ABSTRACT

Title of Dissertation:	ESSAYS ABOUT THE ELECTRICITY SECTOR IN CHINA
	Guanghui Que Doctor of Philosophy, 2019
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China, with the largest electricity consumption market in the world, is in the process of market-oriented reform on its electricity industry and trying to encourage energy saving and enhance energy efficiency by implementing nonlinear pricing mechanisms. This thesis broadly investigates such policies through three related essays.

The first essay investigates how Chinese households have responded to new nonlinear pricing schemes and estimates the price and income elasticities of demand. I use three complementary approaches. Based on an extensive household-level administrative dataset, I first perform a bunching test to see if consumers appear to be responding to non-linear pricing. Second, I estimate a double-log demand function using household level consumption data during peak and off-peak time. I use instrumental variable techniques to address issues of endogeneity. Third, using survey data with extensive information about the stock of energy-using durables owned by households, combined with monthly usage records, I fit a structural model that includes time-of-use and increasing block rates pricing. I find evidence of remarkable heterogeneity in the price and income elasticities, depending on the stock of appliances, income level, and total electricity consumption. This provides support for the notion that increasing block rates give stronger incentives to households with higher consumption levels. Policy simulations under two alternative scenarios show that households do decrease their total electricity consumption significantly when the pricing schemes changes from uniform pricing to non-linear pricing such as time-of-use pricing and increasing block rates.

The second essay investigates the vertical integration economies between transmission and distribution of the electricity industry. Using unique administrative cost data of 24 province utility companies in China, I first estimate a quadratic cost

function. To investigate the vertical integration economies thoroughly, I define transmission and distribution based on three counterfactual scenarios, treating the 220kV and above network, 110kV and above network, 35kV and above network as transmission under the first, second, and third scenarios respectively. Then I estimate the vertical integration economies under these three scenarios. Results show that there do exist significant vertical integration economies and that the vertical integration economies have grown over time. I also find evidence of remarkable heterogeneity in the vertical integration economies. Utility companies with high consumption intensity have larger vertical integration economies. Also, vertical integration economies are larger under first scenario than second and third scenarios. All these results support the conclusion that currently, the separation of transmission and distribution would cause significant cost increase, which will be transferred to end consumers.

The third essay investigates how stock prices of generation companies and major industrial electricity users react to the electricity on-grid and retail tariff adjustments and announcements of future market-oriented reform plans in China using the event-study method. Attention is restricted to publicly listed generation companies and major industrial electricity users. Using two different windows periods (5 business days before and after the events, the short-term, and 10 business days before and after the events, the mid-term), I find that stock prices do not respond significantly to the announced future reform plans. This may betray the consumer's belief that the future reform plans will not be implemented effectively and thoroughly in China. By contrast, the stock prices of generation companies and major electricity consumers do react significantly and negatively to tariff adjustments in both the short- and the mid-term.

ESSAYS ABOUT THE ELECTRICITY SECTOR IN CHINA

by

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List of Abbreviations

2SLS	Two-stage least squares
CASS	Chinese Academy of Social Science
CDD	Cooling Degree Days
CSG	China South Power Grid
DCC	Discrete-Continuous Choice
FFCQ	Flexible Fixed Costs Quadratic Cost Functions
GDP	Gross Domestic Product
GMM	General Moment Method
HDD	Heating Degree Days
IBR	Increasing Block Rate
ICA	Interstate Commerce Act
IV	Instrumental Variable
MLE	Maximum Likelihood Estimation
MQCF	Multistage Quadratic Cost Function
NOAA	National Oceanic and Atmospheric Administration
SGCC	State Grid Cooperation of China
SP	State Power
TCE	Tons of Standard Coal Equivalent
TDD	Total Degree Days
TOU	Time-Of-Use
VIE	Vertical Integration Economies

1 Consumer Behavior and Household Electricity Demand Estimation under Nonlinear Pricing: New Evidence from China

1.1 Introduction

Discussions over whether complex pricing mechanisms such as two-part tariff, time-of-use (TOU) pricing, increasing block rate (IBR), and real time pricing, should be implemented for electricity, water, and other utilities have continued for half a century (Joskow and Wolfram, 2012). There are several rationales for using nonlinear pricing in the electricity sector. From a usage efficiency perspective, nonlinear pricing better addresses the fact that the marginal cost of electricity generation varies widely throughout the day, which ideally should be reflected in the prices charged to consumers. Accordingly, peak and off-peak electricity consumption should be charged differently. Nonlinear pricing is also desirable from an investment perspective. If TOU and IBR pricing schemes match policy makers' expectations, they can significantly decrease total investment in infrastructure. For example, if total peak consumption in China decreases by 1% or moves to non-peak time, this can save more than three billion dollars in investment per year[1]. Thanks to the development of metering technology, the implementation cost of nonlinear pricing mechanisms has dropped significantly. Economists and policy makers have renewed their effort to reform electricity pricing and move away from the traditional linear pricing (Joskow and Wolfram, 2012).

[1] Based on the investment data from China Electric Power Yearbook (2011).

The importance of reforming electricity prices is crucial for the future of the Chinese electricity market, perhaps more so than in any other country. China, with Gross Domestic Product (GDP) at around 50% of the USA GDP, has the largest energy and electricity consumption market in the world. More importantly, half of the increase in energy consumption worldwide from 2000 to 2010 came from China. China's energy consumption soared in the last thirty years, from 571 million tons of standard coal equivalent (TCE) in 1978 to 3,617 million TCE in 2012, a 533 percent increase. During the same period, electricity consumption increased even faster, from 300 billion kWh to 4,976 billion kWh, a 1,555 percent increase[2]. Utility companies invested about 300 billion dollars per year on generation and transmission capacity to meet the increasing electricity demand[3]. Meanwhile, electricity prices have not kept up with this increasing demand and have remained low, only about 8¢/kWh on average.

Many economists in China criticize the low prices of electricity and the uniform pricing scheme. The electricity price in China typically only adjusts once every 2-5 years to maintain social stabilization and control inflation. To research consumer behavior and household demand of electricity, and to test the effect of nonlinear pricing such as TOU and IBR pricing, China implemented different experiments in four large cities. In 2001, Shanghai, the largest city in China, changed uniform pricing to TOU pricing. In 2004, Hangzhou, another large city near Shanghai, implemented a different experiment and changed uniform pricing to TOU plus IBR

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[2] Based on the data from BP Statistical Review of World Energy (2011, 2012, 2013)

[3] Based on the data from China Electric Power Yearbook (2011).

pricing. In 2004, Chengdu and Fuzhou changed their uniform pricing to IBR pricing. These experiments provide a valuable opportunity to study how consumer behavior changes and how household respond to nonlinear pricing.

How consumers respond to nonlinear pricing is a controversial topic. A few papers argue that consumers cannot understand complicated pricing schemes well (Liebman and Zeckhauser, 2004), and that consumers respond to average price instead of marginal price (Shin, 1985; Borenstein, 2009; Ito, 2014; Carter and Milon, 2005; and Wichman, 2014). One thing is clear: With nonlinear pricing, both marginal and average price are endogenous with consumption. This is addressed using instrumental variable approaches (McFadden et al, 1977; Wilder and Willenborg, 1975; Hewitt and Hanemann, 1995) or models that impose more structure, such as distributional and other assumptions (Olmstead ed al, 2007; Reiss and White, 2005; Mcrae, 2014). Some of these models allow for price and income elasticities to vary across households.

Much of this literature, however, is based on the US, Europe or other developed countries. Very little evidence is available for China. Previous studies for China have used highly aggregate, time-series data or household-level samples where electricity usage is *imputed* using engineering equations based on the stock of appliances and the characteristics of the dwelling, but not actually observed.

I am the first to study household-level electricity consumption and its response to non-linear pricing using micro-level data based on actual meter readings and over an extended period in time from families in China. In this paper, I examine the effect of the non-linear pricing schemes introduced in China in recent years on electricity consumption.

I use two original and unique sets of data. The first documents monthly electricity consumption, broken into peak and non-peak where appropriate, and prices from a total of 10,000 households drawn at random from the residential customer base of Hangzhou and Shanghai. The sample period spans from January 2001 to December 2011 for both cities. In what follows, I refer to this as to the "administrative" dataset. The second dataset contains extensive household, dwelling, heating/cooling and appliance information, plus monthly electricity usage over three years, from a subset of the households in the administrative dataset.

I measure the effect of nonlinear pricing using three different complementary approaches. First, I check whether consumption displays "bunching" at the cutoffs between blocks in the presence of IBR. My data do reveal clear bunching and significant excess mass at the cutoff points between the tiers[4], which consequently motivates me to investigate the electricity demand using a double-log demand function, followed by a structural model, in the spirit of Reiss and White (2005).

Based on the double-log demand function, which is estimated using instrumental variable techniques, the price elasticities are between –0.25 and -0.37, and are robust across different time periods and cities. These results suggest that people do respond to price changes to an extent similar to that documented at many other locales and that demand is not completely inelastic.

[4] Bunching has rarely been found in previous research in electricity and water consumption (Ito, 2014; Alberini et al., 2017).

Peak and non-peak demand, however, depend crucially on the weather and on how households cope with it by using electric heating and cooling equipment. To study in detail how peak and non-peak usage depend on equipment and household characteristics, I turn to my survey-based dataset, which contains extensive information about each family, dwelling and energy-using durables.

My structural model is similar to, but more elaborate than, the model used by Reiss and White (2005) and Mcrae (2014) because it includes both TOU and IBR pricing simultaneously. Moreover, it exploits a panel dataset because electricity usage at the monthly level was collected from the utility. Results reveal that mean overall own price elasticity and is –0.32, which is broadly consistent with the results from the double-log model, and the mean income elasticity is 0.08. As expected, considerable heterogeneity exists across households depending on how many electric heat pumps (the typical heating and cooling equipment) they own.

Based on the structural estimators, policy simulations under two scenarios are performed to investigate the effect of different pricing schemes on total consumption. I find that changing to the IBR plus TOU pricing from uniform pricing will decrease total consumption significantly, around 8%. If TOU plus IBR pricing is still implemented, but price in the third-tier during peak time is increased by 30%, the total consumption is predicted to decrease significantly, by around 6%. This has potentially huge implications for investment in generation and grid infrastructure in China, given the size of its market, its acceptance in recent times of market-based mechanisms (including pricing) and its recent commitment to be a leader in CO_2 emissions mitigation.

The remainder of this paper is organized as follows: Section 2 describes the data. Section 3 presents the bunching test and double-log demand estimation results. The structural model and estimation results are presented in Section 4. Section 5 presents the policy simulation, and conclusions follow in Section 6.

1.2 Data

1.2.1 Data Summary

This paper is based on two different types of datasets: administrative data and household-level survey data, each in Hangzhou and Shanghai. The first dataset, administrative data, is exported directly from the utility companies' marketing management system, and contains monthly electricity consumption, bill amounts, and price data for 5,000 households in each city[5]. Each household's monthly consumption data are transferred automatically to the utility's marketing management system by a smart meter. The bill is calculated automatically by the management system based on the usage and the tariff structure. The utility company mails the bill to the households monthly or bi-monthly, depending on the specific bill cycle. Households can check their consumption by reading the smart meter, which typically is conveniently installed outside the apartment or house. Households can also easily check their consumption and bills online or at the utility company's service center. In the remainder of this paper, I refer to this as the administrative dataset.

[5] The bill cycle in Hangzhou and Shanghai is bi-monthly and monthly respectively. Therefore, the utility company provided bi-monthly and monthly consumption in Hangzhou and Shanghai.

The second dataset, household-level survey dataset, comes from a survey conducted by a research team[6], and can be combined with the consumption, bills, and price data provided by the utilities. The consumption data in both datasets are at the monthly level with separate peak time and off-peak time usage. The price information includes each household's marginal price and average price; the latter is simply the bill divided by kWh consumed.

Hangzhou, the tenth largest city in Southeast China, implemented an experiment for residential electricity, changing from a uniform tariff to TOU plus IBR since 2001 in an effort to decrease consumption and enhance energy efficiency. In 2001, Hangzhou first introduced time-of-use pricing. Consumers were allowed to choose between uniform pricing and time-of-use pricing voluntarily. One third of the cost of installing smart meters when transitioning from uniform pricing to TOU pricing, around $15[7], was paid by the customers and the other two-thirds was paid by the utility company. In August 2004, Hangzhou introduced increasing block rates. All households under uniform pricing were required to change to IBR or IBR plus TOU pricing. At the same time, all households already on TOU pricing were converted to IBR plus TOU pricing automatically. Unlike in the 2001 transition, the cost of smart meter is totally paid by the utility company. Because the number of households in Hangzhou is very large, around 3 million households, the transition to IBR or IBR

[6] The research team includes internal researchers from the utility company, State Grid Cooperation of China (SGCC) and economists from the Chinese Academy of Social Science (CASS).

[7] Fifteen dollars is around one month's electricity bill for the typical household in Hangzhou.

plus TOU tariffs was rolled out under the utilities' control[8]. By July 2006, all households had been moved to IBR or IBR plus TOU pricing.

As shown in table 1.1 and figures 1.1 a-d, under uniform pricing, the price was 8.03 ¢/kWh[9] in 2001. Under TOU pricing, the peak price is 8.48 ¢/kWh and the off-peak price is 4.24 ¢/kWh. Under the IBR-only pricing scheme, the marginal block price in each of the three tiers (less than 50 kWh, between 51 kWh and 200 kWh, and greater than 201 kWh per month) was set at 8.15 ¢/kWh, 8.61¢/kWh, and 9.67¢/kWh respectively. Under the IBR plus TOU pricing, the peak time prices are IBR and include three tiers (less than 50 kWh, between 51 kWh and 200 kWh, and greater than 201 kWh per month). The respective prices were 9.47 ¢/kWh, 9.97¢/kWh, and 11.13¢/kWh respectively. During off-peak time, the price was set at 4.8 ¢/kWh. The peak time under TOU and IBR plus TOU was from 8 AM to 10 PM, and the off-peak was from 10PM to 8 AM.

Shanghai, the largest city in China, changed from uniform pricing to TOU pricing in 2001 and kept the TOU pricing until December 2011. The peak time was from 8 AM to 10 PM, and the off-peak was from 10PM to 8 AM. Under the TOU pricing, the peak price is 9.35 ¢/kWh and the off-peak price is 4.65 ¢/kWh.

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[8] The roll out is based on districts and mandatory. Therefore, households under uniform pricing did not have a choice and must transferred to IBR or IBR plus TOU.

[9] The initial price is in RMB, Chinese currencies, and is converted to the US dollar under exchange rate 7:1 or 1 dollar equals to 7 RMB.

Table 1.1 Price Level in Hangzhou and Shanghai

			Hangzhou	Shanghai
Uniform Pricing (¢/kWh)			8.03	
Time-Of-Use (TOU) pricing (¢/kWh)	*Peak*		8.48	9.35
	Off-Peak		4.24	4.65
Increasing Block Rate (IBR) Pricing (¢/kWh)		*Tier 1*	8.15	
		Tier 2	8.61	
		Tier 3	9.67	
Time-Of-Use (TOU) Plus Increasing Block Rate (IBR) Pricing (¢/kWh)	*Peak*	*Tier 1*	9.47	
		Tier 2	9.97	
		Tier 3	11.13	
	Off-Peak		4.8	

Figure 1.1a Time-Of-Use Pricing in HangZhou

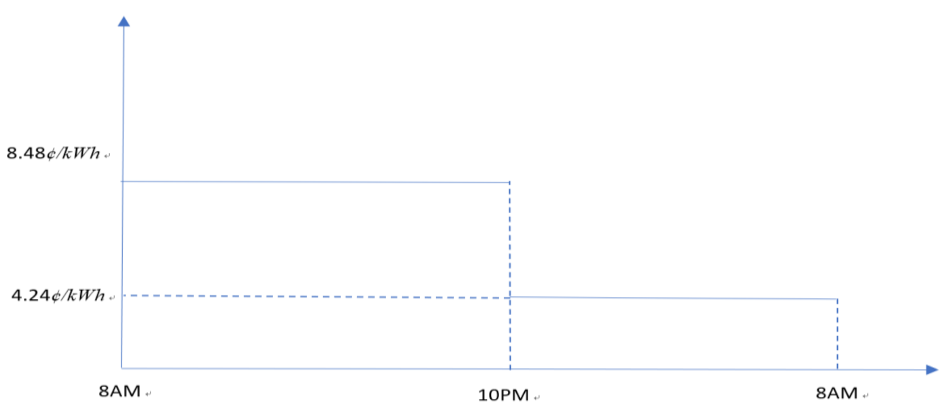


Figure 1.1b Increasing Block Rate in HangZhou

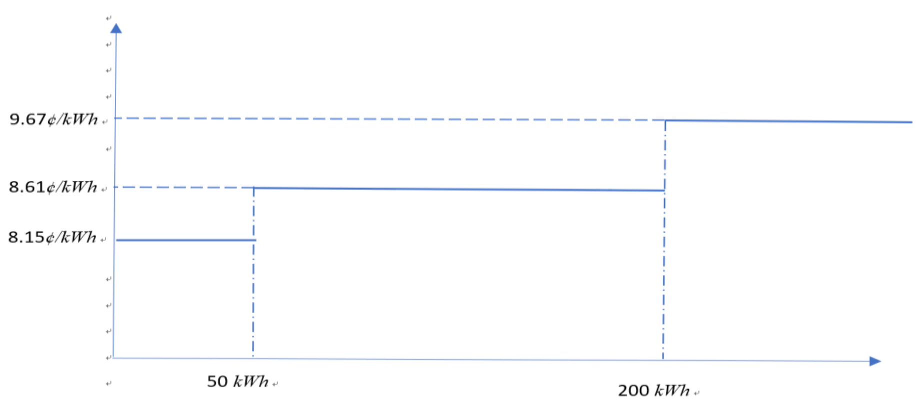


Figure 1.1c Time-Of-Use Pricing Plus Increasing Block Rate in HangZhou

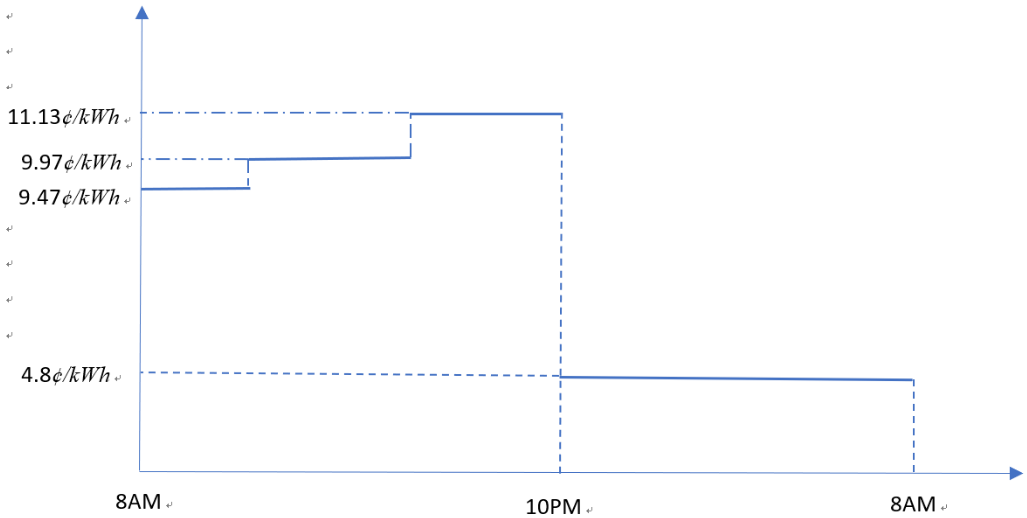
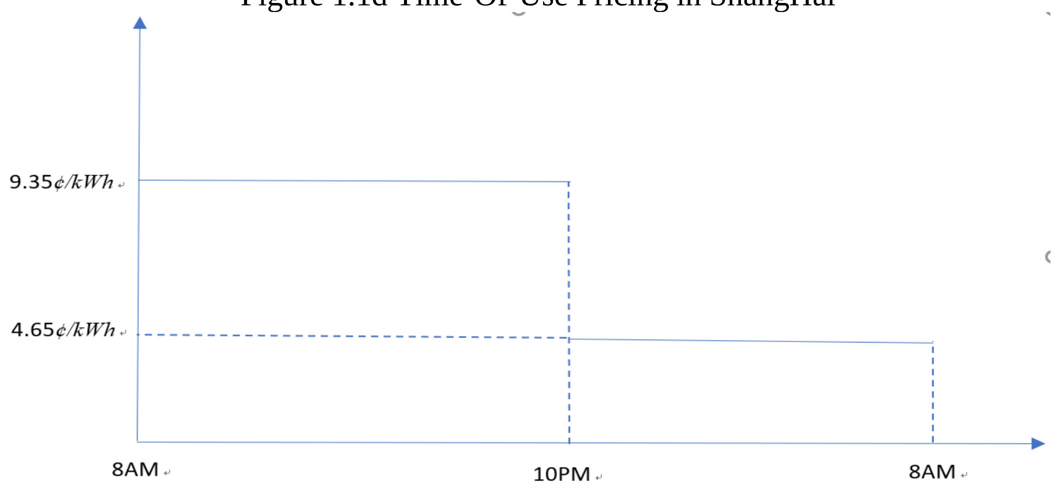


Figure 1.1d Time-Of-Use Pricing in ShangHai



Under confidentiality agreements, I was able to obtain 5,000 households' bi-monthly meter reading, bills, and prices from January 2003 to December 2011 in Hangzhou and 5,000 households' monthly data from January 2008 to December 2011 in Shanghai.

