In Between the State and the Market: An Empirical Assessment of the Early Achievements of China's 2015 Electricity Reform

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Abstract

This is the first study to investigate and quantify the extent to which the 2015 reform has already impacted the economic and technical performance as well as the security of supply of China's electricity sector. We use provincial data from 2003 to 2018 to estimate the impacts of the reform on on-grid prices, average retail electricity prices (including those for households) and supply reliability. We adopt fixed effect models together with other dynamic panel data models. We find that the 2015 reform has already had a negative impact on on-grid prices of electricity generated from thermal energy and on overall average retail prices, but the impacts on other prices are not statistically significant. Our results also suggest that the 2015 reform has had significantly negative impacts on technical efficiency, as measured by the coal burned per unit of thermal generation, but no impact on the line loss rate of electricity transmission. In addition, our empirical analysis suggests that the 2015 reform has reduced reliability and increased the instances of supply interruptions. These results are robust to different estimators and models. Finally, the effect of the reform is heterogeneous across regions. Our findings suggest that additional steps are needed to further improve the overall economic efficiency of the electricity sector in China, despite significant progress arising from the 2015 reform. The results may also provide useful lessons for other developing economies aiming to reform their power sectors and who are facing similar choices between the roles of the state and the market in ensuring efficient outcomes. **JEL classification:** L94; P21; P28.

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1 Introduction

China launched a new wave of reform of its electricity sector in March 2015. The reform aimed at promoting more competition in the generation and retail sectors, and to set transmission and distribution (T&D) prices based on the grids' efficient operational costs, including a reasonable profit margin, as dictated by best practice economic regulatory principles.[1] The reform also aimed at improving both technical efficiency (at the generation and grid segments) and reliability of supply. The electricity sector of China is the world's largest and accounts for well over 20% of the world's electricity supply (Pollitt, 2020). Therefore, China's move to liberalize its electricity sector is relevant globally as many economies are striving to create competitive wholesale and retail electricity markets.

The 2015 reform has achieved a number of impressive outcomes (Pollitt, 2020). For example, every province has set up at least one electricity trading center to promote the development of market mechanisms. As many as 3600 companies had registered as electricity retailers as of August 2018. Around 2.1 trillion KWh of electricity, accounting for almost 40% of the total electricity sales, were sold through market mechanisms in 2018. Regulated T&D prices have been implemented in all provinces, with pilots in five provinces (Yunnan, Guizhou, Anhui, Ningxia and Hubei) commencing in 2015, and other provinces following in subsequent years. The revenue of the grid companies was reduced by about 60 billion RMB as a result of the introduction of regulated T&D prices.[2]

However, five years after the reform, the role of the state still remains pervasive in the sector, and markets and competition have developed at a slower pace than anticipated. The sales of electricity are still mainly controlled by grid companies, with other electricity sellers unable to compete and gain market share from the state-owned grid companies, which continue to have substantial market power. In addition, grid companies control the dispatch of electricity and most electricity trading centers. The fairness and transparency of electricity trading, required for the development of efficient markets, cannot be guaranteed without the operational independence of both dispatch and trading.

The need for additional reform to meet the energy policy objectives of decarbonisation, supply security and affordability is widely known. For example, the central government of China has issued a number of policy documents to extend the electricity sector reform.[3] Academic studies have also identified the warning signs that the 2015 reform failed to achieve its aims (e.g., Davidson and Pérez-Arriaga, 2020).

There are many studies that have examined the impact of the 2015 electricity reform on par-

[1]Grid companies purchase electricity from generating companies and resell it to end users or other electricity resellers. Under the previous regulatory arrangements, grid companies were remunerated by the difference between the purchase and sale prices.

[2]More details see `http://www.chinapower.com.cn/focus/20181029/1252973.html`.

[3]For example, the *Notice on Actively Promoting Electricity Market-based Trading to Further Improve the Trading Mechanism* by the National Development and Reform Commission (NDRC) and National Energy Bureau (NEB) in October 2018. More details see `http://www.gov.cn/zhengce/2019-08/14/content_5421133.htm`.

ticular aspects (Pollitt, 2020); for example, on electricity generation efficiency (e.g., Li et al., 2019), electricity production (e.g., Wang and Li, 2019), and economic efficiency of the electricity sector and electricity prices (e.g., Yin et al., 2019). These studies found that the new round of reform improved electricity generation efficiency, enhanced the productive efficiency of the electricity sector, reduced energy prices for households, and increased renewable energy generation. There are also studies that have examined the impact of the reform on particular provinces (e.g., Cheng et al., 2018; Liu et al., 2019) or on specific issues, such as electricity pricing (e.g., Sun, 2015), subsidies (e.g., Wang and Lin, 2017a,b), or the dispatch mechanism (e.g., Wei et al., 2018; Chen et al., 2020).

