - c q_I)$$

$$\text{subject to } \pi = p_R q_R + p_I q_I - c q_R - c q_I \geq \pi^* \geq 0$$

To solve the optimization problem we first construct the Lagrange function:

$$L = \beta_1 \int_{p_R}^{\infty} q_R(p_R) dp_R + \beta_2 \int_{p_I}^{\infty} q_I(p_I) dp_I + (1 - \beta_1 - \beta_2)[p_R q_R + p_I q_I - c q_R - c q_I] + \lambda[p_R q_R + p_I q_I - c q_R - c q_I - \pi^*] \quad (2)$$

Take the partial derivative of the objective function with respect to p_R , p_I , and derive the first-order conditions:

$$\frac{\partial L}{\partial p_I} = -\beta_2 q_I + (1 - \beta_1 - \beta_2)[q_I + p_I q'_I - c q'_I] + \lambda[q_I + p_I q'_I - c q'_I] = 0 \quad (3)$$

$$\frac{\partial L}{\partial p_R} = -\beta_1 q_R + (1 - \beta_1 - \beta_2)[q_R + p_R q'_R - c q'_R] + \lambda[q_R + p_R q'_R - c q'_R] = 0 \quad (4)$$

With the usual definition of price elasticity $\varepsilon_I = \frac{\partial q_I}{\partial p_I} \frac{p_I}{q_I}$, we can obtain:

$$p_I = \frac{c}{1 - \frac{\beta_1 + 2\beta_2 - (1 + \lambda)}{1 + \lambda - (\beta_1 + \beta_2)} \frac{1}{\varepsilon_I}}$$

Similarly, we have:

$$p_R = \frac{c}{1 - \frac{2\beta_1 + \beta_2 - (1 + \lambda)}{1 + \lambda - (\beta_1 + \beta_2)} \frac{1}{\varepsilon_c}}$$

Therefore, the optimal prices depend on the value of the Lagrange multiplier λ , the two weights β_1 and β_2 , marginal cost c and each sector's price elasticity ε_i .

Based on the formulas of p_I and p_R , we can discuss the relationship between the prices and marginal cost under different values of parameters. First, when λ is equal to 0, and $2\beta_1 + \beta_2 = 1$, then $p_I = p_R = c$. In this case the optimal prices of electricity are equal to the marginal cost. In addition, when $\lambda = 0$, there are other relations between β_1 and β_2 , but the relationship between prices and cost are undetermined.

Secondly, we discuss the case with λ greater than 0. From equation (3) and (4), we can obtain:

$$\begin{aligned} \lambda &= \frac{(\beta_1 + 2\beta_2 - 1)q_I + (\beta_1 + \beta_2 - 1)(p_I - c)q'_I}{q_I + (p_I - c)q'_I} \\ &= \frac{(2\beta_1 + \beta_2 - 1)q_R + (\beta_1 + \beta_2 - 1)(p_R - c)q'_R}{q_R + (p_R - c)q'_R} \end{aligned}$$

Via simplification, we can represent p_I as a function of p_R :

$$p_I = f(p_R) = \frac{\beta_2(p_R - c)q_I q'_R - (\beta_1 - \beta_2)q_I q_R}{\beta_1 q_R q'_I} + c \quad (5)$$

Substituting $p_I = f(p_R)$ into the profit equation ($\pi = \pi^*$), we obtain:

$$p_R - c = \frac{(\beta_1 - \beta_2)q_I^2 q_R + \beta_1 q_R q'_I \pi^*}{\beta_1 q_R^2 q'_I + \beta_2 q_I^2 q'_R} \quad (6)$$

$$p_I - c = \frac{(\beta_2 - \beta_1)q_I q_R^2 + \beta_2 q_I q'_R \pi^*}{\beta_1 q_R^2 q'_I + \beta_2 q_I^2 q'_R} \quad (7)$$

From equations (6) and (7), we can see the relationship between the price and the cost under different parameter ranges, when $\lambda > 0, \pi \geq \pi^*$:

1. if $\beta_1 = \beta_2$, $c < p_I < p_R$.
2. If $\beta_1 < \beta_2$, $p_R > c$, if π^* is large enough, and $p_I < c$, this is reverse Ramsey pricing.