To analyze the impact of the TOU and IBR pricing schemes more thoroughly, in 2012 a survey was conducted in Shanghai and Hangzhou. The survey questionnaire focused on household and dwelling characteristics, appliance stock, and income information. We randomly selected 500 households from the 5,000 households in Hangzhou and Shanghai respectively, and mailed the questionnaire to these households in June 2012. By the end of June 2012, 132 households in Hangzhou and 105 households in Shanghai had mailed back the questionnaire.[10]

The survey data covers demographic, appliances stock, electricity usage habits, and income levels. The demographic information includes the number of people living in the house, the number of seniors,[11] house area, and the number of bedrooms and parlors. The appliances stock information includes the number of air conditioners, refrigerators, televisions, and the ownership of heaters, washers, dishwashers, microwave ovens, and electric ovens. The electricity usage habits information includes whether the household heats the home with electricity during the winter using a heat pump, electric heater, or other equipment; whether they cook with electricity, gas, natural gas, or other fuel; and whether water is heated with electricity, gas, solar power, or other energy. The income information is elicited using categories (monthly income below 8,000 RMB, between 8,000 RMB and 15,000 RMB, and greater than 15,000 RMB)[12]. The monthly weather information, total degree days, is collected from the National Oceanic and Atmospheric Administration (NOAA) and combined with other information.

[10] The reasons behind the low mail back rate is unknown, although the research team promised to give 100 RMB (around $16) to each household that mailed back the questionnaire.

[11] Seniors are defined as the family members whose age is above 65.

[12] Under the exchange rate 7:1 (1 dollar equal to 7 RMB), the monthly income in dollar are $1,143, between $1,143 and $2,143, and greater than $2,143 respectively.

1.2.2 Administrative Data

Summary statistics of the administrative data are given in table 1.2. As shown in table 2, monthly peak, off-peak, and total consumption in Hangzhou are 142.98 kWh, 124.55 kWh, and 268.70 kWh respectively, which are higher than those in Shanghai, 129.02 kWh, 116.52 kWh, and 245.17 kWh respectively. As noted previously, the peak time was 14 hours and the off-peak was 10 hours each day, consequently, it is not surprising that peak consumption over a month is higher than off-peak consumption over the month even though the peak price is higher. Therefore, I also present the consumption during peak and off-peak in table 1.2 and figure 1.2 on a per-hour basis.[13]

As shown in figure 1.2a and 1.2b, consumption increases over time except during the financial crisis and recession of 2008 and 2009. Consumption also shows significant seasonal fluctuations. The peak season during the year is the summer, especially August and September, when the air conditioner load is extremely high. The second peak season is during the winter, mainly February, when the heating load is high.

[13] I only present the consumption per hour during peak and off-peak of the administrative data in figure 1. The survey data has similar trend as the administrative data but are not reported here.

Table 1.2 Summary Statistics of Administrative Data

Variable		Hangzhou			Shanghai		
		Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Peak	Average Monthly Consumption (kWh)	142,763	142.98	147.06	238,760	129.02	104.45
Peak	Average Consumption Per Hour (kWh)	142,763	10.21	10.50	238,760	9.21	7.46
Peak	Average Peak Price[14] (¢/kWh)	142,763	9.03	0.52	239,934	9.35	0
Off-Peak	Average Monthly Consumption (kWh)	142,608	124.55	101.56	232,018	116.52	105.71
Off-Peak	Average Consumption Per Hour (kWh)	142,608	12.45	10.15	232,018	11.65	10.57
Off-Peak	Average Off-peak Price (¢/kWh)	142,608	4.33	.045	239,934	4.65	0
Total	Average Monthly Consumption (kWh)	142,763	268.70	244.58	239,934	245.17	201.13
Total	Monthly Total Degree Days	142,763	429.75	206.33	239,934	437.58	210.81

[14] The peak and off-peak price given in this table and following tables are nominal prices. The price used in the regression are real prices based on the annual consumer price index and are expressed in 2003 RMB.

Figure 1.2 Average Monthly Consumption Per Hour During Peak and Off-Peak

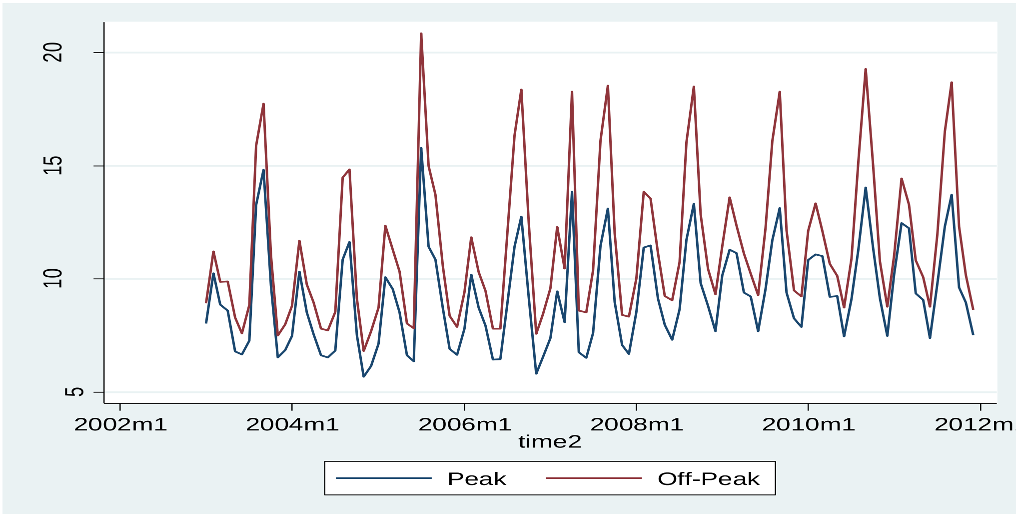


Figure 1.2a Average Monthly Consumption Per Hour in Hangzhou

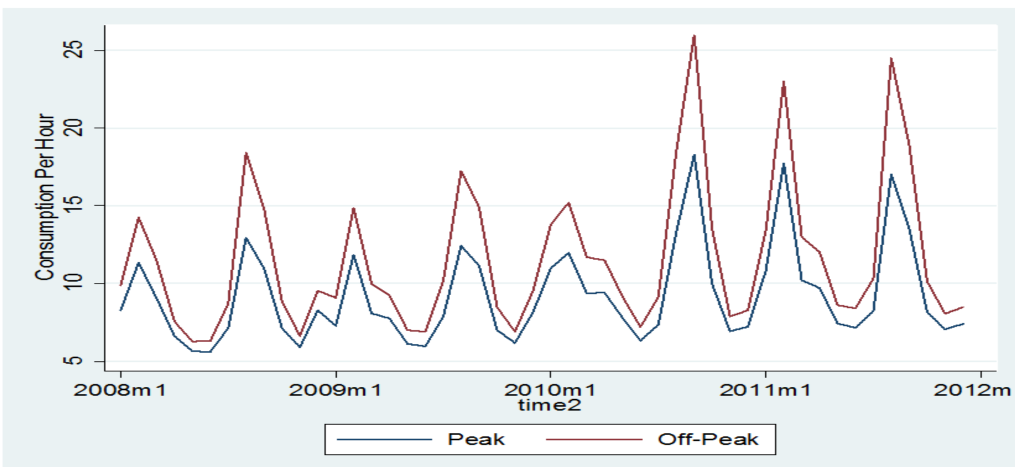


Figure 1.2b Average Monthly Consumption Per Hour in Shanghai

1.2.3 Survey Data

Summary statistics of the survey data are given in table 3a, 3b, and 3c respectively.[15] As shown in table 1.3a, the average peak, off-peak, and total

[15] The price, consumption, and weather data are from the utility companies and NOAA.

consumption are 140.73 kWh, 121.71 kWh, and 262.45 kWh in Hangzhou, and 143.78 kWh, 129.76 kWh, and 273.54 kWh in Shanghai, respectively. As shown in table 1.3b, on average, three persons live in the house and 28% households include a senior. For the stocks of appliances, almost all households (around 95%) have an air-conditioner, washer, television, and refrigerator. Very few families have central air-conditioning, dishwasher, and an electric oven. Almost all households (around 95%) have one refrigerator. Fifteen percent, 53%, 21%, and 9% families have one, two, three, and four air-conditioners, respectively.

Table 1.3a Summary Statistics of Survey Data: Price and Consumption

Variable		Hangzhou			Shanghai		
		Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Price (¢/kWh)	Average price	2,146	6.73	0.61	3,778	7.95	0.53
	Average Peak Price	2,146	8.83	0.18	3,778	9.35	0
	Marginal Peak Price	2,146	9.12	0.39	3,778	9.35	0
	Average Off-peak Price	2,146	4.36	0	3,778	4.65	0
Electricity Consumption (kWh)	Average Monthly Peak Consumption	2,146	140.73	74.60	3,778	143.78	92.56
	Average Monthly Off-peak Consumption	2,146	121.71	63.20	3,778	129.76	93.51
	Average Monthly Total Consumption	2,146	262.45	124.75	3,778	273.54	178.92

Most households heavily depend on electricity for heating, cooling, cooking, and heating water. As shown in table 1.3c, 93% of the families heat their homes with electricity, using heat-pumps or an electric heater, 69% of the families cook with electricity, and 75% of the families heat their water with electricity. These usages are likely to create peak loads, especially during the peak seasons of summer and winter. Fifty-four percent of the families have a monthly income below 8,000 RMB, 36% between 8,000 RMB and 15,000 RMB, and only 8% is higher than 15,000 RMB.

Table 1.3b Summary Statistics of Survey Data: Demographic, Dwelling, and Appliances

Variable		Hangzhou			Shanghai		
		Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Demographic and Dwelling Information	Number of Persons	2,146	3.10	1.07	3,778	3.53	1.17
	Number of members older than 65	2,146	.74	.86	3,778	.74	.92
	Number of member younger than 65	2,146	2.13	1.24	3,778	2.43	1.16
	House net area	2,146	56.63	22.95	3,778	77.53	36.90
	House gross area	2,146	70.90	24.37	3,778	94.07	40.68
	Number of bedrooms	2,146	2.19	.58	3,778	2.33	.92
	Number of parlors	2,146	1.12	.35	3,778	1.20	.68
Stocks of Appliances	=1 if have air conditioner	2,146	.98	.12	3,778	.99	.09
	=1 if have central air conditioner	2,146	.008	.091	3,778	0	0
	Number of air conditioner	2,146	2.23	.849	3,778	2.67	1.05
	=1 if use electric fan	2,146	.95	.20	3,778	.86	.34
	number of refrigerators	2,146	1.06	.33	3,778	1.12	.35
	number of televisions	2,146	1.86	.71	3,778	2.25	.91
	=1 if own a washer	2,146	.94	.21	3,778	.99	.09
	=1 if own a dishwasher	2,146	.05	.21	3,778	.019	.13
	number of desktop computers	2,146	1.16	.75	3,778	1.33	.88
	=1 if own a microwave oven	2,146	.74	.43	3,778	.92	.26
	=1 if own an electric oven	2,146	.094	.29	3,778	.20	.40

Table 1.3c Summary Statistics of Survey Data: Usage Habits, Income, and Weather

Variable		Hangzhou			Shanghai		
		Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Usage Habit Information	=1Heated by air conditioner	1,652	.82	.37	3,778	.85	.35
Usage Habit Information	=1if Heated by electric heater	1,652	.54	.49	3,778	.52	.49
Usage Habit Information	=1 if heated by other equipment	1,652	.07	.26	3,778	.06	.24
Usage Habit Information	=1 if cooking with electricity	2,146	.69	.46	3,778	.64	.47
Usage Habit Information	=1 if cooking with natural gas	2,146	.89	.30	3,778	.86	.34
Usage Habit Information	=1 if cooking with other energy	2,146	0	0	3,778	0	0
Usage Habit Information	=1 if bath water is heated by electricity	2,146	.75	.43	3,778	.28	.45
Usage Habit Information	=1 if bath water is heated by natural gas	2,146	.25	.43	3,778	.78	.40
Usage Habit Information	=1 if bath water is heated by solar power	2,146	.06	.25	3,778	.03	.19
Usage Habit Information	=1 bath water is heated by other	2,146	.008	.09	3,778	0	0
Income Information	=1 if monthly income is below 8,000 RMB	2,146	.54	.49	3,778	.35	.47
Income Information	=1 if monthly income s between 8,000 RMB and 15,000 RMB	2,146	.36	.48	3,778	.43	.49
Income Information	=1 if monthly income is above 15,000 RMB	2,146	.08	.27	3,778	.21	.40
Weather Information	Monthly Total Degree Days	2,146	435.01	203.99	3,778	436.20	209.47

1.2.4 Comparison of Survey Households with Census Data and Non-Participating Households

Because the survey households are a subset of the households in the administrative dataset, one concern is whether the households that participated in the survey are representative. I compare the survey data and city-level census data to explore possible selection biases. As shown in table 1.4a, the households that participated in the survey had similar stock of appliances, in terms of refrigerators, air conditioners, TVs, computers, washers, and microwave ovens as compared to the city-level census data. The households that participated in the survey are larger and had a significantly higher share of seniors, which may explain why they participated in the survey. Seniors, and especially retired seniors living with their families, often are willing to contribute to the family by monitoring and saving on electricity consumption. They also have more free time to understand the tariff structure clearly and plan appliance use for non-peak time and motivation to complete and mail back the questionnaire.

Another concern is whether the households that participated the survey had different consumption and price response compared with the households that received the questionnaire but did not participate in the survey[16]. As shown in table 1.4b, the peak, off-peak, and overall consumption of surveyed households are 140.73 kWh, 121.71 kWh, and 262.45 kWh respectively. In comparison, the surveyed households' consumption is slightly higher than the non-survey households' consumption. The

[16] Whether the price elasticities are different between survey household and non-survey households is tested in section 3.

peak, off-peak, and overall consumption of the surveyed households during summer and winter are also slightly higher than the non-survey households. The differences of consumption between surveyed and non-survey households are around 8 percent.

Table 1.4a Comparison of Survey Households and City-level Census in Hangzhou

	No. of Persons	No. of seniors (%)	Housing area /person (m2)	No. of Refrigerators	No. of ACs	No. of TVs	No. of Desktops	No. of Washers	No. Microwave Ovens
Surveyed Households	3.10	28.3%	24.78	1.06	2.23	1.86	1.16	0.94	0.74
City-level Census	2.71	17.8%	25.3	1.02	2.12	1.76	1.09	0.96	0.73
Difference (%)	12.58	37.10	-2.10	3.77	4.93	5.38	6.03	-2.13	1.35

Table 1.4b Comparison of Survey and Non-Survey Households in Hangzhou

	Average Monthly Consumption			Summer Monthly Consumption			Winter Monthly Consumption		
	Peak (kWh)	Off-Peak (kWh)	Total (kWh)	Peak (kWh)	Off-Peak (kWh)	Total (kWh)	Peak (kWh)	Off-Peak (kWh)	Total (kWh)
Surveyed Households	140.73	121.71	262.45	157.43	148.56	306.00	135.14	111.35	246.49
Non-Surveyed Household	128.37	113.34	241.71	143.24	136.31	279.55	118.36	107.21	225.57
Difference (%)	8.78	6.88	7.90	9.01	8.25	8.64	12.42	3.72	8.49

1.3 Bunching Test and Double-Log Demand Estimation

1.3.1 Bunching Test

This subsection presents results from a bunching test at the kink points between the blocks of the IBR using graphical and statistical evidence. Whether consumers bunch at kink points under nonlinear pricing is an interesting and controversial topic. Saez (2012) and Chetty et al. (2011) find bunching at the kink points, measure excess mass, and calculate elasticities at kind points when investigating the taxpayers' response to the nonlinear tax rates. Ito (2012) does not find bunching around the block cutoffs when investigating consumer response to nonlinear increasing electricity pricing. Alberini et al (2017) find bunching based on Ukraine consumption data.

I performed a graphical bunching test first using bi-monthly electricity consumption data from Hangzhou. Because the billing period in Hangzhou is bi-monthly, the actual cutoff values are adjusted from 50kWh and 200kWh for single month to 100kWh and 400kWh for bi-month respectively[17]. As pointed out in the previous section, the experiment in Hangzhou is voluntary; households can choose an IBR only pricing or an IBR plus TOU pricing scheme. Using the consumption data from 2004 to 2011, the bunching test results are presented in figure 1.3. For the households with IBR pricing only,[18] there is clear evidence of bunching at the kink points, 100kWh and 400kWh, especially at the cutoff between the second and third

[17] The utility companies' management system does this adjustment automatically.

[18] 77,915 observations are using when conducting this bunching test.

block. This suggests that consumers under IBR pricing in Hangzhou do understand and respond to the nonlinear pricing. There is no evidence of bunching at any cutoff for the households with TOU plus IBR pricing.[19]

To formally test for bunching, I fit a polynomial function of consumption frequency and consumption and measure the excess mass at the kink points. First of all, observations are placed in bins. Initially, the bin width is 2 kWh[20] and I use the observations that fall 5 bins above and 5 bins below the kink point[21], but exclude the bins exactly above and below the kink point, to run the polynomial function consumption frequency regression. I fit equation (1.1):

$$F_i = \sum_{j=0}^{5} \beta_j (C_i)^j + \sum_{t=-5}^{5} \delta_t \cdot 1[i = t] + \varepsilon_i \qquad (1.1)$$

where F_i is the frequency of observation in i, C_i is consumption, and $1[i = t]$ denotes a dummy for whether the consumption is in bin i. Predicted consumption frequency $\widehat{F_i}$ in one bin greater and one bin less than the cutoff point is calculated using the estimated coefficients. Finally, excess mass $\widehat{m}$ is calculated using the actual frequency and predicted frequency:

$$\widehat{m} = \frac{\sum_{-1}^{1} F_i - \widehat{F_i}}{\widehat{F_i}} \qquad (1.2)$$

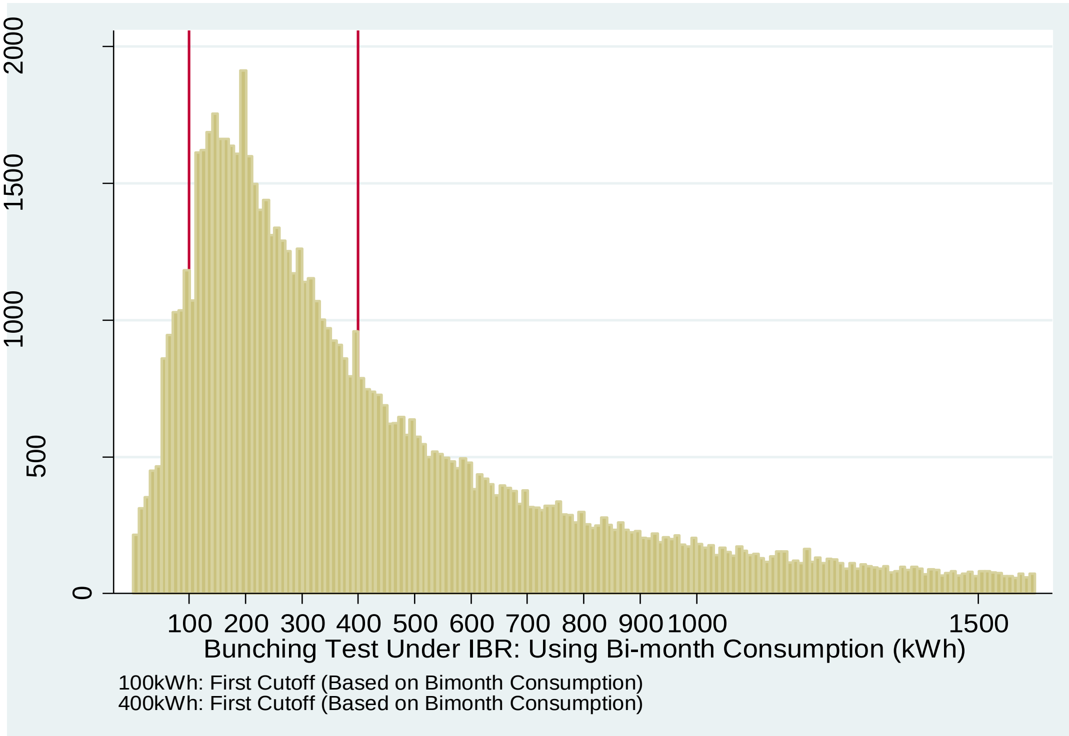
As shown in table 1.5, under IBR pricing, there exists significant bunching at the second cutoff point, 200 kWh, but no significant excess mass at the first, 50 kWh. Under the IBR plus TOU pricing, there is no significant excess mass at either.

[19] 109,379 observations are when conducting this bunching test.

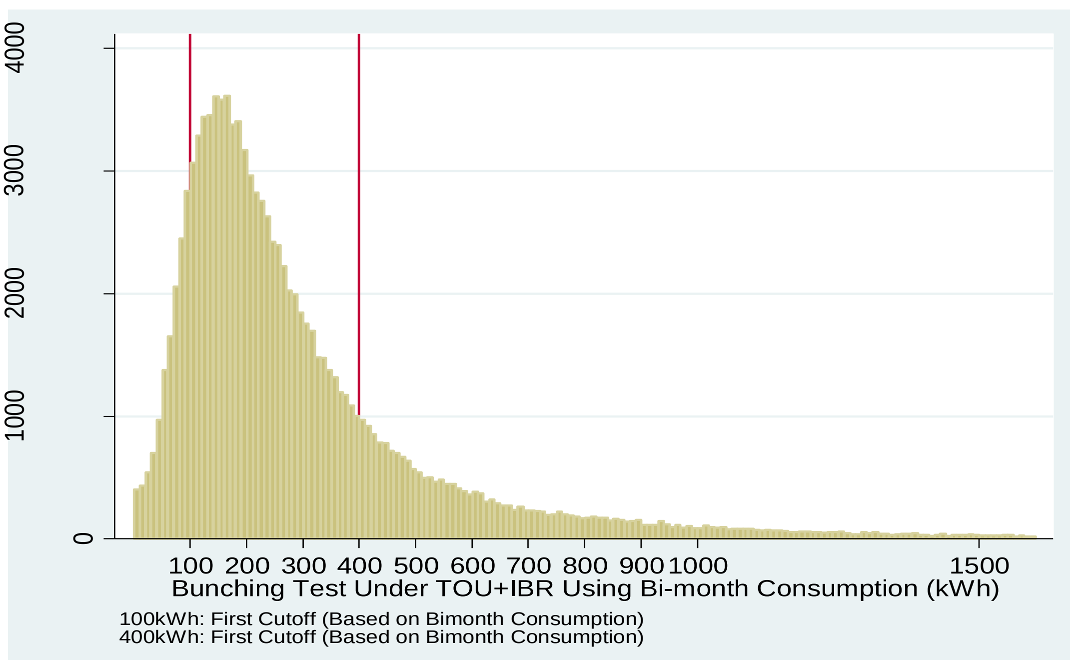
[20] I also set the bin equals to 1 kWh, 3 kWh, and 5kWh, the results are similar.

[21] I also use 7 bins and 10 bins greater and less than the kink point, the results are similar.

Figure 1.3 Bunching Test Results



Panel A: Bunching Test under IBR Pricing in Hangzhou



Panel B: Bunching Test under IBR Plus TOU Pricing in Hangzhou

It might seem surprising that both graphical and statistical evidences confirm there is bunching under IBR pricing but not under IBR plus TOU pricing. This puzzling result may be from the pricing scheme itself. Under the IBR plus TOU pricing, because the difference between peak and off-peak price, at least 4.67 cent/kWh, is significantly larger than the difference among peak price tiers, at most 1.66 cent/kWh, households under IBR plus TOU pricing will optimize their consumption between peak and off-peak rather than during peak time. Another possible explanation may be a matter of salience. With two simultaneous nonlinear pricing mechanisms combined, time-of-use pricing and increasing block rate, the consumers will find it is difficult to keep track of both. They choose to the one that is easier to figure out and has the strongest price signal, the time-of-use pricing. One more potential explanation is the self-selection. Because consumers can choose between uniform pricing and TOU pricing, or between IBR pricing and TOU plus IBR pricing, among different time periods, the more price sensitive households should have selected TOU pricing or TOU plus IBR pricing among different time periods to maximize their utility bill saving.

Table 1.5 Excess Mass at Kink Points

	IBR				IBR+TOU		
	Actual Frequency	Predicted Frequency	t-value		Actual Frequency	Predicted Frequency	t-value
200 kWh	0.249	0.198	3.22	200 kWh	0.198	0.178	1.57
100 kWh	0.267	0.152	6.79	100 kWh	0.392	0.387	0.39
50 kWh	0.214	0.187	1.44	50 kWh	0.453	0.461	-0.29

1.3.2 Double-Log Demand Estimation

To estimate the price elasticities using the administrative data and survey data, I fit the following regression model.

$$logE_{ijt} = \beta_{0\mathrm{i}} + \beta_1 logP_{ijt} + \beta_2 TDD_{it} + \sum \gamma_k Year_k + \sum \delta_r Month_r + \varepsilon_{ijt} \quad (1.3)$$

where i denotes household, j denotes peak/off-peak, t is time (month), E_{ijt} is consumption per hour by household i, peak or not j, month and year t, P_{ijt} is the price faced by household i during peak and off-peak time j at time t. TDD is Total Degree Days in each month, $\mathrm{TDD} = \mathrm{HDD} + \mathrm{CDD}$, where HDD is Heating Degree Days and CDD is Cooling Degree Days, Year is a set of year dummies, and Month is a set of month dummies. In this model, I use the year and month dummies to control for the effect of daylight, holidays, the economy etc. that affect consumption to the same extent. Because I use TDD instead of HDD and CDD in this model, the implication is that one HDD has same effect as one CDD. I also have households fixed effects in the model.

One concern is the price variation. To avoid any potential social and political instability, the government only adjusts the residential electricity prices once every two or three years. During our sample period, Shanghai did not change its prices and Hangzhou only changed once. Therefore, there are only two price levels in Shanghai and only six price levels in Hangzhou (two price levels from TOU pricing and four price levels from IBR plus TOU pricing) during my study period. To get more price variation, I also pool the data from different tariffs, TOU and IBR plus TOU, and from different cities, Shanghai and Hangzhou. The assumption behind the pooling is that consumers respond to the price in the same way regardless of the tariff scheme and location.

Another concern is the price used in the model. Because the pricing scheme in Shanghai is TOU only, the marginal and average price during peak (or off-peak time) is the same in Shanghai. The same is true for households under TOU only pricing in Hangzhou. The challenge is what price, or what peak price,[22] should be used for the households under IBR plus TOU pricing. I use the marginal price because the bunching test suggests that households in Hangzhou respond to non-linear pricing.

Even when the marginal price is used, there still exists endogeneity under the IBR pricing. Therefore, I instrument for it following the approach developed by McFadden, Puig, and Kirschner (1977). The basic idea of this approach is a 2 SLS regression. In the first stage, the McFadden method first runs a regression of the actual consumption on all the exogenous variables but exclude the price variable(s). The predicted consumption level of each household at each time can be calculated based on the first stage results. Then, the predicted marginal price is calculated based on the predicted consumption level and the predicted price is used as the instrumented variable in the second stage[23].

[22] As pointed previously, the peak pricing is IBR and the off-peak pricing is uniform.

[23] Another method is the 2SLS developed by Wilder and Willenborg (1975). In the first stage of the 2SLS model, marginal prices are regressed on all the exogenous variables but exclude the consumption. The predicted marginal prices are then used in the second stage regression. I also run this 2SLS model, the results are similar to the McFadden IV method.

1.3.3 Results for Double-Log Demand Estimation

The estimation results from fitting equation (1.3) to the administrative dataset and to the subset that also participated in the survey are presented in table 1.6 and table 1.7.

Table 1.6 Estimated Price Elasticities Using Administrative Data
All Models Include Month and Year Dummies and Households Fixed Effects[24]

Variable	IBR plus TOU in Hangzhou		TOU in Hangzhou	TOU in Shanghai	Hangzhou & Shanghai Pooled	
	Fixed Effect	McFadden Instrument			Fixed Effect	McFadden Instrument
Ln_price	-0.294*** (-98.40)	-0.345*** (-113.75)	-0.338*** (-65.65)	-0.261*** (-103.72)	-0.278*** (-149.02)	-0.294*** (-156.83)
Total Degree Days	0.00014*** (8.00)	0.00014*** (7.97)	0.000161*** (15.82)	0.000198*** (13.21)	0.00021*** (20.63)	0.00021*** (20.67)
Constant	1.553*** (43.26)	1.511*** (42.38)	1.829*** (26.88)	1.477*** (146.72)	1.469*** (158.51)	1.455*** (157.31)
N	216760	216760	68470	451439	736660	736660

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As shown in table 1.6, for the full administrative data, the price elasticity of households under TOU pricing in Hangzhou is -0.34. The price elasticities of households under IBR plus TOU pricing in Hangzhou are -0.29, and -0.35 for the fixed effect model and McFadden method, respectively. The price elasticity of administrative data in Shanghai is -0.26, indicating lesser responsiveness to price than in Hangzhou. When pooling administrative data in Hangzhou and Shanghai, the price

[24] Colum McFadden Instrument presents the results from 2 SLS or McFadden Instruments.

elasticities are -0.28 and -0.29 for the fixed effect model and McFadden method, respectively.

As shown in table 1.7, the price elasticities for the subset who participated in the survey in Hangzhou are -0.28 and -0.32 for the fixed effect and McFadden instrument, which is similar to the large sample administrative data. The price elasticity of the survey households in Shanghai is -0.27, similar to the large sample data, too. When pooling survey data in Hangzhou and Shanghai, the price elasticities are -0.28 and -0.29 for the fixed effect model and McFadden instrument, respectively.

Table 1.7 Estimated Price Elasticities Using Survey Data

All Models Include Month and Year Dummies and Households Fixed Effects

Variable	Hangzhou (IBR Plus TOU)		Shanghai (TOU)	Hangzhou & Shanghai Combined	
	Fixed Effect	McFadden Instrument		Fixed Effect	McFadden Instrument
Ln_price	-0.283*** (-14.96)	-0.318*** (-16.76)	-0.267*** (-17.83)	-0.283*** (-23.83)	-0.296*** (-24.84)
Total Degree Days	-0.00014 (-1.13)	-0.00014 (-1.16)	0.00048*** (5.26)	0.00032*** (4.54)	0.00032*** (4.55)
Constant	1.591*** (25.11)	1.561*** (24.80)	0.00048*** (5.26)	1.439*** (29.93)	1.429*** (29.77)
N	4292	4292	7484	11848	11848

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Four main conclusions can be drawn from these results. First, the price elasticities are robust across different tariffs, periods, and cities. Second, the price elasticities around -0.3 is in the range of previous research. Third, the price elasticities under different tariffs in Hangzhou are similar, from -0.29 to -0.35, which means consumers’ response and behavior pattern did not change much under different tariff structures. Fourth and last, the price elasticity in Shanghai is somewhat less pronounced than that in Hangzhou although not hugely different. The main reason for this may be that the tariff in Shanghai had not changed in then ten years from 2001 to 2011. Therefore, the households in Shanghai became less sensitive to the pricing scheme.

Other coefficients are also in line with expectations. The coefficients on the total degree days, which is identified from variation with respect to the average for any given month, are positive and significant, although small. Considering the fact that month dummies are also included in the model and that all households in the city are exposed to the same weather, the small coefficient is understandable.

One important question that must be addressed is whether the subset of the administrative sample that participated in the survey exhibits the same price elasticities as the full administrative sample. To answer this question, I fit equation (1.4):

$$logE_{ijt} = \beta_0 + \beta_1 logP_{ijt} + \beta_2 TDD + r_1 logP_{ijt} * DS + r_2 TDD * DS + \sum \gamma_k Year_k + \sum \delta_r Month_r + \varepsilon_{ijt} \qquad (1.4)$$

where DS is a dummy variable denoting whether the household is part of the survey data. The estimates of r_1 and r_2 are 0.00065 and -0.00019, with t-value 0.03 and -1.34 respectively, indicating that the difference of price elasticities between administrative data and survey data is not significant at the conventional level.

1.4 Structural Model Evidence: Demand Estimation under TOU Plus IBR Pricing in Hangzhou

A discrete-continuous choice (DCC) assumption can be developed and estimated to study the contribution by each piece of electrical equipment during peak and off-peak time. Reiss and White (2005) build an elegant structural model to estimate consumers' elasticity under the DCC assumption and use detailed information, including demographic and appliance information, to estimate the price elasticity more accurately. It needs to be pointed out that the structural model assumes consumers should understand and respond to the nonlinear pricing mechanisms such as time-of-use pricing and increasing block rate. Based on the bunching test results in section 1.3, the consumers in HangZhou do understand and respond to the nonlinear pricing, at least partly, which motivates me to investigate the electricity demand using a structural model.

I use a structural model similar to Reiss and White (2005) in this section for several reasons. First and most importantly, as pointed out by Reiss and White (2005), in their approach, the income effect is ignored or be assumed does not dominate the substitution effect, the non-price effects, such as demographics and other households characteristics, are identified based on the consumption variation among households on the same price tier, and the price effect is identified based on the remaining difference among households on different price tiers. Therefore, their structural model only needs variation in appliance stock to identify the price elasticities and does not necessarily need price variation[25]. The data used in this section are the survey data in Hangzhou, which contain four price levels. The pricing schemes did not change during the study period, as pointed previously. Therefore, to identify the price elasticities efficiently, Reiss and White model is the best choice.

The second reason I use the Reiss and White model is because it can determine the heterogeneity of price and income elasticities, which is important for policy simulation and welfare analysis. The final reason is that the survey data have all required information by the Reiss and White model, namely detailed information of a household's appliance stock and other demographic information.

Because I have survey data in Hangzhou and the pricing scheme is IBR during the peak and uniform during the off-peak, I must modify Reiss and White's (2005) approach to adapt it to my situation. I first model demand with increasing block rate, and then add the time-of-use pricing into the model.

1.4.1 Model Setting

A. Modelling Demand with IBR Pricing

Consumers face a nonlinear budget constraints problem under nonlinear pricing, which results in a complex discrete-continuous choice (DCC) problem. This problem means that consumers should respond to the whole price schedule. Under the situation with nonlinear electricity pricing, such as three-tier increasing block rates

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[25] Reiss and White (2005) specifies electricity demand at the level of the individual appliance first, then aggregate these appliance-level demand specifications to model household electricity demand. Of course, if there exists price variation, it would provide the second source to identify the price elasticities.

during peak time in Hangzhou, considering consumers with quasi-linear utility function[26], the optimal demand x^* satisfies

$$x^* = \begin{cases} x^*(p1) & if\ x^*(p1) \le \overline{x_1} \\ \overline{x_1} & if\ x^*(p1) = \overline{x_1} = x^*(p2) \\ x^*(p2) & if\ \overline{x_1} \le x^*(p1) \le \overline{x_2} \\ \overline{x_2} & if\ x^*(p2) = \overline{x_2} = x^*(p3) \\ x^*(p3) & if\ \overline{x_2} \le x^*(p1) \end{cases} \quad (1.5)$$

where $\overline{x_1}$ and $\overline{x_2}$ are the first and second kink point respectively, p1, p2, and p3 are the first, second, and third tier price respectively. We can also “linearize” the budget constraint and express the demand function as：

$$x^* = x(p^*, y^*)$$

where p^* represents consumers’ marginal willingness-to-pay and y^* represents the perceived income that induce x^* at p^*. Under the three-tier increasing block rate, p^* is p1, p2, and p3, y^* is the virtual income that can be expressed as

$\mathrm{y1} = y$, $\mathrm{y2} = y + \overline{x_1} * (p2 - p1)$, and $\mathrm{y3} = y2 + \overline{x_2} * (p3 - p2)$

Suppose the econometric form of the consumers’ demand function is

$$\mathrm{x(p, y, z, \varepsilon; \beta)}$$

where z represents the consumers’ demographic information such as family size, number of rooms and income, ε represents consumption shock caused by unobserved characters, β is a set of coefficients to be estimated. Under an increasing three-tier price scheme, x^* can be re-written as equation (1.6):

[26] This assumption is logical in theory and reality. Electricity expenditures account for less than 5% percent of the total income or total expenditure in China.

$$x^* = \begin{cases} x(p1, y1, z, \varepsilon; \beta) & if\ \varepsilon < c1 \\ \overline{x_1} & if\ c1 \le \varepsilon \le c2 \\ x(p2, y2, z, \varepsilon; \beta) & if\ c2 < \varepsilon < c3 \\ \overline{x_2} & if\ c3 \le \varepsilon \le c4 \\ x(p3, y3, z, \varepsilon; \beta) & if\ c4 < \varepsilon \end{cases} \quad (1.6)$$

As pointed out by Reiss and White (2005), c_j *is the maximum or minimum value of* ε *for which consumption occurs on tier j*. In the case of three-tiers, c1 $= \overline{x_1} - x(p1, y1, z, \varepsilon; \beta)$, c2 $= \overline{x_1} - x(p2, y2, z, \varepsilon; \beta)$, c3 $= \overline{x_2} - x(p2, y2, z, \varepsilon; \beta)$, and c4 $= \overline{x_2} - x(p3, y3, z, \varepsilon; \beta)$. If the income effect is not very strong, $c_1 < c_2 < c_3 < c_4$ should hold. $\mathrm{p_j}$ and y_j are defined as previously.

Because electricity is used by appliances but does not directly enter into the households' utility function, for the kth appliance owned by the household, the electricity consumption, $\mathrm{x_k}$, can be expressed as:

$$\mathrm{x_k} = \mathrm{\alpha_k p + r_k y + z_k{}'\delta_k + \varepsilon_k} \qquad (1.7)$$

The parameters $\mathrm{\alpha_k}$, $\mathrm{r_k}$, $\mathrm{\delta_k}$ are assumed to be constant across households. According to Dubin and McFadden (1984), the utility maximizing household's total electricity consumption can be expressed as:

$$x = \sum_k d_k \alpha_k p + \sum_k d_k \gamma_k y + \sum_k d_k z_k{}' \delta_k + \sum_k d_k \varepsilon_k \qquad (1.8)$$

where x is the household's total electricity consumption, $\mathrm{d_k} = 1$ if the household has appliance k, and $\mathrm{d_k} = 0$ if not. The advantage of this type of function is that it allows me to estimate each household's price and income elasticities based on their different appliance stock and, therefore, gets the heterogeneity of price and income elasticities.

Assuming $\varepsilon \sim N(0, \sigma^2)$ and $\mathrm{x(p, y, z, \varepsilon; \beta) = x(p, y, z; \beta) + \varepsilon}$, the expected consumption under three-tier increasing block rate can be expressed as:

$$\mathrm{E}\left(\mathrm{x}^{*}\middle|w\right)=[\mathrm{x}(\mathrm{p1,y1,z;\beta}) - \sigma\cdot\tau_1]\cdot\Phi_1 + \overline{x_1}\cdot[\Phi_2-\Phi_1] +$$

$$x(p2,y2,z,;\beta)\cdot[\Phi_3-\Phi_2] - \sigma\cdot[\tau_3\Phi_3-\tau_2\Phi_2]+\overline{x_2}\cdot[\Phi_4-\Phi_3] \quad (1.9)$$

$$+[\mathrm{x(p3,y3,z;\beta)}+\sigma\cdot\tau_4]\cdot[1-\Phi_4]$$

where Φ_j and φ_j are the standard normal distribution and normal density at $\frac{c_j}{\sigma}$, $\tau_1 = \varphi_1/\Phi_1$, $\tau_2 = \varphi_2/\Phi_2$, $\tau_3 = \varphi_3/\Phi_3$, and $\tau_4 = \varphi_4/(1-\Phi_4)$. w is observable variables that affect electricity consumption. Similarly, we can get the expression of $\mathrm{E}\left(\mathrm{x}^{*2}\middle|w\right)$.

If consumption is measured annually or every few months, let x_t^* denote consumer i's electricity consumption in month t, then

$$x_a^* = \sum_{t=1}^{n} x_t^*$$

where x_a^* is consumer i's aggregate consumption and n is the number of months (for annual consumption, n=12). Using the expression for x_a^*, we can get the expression $\mathrm{E}(\,x_a^*|w)$ and $\mathrm{E}\left(\,x_a^{*2}\middle|w\right)$.