3. Similarly, if $\beta_1 > \beta_2$, $p_R < c < p_I$. The optimal pricing rule in this case is Ramsey pricing.

There are several possible reasons for the three results above. As for the first result $\beta_1 = \beta_2$, the industrial price is lower than the residential price possibly because of the higher price elasticity of industrial demand and the lower elasticity of residential demand.

Regarding the second result, if the government puts more weight on the industrial demand ($\beta_1 < \beta_2$), in order to encourage the development of industrial sectors, it tends to set a lower level of electricity price to reduce the production cost of industrial firms.

Lastly, when the government puts more emphasis on the welfare of residential sector ($\beta_1 > \beta_2$), it lowers the residential price of electricity to encourage more household electricity consumption. Therefore, the regulation objective of the government materially affects the optimal electricity pricing, which might lead to the structural distortion of sales price in the traditional economic sense. Dong, Jiang, and Li (2020) argue that when there is a capacity constraint, there is the same conclusion.

In short, the above results imply that when the regulator values more on the residential sector, the residential electricity price should be less than the average cost and the industrial price would be higher than the average cost, which is the reverse Ramsey pricing rule.

3. CALIBRATION

To numerically demonstrate that reverse Ramsey pricing could be optimal in the PRC in certain circumstances, we need to calibrate the optimization model first, then calculate the surplus for these two sectors in different price-quantity combinations.

We use the actual data of the PRC's power industry in 2018 to calculate the optimal electricity prices and social welfare under different weights. We obtain P_R and P_I in 2018 from the China Statistical Yearbook 2019.³

To simulate social welfare, we need to be able to calculate the objective function and profit constraints π^* , and the most difficult part is obtaining the demand function for each of these two sectors. To simplify our computation of social welfare, we assume the demand functions of two sectors have constant price elasticities. The PRC's electricity price changes have always been small, so this assumption should not be a problem.

As the objective function of the model is to maximize the weighted sum of the surplus of the two sectors and the profit of the grid company, once we have the demand function, it is easy to calculate the objective function. Under the constant elasticity assumption, with the actual data prices and quantities, we only need price elasticities to calculate the demand function. We obtain the elasticities by adopting the estimated coefficients of Li, Jiang, and Li (2020) as their study is quite recent and the coefficient number is well within the range of other similar studies. The residential price elasticity is -0.062, and the elasticity of the industrial sector is -1.62.⁴ Once the demand function is obtained, the utility of the two sectors can be calculated by numerically integrating their respective demand functions.

³ Since the actual electricity prices in the PRC are quite complex, as they include time-of-use prices and tiered prices in both residential and industrial sectors, here we only use the average electricity prices for these two sectors.

⁴ The detailed data and estimation process can be seen in Li, Jiang, and Li (2020).

Table 1: Summary of Price Elasticity of Electricity Demand

	Residential	Source	Industrial	Source
Price elasticity	[-0.668, -0.028]	Lin and Jiang 2010; Li and Sun 2011; Chen and Zuo 2018; Pu et al. 2020; Liu et al. 2020	[-1.779, -0.431]	Zhou and Feng 2017; Chen and Zuo 2018; Liu et al. 2020

Many related studies have estimated electricity demand in the PRC. Due to the limited micro-level data, most studies use macrodata for estimation. Various estimation results are summarized in Table 1. Bear in mind that price elasticity is not the focus of this paper, but only one set of parameters in the model. We will use the parameter value from Li, Jiang, and Li (2020) to do the simulation first, and we will check the robustness of the results using other parameter values later.

Then, we discuss the calculation of the profit constraint. Because we don't have the cost data, we use the reported profit and cost data of the grid company to calculate the average electricity cost. We use the following formula to calculate the total cost in the electricity industry:

$$\text{Total Cost} = \text{Total Revenue} * (1 - \text{profit rate})$$

The profit rate data come from the State Grid and the China Southern Power Grid.⁵ We weight the rates by the two companies' electricity sales in 2018. The residential electricity price was 0.520 yuan/kWh, the industrial electricity price was 0.741 yuan/kWh, and the residential and industrial electricity consumption was 969 billion kWh and 4734 billion kWh, respectively, with a profit rate of 0.022. We assume that grid companies need to achieve at least actual profit every year, and the total profit in 2018 was 8.6 billion yuan. Therefore, the profit constraint value of π^* is 8.6 billion and the average cost c is 0.688 yuan/kWh.