B. Modelling Demand With both TOU and IBR Pricing

Because the pricing scheme in Hangzhou is TOU plus IBR, and because the bill period is bi-monthly, I include off-peak price into peak time demand and peak price into the off-peak demand, and aggregate the demand over the billing period. Denoting that x_{ij} be the demand at month i and j-th tier price and j-th income, the electricity demand for appliance k and total demand during the peak time can be expressed as:

$$x_{kp}^* = \alpha_{\mathrm{pk}}p_p + \mathrm{r_{pk}y} + \mathrm{z_{kp}}'\delta_\mathrm{k} + \rho_{pk}p_v + \varepsilon_{\mathrm{pk}} \quad (1.10)$$

$$x_p^* = \sum_k d_k\alpha_{\mathrm{pk}}p_p + \sum_k d_k\mathrm{r_{pk}y} + \sum_k d_k\mathrm{z_{kp}}'\delta_\mathrm{k} + \sum_k \rho_{pk}p_v + \sum_k d_k\varepsilon_{\mathrm{pk}} \quad (1.11)$$

Where p_p and p_v denote the marginal price faced by the household during the peak and off-peak time respectively.

For convenience, we can rewrite equation (11) as:

$$x_p^* = \alpha_p p_p + \gamma_p y + z_p' \delta + \rho_p p_v + \varepsilon_p \tag{1.12}$$

by defining $\alpha_p = \sum_k d_k \alpha_{\mathrm{pk}}$, $\gamma_p = \sum_k d_k \mathrm{r}_{\mathrm{pk}}$, and so on.

The optimal electricity demand during the off-peak time can be expressed as

$$x_v^* = \alpha_v p_v + \gamma_v y + z_v' \delta + \rho_v p_p + \varepsilon_v \tag{1.13}$$

α_v, γ_v and others are defined similarly.

Then, the optimal peak time demand in month i can be expressed as:

$$x_{ip}^* = \begin{cases} x_{i1} = x_p(p1, y1, z, \varepsilon; \beta) & if \, \varepsilon_p < c1 \\ \overline{x_1} & if \; c1 \leq \varepsilon_p \leq c2 \\ x_{i2} = x_p(p2, y2, z, \varepsilon; \beta) & if \; c2 < \varepsilon_p < c3 \\ \overline{x_2} & if \; c3 \leq \varepsilon_p \leq c4 \\ x_{i3} = x_p(p3, y3, z, \varepsilon; \beta) & if \; c4 < \varepsilon_p \end{cases} \tag{1.14}$$

where,

$$x_{i1} = x_p(p1, y1, z, \varepsilon; \beta) = \alpha_p p_1 + \gamma_p y_1 + z_p' \delta + \rho_p p_v + \varepsilon_p$$

$$x_{i2} = x_p(p2, y2, z, \varepsilon; \beta) = \alpha_p p_2 + \gamma_p y_2 + z_p' \delta + \rho_p p_v + \varepsilon_p$$

$$x_{i3} = x_p(p3, y3, z, \varepsilon; \beta) = \alpha_p p_3 + \gamma_p y_3 + z_p' \delta + \rho_p p_v + \varepsilon_p$$

The first month's total consumption is:

$$x_1^* = x_{1p}^* + x_{1v}^*$$

The total consumption during the bi-month billing period is then:

$$x_a^* = x_1^* + x_2^*$$

Therefore, the expected demand in month i is:

$$\mathrm{E}[x_i^* | w_i] = \mathrm{E}\left[x_{ip}^* | w_i\right] + \mathrm{E}[x_{iv}^* | w_i]$$

$\mathrm{E}\left[x_{ip}^* | w_i\right]$ is the expected peak consumption in month i, $i = 1, 2$.

$$\mathrm{E}\left[x_{ip}^{*}|w_i\right] = (x_{i1} - \sigma\tau_{\mathrm{i1}})\Phi\left(\frac{c_{i1}}{\sigma}\right) + \overline{x_1}\left[\Phi\left(\frac{c_{i2}}{\sigma}\right) - \Phi\left(\frac{c_{i1}}{\sigma}\right)\right] + (x_{i2} - \sigma\tau_{\mathrm{i3}})\Phi\left(\frac{c_{i3}}{\sigma}\right) -$$

$$(x_{i2} - \sigma\tau_{\mathrm{i2}})\Phi\left(\frac{c_{i2}}{\sigma}\right) + \overline{x_2}\left[\Phi\left(\frac{c_{i4}}{\sigma}\right) - \Phi\left(\frac{c_{i3}}{\sigma}\right)\right] + (x_{i3} + \sigma\tau_{\mathrm{i4}})[1 - \Phi\left(\frac{c_{i4}}{\sigma}\right)]$$

And $\mathrm{E}[x_{iv}^{*}|w_i]$ is the expected off-peak consumption in month i, $i = 1, 2$.

$$\mathrm{E}[x_{iv}^{*}|w_i] = x_{iv}$$

Where Φ_{ij} and φ_{ij} are the standard normal distribution and normal density at $\frac{c_{ij}}{\sigma}$,

$\tau_{\mathrm{i1}} = \varphi_{i1}/\Phi_{i1}$, $\tau_{\mathrm{i2}} = \varphi_{i2}/\Phi_{i2}$, $\tau_{i3} = \varphi_{i3}/\Phi_{i3}$, and $\tau_{i4} = \varphi_{i4}/(1 - \Phi_{i4})$.

Therefore, the aggregated expected demand during the billing period is:

$$\mathrm{E}[x_a^{*}|W] = \mathrm{E}\left[x_{1p}^{*}|w_1\right] + \mathrm{E}[x_{1v}^{*}|w_1] + \mathrm{E}\left[x_{2p}^{*}|w_2\right] + \mathrm{E}[x_{2v}^{*}|w_2]$$

$$\mathrm{E}[(x_a^{*})^2|W] = \mathrm{E}\left[\left(x_{1p}^{*}\right)^2|w_1\right] + 2\mathrm{E}\left[x_{1p}^{*}|w_1\right]\,\mathrm{E}[x_{1v}^{*}|w_1] + \mathrm{E}[(x_{1v}^{*})^2|w_1]$$

$$+2[x_1^{*}|w_1][x_2^{*}|w_1] + \mathrm{E}\left[\left(x_{2p}^{*}\right)^2|w_2\right] + 2\mathrm{E}\left[x_{2p}^{*}|w_2\right]\,\mathrm{E}[x_{2v}^{*}|w_{21}] + \mathrm{E}[(x_{2v}^{*})^2|w_2]$$

$\mathrm{E}[(x_a^{*})^3|W]$, and $\mathrm{E}[(x_a^{*})^4|W]$ can be obtained similarly, which will be used in the empirical estimation of the covariate matrix.

C. Estimation method including demand structure information

Methods to estimate this model include the double-error MLE developed by Hausman (1985) and Moffit (1986, 1990) and GMM. I use the GMM method in this part based on the first and second moments.

$$\mathrm{u1} = x_a - h_1(W, \theta) \qquad (1.15)$$

$$\mathrm{u2} = (x_a)^2 - h_2(W, \theta) - 2h_1(W, \theta)(x_a - h_1(W, \theta)) \qquad (1.16)$$

where x_a is the real aggregate consumption, $h_i(W, \theta) = E[(x_a)^i|W]$ is the r-th conditional moment, W is the matrix/vector of observable variables, and θ the unknown parameters. Typically, though I can get the consistent coefficient estimation only using the first moment equation, the second moment equation is used to estimate the efficient estimator and covariance matrix.

Under TOU plus IBR pricing, these two moments are not enough to get consistent estimators. Demand structure information should also be included. The fact that the share of off-peak and peak consumption is observed means that I am able to match those shares. Therefore, I add another moment that uses the structural information. The moment of demand structure information can be expressed as:

$$u_r = \frac{x_p}{x_v} - h_r(W, \theta) \qquad (1.17)$$

where $h_r(W, \theta)$ can be expressed as:

$$h_{r1} = \mathrm{E}\left[\frac{x_p^*}{x_v^*} | w\right] \qquad (1.18)$$

Another problem is how to get the optimal instruments. Similar to Reiss and White (2005), letting β denote the demand parameters and ϵ a vector of variances, so $\theta = (\beta, \epsilon)$, the optimal instruments are:

$$z_1(\mathrm{W}, \theta)' = \nabla_\beta h_1(W, \theta)$$

$$z_2(\mathrm{W}, \theta)' = \begin{bmatrix} \nabla_\beta h_2(W, \theta) \\ \nabla_\epsilon h_2(W, \theta) \end{bmatrix}$$

$$z_r(\mathrm{W}, \theta)' = \nabla_\beta h_r(W, \theta)$$

Therefore, I build the moment equation according to the orthogonality condition $E\left[z_r' u_r\right] = 0$. The estimation minimizes the GMM distance metric or the objective function $\|\mathrm{Au}(\theta)\|^2$, where **A** is the weight matrix and keeps unchanged in each iteration, and $\mathrm{u}(\theta)' = [\mathrm{u}_1(\theta)'\mathrm{u}_2(\theta)'\mathrm{u}_r(\theta)']$. $\mathbf{A} = \tilde{\mathbf{R}}\tilde{\mathbf{Z}}'$, where $\tilde{\mathbf{Z}}$ is the instrument matrix calculated on initial consistent estimators[27], and $\tilde{\mathbf{R}}$ is the Cholesky root of $\left[\tilde{\mathbf{Z}}'\tilde{\boldsymbol{\Omega}}\tilde{\mathbf{Z}}\right]^{-1}$, where $\tilde{\boldsymbol{\Omega}}$ is the covariance matrix $\mathrm{E}[\mathrm{u}(\theta)\mathrm{u}(\theta)'|W]$ calculated on initial consistent estimators. The covariance matrix can be calculated analytically or numerically. I use the analytical expressions in my program and estimation process[28].

From the equations above, the demand error of each household can be written as, which is heteroscedastic:

$$\mathrm{var}(\varepsilon) = \sum_{j=1}^{K}\sum_{j=1}^{K} d_j d_k cov(\varepsilon_j, \varepsilon_k) = \sigma(d_1, d_2, \cdots, d_k)^2 \quad (1.19)$$

1.4.2 Estimation Results

A. Grouping Households

The data used for the structural model are the survey data in Hangzhou. I provided summary statistics for these in the data section, but I still have two issues that need to be addressed. The first is how to separate the households into different groups[29]. I wish to divide households into different groups to see if the price elasticities are different across the groups. The groups must reflect the differences across households and each should be comprised of sufficiently numerous households. Although I have main appliances in the survey data such as air conditioners, refrigerators, televisions, and washers, the only appliance for which I observe significant difference across the households in my sample is air conditioners.

[27] Initial consistent estimators are calculated only using the first order conditional moment.

[28] Because the survey sample and the difference among households are small, analytical method works better than numerical one.

[29] It needs to point out that the grouping is not necessary for estimation. The grouping is only used to see if the price elasticities are different across the groups.

Therefore, I separate the households into two groups. The first group includes the households that own one or no air conditioner and the second group includes the households with two or more air conditioners.

Next, I must decide which peak time marginal price to include in the off-peak time electricity consumption. I use the iteration method to make sure the peak time marginal prices are consistent. First, I use the actual marginal price that each household faces during the peak. After getting convergence and estimated coefficients, I then estimate the expected peak marginal price based on the estimation results. Next, I re-estimate the coefficients again using the expected peak marginal price. The iteration process repeats until the estimators converge. The final converged estimators only have a nominal change compared to the first step results.

B. Marginal Effects Results

The estimated marginal effects in Hangzhou are shown in table 1.8. The signs of almost all estimators are consistent with expectations. The own price marginal effects are negative, and the marginal effects in peak time are stronger. For example, the -85.04 and 24.24 estimator for peak price means that if the peak price increase one cent per kWh, or around 11%, bi-monthly peak consumption would decrease 85 kWh and off-peak consumption would increase 24 kWh. At the same time, the peak time price marginal effects vary significantly across households with different appliances. The off-peak own price marginal effects are also negative, but it absolute values are remarkably smaller and do not vary significantly among different groups. The difference between peak and off-peak own price marginal effects means that households are more sensitive to the peak price than to the off-peak price. The cross-

Table 1.8 Estimated Marginal Effects

Explanatory variables	Households with one or no air-conditioner		Households with two or more air-conditioners	
	Peak Consumption	Off-peak Consumption	Peak Consumption	Off-peak Consumption
Constant	109.99*** (0.52)	73.69*** (0.500)	35.24*** (0.56)	23.32*** (0.470)
Peak price	-85.04*** (0.86)	24.24*** (0.84)	-44.83*** (0.92)	10.15*** (0.83)
Off-peak price	1.99 (1.80)	-15.38*** (1.74)	2.07 (1.93)	-7.37*** (1.79)
Income	6.73*** (0.47)	-1.29*** (0.46)	6.68*** (0.49)	1.03*** (0.23)
Family scale	3.52*** (0.16)	-7.93*** (0.15)	1.80*** (0.17)	-3.51*** (0.13)
Number of rooms	2.47*** (0.15)	-10.88*** (0.15)	1.79*** (0.16)	-8.11*** (0.13)
House net area	0.54*** (0.01)	0.32*** (0.01)	0.82*** (0.01)	0.24*** (0.01)
Number of person above 65	0.23 (0.46)	-7.72*** (0.45)		
Average temperature	-0.07** (0.03)	0.77*** (0.03)		
Heating Degree Days	-0.66*** (0.08)	1.29*** (0.08)	1.95*** (0.09)	0.57*** (0.06)
Cooling Degree Days	0.19*** (0.05)	-0.27*** (0.05)	1.65*** (0.05)	-0.55*** (0.06)
Cooking with electricity	0.11 (0.63)	3.63*** (0.61)		
Heating bath water with electricity	-0.02 (0.59)	5.07*** (0.57)		
Year2009	-0.32 (0.89)	4.51*** (0.86)		
Year2010	-1.26 (0.90)	2.30*** (0.86)		
Billing month	-2.57*** (0.80)	3.41*** (0.77)		

asymptotic standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

price effects are all positive. Moreover, the cross-price effects are asymmetric: households' peak consumption does not respond to the off-peak price much, but the off-peak consumption does have marked response to the peak price.

The overall income effects and the peak time income effects are positive, but the off-peak time income effects are negative. This result means that households with higher income consume more during peak time but less during off-peak time, which will be discussed in detail in the income elasticity section below.

C. Price and Income elasticities

Calculating price and income elasticity under nonlinear pricing is more complex than under flat pricing. Under IBR pricing, a change of marginal price may have three possible outcomes. The first one is that consumers stay in the current tier but change their consumption. The second effect is that the consumers jump to another tier. The third outcome is that the consumption doesn't change at all. Therefore, the calculation of elasticity must consider this special character of households' behavior on the margin. The details about how to calculate price and income elasticities are given in Appendix B. Mean price and income elasticities are presented in table 1.9. Almost all of the elasticities results are consistent with expectations and previous studies from US or Europe. Table 1.9 shows that the elasticities vary across households.

The mean overall own price elasticity is -0.32, the mean peak own price elasticity is -0.49 and the mean off-peak own price elasticity is -0.04. The overall and peak time elasticities for household group with one or no air-conditioners are -0.24 and -0.37, respectively. These results are significantly smaller than the overall and peak time elasticities for households groups with two or more air conditioners, -0.33

and -0.50, respectively. The households with two or more air conditioners have stronger elasticity means that the IBR can achieve its goal of giving household with more appliances bigger incentive to decrease consumption.

Table 1.9 Mean Price and Income Elasticities

	Own price elasticity			Cross price elasticity		Income elasticity		
	Overall	Peak	Off-peak	Off-Peak price/peak consumption	Peak price/ off-peak consumption	Overall	Peak	Off-peak
All households	-0.315	-0.489	-0.04	0.011	0.210	0.08	0.13	-0.01
Households with one or no air conditioner	-0.241	-0.372	-0.04	0.010	0.203	0.08	0.14	-0.01
Households with two or more air conditioners	-0.325	-0.505	-0.04	0.013	0.212	0.08	0.14	-0.01

The off-peak own price elasticity is very small. The main reason may be that the off-peak consumption is basic and necessary consumption, which is relatively insensitive to price. Another possible reason may be lack of price variation during off-peak time[30].

The cross-price elasticity is positive and asymmetric. The mean cross price elasticity between off-peak price and peak consumption is 0.01, and the mean cross price elasticity between peak price and off-peak consumption is 0.21. This result has the important policy implication that increasing the peak price can significantly

[30] Considering the fact that the off-peak price elasticities are pretty small, I do a robust test to see how the overall price elasticities changes when the absolute value off-peak price elasticities change from -0.04 to -0.1, -0.15, and -0.20. The results show that the overall price elasticities will change to -0.35, -0.37, and -0.41 respectively, which are still in the acceptable range.

incentivize consumers to move their consumption from peak to off-peak. However, increasing the off-peak price have very small effect on peak consumption.

The mean income elasticity is 0.08, which is significant but small. The income elasticity during peak time is positive and larger than the overall one, which means that households with higher income are prepared to consume more electricity during peak time and pay for it. The off-peak income elasticity is negative but small. Both results are consistent with trends observed in China in recent years: Households with higher incomes prefer to have dinner and other leisure and recreational activities that use energy in the evening.

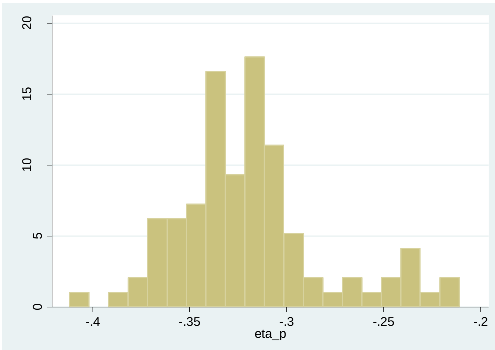
D. Heterogeneity

As shown in figure 1.4, all elasticities have significant and considerable heterogeneity among households. As shown in panel A, about 80 percent of households' own price elasticity is between -0.29 and -0.37, which seems to be smaller than our expectation, but it is very similar to the results of Reiss and White (2005) regarding the price elasticity in California.

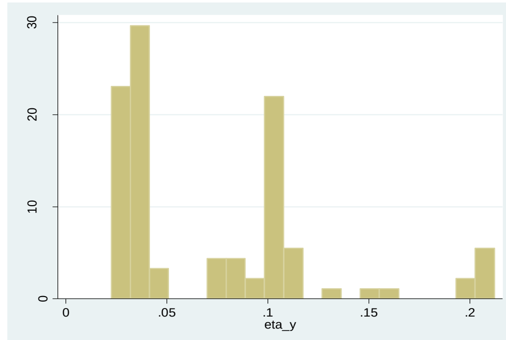
Panel C and panel D show that peak time own price elasticities are quite large, about 80 percent of households' peak time own price elasticities are between -0.39 and -0.60. The off-peak own price elasticities are quite small, only around -0.05. At the same time, the off-peak own price elasticities are more asymmetric and negatively skewed than the peak time own price elasticities, which confirms the conclusion that the demand in off-peak is basic and necessary consumption.

Figure 1.4 Price and Income Elasticities

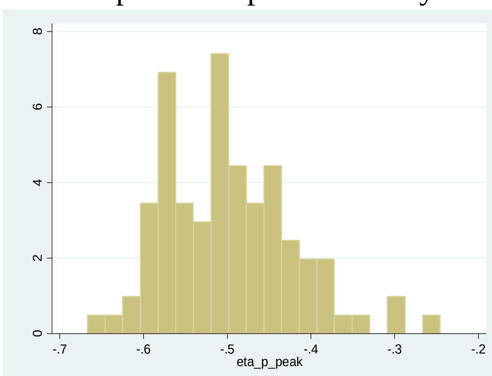
Panel A: Overall own price elasticity



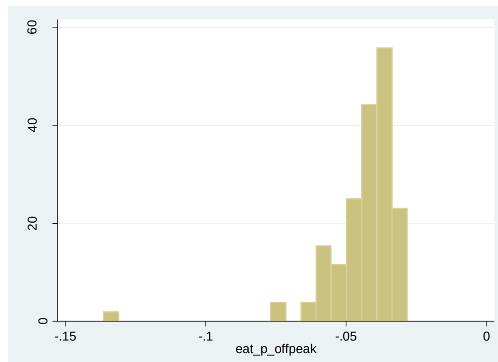
Panel B: Overall income elasticity



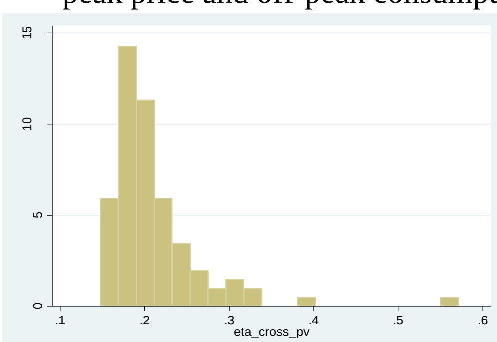
Panel C: peak own price elasticity



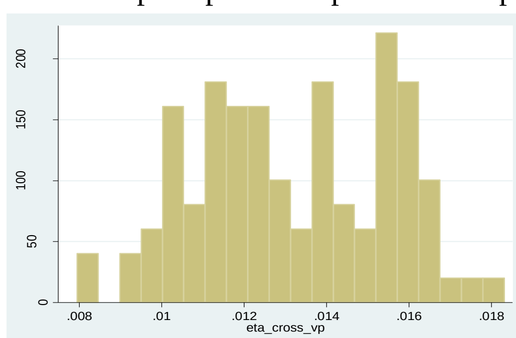
Panel D: off-peak own price elasticity



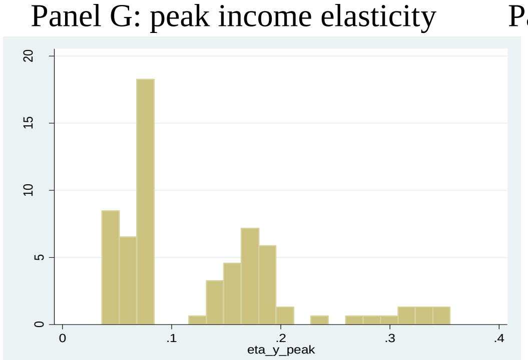
Panel E: cross price elasticity between peak price and off-peak consumption



Panel F: cross price elasticity between off-peak price and peak consumption



Panel G: peak income elasticity



Panel H: off-peak income elasticity

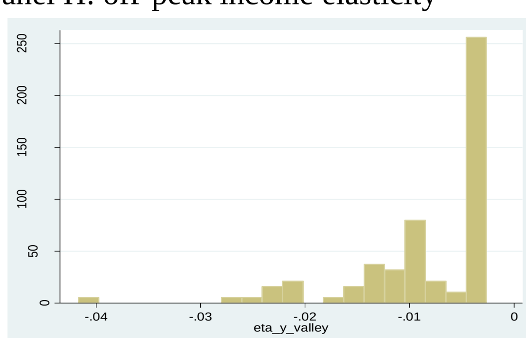


Table 1.10 presents price elasticities among households with different income and consumption levels. As shown in the table, the households with higher consumption have higher price elasticity. These results meet our expectation that nonlinear pricing has different effects among different households and has important policy implications that, when increasing block rate is implemented, the first price tier should be set low enough to ensure low income households' basic electricity consumption. At the same time, the last price tier can be set high to give households with more appliances and greater consumption enough incentive to decrease their consumption.

Table 1.10: Price Elasticities among Different Income and Consumption Levels

Household Month Income ($)	Global Own Price Elasticity	Monthly Consumption	Global Own Price Elasticity
Less than 8,000 RMB	-0.32	Less than 50 kWh	--
Between 8,000 RMB and 15,000 RMB	-0.32	50 kWh to 200 kWh	-0.30
Greater than 15,000 RMB	-0.28	Greater than 200 kWh	-0.32

1.5 Policy Simulation

After July 1st, 2012, Hangzhou adjusted its pricing scheme, making two main changes. As shown in table 1.11, the first change is adjusting the billing period from monthly to annual; the second change is increasing the second and third-tier prices during the peak time and introducing IBR during off-peak time. Therefore, in this section, as shown in table 1.12, I assume two scenarios in order to predict counterfactual consumption, had those changes not occurred, and to analyze the change of consumer behavior based on estimated elasticities in previous section. The results of simulated consumption are presented in table 1.13.

Table 1.11 New Tariff after 1st July 2012 in Hangzhou

Before Adjustment (cent/kWh)			After Adjustment (cent/kWh)		
Billing	Peak	Off-peak		Peak	Off-peak
<50kWh per month	9.47	4.8	<2760kWh per year	9.47	4.8
51kWh~200kWh per month	9.97	4.8	2761~4800kWh per year	10.3	5.63
>201kWh per month	11.13	4.8	>4801kWh per year	14.47	9.8

The purpose of scenario A is to investigate consumer behavior when the nonlinear pricing changed to uniform pricing. In other words, in this scenario, I am removing the IBR and TOU pricing and putting back simpler pricing schemes. In scenario A, I assume the IBR plus TOU pricing was changed to TOU pricing only (scenario A1) and uniform pricing (scenario A2). In scenario A1, I assume the pricing scheme is time-of-use pricing only[31], which means both the peak and off-peak prices are uniform. In scenario A2, I assume the pricing scheme is uniform over the whole day. The uniform price is assumed to be the actual average price, calculated by dividing all households' actual total expenditure by their actual total consumption.

After the changing of pricing schemes, total consumption increases under scenario A1 and A2. When the pricing scheme changes from IBR plus TOU pricing

[31] Under the TOU only pricing, the peak time uniform price is calculated by dividing all households' actual peak time expenditure by their actual peak time consumption. The off-peak price is identical to the previous uniform price.

to TOU only pricing, the total consumption only increases around 1.5%, but the total consumption increases around 8% when the pricing scheme changes to uniform pricing. These results confirm the conclusion, from the bunching test and demand estimation approaches, that households will optimize their consumption between peak and off-peak but they respond little to IBR pricing. The results also suggest another important policy implication that the time-of-use pricing help decrease total consumption. The main reason may be that, under TOU pricing, it is easy for the households to understand the tariff structure and to plan appliance use accordingly.

Table 1.12 Simulation Scenarios

		Old Tariff	Scenario A		Scenario B		
			A1	A2	B1	B2	B3
First Kink point (kWh)		50	--	--	50	50	50
Second Kink point (kWh)		200	--	--	200	200	200
Peak price (¢/kWh)	Tier 1	9.47	--	--	9.47	9.47	9.47
	Tier 2	9.97	--	--	10.3	10.3	10.3
	Tier 3	11.13	--	--	14.47	14.47	14.47
Off-peak price (¢/kWh)		4.8	4.8	--	4.8	5.63	9.8

Table 1.13 Results of Consumption under Different Scenarios

Group	Previous Consumption	**A**		**B**		
		A1	**A2**	**B1**	**B2**	**B3**
All	184.86	187.56	199.41	178.63	178.09	175.40
Households with one or no air conditioner	173.38	175.53	185.66	168.11	167.53	164.61
Households with two or more air-conditioners	177.39	179.21	186.82	172.77	172.18	169.19

Scenario B is based on the new tariff and designed to investigate what happens if the peak and off-peak prices are raised significantly. During the peak time, I assume the pricing mechanisms is still IBR but the second and third tiers during peak time changes to 10.3 ¢/kWh and 14.47 ¢/kWh, which means increase by 3% and 30%, respectively. During the off-peak, the price is still uniform stays at 4.8 ¢/kWh[32], changes to 5.63 ¢/kWh, and changes to 9.8 ¢/kWh respectively in scenario B1, B2, and B3 respectively. The results show total consumption decreases around 3% when only the peak prices are increased under scenario B1. If the off-peak price increases 17% or even 100% in addition to the increase of the peak price (as assumed under scenarios B2 and B3), total consumption only decreases around 3% and 5% respectively. The results of scenario B show that the off-peak price has only a minimal effect on total consumption.

Of interest is the heterogeneity of the effect among different groups. Under scenario A, households with more appliances and, therefore, the highest consumption and price elasticity, increase consumption more than other groups when the pricing schemes changes to uniform pricing and the cutoff value increase. When the peak and off-peak prices increase significantly in scenario B, households with more appliances decrease consumption more than other groups. These results suggest that the IBR and TOU pricing can achieve their policy goals of providing more incentives to the households with relatively high consumption levels.

[32] In my structural model, the off-peak is uniform price. If I want to simulate the situation that both peak and off-peak pricing are IBR, I need to rebuild and re-estimate the model, but I do not have relative dataset. Therefore, I can only do policy simulations under the assumption that the off-peak price is uniform.

The results of the policy simulations also provide valuable insight on how nonlinear pricing schemes can benefit China. From an investment perspective, considering the fact that residential electricity consumption accounts for around 15 percent of total consumption in China, implementing TOU can help decrease around 1 percent of total consumption. While this may seem a small share, according to investment data from China Electric Power Yearbook (2011)[33], implementing time-of-use and increasing block rate pricing can save around 80 billion kWh consumption and, consequently, around 19 billion dollars investment in generation capacity plus 13 billion dollars investment in grid.

1.6 Conclusions

Consumers' behavior under nonlinear pricing determines whether nonlinear pricing policies can achieve its policy goals. If consumers cannot understand the sophisticated nonlinear pricing schedule and respond to it, the nonlinear pricing policy cannot accomplish its goals. Based on an extensive and unique dataset from China, the results from graphical and statistical evidences of bunching, double-log demand estimation, and structural discrete-continuous choice (DCC) model in this paper indicate that Chinese households do understand and respond to the complex pricing schedule.

[33] China total electricity consumption in 2013 is 5523 billion kWh, the average using hours of generation capacity is 4300 hours per year, and generation capacity investment is around 1,000 dollars per kW. Grid investment to transfer and distribute the generated electricity to households is typically 0.75 times that of the generation investment. The fuel and other maintenance cost is around 3.8 cent/kWh.

At the same time, the policy simulation shows that nonlinear pricing such as time-of-use pricing and increasing block rates can provide significant incentive to households to optimize their consumption. Changing from uniform pricing to TOU and/or TOU plus IBR pricing can significantly decrease total consumption, especially consumption during peak time. Therefore, to reduce electricity demand and enhance energy efficiency, it is appropriate for China to implement nonlinear pricing mechanisms such as time-of-use pricing and increasing block rate. At the same time, the results also show that, if only one type of nonlinear pricing were to be implemented, households don't respond as much as expected to IBR pricing, they respond more to TOU pricing. Therefore, compared to introduce increasing block rates only, it would be better to introduce time-of-use pricing or time-of-use pricing plus increasing block rates.

2 Vertical Integration Economies between Transmission and Distribution: Evidence from China

2.1 Introduction

The traditional structure of the electricity industry in most countries consisted in vertically integrated utilities that generate electricity, transmit electricity from generation plants to local consumption centers, and distribute electricity to end consumers. In the last two decades, technological change in the generation sector makes competition among generators possible and market-oriented reforms in electric power industry were implemented in many countries. The main direction of the reform is to separate the generation from downstream transmission and distribution, and build the wholesale electricity market. At the same time, transmission and distribution continue to be vertically integrated in most countries.

In 2002, China implemented its most important market-oriented reform in the power industry: generation was separated from transmission and distribution, which has greatly promoted China power industry's competition and efficiency[34]. However, in recent years, China's power industry reform was progressed very slow. The proposed wholesale electricity market has not been built. Some economists argue that the reform is at a crossroads again. There are heated debates about how to advance future reform, especially the wholesale electricity market and the reform of transmission and distribution sectors. Because transmission and distribution are still

[34] Please see next section for more details about China power industry.

vertically integrated in China, separation of transmission and distribution is put on the table by policy makers and economists. In general, the point of view supporting transmission-distribution separation emphasizes the benefits of the reform and believes the separation will be an effective way to form a competitive wholesale electricity market, by increasing the number of participants in the wholesale market. That this is so hotly debate suggests that, we should first investigate whether there exist vertical integrated economies between transmission and distribution and how large such vertical economies are.

In the early 1980s, economists began to focus on the vertical integration economies in the power industry. Weiss (1975) pointed out that there were significant vertical economies in the electricity industry; Landon (1983) specified that the vertical separation would generate transaction costs and information cost; Joskow and Schmalensee (1983) pointed out that the vertical economies came from many aspects such as common cost and coordination cost, among others. The empirical literature on vertical integration economies has much grown, starting from the mid-1980s. For example, Kaserman and Mayo (1991), Kwoka(1996), Hayashi，Goo & Chamberlin (1997), Kwoka（2002), Jara-Díaza et al. (2004), Nemoto and Goto (2004), and Fraquelli, Piacenza & Vannoni (2005) find there exist significant vertical integration economies between generation and distribution.

Kaserman and Mayo (1991) first estimate a multistage quadratic cost function with firm-specific input prices and other hedonic variables to investigate the vertical integration economies between generation and distribution. The data used by Kaserman and Mayo (1991) is 74 firms in 1981 from US. Amon the 74 firms, 50 firms were vertical integrated. Based on the cost function estimation, Kaserman and Mayo (1991) then calculate the vertical integration economies and find significant vertical economies between generation and distribution.

Kwoka (2002) use quadratic cost function with input prices and hedonic variables to research the vertical integration economies between generation and distribution. The data used in Kwoka (2002) is 147 investor-owned utilities in 1989 from US. Kwoka (2002) found that vertical economies can be very substantial and that the largest vertical integration economies arise when generation and distribution is fully vertical integrated.

Jara-Díaza et al. (2004) uses quadratic cost function similar to Kaserman and Mayo (1991) and Kwoka (2002) with input prices but without hedonic variables to investigate the vertical integration economies between generation and distribution. The data sued by Jara-Díaza et al. (2004) is from 12 firms that provide generate and distribute services in Spain, from 1985 to 1996, with 106 observations in total. Jara-Díaza et al. (2004) also find significant vertical integration economies.

Nemoto and Goto (2004) investigate the technological externality between the generation and transmission–distribution stages and research the vertical integration economies indirectly using a shadow cost function based on the penal data from nine Japanese electric utility firms over the 1981–1998 period. Nemoto and Goto (2004) find the technological externality between generation and transmission-distribution stages, which suggests economies of vertical integration indirectly.

Most of the previous articles focus on the vertical integration economies between generation and grid, which account for around 3% to 90% of the total cost. There is no research yet about the vertical integration economies between transmission and distribution.

Compared to previous research, this paper is the first to focus on the vertical integrated economies between transmission and distribution using 24 utility companies' administrative data including detailed cost information from 2004 to 2009 in China[35]. To estimate the cost and to derive an explicit and general measure of vertical integration economies, I build a quadratic function that relates the varying degrees of vertical integration to cost differences. To incorporate the unique features of the electric power industry, the model builds three scenarios, defines the 220kV grid and above, 110kV grid and above, 35 kV grid and above as transmission respectively. The results show that there do exist significant vertical integration economies between transmission and distribution, around 1 billion dollars per year per utility company on average or around 20 percent of the total cost. I also find that the vertical integration economies have grown over time and that the utilities facing customers with high consumption intensity have larger vertical integration economies. In other words, separating transmission and distribution would raise cost, and this increase would then be transferred to end consumers.

The remaining contents of this paper are organized as follows: Section II gives brief background of China power industry especially the transmission and distribution

[35] The cost data is directly from the annual operation and financial reports of the provincial utility companies.

sectors. Section III presents the empirical model and the data. Section IV gives the empirical results of cost function and vertical integration economies, and Section V proposes conclusions and policy recommendations.

2.2 Brief Background of China Power Industry and Sources of Vertical Integration Economies

2.2.1 Brief Background of China Power Industry

In 2002, China had separated generation from transmission-distribution-retail sectors. Currently, generation sector in China is considered competitive and most generation plants are owned by state-owned generation companies. The transmission and distribution sectors are still highly vertical integrated in China. The State Grid cooperation of China (SGCC) and China Southern Power Grid (CSG) own and operate almost all transmission and distribution grid network in China. State Grid cooperation of China and China Southern Power Grid own and operate transmission and distribution grid network in 26 and 5 provinces respectively (as shown in figure 2.1). SGCC and CSG purchase electricity from independent generation companies at tariffs set by the central government, named on-grid tariff, and sell to the end consumers at tariffs set by the provincial governments, named retail tariff. Unlike most countries in the worldwide, the revenue of SGCC and CSG are not based on the rate-of-return regulation, but from the difference between electricity sale and the cost of purchased power[36], as shown in equation (2.1).

[36] These two grid companies only own a few pumped storage power stations for power system black start.

$$\text{Revenue} = \text{RT} * \text{RQ} - \text{OGT} * \text{PQ} \quad (2.1)$$

where RT is the retail tariff set by the provincial governments, RQ is the electricity quantity sold to end consumers, OGT is the on-grid tariff set by the central government, and PQ is the purchased quantity from generation companies.

Figure 2.1 Service Area of Grid Companies in China

For the retail sector, China is introducing competition in retail sector now by allowing new power dealers purchase electricity from generation plants and sell electricity to end consumers directly. However, currently, SGCC and CSG provide retail service to most end consumers, more than 95 percent of total consumption. By now, China has not built any wholesale electricity market yet although several provincial wholesale markets are under researching.

The cost data used in this article are from 24 provincial utility companies at SGCC. As the largest utility company in the world, SGCC provides transmission, distribution, and retail service to more than 1.1 billion people and more than 88 percent area in China. At 2017, SGCC sell more than 3874 billion kWh electricity to end consumers and get 332 billion dollars revenue.

2.2.2 Sources of Vertical Integration Economies

The different sectors such as generation, transmission, and distribution, in the electricity industry have stronger technological links than other industries for two unique aspects of operation. The first is the real time balance requirement of the system. Because the electricity is hard to store, or the storage cost is very high, the system operator must coordinate the operation of different sectors, generation, transmission, distribution, and demand, to balance the supply and demand at all times. The second is that electricity flows abide specific physics law, which means that any small unexpected failure, if not handled by immediate coordinated operation, could cause large scale blackouts. These technological links are stronger between transmission and distribution than that between generation and transmission-distribution. Actually, from an engineering viewpoint, the transmission–distribution sectors should operate as a unified network. The vertical integration economies between transmission and distribution may come from:

--Share of common costs such as routine maintenance devices, materials, human resources of engineers, and technology improvements from research and development.

--Coordination on network planning especially on transmission and distribution network expansion to get minimize long term investment cost.

--Coordination of generation capacity plan and demand side management to meet medium- and long-term capacity requirement with least cost.

-- Coordination of system operation such as least-cost dispatch in short term to get minimum operation cost.

--Coordination of system operation such as real time demand control to avoid system failures.

2.3 Empirical model and Data

2.3.1 Empirical model

To assess vertical integration economies, I must build a cost function for the electricity industry. There are three main methods to estimate the electricity industry cost function. The first is Generation Unit-level Marginal Cost Estimation by BBW (2002), dating back to Borenstein & Bushnell (1999), also used by Borenstein et al. (2002), Mansur (2008) and Cicala (2017). This method is mainly used to check the electricity wholesale market's market power by estimating the marginal (variable) cost of generation plants and does not include the fixed cost. The marginal costs for each generation plant or unit are calculated as: Marginal Cost = HR * FC + OC, where HR is heat rate, FC is fuel cost, OC is operating and maintenance cost. This method needs detailed plant- or unit-level generation cost data.

The second method is the Input Demand Functions to evaluate the impact of regulatory reforms by estimating inputs, such as labor, fuel, and non-fuel, demand functions. This method is first used by Fabrizio et al (2007) and many papers following this method. This method estimates the input demand, especially the changes in input demand associated with restructuring of electricity industry. This method also need plant- or unit-level cost data including labor cost, fuel cost, and non-fuel cost.

The third method is the Cost Function Estimation by Lau (1974), Christensen and Greene (1976), Kaserman and Mayo (1991), Kwoka (2002), among others, to check whether there exist economies of vertical integration or economies of scope. This method typically uses trans-log cost functions, multistage quadratic cost function (MQCF) or the Flexible Fixed Costs Quadratic (FFCQ) cost functions. Quadratic cost functions are the most frequently used in recent papers. When empirically measuring the vertical integration economies, multistage quadratic cost functions are more frequently used than other cost functions because the quadratic cost function can handle zero output situations. The data used in this empirical work typically including total cost, labor cost, capital cost, and fuel cost, operating cost, and output data.