To summarize, all the parameters we used in our benchmark simulation are shown in Table 2.

Table 2: Calibrated Parameters

Parameters	Value	Source
ε_R	-0.062	Li et al. (2020)
ε_I	-1.62	Li et al. (2020)
P_R	0.52	China Statistical Yearbook 2019
P_I	0.74	China Statistical Yearbook 2019
Average cost (yuan/kWh)	0.69	Calculated from data
π^* (billion yuan)	8.6	Data

4. SIMULATION RESULTS

With the price elasticities and cost parameters, the theoretical model can be numerically optimized. Firstly, we focus on the optimal pricing levels of two sectors under different weights. To highlight the change in electricity price caused by the difference in weights, we set the weight on operator profit to be 0.3 in all scenarios. Then we solve the optimal

⁵ Source: <http://www.fortunechina.com/global500/15/2019>.

prices for different sectors under the profit constraints. The optimization results are shown under different weights in the following table:

Table 3: Prices and Welfare under Different Weights

Weight		Price (yuan)		Welfare (billion yuan)		
Residential	Industrial	Residential	Industrial	Residential	Industrial	Total Welfare
0.2	0.5	2.587	0.529	83.99	299.03	38.30
0.3	0.4	1.692	0.599	132.63	222.83	35.55
0.333	0.333	0.896	0.701	151.33	162.89	31.42
0.4	0.3	0.856	0.714	181.76	143.66	32.54
0.5	0.2	0.413	1.032	228.83	38.30	26.71

From the above table, we can see that in our modified Ramsey model with equity consideration, the greater the weight for a sector, the lower the electricity price will be. When the weight of the residential sector is large enough and that of the industrial sector is small enough, the optimized electricity prices conform to the reverse Ramsey principle.

The results of Table 3 indicate that the weights themselves are significant and noteworthy. Different weights imply a different optimal pricing mechanism and a different level of social welfare. In the electricity reform process, it is essential to know the true weights of the regulators. Actually, we can use the actual electricity prices to find the most likely weighting structure. In our simulation, the optimal prices produced by the weights [0.421 (residential), 0.273 (industrial)] are very close to the actual prices (residential price 0.52 yuan and industrial price 0.741 yuan, respectively). In future simulation and policy design, we can use these weights [0.421 (residential), 0.273 (industrial)] as our benchmark analysis.

Lastly, we also simulate the actual price reform policy (i.e., the 10% reduction we mentioned in the introduction section) to solve for the optimal prices. In the 2018 and 2019 reports on the work of the government, the grid companies were required to reduce the average electricity price for industrial and commercial sectors by 10%. Recently the government also requested a 5% reduction of the average industrial and commercial electricity prices. Here we add one more constraint (5% or 10% industrial price reduction) in our optimization problem and solve for the optimal prices. And the simulation results are shown in Table 4:

Table 4: Optimized Prices with 5% or 10% Industrial Electricity Price Reduction

Weight		5% Reduction		10% Reduction	
Residential	Industrial	Optimized Prices		Optimized Prices	
		Residential	Industrial	Residential	Industrial
0.421	0.273	0.906	0.704	1.132	0.667

In reality, the grid companies only reduced the industrial prices and the residential prices have remained the same for most areas. Therefore, the actual pricing mechanism is still reverse Ramsey pricing. However, as we can see from Table 4, the new optimal prices should have been Ramsey pricing. Adopting Ramsey pricing would have improved the PRC's social welfare.

5. ROBUSTNESS CHECK

We use elasticities (-0.062 , -1.62) in our benchmark simulation and find that if the resident weight is large enough (the industry weight is small enough), the pricing mechanism should be reverse Ramsey pricing. In order to test whether the conclusion is dependent on price elasticities, we select different elasticities to do the robustness test.

From the range of elasticities from other studies, we fixed residential price elasticities at -0.03 . However, we use three different industrial elasticities: -1.78 , -1.1 , and -0.43 . Three simulation results are shown in Table 5, where we still find that if the residential weight is large enough (and the industry weight is small enough), the optimal pricing mechanism should be reverse Ramsey pricing.