The basic idea to investigate the vertical integration economies is using the concept and measure of economies of scope. If the cost of producing two products jointly is less than the sum of the costs of producing these two products separately, we can conclude that there exist vertical integration economies. In other words, if equation (2.2) holds, there exists vertical integration economies. In equation (1), $C(T, D; w)$ is the cost of providing transmission and distribution services jointly, $C(T, 0; w)$ and $C(0, D; w)$ is the cost of providing transmission and distribution services separately.

$$C(T, D; w) < C(T, 0; w) + C(0, D; w) \qquad (2.2)$$

To estimate the vertical integration economies, I must first choose the specific cost functional form. This article uses a quadratic cost function similar to Christensen and Greene (1976), Kaserman and Mayo (1991), Kwoka (2002), among others, for several reasons. First of all, compared to a trans-log cost function, a quadratic cost function is well suited to measuring economies of scope and economies of vertical integration, which involve zero outputs. Secondly, a quadratic function requires fewer behavioral assumptions than trans-log cost function. The basic assumption, according to Shephard's lemma, for the trans-log cost function is that the company tries to minimize cost, which typically does not hold for regulated utility companies. The third reason is that the BBW (2002) method can only get the generation marginal cost, not the whole supply cost including transmission and distribution. The specific form of the joint quadratic cost function of providing transmission and distribution services is described in equation (2.3).

$$\begin{aligned}
\mathrm{TC} = \alpha_0 &+ (\alpha_1 Q_T + \alpha_2 Q_D + \alpha_{11} Q_T^2 + \alpha_{22} Q_D^2 + \alpha_{12} Q_T Q_D) \\
&+ (\beta_1 P_L + \beta_2 P_C + \beta_3 P_E) \\
&+ (\beta_{11} Q_T P_L + \beta_{12} Q_T P_C + \beta_{13} Q_T P_E + \beta_{21} Q_D P_L + \beta_{22} Q_D P_C + \beta_{23} Q_D P_E) \\
&+ (\delta_1 Q_T Q_D P_L + \delta_2 Q_T Q_D P_C + \delta_3 Q_T Q_D P_E) \\
&+ \tau_1 \mathrm{HQ} + \tau_2 \mathrm{DENSE} + \tau_3 \mathrm{RUSE} + \tau_4 \mathrm{IUSE} \\
&+ \sum_{i=2004}^{2009} \gamma_i \, \mathrm{YEAR}_i + \sum_{j=1}^{24} \theta_j \, \mathrm{R}_j
\end{aligned} \tag{2.3}$$

where TC is the total cost of providing transmission and distribution service. Q_T is the transmission output. Q_D is the distribution output. P_L, P_E, and P_C are the labor price, cost of purchased power, and the capital price, respectively. HQ, DENSE, RUSE, and IUSE are the percent of electricity sold at high voltage (220kV and 110kV) level, consumption intensity, the ratio of residential electricity consumption, the ratio of industrial electricity consumption, respectively. HQ, DENSE, RUSE, and IUSE are the hedonic variables to control for the fixed effect. $YEAR_i$ is used to capture the time trend, and R_j is the company specific dummy variables.

2.3.2 Data Description

The data used in this research covers utility companies' administrative data from 24 provinces including detailed cost information from 2004 to 2009, around 141 observations[37]. All the data are directly from the utility companies' management information system and/or internal annual financial reports and operation reports. Compared to previous literature, the number of observations is reasonably large. For example, Kaserman and Mayo (1991) and Kwoka (2002) use around 90-120 observations in their articles to investigate vertical integration economies between generation and grid network.

The total cost of providing transmission and distribution service includes routine maintenance cost, depreciation cost, materials cost, human resource cost, purchased power cost, and financial cost, among others. Because the utilities companies in China also provide other type of services in addition to the transmission and distribution services, the total cost used here only include the total cost related to the transmission and distribution.

Transmission and distribution output are defined as electricity quantity transmitted and distributed. The typical definition of the transmission and distribution

[37] One company's data are missing for year 2004, 2005, and 2006.

output includes the electricity to be transmitted and distributed, and/or the length of transmission and distribution lines, among others. Because the main function and services of the transmission and distribution network is to deliver electricity to consumers, the electricity to be transmitted and distributed should be the best one to describe the transmission and distribution outputs.

The labor price is defined as the average annual salary paid to employers in each utility company. The price of purchased power is defined as the average price of purchased electricity[38]. The capital price is calculated based on the debt asset ratio[39].

Summary statistics of the data are displayed in table 2.1. There is much heterogeneity among utilities. For example, the total electricity consumption varies from 15 billion kWh to 267 billion kWh per year, the highest province's consumption is around 17 times the lowest. The consumption structure also has huge differences, the percent of power sold to big industrial customers (%) varies from 20% to 80%. More importantly, the hedonic variables vary widely too. For example, the consumption intensity varies from 9 kkWh/km^2 to 14,640 kkWh/km^2, the highest is 915 times the lowest. These wide variations are helpful for the identification of cost function. At the same time, we would also expect that the vertical integration economies themselves to be heterogenous among utility companies.

[38] The utility companies in China purchase power from independent generation companies. The price for each generation company or even each generation plant (unit) is decided by the government.

[39] When calculate the capital cost, I first need to decide the return of the equity. Here, I choose 10% as the return of the equity.

Table 2.1 Summary Statistics of Data

Variables	Obs	Mean	Std. Dev.	Min	Max
Total Cost (billion dollar) [40]	141	4.57	3.52	0.61	19.57
Quantity of purchased electricity (MkWh)	141	81,800	55,700	16,400	285,000
Quantity of electricity sold to end consumers (MkWh)	141	76,800	53,100	15,000	267,000
Quantity of electricity sold at 220kV (MkWh)	141	3,066	3,150	0	15,200
Percent of electricity sold at 220kV (%)	141	4.28	4.42	0	21.29
Quantity of electricity sold at 110kV (MkWh)	141	9690	8387	0	48800
Percent of electricity sold at 110kV (%)	141	13.93	9.21	0	49.38
Quantity of electricity sold at 35kV (MkWh)	141	10,200	7713	867	52,100
Percent of electricity sold at 35kV (%)	141	15.46	9.88	0.84	48.64
Price of capital (%)	141	4.80	0.90	3.28	8.19
Price of purchased power (￥/kkWh)	141	280.66	59.38	143.77	414.2
Price of labor ($)	141	7,347	2,921	2,507	20,338
Consumption Intensity (kkWh/km^2)	141	1,273	2,628	9	14,640
Percent of power sold to big industrial customers (%)	141	48.93	14.47	20.81	86.58
Percent of power sold to residential customers (%)	141	10.40	5.33	2.83	22.83

[40] All data are converted from nominal value to real value using GDP deflator.

2.4 Empirical results

2.4.1 Cost Function

Before estimating the cost function, another question needs to be answered, namely how to define transmission and distribution. Although the network at 110kV is typically defined as the transmission in US, Europe, and most countries[41], how to define transmission and distribution is controversial in China. A few engineers and economists have suggested defining transmission and distribution by the function of the network, which would cause different definition of transmission and distribution among different provinces. For example, the 500kV network would be definitely treated as transmission in most countries and most provinces in China. However, the main function of the 220kV network in big cities such as Beijing and Shanghai are to distribute electricity to end consumers. If we define transmission by function, the 220kV network should be defined as transmission in most provinces and as distribution in big cities, which would cause unexpected confusion. In this paper, I define transmission and distribution by voltage level, following the classification by most engineers, economists, and policy makers. I also check the robustness of my results using three alternative scenarios.

The first scenario defines the 220kV and above network as transmission, and 110kV and below as distribution. Similarly, the second scenario defines the 110kV and above network as transmission, and 350kV and below as distribution, and the

[41] Defining 110kV and above network as transmission is well accepted worldwide. For example, it is used at Wikipedia. https://en.wikipedia.org/wiki/Electric_power_transmission.

third scenario defines the 350kV and above network as transmission, and 10kV and below as distribution.

The main results of the cost function estimation are reported in the table 2.2. I also report the cost function estimation results with and without input price variables. To do a robustness check, I estimate the cost function without including consumption intensity, the ratio of big industrial consumption, and the ratio of residential consumption. The results without these variables are very similar to the main results. I also interact these variables (consumption intensity, ratio of residential consumption, and ratio of industrial consumption) with Q_T*Q_D. The results are likewise very similar to the main results[42].

Almost all coefficients are consistent with our expectation, especially the coefficient of Q_T*Q_D. The coefficient of Q_T*Q_D is negative and significant in most cases, which means that there do exist significant vertical integration economies between transmission and distribution. The coefficients of transmission and distribution outputs (Q_T and Q_D) are positive and significant, which means the more electricity to be transmitted and distributed, the higher the total cost. At the same time, the coefficients of $(Q_T)^2$ and $(Q_D)^2$ are negative and significant, at least in a few scenarios, which means that there exists economies of scale in providing transmission and distribution services. The coefficients of input price (P_L,P_E, and P_K) are not significant.

[42] These two results are not reported here.

Table 2.2 Cost Function Estimation

	First Scenario		Second Scenario		Third Scenario	
	Without Input Price	With Input Price	Without Input Price	With Input Price	Without Input Price	With Input Price
Q_T	294.88 (2.13) **	277.20 (1.75) *	188.17 (2.75) ***	230.65 (2.56) **	143.67 (2.08) **	207.72 (2.30) **
Q_D	528.63 (2.18) **	580.44 (1.94) *	430.38 (2.73)***	314.73 (1.50)	344.30 (1.59)	237.32 (0.92)
$(Q_T)^2$	1.26e-07 (0.23)	1.76e-07 (0.30)	-1.92e-07 (-0.86)	-1.08e-07 (-0.39)	-4.78e-07 (-2.22) **	-3.96e-07 (-1.39)
$(Q_D)^2$	1.01e-06 (1.90) *	1.01e-06 (1.82) *	6.90e-07 (2.68) ***	6.98e-07 (2.44) **	3.73e-07 (1.26)	3.29e-07 (0.99)
Q_T*Q_D	**-2.43e-06 (-1.91) ***	**-2.10e-06 (-1.09)**	**-2.65e-06 (-2.66)*** **	**-3.46e-06 (-2.57) ****	**-2.67e-06 (-2.11) ****	**-3.56e-06 (-2.25) ****
P_L		-26022.14 (-0.33)		-53746.77 (-1.01)		-84560 (-1.79)*
P_E		1.82e+07 (0.51)		3.27e+07 (1.10)		4.68e+07 (1.67) *
P_C		-6.04e+10 (-0.80)		-1.55e+10 (-0.24)		-4.21e+10 (-0.64)
Q_T*P_L	.00041 (0.4)	.00065 (0.71)	.00030 (0.58)	.000762 (1.08)	-.00019 (-0.41)	.00076 (1.06)
Q_T*P_E	.52 (1.22)	.39 (0.78)	.89 (3.45) ***	.59 (1.61)	1.34 (5.64) ***	.81 (2.17) **
Q_T*P_C	617.13 (0.48)	1013.78 (0.70)	859.98 (1.26)	963.61 (1.13)	330.74 (0.48)	655.82 (0.72)
Q_D*P_L	-.00019 (-0.12)	-.000098 (-0.04)	-.00052 (-0.66)	.00024 (0.22)	.000026 (0.03)	.00096 (0.98)
Q_D*P_E	1.96 (2.97) ***	1.90 (2.19) **	1.74 (3.43) ***	1.31 (2.07) **	1.15 (1.72) *	.70 (0.98)
Q_D*P_C	-1146.27 (-0.56)	125.29 (0.05)	-1455.42 (-1.12)	-1458.58 (-0.74)	-492.58 (-0.28)	-128.56 (-0.05)
Q_T*Q_D*P_L	3.63e-12 (0.84)	2.66e-12 (0.32)	3.96e-12 (1.44)	-9.35e-13 (-0.18)	5.85e-12 (1.70) *	-2.50e-12 (-0.44)
Q_T*Q_D*P_E	-2.04e-09 (-1.08)	-1.71e-09 (-0.43)	-3.55e-10 (-0.19)	2.65e-09 (0.81)	1.75e-10 (0.07)	4.62e-09 (1.28)
Q_T*Q_D*P_C	.000017 (2.90) **	.000011 (1.01)	.000020 (3.31) ***	.000020 (2.11) **	.000023 (2.86) ***	.000021 (1.72) *
DENSE	-1927666 (-1.51)	-2036145 (-1.55)	-2432119 (-4.34)***	-2507147 (-4.10)***	-2239632 (-3.80) ***	-2419500 (-3.85)***
RUSE	7.96e+09 (1.91) *	7.83e+09 (1.74) *	8.74e+09 (2.50) **	7.25e+09 (1.92) *	9.55e+09 (2.79) ***	7.81e+09 (2.18) **
IUSE	-4.93e+09 (-0.61)	-9.04e+09 (-0.95)	-7.97e+09 (-1.19)	-1.06e+10 (-1.39)	-4.61e+09 (-0.57)	-1.10e+10 (-1.22)
CONS	-5.09e+09 (-1.33)	-4.24e+09 (-0.52)	-4.18e+09 (-1.51)	-8.76e+09 (-1.43)	-7.32e+09 (-2.57) **	-1.19e+10 (-2.11) **

t values are reported in the bracket.

**** significant at 1% level ** significant at 5% level * significant at 10% level*

Consumption intensity has significant impact on total cost. The coefficient of consumption intensity is negative and significant in most cases, which means that the utility companies with lower consumption intensity have higher total cost. The coefficients of percent of electricity sold to residential consumers are positive and significant in most cases, which means that providing service to residential consumers raises costs.

2.4.2 Vertical Integration Economies

In previous articles such as Kaserman and Mayo (1991), Kwoka（2002), and Jara-Díaza et al. (2004), the vertical integration economies (VIE) are calculated similar to economies of scope using equation (2.4).

$$\mathrm{VIE} = \mathrm{C(T, 0; w)} + \mathrm{C(0, D; w)} - \mathrm{C(T, D; w)} \qquad (2.4)$$

where $\mathrm{C(T, D; w)}$ is the total cost of providing transmission and distribution services by the integrated utility companies. After separating transmission and distribution, the dis-integrated transmission companies and distribution companies only provide transmission or distribution services. Therefore, $\mathrm{C(T, 0; w)}$ and $\mathrm{C(0, D; w)}$ are the cost of the dis-integrated transmission companies and distribution companies respectively. If the sum of $\mathrm{C(T, 0; w)}$ and $\mathrm{C(0, D; w)}$ are greater than the $\mathrm{C(T, D; w)}$, there exists vertical integrated economies.

However, it should be pointed out that equation (4) implicitly assumes that all fixed cost is common cost. In other words, if there had been separation, the fixed cost would have been incurred by both the new transmission company *and* the new distribution company after the separation. More specifically, let FC denote the fixed cost in equation (2.3).

$$\mathrm{FC} = \alpha_0 + (\beta_1 P_L + \beta_2 P_C + \beta_3 P_E) + +\tau_1 \mathrm{HQ} + \tau_2 \mathrm{DENSE} + \tau_3 \mathrm{RUSE} + \tau_4 \mathrm{IUSE} \quad (2.5)$$

If VIE is calculated based on equation (2.4), then

$$\mathrm{VIE} = \mathrm{FC} - (\alpha_{12} + \delta_1 P_L + \delta_2 P_C + \delta_3 P_E) Q_T Q_D \quad (2.6)$$

because FC appears in both $\mathrm{C}(\mathrm{T}, 0; \mathrm{w})$ and $\mathrm{C}(0, \mathrm{D}; \mathrm{w})$.

The assumption that all fixed cost is common cost typically does not hold in reality. To avoid imposing this assumption, I introduce s, which denotes the replacement share of the fixed cost after the counterfactual separation, where $0 \leq \mathrm{s} \leq 1$. More importantly, after introducing s, I can calculate the upper and lower bound of the vertical integration economies. More specifically, the vertical integration economies can be calculated using equation (2.7):

$$\mathrm{VIE} = \mathrm{s} * \mathrm{FC} - (\alpha_{12} + \delta_1 P_L + \delta_2 P_C + \delta_3 P_E) Q_T Q_D \quad (2.7)$$

If $\mathrm{s} = 0$, the separation does not increase any fixed cost and equation (2.7) gives the lower bound of the vertical integration economies. When $\mathrm{s} = 1$, the separation doubles the fixed cost and equation (2.7) gives the upper bound of the vertical integration economies.

The estimated vertical integration economies are reported in table 2.3.

First of all, the results show that there do exist significant vertical integration economies between transmission and distribution. For example, the vertical integration economies for the first scenario, on average, amount to around 1.25 to

1.46 billion dollars[43] for each province utility company each year, which account for 15 to 20 percent of the total cost. In other words, the total vertical integration economies for all of the 24 utility companies should be around 30 billion dollars per year.

Table 2.3 Results of Vertical Integration Economies

		First Scenario (220kV+ as T)		**Second Scenario (110kV+ as T)**		**Third Scenario (35kV+ as T)**	
		S = 0	**S = 1**	**S=0**	**S=1**	**S=0**	**S=1**
VIE Value (billion dollars)	**Average**	**1.25**	**1.46**	**0.77**	**0.93**	**0.22**	**0.46**
	2004	0.65	0.81	0.48	0.58	0.05	0.24
	2005	0.61	0.79	0.39	0.52	-0.02	0.19
	2006	0.99	1.19	0.60	0.76	0.09	0.33
	2007	1.41	1.61	0.91	1.06	0.34	0.58
	2008	1.54	1.79	0.89	1.07	0.27	0.55
	2009	2.11	2.36	1.25	1.44	0.53	0.82
VIE/Total Cost (%)	**Average**	**15.09**	**20.24**	**10.40**	**13.59**	**4.81**	**10.19**
	2004	14.23	19.03	13.53	15.28	1.57	8.33
	2005	9.75	15.74	7.89	11.45	-0.56	5.91
	2006	12.70	18.65	8.39	12.37	2.12	7.91
	2007	17.42	22.29	11.65	14.84	6.93	11.90
	2008	16.76	21.43	10.18	13.29	4.94	9.90
	2009	19.22	23.73	11.52	14.68	8.25	12.80

Secondly, the vertical integration economies have grown over time. For example, the average vertical integration economies increase from 0.65 billion dollars

[43] Assume the exchange rate between dollar and Yuan is 7:1, or one dollar equals to 7 Yuan.

at 2004 to 2.11 billion dollars at 2009, on average, for each utility company. The results for the second and third scenarios have similar trends.

Thirdly, the replacement share of the fixed cost does affect the results of vertical integration economies. For example, under the first scenario, the upper bound of vertical integration economies is around 1.17 time the lower bound. The same trend holds for the second and third scenarios.

Last and most important, there exists significant heterogeneity in the vertical integration economies under different scenarios and among utility companies. For example, the vertical integration economies under the first scenario are greater than in the second scenario, which in turn are greater than in the third scenario. The vertical integration economies for each utility company, on average, are 1.25 billion dollars, 0.77 billion dollars, and 0.22 billion dollars for first, second, and third scenario respectively. In other words, there exist more common cost between 220kV and 110kV than that between 110kV and 35kV, and the connections and coordination requirements between 220kV and 110kV is stronger than that between 110kV and 35kV.

At the same time, the vertical integration economies have significant heterogenous among different provinces. For example, the provinces with higher consumption intensity have larger vertical integration economies[44], which means that the connections and coordination requirements between transmission and distribution in these provinces are higher. More importantly, as shown in figure 2.2 a-c, under the

[44] The results of each province utility companies' vertical integration economies are not reported here.

first scenario, almost all province utility companies' vertical integration economies are positive. However, under the second scenario, few province utility companies' vertical integration economies change from positive to negative, compared to the first scenario. Under the third scenario, half of the province utility companies' vertical integration economies are negative, which means they would save money by splitting transmission and distribution.

All of these results have important policy implications. For example, if we define the 220kV and above network as transmission and 110kV and below as distribution, the vertical integration economies should be an important issue for utility companies in all provinces, and the separation of transmission and distribution should increase a large part of total cost, which will be transferred to end consumers. For another example, if the government decide to separate transmission and distribution, for any political or economic reasons, the government should at least define 110kV as transmission, considering the scale of vertical integration economies, to avoid increasing huge cost.

Table 2.4 summarizes the results from previous empirical studies on vertical integration economies in other countries. I remind the readers that previous researches focuses on the vertical integration economies between generation and grid (transmission & distribution) while this paper focuses on that between transmission and distribution. From the engineering point of view, the cooperation and coordination requirements between transmission and distribution are definitely higher than that between generation and grid. In other words, the vertical integration economies between transmission and distribution should be larger than that between generation and grid. Compared to previous research, our results are reasonable.

Figure 2.2 Vertical Integration Economies Under Three Scenarios

Figure 2.2a: VIE under first Scenario

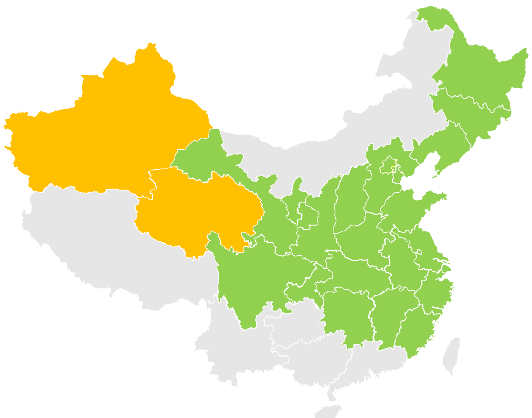
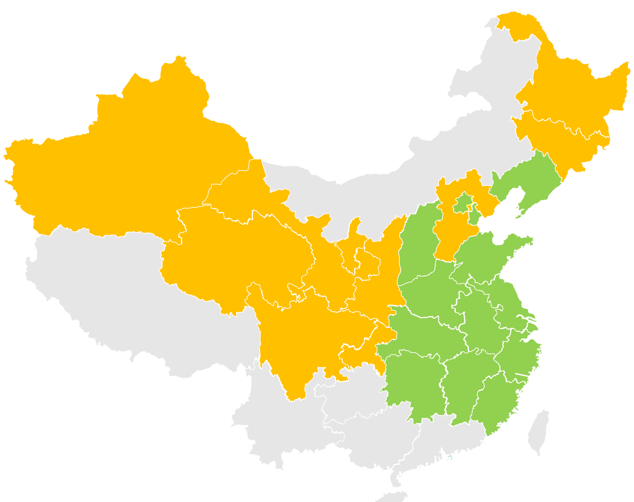


Figure 2.2b: VIE under first Scenario

Figure 2.2c: VIE under third Scenario



Green means positive VIE, Yellow means negative VIE or diseconomies; Gray mean data not available.