Table 5: Optimized Price with Different Elasticity

	Weight		Price (yuan)	
	Residential	Industrial	Residential	Industrial
Resident elasticity	0.5	0.2	0.413	1.032
-0.03	0.4	0.3	0.800	0.726
	0.333	0.333	0.867	0.707
Industry elasticity	0.3	0.4	1.524	0.595
-0.43	0.2	0.5	2.257	0.489
Resident elasticity	0.5	0.2	0.413	1.032
-0.03	0.4	0.3	0.911	0.698
	0.333	0.333	0.886	0.708
Industry elasticity	0.3	0.4	1.793	0.569
-1.1	0.2	0.5	2.715	0.472
Resident elasticity	0.5	0.2	0.477	1.030
-0.03	0.4	0.3	0.915	0.702
	0.333	0.333	0.925	0.695
Industry elasticity	0.3	0.4	1.962	0.563
-1.78	0.2	0.5	3.071	0.472

In the appendix, we show that the results are robust if we fix industrial price elasticities and change the value of residential price elasticities.

6. CONCLUSION

This paper rationalizes the reverse Ramsey pricing in the PRC's electricity industry and demonstrates theoretically and numerically that it could be the optimal pricing mechanism in certain circumstances. The consideration of social equity by government will directly affect the choice of electricity pricing mechanism. The electricity cross-subsidy might not be efficient in the traditional sense. However, after accounting for the social equity, reverse Ramsey pricing could be optimal and efficient under those constraints.

The PRC has been reducing industrial electricity prices in recent years. The government is gradually switching to the Ramsey pricing mechanism. However, the electricity price reform needs a transitional period if there is a social equity concern. Some researchers have suggested other forms of electricity subsidies to achieve more efficiency and equity. For example, some kinds of targeted subsidies based on residents' electricity consumption as proposed by Lin, Jiang, and Li (2009) can improve the equity of the industry without loss of efficiency. Besides, the regulators can simulate more policies using a similar framework to the one we have illustrated in this paper.

REFERENCES

- Chen, Y. and Y. Zuo. 2018. Research on price elasticity of demand and cross-subsidies for industrial and residential power users. *China Prices*, (07):56–59 (in Chinese).
- Dong, C., Y. Jiang, and Y. Li. 2020. Electricity Cross-subsidy: Ramsey Pricing or Reverse Ramsey Pricing? Working paper. (in Chinese)
- Feldstein, M. S. 1972. Equity and efficiency in public sector pricing: the optimal two-part tariff *The Quarterly Journal of Economics*, 86(2): 175–187.
- Li, H., L. Dong, and M. Xie. 2011. The impact of the abolition of gas and electricity subsidies on the life of Chinese residents. *Economic Research*. 46(02): 100–112 (in Chinese).
- Li, P. and S. Sun. 2015. Study on the influence of different price decision models on urban electricity consumption: a case study of Harbin. *Energy Saving Technology*, 33(06): 503–508 (in Chinese).
- Li, Y., Y. Jiang, and S. Li. 2020. The estimation and policy implications of price and income elasticities of electricity: evidence from residential market in China. *Regional Science, Policy and Practice*, (forthcoming).
- Lin, B. 2004. Power shortage, short-term measures and long-term strategies. *Economic Research*, (03): 28–36.
- Lin, B., Z. Jiang, and J. Lin. 2009. Targeted tariff subsidies contribute to energy equity and efficiency. *Financial Research*, (11): 1–18 (in Chinese).
- Lin, B. and Z. Jiang. 2011. Estimates of energy subsidies in China and impact of energy subsidy reform. *Energy Economics*, 33(2): 273–283.
- Liu, S., J. Yao, and Z. Ye. 2015. Cross-subsidy method and reform measures of China's sales electricity price – empirical analysis based on Shanghai Electric Power household control data. *Price Theory and Practice*, (08): 26–28 (in Chinese).
- Liu, Z., P. Zhu, D. Yang, and Y. Feng. 2020. Cross-subsidy, industrial power cost reduction and carbon price mechanism design. *Economics (quarterly)*, 19(02): 709–730 (in Chinese).
- Lu, D. and Y. Yu. 2017. Governmental Regulatory targets and distorted price structure of sales [J]. *Research on Financial and Economic Issues*, (02): 26–34 (in Chinese).
- Pu, L., X. Wang, Z. Tan, H. Wang, J. Yang, and J. Wu. 2020. Is China's electricity price cross-subsidy policy reasonable? Comparative analysis of eastern, central, and western regions. *Energy Policy*, (138), forthcoming.
- Qi, F., L. Zhang, B. Wei, and Q. Que. 2008. An application of Ramsey pricing in solving the cross-subsidies in Chinese electricity tariffs. 2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, IEEE.
- Qi, F., L. Zhang, B. Wei, and Q. Qu. 2020. Research on sales electricity price based on Ramsey pricing theory. *Power Demand Side Management*, 12(02): 24–27, 52.
- Ramsey, F. P. 1927. A Contribution to the Theory of Taxation. *The Economic Journal*, 37(145), 47–61.