Table 2.4 Results of Vertical Integration Economies (VIE) in Previous Studies

Results	Type of vertical economies	Exist or not	Proportion of vertical integration economies
Kaserman & Mayo（1991）	Generation and grid	Yes	3%-90%
Kwoka（1996）	Generation and grid	Yes	6%-64%
Hayashi, Goo & Chamberlin (1997)	Generation and grid	Yes	7%-32%
Kwoka（2002)	Generation and grid	Yes	3%-73%
Fraquelli, Piacenza & Vannoni（2005）	Generation and grid	Yes	3%-44%

2.5 Conclusions

Bases on the administrative cost data from 24 province level utility companies, by estimating a long-term quadratic cost function, this paper estimates vertical integration economies between transmission and distribution in China’s power industry. The results show that there does exist significant vertical integration economies and the vertical integration economies have grown over time, under all three scenarios. More importantly, I also find evidence of remarkable heterogeneity in the vertical integration economies. Utility companies with high consumption intensity have larger vertical integration economies. Also, vertical integration economies are larger under first scenario than second and third scenarios. At the same time, all companies under first scenario have positive vertical integration economies. However, under second scenario, few companies’ vertical integration economies are very small or change from positive to negative. Under third scenario, around half companies’ vertical integration economies change from positive to negative.

All these results support the conclusion that currently, the separation of transmission and distribution would cause significant cost increases, which would be transferred to end consumers. Based on the results of the vertical integration economies studied in this dissertation, the separation of transmission and distribution should not be implemented. At the same time, if the government really wants to implement the transmission-distribution separation, we should at least define 110kV and above as transmission. However, it needs to be emphasized that even such a separation will also increase the total cost significantly.

3 Stock Price Reaction to Market-oriented Reform and Price Regulations: Evidences from China Power Industry

3.1 Introduction

An event study method is an empirical analysis that attempts to measure the effect of an (unexpected) event, such as government regulation and policies, merger or earning announcement, on firms' stock prices[45]. The event study method assumes that the market processes information about the event in an efficient and unbiased manner. In other words, the impact of an event would be instantly and effectively reflected in stock prices. The second assumption of the event study method is that the event is unexpected or unforeseen and has not yet been factored into the stock price. Under this assumption, the abnormal returns, if they exist, indicate the market reaction to the unanticipated event. The third assumption is that there are no other confounding events which might be responsible for the stock price change. In other words, the effect of other events is isolated.

The event study method has been widely used in many fields such as accounting and finance, political economics, marketing, law and economics. For example, event studies have been used in financial economics to test market efficiency (Brown and Warner, 1980, and Fama, 1991). In the accounting literature, the event study has been used to test the effect of earning announcements or merger on stock price, return

[45] Stock prices (or abnormal returns) are used by most of previous literature on event study, only several articles examine stock trading volume, among others.

variances, and trading volume (Beaver, 1968, Patell, 1976, and Kothari, Leone, and Wasley, 2005).

The event study method has also been used to examine the effect of regulation. As suggested by Schwert (1981), it is more powerful and accurate to use stock price data over accounting data to measure the effects of proposed regulation policies on an industry. Therefore, most of the previous articles using stock prices to research the effect of government regulations. For example, Binder (1985), Gilligan, Marshall and Weingast (1988) investigate the effect of the Interstate Commerce Act (ICA) on railroad stock returns. Bradley and Jarrell (1986) use a similar event study method but with oil regulation on related companies' stock prices.

While the electricity sector has been deregulated in the US and other countries, China's electricity industry is still highly regulated and in the progress of adopting deregulation and market-oriented reform. Therefore, it provides us with a chance to research the stock price reaction to government regulation. In this paper, I investigate whether the release of these reforms, such as future market-oriented reform plans and prices adjustments have significant effect on publicly listed generation companies' stock price.

I focus on three research questions. The first research question is how the stock prices of electricity generation companies respond to announce on-grid tariff adjustments. Because most of the generation companies are publicly listed companies and no grid companies are publicly listed, I focus on the adjustments of the on-grid electricity tariffs[46] adjustments, and especially the on-grid tariffs adjustment for coal-

[46] On-grid tariff in China means the price at which the generation plants sell electricity to grid companies.

fired generation plants. The on-grid tariff adjustments should have direct impact on the affected generation companies' future revenue and profit. Moreover, the impacts on revenue and profit can be calculated easily. We should expect that the stock prices of electricity generation companies respond to this type of polices immediately or in short-term.

The second research question is whether the stock prices of major industrial electricity users responded to retail tariff adjustments. The major industrial electricity users such as the companies in the aluminum, steel, and papermaking industries are very electricity-intensive. Therefore, the electricity cost account for a large percent of their total cost. For example, for the electrolytic aluminum companies, the electricity costs can account for around 45 percent of the total cost. For the steel and paper making companies, the electricity cost typically accounts for around 6 percent and 8 percent of their total cost respectively. Therefore, we should expect the stock prices of these major electricity users respond to retail tariff adjustments.

The third research question is whether the stock prices of utility companies responded to future or long-term reform plans. Because those plans only have medium- and long- term effects and their impacts on revenue and profit are hard to estimate, the impact of these plans on stock prices is ambiguous.

By investigating the stock prices' reaction of generation companies and major industrial electricity users, we can test the investor's reaction to these tariff adjustments and reform plans and to further test whether the market is efficient or whether investors are rational. Combined with the results from chapter 1, the results of this chapter should help us to understand whether related stakeholders understand and respond to market-oriented reforms in China.

The reminder of the paper is organized as follows. Section II discusses the brief history and background of China power industry, especially the industry market-oriented reform backgrounds. Section III describes the data and the selection of companies and events. Section IV outlines the methodology and Section V reports main results. Section VII is the conclusion.

3.2 Brief Background on China's Power Industry

Before 2002, the power industry in China was highly vertically integrated. Almost all of the transmission and distribution network and around 80% generation capacity were owned and operated by the State Power (SP). In 2002, China implemented the most important market-oriented reform in its electricity industry history. The most important aspects of this reform included separating the vertically integrated and stated-owned companies to independent generation and grid (including transmission and distribution) companies. After the reform, the generation plants owned by State Power were separated to five state-owned generation companies. The transmission and distribution sectors were separated to two companies: State Grid Cooperation (SGCC) and China Southern Grid (CSG). SGCC owns and operates around 85% of the transmission and distribution in China, and CSG owns and operates the other 15%. In the retail sector, only the SGCC and CSG are allowed to sale electricity to end customers.

China does not yet have an electricity wholesale market yet, for now. All prices including on-grid tariff and retail tariff are set by the central or provincial government. The generation companies sell electricity to the Grid companies, at given price, called on-grid tariffs, which are set by the central government. More importantly, in China, the generation price is not set according to rate-of-return regulation like in the US and other countries and is set before the generation plant's completion of construction. Before 2004, each generation plant or generation unit's price was set differently, based on the generation plant's or generation unit's forecasted fixed and variable costs. After 2004, the on-grid tariff of all new generation plants built after 2004 was set identical for all plants, called as "Benchmark Generation Tariffs". According to the government's policies, the on-grid tariffs or the benchmark generation tariffs should be adjusted when the fuel costs change significantly, but in practice the price is rarely adjusted because of other policy or political concerns.

Grid companies purchase electricity from generation companies, transmit and distribute the electricity, and sell it to the end users. The electricity retail prices, the tariffs, are set by the local provincial governments. Typically, the residential price will only change at most once every two or three years, while the commercial and industrial price will change when the generation price changes significantly. More importantly, there exist very significant cross-subsidies in China's retail tariffs. While the residential price is higher than industrial price in most developed countries, China's residential price is, in contrast, much lower than the industrial price.

After the 2002's reform, China had announced other market-oriented reforms such as five-year electricity industry reform plans to build a wholesale electricity market, enhance efficiency, and embrace retail competition. However, most of these reform plans had not been implemented effectively.

3.3 Event Selection and Data

In an event study, the first and most important step is the selection of the events. As described in the previous section, because the power industry in China is still highly regulated by the government, the most important events should be the announcement of future reform plans and tariff adjustments. Starting in 2002, the central government, in charge of the reform progress, released three reform plans - in 2002, 2007, and 2015 respectively. However, it should be pointed out that many reform measures contained in the 2002 reform plan have not yet been realized, not even after some 16 years. The serious delay shows the complexity and difficulty of the market-oriented reform of China's power industry.

Since 2002, the government released one tariff adjustment mechanism in 2004 and adjusted the coal-fired on-grid tariff twice in 2006 and 2011, each time increased by 0.02 Yuan per kWh ($0.003 per kWh). Since 2004, the government have increased the retail tariffs twice significantly[47], on 2009 and 2011 respectively, each time increased around 0.003 Yuan per kWh ($0.004 per kWh). Obviously, two on-grid tariff adjustments and very few retail tariff adjustments in around 16 years are not

[47] It needs to be pointed out that these retail tariff adjustments did not apply to the residential consumers.

enough to reflect the huge change in the price of coal, which has at least tripled during the same period. The main reasons behind the very few tariff adjustments are policy and political concerns. In order to control inflation and avoid any potential social instability, the government was very careful about electricity tariff adjustments, especially price increases, and almost never increased the price enough to reflect the changing cost of the fuel.

The main reform plans, on-grid tariff adjustments, and retail tariff adjustments are summarized in table 3.1. Event 1 to event 3 are release of future reform plans. Even 4 to Event 6 are on-grid tariff adjustments. Event 7 and event 8 are retail tariff adjustments.

For the release of future and reform plans and on-grid tariff adjustments, I use the data from 10 publicly listed generation companies, including 8 coal-fired companies and 2 hydro power companies. I do so for three reasons. The first reason is that there are no publicly listed grid companies in China, so only generation companies' data can be used. The second reason is that there are no privately owned publicly listed generation companies. Therefore, I can only choose the generation companies owned by the central government or provincial governments. Third and last, some of the generation companies were listed for less than 3 years at the date of the events. I do not include such companies in the analysis.

For the retail tariff adjustments, I use the data from 10 publicly listed electrolytic aluminum companies. As pointed in previous sections, electricity cost account for around 45 percent of electrolytic aluminum companies' total cost. Therefore, we can expect the retail tariff adjustments to have significant effect on related companies costs and profits.

All companies' return data and the market return data are from Google Finance. To test the short- and mid-term stock price reaction, I define windows of 5 business days before and after the event as short-term, and 10 business days before and after the event as mid-term. The basic information about the data is summarized in table 3.2 and table 3.3[48].

Table 3.1 Main Reform Plans and Tariff Adjustments

Type	Event Number	Announcement Description	Announcement date
Reform Plans	Event No. 1	Reform of the Power Industry	11th April 2002
	Event No. 2	Reform Plans of the Power Industry during the 11th five-year plan	6th April 2007
	Event No. 3	Further Reform Plans of the Power Industry	15th March 2015
On-Grid Tariff Adjustments	Event No. 4	Release the tariff adjustment Mechanism	15th December 2004
	Event No. 5	Increase coal-fired generation plant's on-grid tariffs	30th June 2006
	Event No. 6	Increase coal-fired generation plant's on-grid tariffs	30th November 2011
Retail Tariff Adjustments	Event No. 7	Increase retail tariffs	20th November 2009
	Event No. 8	Increase retail tariffs	30th November 2011

[48] Because only the coal-fired generation companies' on-grid tariffs were adjusted in event 5 and event 6, two hydro generation companies' stock prices are not included in event 5 and event 6. At the same time, three companies were not listed during event 1. Therefore, the total numbers of observations are 1202 and 610 for the mid- and short-term stock price reaction analysis, respectively.

Because only the coal-fired generation companies' on-grid tariffs were adjusted in event 5 and event 6, two hydro generation companies' stock prices are not included in event 5 and event 6. At the same time, three companies were not listed during event 1. Therefore, the total numbered observations are 1002 and 510 for the mid- and short-term stock price reaction analysis respectively.

Table 3.2 Summary of the Data: 10 business days before and after the events

Variable	Number of Observations	Mean	SD	Min	Max
Companies' Return	1202	0.38	2.65	-8.87	10.18
Market Return	1202	0.24	1.52	-6.33	6.81

Table 3.3 Summary of the Data: 5 business days before and after the events

Variable	Number of Observations	Mean	SD	Min	Max
Companies' Return	510	0.49	2.45	-8.13	10.01
Market Return	510	0.48	1.28	-3.27	6.80

3.4 Empirical Methodology

The event study method has been used to examine the effect of regulation on related companies' stock prices. Binder (1985) investigates the effect of regulations and deregulations in railroad industries on stock prices using event studies in a multivariate regression model and finds significant price changes based on daily and monthly returns data. However, Gilligan, Marshall and Weingast (1988) find that the passage of the Interstate Commerce Act (ICA) had mixed effects on railroad stock returns. Smith, Bradley and Jarrell (1986) use a similar method but with oil regulation and finds that oil regulation does have positive effect on related companies' stock price. Other papers also investigate the effect of regulation and deregulation in other sectors on the stock market.

The event study method has also been used to research stock prices reaction to environmental regulation and policies, carbon emission regulation, carbon market policies, and environmental disasters and pollution alerts. For example, Garber and Hammitt (1998) investigate the stock returns to Superfund liability using monthly data of 73 chemical companies from 1988 to 1992. They find that additional exposure does increase large firms' cost of capital but not for the smaller firms. Khanna et al. (1998) examines the stock market reactions to the public disclosure of toxic waste using daily stock prices data from 91 American firms. They find that there exists significant negative stock market returns during the events of the disclosure of toxics release inventory in the years 1990-1994. For another example, Bushnell et al. (2013) research the stock return to tradable carbon permit regulations in Europe using daily data from companies in carbon intensive industries and find that firms tended to be carbon or electricity intensive and that the tradable permit regulations benefit several industries such as electricity, alternative energy and oil equipment and mining.

There also have a few researches based on the event study method using data from China. For example, Xu et al. (2012) examine the stock prices reaction to disclosure of environmental violation events in China based on daily stock market return under different event windows. They find that the market values do react negatively to the events. Kong et al. (2012) study the market values reaction to environmental protection efforts in China and find that the environmental policy increases the market values of firms in the environmental industry.

Although the event study method was introduced since 1970s and has been widely used in different fields, the main method and the basic statistical format of event studies have not changed significant over time (Kothari S. P. and Warner J. B. 2006). To conduct an event study, the first step is to identify the events and specify the date of the events. Typically, the announcement date of the event is defined as event date. After identifying the events, the second step is to decide the timeline or the time window around the event date – usually days. Among the three assumptions underlying the event study, one key concern is how to handle the possible event/information leaking problem (Dube, Kaplan, Naidu. 2011). This is generally done using a long horizon time window period, such as a 5-day or 10-day window period instead of a 2-day or 3-day window period.

I use an event study in a multivariate regression model framework. The basic regression equation is:

$$R_{it} = a_0 + b_0 R_{mt} + b_1 D_c + \sum_{j=1}^{6} d_j\, D_{jt} + e_{it} \qquad (3.1)$$

where R_{it} is the return on firm i at time t, R_{mt} is the return on the market index, D_{jt} is a dummy variable equal to 1 if event j occurred at time t, and 0 otherwise, e_{it} is a random disturbance. D_c is dummy variable indicating whether the company is owned by the central government or provincial governments. D_c equals 1 when the generation company is owned by central government. D_c equals 0 when the generation company is owned by provincial governments. Typically, the companies owned by central government have larger installed capacities, higher generating efficiency measured as heat rate, and lower operation cost than those owned by provincial governments.

Another challenge of this research is how to deal with the possible leakage of the regulation policies[49]. One way is to use a longer time window such as 20 days before and after the announcement of polices. According to Binder (1985), even monthly return can be used to conduct an event study. In this research, to deal with the possible leakage problem, I run the regression two times for each type of event, once for the mid-term and once for the short-term, as defined in section 3.

3.5 Empirical Results

As pointed out in previous sections, we can expect the retail tariff adjustments have significant effect only on electrolytic aluminum companies' cost and profit but not on generation companies' income and profits. By contrast, the electricity industries' future reform plans and on-grid tariff adjustments should not have direct and significant effect on electrolytic aluminum companies' costs and profits. Therefore, in addition to run separate regressions only use the data from generation companies or electrolytic aluminum companies, I also run a pooled regression using data from generation companies and electrolytic aluminum companies. The results from the separate regressions and pooled regression are very similar.

[49] For example, the price adjustment decision could be leaked to investor by insider. Before the price adjustment decision had been announced, that information is classified as different secret levels. However, it is still possible that this information could be got by investors before the announcement dates.

The main results are given in table 3.4 and table 3.5.

The results for the short-term are given in table 4. In the short-term, using 5 business days' data before and after the events, the coefficients for the market return are significant and positive for all companies, central government owned companies, and provincial governments owned companies. This is as expected and show that specific companies returns are high related with the whole market's return. At the same time, the coefficients for the local companies are larger than that for the central companies, which means the central government owned companies' stock price are more stable and provincial governments owned companies' stock price are more flexible.

The coefficients for the reform plans are interesting. It is surprising to see that the coefficients for almost all reform plans are not significant, except the coefficients for the second event, which are significant and positive. Actually, the second event, the reform plans during the 11th five-year, is less important compared to other three reform plans. These results are very interesting and not consistent to my initial expectations. First of all, taken together, these results show that the stock price did not respond significantly to the announcement of future reform plans, at least in the short-term. The reason behind this is easy to understand. As mentioned above, even the reform plan published in 2002 has not been fully implemented by now. If investors anticipated this, it is not surprising that the market did not react to the future reform plans.

Second, the coefficients for the second event, Reform Plans for the Power Industry during the 11th five-year, is significant and positive. The main reason may be that the second event happened during the unprecedented bull market in China at that time, in 2007. During that bull market environment, virtually any information was interpreted as good news and would pull the companies' price up significantly. Lastly, we can see that the second event did not impact the central government owned companies' stock price significantly but did impact the provincial governments owned companies' stock price significantly. This is also consistent with the character of the bull market in China. At that time, the small companies' stock prices increased more than the big companies' stock prices.

The coefficients for the on-grid tariff adjustments are also very interesting. In the short term, the coefficients for the two price increases are significant and negative. Because both of event 5 and event 6 were the increase of the generation price, the negative coefficient is amazing. Although the negative coefficients are not consistent with the expectations at first glance, they are explainable. As mentioned in the previous section, China generation plants' on-grid tariff are highly regulated by the central government. Although the government released the Tariff Adjustment Mechanism in 2004 (event 5) the government rarely adjust the generation on-grid tariff according to this mechanism. When the coal price increased significantly (more than tripled) during 2004 to 2006, most generation plants in China did not make any profits and even began to experience large losses. Indeed, the tariff adjustments in 2006 and 2011 (event 5 and event 6) were just the measures to make sure the generation plants would not go bankrupt and could keep running. In other words, these two tariff adjustments, only around 0.3 cent in dollar each time, were significantly lower than most investors' expectation, which could explain the negative coefficients.

The coefficients for the retail tariff adjustments are negative, as expected. In the short term, the coefficients for the two retail price increases are significant and negative, which proves that the retail tariff adjustments will affect the electrolytic aluminum companies costs and profits significantly. At the same time, it also proves that the retail tariff adjustments are unexpected.

The results for the mid-term are given in table 3.5. In the mid-term, using 10 business days' data before and after the events, the coefficients for the market return are significant for total companies, central government owned companies, and provincial governments owned companies, consistent to the expectations. These coefficients are not very different from the short-term results. The coefficient for the provincial governments owned companies are also larger than that for the central companies.

The coefficients for the future market-oriented reform plans in the mid-term are very similar to those for the short-term. It is still only the coefficients for the second event are significant and positive. However, compared to the short-term results, the difference between the central government owned companies and the provincial governments owned companies become smaller. The coefficients for the on-grid and retail tariff adjustments in the mid-term are also very similar to those for the short-term.