- Ye, Z., Y. Wu, C. Li, P. You, S. Yang, and Y. Sun. 2017. Key problems and solutions of cross-subsidies of selling electricity price in China. *Price Theory and Practice*, (04): 20–24 (in Chinese).
- Zhang, X. and Z. Liu. 2015. Residential power demand under time-sharing and stage-pricing: analysis based on DCC model. *Economic Research*, 50(03): 146–158.
- Zheng, X. and J. Fu. 2015. Power cross-subsidy is a double dividend with Chinese characteristics [N]. *China Energy News*, March 23, (005) (in Chinese).
- Zhou, Y. and Y. Feng. 2017. Electricity price reform and carbon dioxide emissions in China: empirical research and policy implications from the municipal level. *Urban and Environmental Studies*, (01): 85–99 (in Chinese).

APPENDIX

Table A1: Optimized Price with Different Price Elasticities

	Weight		Price (yuan)	
	Residential	Industrial	Residential	Industrial
Resident elasticity	0.5	0.2	0.413	1.032
–0.03	0.4	0.3	0.800	0.726
	0.333	0.333	0.867	0.707
Industry elasticity	0.3	0.4	1.524	0.595
–0.43	0.2	0.5	2.257	0.489
Resident elasticity	0.5	0.2	0.413	1.032
–0.03	0.4	0.3	0.911	0.698
	0.333	0.333	0.886	0.708
Industry elasticity	0.3	0.4	1.793	0.569
–1.1	0.2	0.5	2.715	0.472
Resident elasticity	0.5	0.2	0.477	1.030
–0.03	0.4	0.3	0.915	0.702
	0.333	0.333	0.925	0.695
Industry elasticity	0.3	0.4	1.962	0.563
–1.78	0.2	0.5	3.071	0.472
Resident elasticity	0.5	0.2	0.413	1.032
–0.35	0.4	0.3	0.520	0.741
	0.333	0.333	0.724	0.736
Industry elasticity	0.3	0.4	0.849	0.723
–0.43	0.2	0.5	1.172	0.693
Resident elasticity	0.5	0.2	0.413	1.032
–0.35	0.4	0.3	0.644	0.759
	0.333	0.333	0.763	0.729
Industry elasticity	0.3	0.4	0.969	0.708
–1.1	0.2	0.5	1.239	0.690
Resident elasticity	0.5	0.2	0.459	1.020
–0.35	0.4	0.3	0.691	0.750
	0.333	0.333	0.790	0.724
Industry elasticity	0.3	0.4	1.035	0.701
–1.78	0.2	0.5	1.268	0.690
Resident elasticity	0.5	0.2	0.413	1.032
–0.67	0.4	0.3	0.553	0.777
	0.333	0.333	0.706	0.740
Industry elasticity	0.3	0.4	0.767	0.738
–0.43	0.2	0.5	1.013	0.724
Resident elasticity	0.5	0.2	0.413	1.032
–0.67	0.4	0.3	0.600	0.768
	0.333	0.333	0.729	0.736
Industry elasticity	0.3	0.4	0.831	0.731
–1.1	0.2	0.5	1.004	0.724
Resident elasticity	0.5	0.2	0.456	1.014
–0.67	0.4	0.3	0.637	0.761
	0.333	0.333	0.747	0.734
Industry elasticity	0.3	0.4	0.868	0.727
–1.78	0.2	0.5	1.000	0.723