Table 3.4 Short-term results

		All Companies	Central government owned companies	Local government owned companies
	Market Return	.86 *** (11.07)	.81 *** (8.27)	.90 *** (7.71)
	Central Dummy	-.18 (-0.98)	--	--
Announcement of Reform Plans	Reform for the Power Industry--2002	-.05 (-0.13)	.30 (0.62)	-.28 (-0.51)
	Reform Plans for the Power Industry during the 11th five-year plan--2007	1.05 *** (3.19)	.33 (0.84)	1.77 *** (3.42)
	Further Reform Plans for the Power Industry--2015	.02 (0.07)	.08 (0.21)	-.04 (-0.08)
	Release the Tariff adjustment Mechanism--2004	-.35 (1.02)	-.64 (-1.49)	-.10 (-0.20)
On-Grid Tariff Adjustments	Increase coal-fired generation plant's on-grid tariffs --2006	-1.33 *** (-3.71)	-2.12 *** (-4.94)	-.55 (-1.00)
	Increase coal-fired generation plant's on-grid tariffs --2011	-.87 *** (-2.31)	-1.11 *** (-2.29)	-.67 (-1.20)
Retail Tariff Adjustments	Increase retail tariffs --2009	-2.54 *** (-3.47)	-2.37 *** (-2.64)	-2.59 *** (-3.03)
	Increase retail tariffs --2011	-2.57 *** (-3.25)	-2.43 *** (-2.93)	-2.64*** (-3.73)
	Constant	.26 (1.64)	.25 (1.56)	.10 (0.52)
	R-Square	0.2893	0.35	0.27

t values are reported in the bracket.
**** significant at 1% level*
*** significant at 5% level*
** significant at 10% level*

Table 3.5 Mid-term results

		Total Companies	Central government owned companies	Local government owned companies
	Market Return	.90*** (19.11)	.75*** (11.61)	1.03*** (15.18)
	Central Dummy	-.13 (-0.94)		
Announcement of Reform Plans	Reform for the Power Industry--2002	-.02 (-0.09)	.11 (0.28)	-.13 (-0.31)
	Reform Plans for the Power Industry during the 11th five-year plan--2007	1.42*** (5.83)	1.26*** (3.99)	1.57*** (4.31)
	Further Reform Plans for the Power Industry--2015	-.25 (-1.04)	-.01 (-0.02)	-.47 (-1.31)
	Release the Tariff adjustment Mechanism--2004	-.24 (-0.93)	-.34 (-0.97)	-.14 (-0.40)
On-Grid Tariff Adjustments	Increase coal-fired generation plant's on-grid tariffs--2006	-.05 (-0.19)	-.01 (-0.04)	-.10 (-0.25)
	Increase coal-fired generation plant's on-grid tariffs --2011	-.47* (-1.65)	-.68* (-1.69)	-.30 (-0.76)
Retail Tariff Adjustments	Increase retail tariffs --2009	-3.72*** (-4.23)	-3.63*** (-4.82)	-3.79*** (-3.89)
	Increase retail tariffs --2009	-3.68*** (-5.21)	-3.57*** (-3.64)	-3.73*** (-4.72)
	Constant	.19 (1.59)	.09 (0.73)	.15 (1.06)
	R-Square	0.3089	0.27	0.34

t values are reported in the bracket.
**** significant at 1% level*
*** significant at 5% level*
** significant at 10% level*

3.6 Conclusions

Using the event-study method, this paper investigates how publicly listed companies' stock price react to the future market-oriented reform plans, on-grid tariff adjustments, and retail tariff adjustments in China's power industry. In this paper, the events are separated into three groups, future market-oriented reform plans, on-grid tariff adjustments, and retail tariff adjustments. To get more accurate results, this paper conducted the regressions using two different windows - 5 business days before and after the events (the "short term") and 10 business days before and after the events (the "mid-term") respectively.

About the announcement of future market-oriented reform plan events, this paper finds that the stock prices do not respond significantly to the reform plans in either the short- or the mid- term. This suggest that investors are convinced that the future reform plans would unlikely be implemented effectively and thoroughly in China. The only exception is the Reform Plans for the Power Industry during the 11th five-year which was released in 2007 and has positive and significant effect on the publicly listed companies' stock price. The main reason for this may be the unprecedented bull market in China at that time.

About the on-grid tariff adjustment events, the paper finds that the stock price react significantly and negatively to tariff increase in both of short- and mid-term. Although the negative coefficients are surprising, the main reason behind this fact may be that the tariff adjustments were significantly later and not enough to make up the increase of fuel cost. In terms of the retail tariff adjustment events, the paper finds that the stock prices of major industrial electricity users react significantly and negatively to retail tariff increase in both of short- and mid-term, showing that the price increase will affect these companies' cost significantly and that the tariff adjustments are unexpected.

Although this paper is the first paper focusing on stock price reaction to regulation using China's power industry data, there are several improvements can be made in the future. The first is to increase the events number to get more persuasive and conclusive results. The second is using more companies' data to get accurate results.

Appendices

Appendix A: Optimal Instruments

A1: Partial Derivatives of $\boldsymbol{h_1}$ (first conditional moment)

Partial Derivatives of Peak Coefficients

$$\frac{\partial h_1}{\partial \beta} = A + B$$

$$\text{A} = \frac{\partial E(x_{1p}^*)}{\partial \beta} = \Phi\left(\frac{c_{11}}{\sigma}\right) p_1 + \left(\Phi\left(\frac{c_{13}}{\sigma}\right) - \Phi\left(\frac{c_{12}}{\sigma}\right)\right) p_2 + \left(1 - \Phi\left(\frac{c_{14}}{\sigma}\right)\right) p_3$$

$$\text{B} = \frac{\partial E(x_{2p}^*)}{\partial \beta} = \Phi\left(\frac{c_{21}}{\sigma}\right) p_1 + \left(\Phi\left(\frac{c_{23}}{\sigma}\right) - \Phi\left(\frac{c_{22}}{\sigma}\right)\right) p_2 + \left(1 - \Phi\left(\frac{c_{24}}{\sigma}\right)\right) p_3$$

For Income coefficients, replace p_1, p_2, p_3 with y_1, y_2, y_3 respectively.

For p_v and control variable z, replace p_1, p_2, p_3 with p_v or z .

Partial Derivatives of Off-peak Coefficients

$$\frac{\partial h_1}{\partial \beta} = C + D$$

$$C = \frac{\partial E\left(x_{1v}^*\right)}{\partial \beta} = p_v$$

$$D = \frac{\partial E\left(x_{2v}^*\right)}{\partial \beta} = p_v$$

For Income coefficients, replace p_v with y_1.

For p_p and control variable z, replace p_v with p_p or z .

A2: Partial Derivatives of $\boldsymbol{h_2}$ (second conditional moment)

Partial Derivatives of Peak Coefficients

$$\frac{\partial h_2}{\partial \beta} = A + B + C + D + E$$

$$A = \frac{\partial E\left[(x_{1p}^*)^2\right]}{\partial \beta} = 2\left[p_1\left(x_{11}\,\Phi\left(\frac{c_{11}}{\sigma}\right) - \sigma\emptyset\left(\frac{c_{11}}{\sigma}\right)\right)\right.$$
$$+ p_2\left(x_{12}\,\Phi\left(\frac{c_{13}}{\sigma}\right) - \sigma\emptyset\left(\frac{c_{13}}{\sigma}\right) - x_{12}\,\Phi\left(\frac{c_{12}}{\sigma}\right) + \sigma\emptyset\left(\frac{c_{12}}{\sigma}\right)\right)$$
$$\left. + p_3\left(x_{13}\left(1 - \Phi\left(\frac{c_{14}}{\sigma}\right) + \sigma\emptyset\left(\frac{c_{14}}{\sigma}\right)\right)\right)\right]$$
$$B = 2\frac{\partial\left[E(x_{1p}^*)E(x_{1v}^*)\right]}{\partial \beta} = 2\left[\Phi\left(\frac{c_{11}}{\sigma}\right)p_1 + \left(\Phi\left(\frac{c_{13}}{\sigma}\right) - \Phi\left(\frac{c_{12}}{\sigma}\right)\right)p_2 + \left(1 - \Phi\left(\frac{c_{14}}{\sigma}\right)\right)p_3\right]x_{1v}$$

$$C = 2\frac{\partial[E(x_1^*)E(x_2^*)]}{\partial \beta} = 2\frac{\partial[E(x_1^*)]}{\partial \beta}E(x_2^*) + 2\frac{\partial[E(x_2^*)]}{\partial \beta}E(x_1^*)$$

$$D = \frac{\partial E\left[(x_{2p}^*)^2\right]}{\partial \beta} = 2\left[p_1\left(x_{21}\,\Phi\left(\frac{c_{21}}{\sigma}\right) - \sigma\emptyset\left(\frac{c_{21}}{\sigma}\right)\right)\right.$$
$$+ p_2\left(x_{22}\,\Phi\left(\frac{c_{23}}{\sigma}\right) - \sigma\emptyset\left(\frac{c_{23}}{\sigma}\right) - x_{22}\,\Phi\left(\frac{c_{22}}{\sigma}\right) + \sigma\emptyset\left(\frac{c_{22}}{\sigma}\right)\right)$$
$$\left. + p_3\left(x_{23}\left(1 - \Phi\left(\frac{c_{24}}{\sigma}\right) + \sigma\emptyset\left(\frac{c_{24}}{\sigma}\right)\right)\right)\right]$$
$$E = 2\frac{\partial\left[E(x_{2p}^*)E(x_{2v}^*)\right]}{\partial \beta} = 2\left[\Phi\left(\frac{c_{21}}{\sigma}\right)p_1 + \left(\Phi\left(\frac{c_{23}}{\sigma}\right) - \Phi\left(\frac{c_{22}}{\sigma}\right)\right)p_2 + \left(1 - \Phi\left(\frac{c_{24}}{\sigma}\right)\right)p_3\right]x_{2v}$$

For Income coefficients, replace p_1, p_2, p_3 with y_1, y_2, y_3 respectively.

For p_v and control variable z, replace p_1, p_2, p_3 with p_v or z .

Partial Derivatives of Off-peak Coefficients

$$\frac{\partial h_2}{\partial \beta} = 2x_{1v}p_v + 2x_{2v}p_v + 2\left\{E\left[x_{1p}^*|w_1\right] + 2E\left[x_{2p}^*|w_2\right]\right\} * p_v + 2\left[E[x_1^*|w_1] + E[x_2^*|w_2]\right] * p_v$$

For Income coefficients, replace p_v with y_1.

For p_p and control variable z, replace p_v with p_p or z .

A3: Partial Derivatives of h_{1r} (first conditional moment on demand structure)

Partial Derivatives of Peak Coefficients

$$\frac{\partial h_{1r}}{\partial \beta} = \frac{1}{E[x_v^*]}\left[\left(\Phi\left(\frac{c_{11}}{\sigma}\right) + \Phi\left(\frac{c_{21}}{\sigma}\right)\right)p_1 + \left(\Phi\left(\frac{c_{13}}{\sigma}\right) - \Phi\left(\frac{c_{12}}{\sigma}\right) + \Phi\left(\frac{c_{23}}{\sigma}\right) - \Phi\left(\frac{c_{22}}{\sigma}\right)\right)p_2\right.$$
$$\left. + \left(2 - \Phi\left(\frac{c_{14}}{\sigma}\right) - \Phi\left(\frac{c_{24}}{\sigma}\right)\right)p_3\right]$$

For Income coefficients, replace p_1, p_2, p_3 with y_1, y_2, y_3 respectively.

For p_v and control variable z, replace p_1, p_2, p_3 with p_v or z .

Partial Derivatives of Off-peak Coefficients

$$\frac{\partial h_{1r}}{\partial \beta} = -2\frac{E\left[x_p^*\right]}{\left(E\left[x_v^*\right]\right)^2} p_v$$

For Income coefficients, replace p_v with y_1 ;

For p_p and control variable z, replace p_v with p_p or z .

A4: Partial Derivatives of h_2 with respect to σ

$$\frac{\partial h_2}{\partial \sigma} = A + B + C + D + E$$

$$\mathrm{A} = \frac{\partial E\left[\left({x_{1p}^*}^2\right)\right]}{\partial \sigma} = 2\left[\sigma\left(\Phi\left(\frac{c_{11}}{\sigma}\right) + \Phi\left(\frac{c_{13}}{\sigma}\right) + 1 - \Phi\left(\frac{c_{12}}{\sigma}\right) - \Phi\left(\frac{c_{14}}{\sigma}\right)\right) + \overline{x_1}\left(\emptyset\left(\frac{c_{12}}{\sigma}\right) - \emptyset\left(\frac{c_{11}}{\sigma}\right)\right)\right.$$
$$\left. + \overline{x_2}\left(\emptyset\left(\frac{c_{14}}{\sigma}\right) - \emptyset\left(\frac{c_{13}}{\sigma}\right)\right)\right]$$

$$\mathrm{B} = 2\frac{\partial[E(x_1^*)E(x_2^*)]}{\partial \sigma}$$
$$= 2\left[E(x_2^*)\left(\emptyset\left(\frac{c_{12}}{\sigma}\right) - \emptyset\left(\frac{c_{11}}{\sigma}\right) + \emptyset\left(\frac{c_{14}}{\sigma}\right) - \emptyset\left(\frac{c_{13}}{\sigma}\right)\right)\right.$$
$$\left. + E(x_1^*)\left(\emptyset\left(\frac{c_{22}}{\sigma}\right) - \emptyset\left(\frac{c_{21}}{\sigma}\right) + \emptyset\left(\frac{c_{24}}{\sigma}\right) - \emptyset\left(\frac{c_{23}}{\sigma}\right)\right)\right]$$

$$\mathrm{C} = \frac{\partial E\left[\left({x_{2p}^*}^2\right)\right]}{\partial \sigma} = 2\left[\sigma\left(\Phi\left(\frac{c_{21}}{\sigma}\right) + \Phi\left(\frac{c_{23}}{\sigma}\right) + 1 - \Phi\left(\frac{c_{22}}{\sigma}\right) - \Phi\left(\frac{c_{24}}{\sigma}\right)\right) + \overline{x_1}\left(\emptyset\left(\frac{c_{22}}{\sigma}\right) - \emptyset\left(\frac{c_{21}}{\sigma}\right)\right)\right.$$
$$\left. + \overline{x_2}\left(\emptyset\left(\frac{c_{24}}{\sigma}\right) - \emptyset\left(\frac{c_{23}}{\sigma}\right)\right)\right]$$

$$\mathrm{D} = 2\frac{\partial\left[E\left(x_{1p}^*|w_1\right)E(x_{1v}^*|w_1)\right]}{\partial \sigma} = 2E(x_{1\mathrm{v}}^*)\left[\emptyset\left(\frac{c_{12}}{\sigma}\right) - \emptyset\left(\frac{c_{11}}{\sigma}\right) + \emptyset\left(\frac{c_{14}}{\sigma}\right) - \emptyset\left(\frac{c_{13}}{\sigma}\right)\right]$$

$$\mathrm{E} = 2\frac{\partial\left[E\left(x_{2p}^*|w_2\right)E(x_{2v}^*|w_2)\right]}{\partial \sigma} = 2E(x_{2\mathrm{v}}^*)\left[\emptyset\left(\frac{c_{22}}{\sigma}\right) - \emptyset\left(\frac{c_{21}}{\sigma}\right) + \emptyset\left(\frac{c_{24}}{\sigma}\right) - \emptyset\left(\frac{c_{23}}{\sigma}\right)\right]$$

Appendix B: Calculation of Price and Income Elasticities

Own price elasticity

To calculate the own price elasticity, I first calculate the expected consumption at month i as

$$\hat{x}_i^* = \hat{x}_{ip}^* + \hat{x}_{iv}^* = E\left[\hat{x}_{ip}^* \middle| w_i; \hat{\theta}\right] + E\left[\hat{x}_{iv}^* \middle| w_i; \hat{\theta}\right]$$

Let $\hat{\alpha}_p$, $\hat{\rho}_p$, $\hat{\alpha}_v$, and $\hat{\rho}_v$ denote the estimates respectively, and the marginal price effects can be expressed as:

$$\frac{dx_{ip}^*}{d(mp_p)}|\hat{x}_{ip}^*, mp_p = \hat{\alpha}_p \cdot \mathbf{1}\left(\hat{x}_{ip}^* \neq \overline{x_1}, \hat{x}_{ip}^* \neq \overline{x_2}\right) + \hat{\gamma} \cdot \overline{x_1} \cdot \mathbf{1}\left(\widehat{\overline{x_1} <} \hat{x}_{ip}^* < \overline{x_2}\right) \cdot 0.03 + \hat{\gamma} \cdot \overline{x_2} \cdot \mathbf{1}\left(\hat{x}_{ip}^* > \overline{x_2}\right) \cdot 0.1$$

$$\frac{dx_i^*}{d(mp_p)}|\hat{x}_{ip}^*, mp_p = \hat{\alpha}_p \cdot \mathbf{1}\left(\hat{x}_{ip}^* \neq \overline{x_1}, \hat{x}_{ip}^* \neq \overline{x_2}\right) + \hat{\gamma} \cdot \overline{x_1} \cdot \mathbf{1}\left(\widehat{\overline{x_1} <} \hat{x}_{ip}^* < \overline{x_2}\right) \cdot 0.03 + \hat{\gamma} \cdot \overline{x_2} \cdot \mathbf{1}\left(\hat{x}_{ip}^* > \overline{x_2}\right) \cdot 0.1 + \hat{\rho}_v$$

$\frac{dx_{iv}^*}{d(mp_v)} = \hat{\alpha}_v$, and $\frac{dx_i^*}{d(mp_v)} = \hat{\alpha}_v + \hat{\rho}_p$

where $1(\cdot)$ is the indicator function. 0.03 and 0.1 are the price differences between the first price tier and the second price tier and that between the second price tier and the third price tier, which are used to get the extra-marginal effect of income on price elasticity (Reiss and White, 2005).

Therefore, the local own peak and off-peak price elasticity can be expressed as

$$\hat{\eta}_{ip} = \frac{\widehat{mp_p}}{\hat{x}_{ip}^*} \cdot \left[\hat{\alpha}_p \cdot \mathbf{1}\left(\hat{x}_{ip}^* \neq \overline{x_1}, \hat{x}_{ip}^* \neq \overline{x_2}\right) + \hat{\gamma} \cdot \overline{x_1} \cdot \mathbf{1}\left(\overline{x_1} < \hat{x}_{ip}^* < \overline{x_2}\right) \cdot 0.03 + \hat{\gamma} \cdot \overline{x_2} \cdot \mathbf{1}\left(\hat{x}_{ip}^* > \overline{x_2}\right) \cdot 0.1 + \hat{\rho}_v\right]$$

$$\hat{\eta}_{iv} = \frac{\widehat{mp_v}}{\hat{x}_{iv}^*} \cdot (\hat{\alpha}_v + \hat{\rho}_p)$$

Then the single month global price elasticity is

$$\hat{\eta}_i = \frac{\hat{x}_{ip}^*}{\hat{x}_i^*} \hat{\eta}_{ip} + \frac{\hat{x}_{iv}^*}{\hat{x}_i^*} \hat{\eta}_{iv}$$

The price elasticity in the billing period, each year, and total sample period can be calculated similarly.

Cross price elasticity

The asymmetric cross price elasticity can be calculated similarly. The cross price between peak price and off-peak consumption is

$$\hat{\eta}_{\mathrm{ipv}} = \frac{\widehat{\boldsymbol{mp_p}}}{\hat{\boldsymbol{x}}^*_{\boldsymbol{iv}}} \cdot \frac{\mathbf{dx}^*_{\boldsymbol{iv}}}{\boldsymbol{d}(\boldsymbol{mp_p})} | \widehat{\boldsymbol{mp_p}} = \frac{\widehat{\boldsymbol{mp_p}}}{\hat{\boldsymbol{x}}^*_{\boldsymbol{iv}}} \cdot \boldsymbol{\rho_v}$$

The cross price between off-peak price and peak consumption is

$$\hat{\boldsymbol{\eta}}_{\boldsymbol{ivp}} = \frac{\widehat{\boldsymbol{mp_v}}}{\hat{\boldsymbol{x}}^*_{\boldsymbol{ip}}} \cdot \frac{\boldsymbol{dx}^*_{\boldsymbol{ip}}}{\boldsymbol{d}(\boldsymbol{mp_v})} = \frac{\widehat{\boldsymbol{mp_v}}}{\hat{\boldsymbol{x}}^*_{\boldsymbol{p}}} \cdot \boldsymbol{\rho_p}$$

Similar to the review of own price elasticity, I calculate the cross price elasticity in the billing period, each year, and total sample period.

Income elasticity

The calculation of income elasticity is simpler and can be expressed as

$$\hat{\eta}_{\mathrm{y}} = \frac{\mathbf{dx}^*_{\boldsymbol{i}}}{\boldsymbol{dy}} | \hat{\boldsymbol{x}}^*_{\boldsymbol{i}}, \widehat{\boldsymbol{mp}} = \hat{\boldsymbol{\gamma}}_{\mathrm{p}} \cdot \mathbf{1}(\hat{\boldsymbol{x}}^*_{\boldsymbol{ip}} \neq \overline{\boldsymbol{x_1}}, \hat{\boldsymbol{x}}^*_{\boldsymbol{ip}} \neq \overline{\boldsymbol{x_2}})$$

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