There is, however, a gap in the literature to measure econometrically the overall economic impact of the 2015 reform.[4] Our study aims to fill this existing gap in the literature. Specifically, we use existing provincial data to estimate the impact of the reform on on-grid prices of electricity generation from different types of energy sources, and on the average retail prices (and those for households). We also assess the effects of the reform on the coal equivalent consumption (i.e., coal burned per KWh) of electricity generation, on the line loss rate of electricity T&D, and on electricity reliability.

Our results show that the 2015 reform has reduced the on-grid prices of the electricity generated from thermal energy by over 4%. The on-grid prices of the electricity generated from other types of energy (e.g., hydropower, gas, wind and solar) are shown not to have been significantly affected by the reform. While the reform has reduced overall average retail electricity prices by over 2%, there has been extraordinary little impact on retail prices faced by households. The reason is the presence of retail electricity price controls for households. This disconnect between the price for generation and the prices faced by households has also been documented in many other developing countries engaged in liberalization (e.g., Joskow, 2008; Pollitt, 2012; Karahan and Toptas, 2013; Bonnet et al., 2013; Pollitt, 2020).

The reform has significantly increased efficiency, measured by coal burned per KWh of generation, while the impact on the line loss rate of T&D is not statistically significant. Contrary to expectations, we found that the 2015 reform has significantly reduced reliability and increased the instances of supply interruptions. The magnitude of reliability reduction is less than 1%, whereas supply interruptions have increased by over 50% when considering the full data sample. This result conforms with existing literature that finds that the frequency and duration of power outages tend to increase with more competition, market size expansion and cross-border trade of electricity (Yu and Pollitt, 2009).

As expected, we find that the treatment effect of the reform becomes more obvious over time. Moreover, the policy effects are heterogeneous when the differences in regional development and grid coverage are considered. For example, we find that the on-grid prices of thermal generation were significantly reduced after the 2015 electricity reform in the eastern provinces, where the economy is more developed. The reform has had little effect on thermal electricity

[4] An exception is Davidson and Pérez-Arriaga (2020) who provide a qualitative assessment of the overall impact of the reform on the electricity sector.

prices in other less developed provinces. In contrast, the policy treatment effect on coal burned per KWh is significantly negative in all regions, except in the eastern region. Moreover, reliability has increased in the west and decreased in the northeast, while supply interruptions have increased by over 100% in the eastern and northeastern regions because of the reform.[5]

We also consider the impact of the reform on the areas covered by the two existing grid companies. We show that supply interruptions have significantly increased within provinces covered by the State Grid Corporation of China (SGCC). In contrast, the reliability of electricity supply has been negatively affected in the provinces covered by the Southern Power Grid Company (SPGC).[6] As discussed in Section 3.3., the heterogeneous estimates reflect differences across regions in terms of economic and technological development, and the generation mix.[7]

Finally, we investigate two potential mechanisms – the adjustment of benchmark on-grid prices and market segmentation – through which the reform could have impacted on-grid prices. We found that the reform induced lower benchmark on-grid prices for thermal generation, and hence on-grid thermal generation prices have also declined. Moreover, we find that market segmentation, as measured by price dispersion between regions, has increased over time. Somewhat counterintuitively, such increase has had a negative impact on on-grid prices of thermal generation. We conjecture that the decrease of on-grid prices is related to the nature of China's political promotion process for local officials. This process can be thought of as a contest where local officials are rewarded based on economic outcomes in their local government regions. This political competition results in officials promoting the construction of thermal plants, leading to reductions in on-grid prices.

This study is the first to assess the broader impact of the 2015 reform on the Chinese electricity sector. The empirical findings highlight the need to liberalize retail prices for households, and to adopt quality of service regulations to mitigate any negative impact on supply reliability. The heterogenous impact of the reform across regions and grid coverage areas underscores the importance of paying attention to the specific circumstances of each region. These findings are also potentially useful for other developing economies and regions whose electricity sectors are caught between the forces of the market and the state, yet are aiming to reform their electricity markets.

The remainder of this paper is organized as follows. Section 2 briefly presents the data and the econometric model. Section 3 conducts the empirical estimation and discusses the estimated outcomes. Section 4 examines the heterogeneity of policy effect, Section 5 tests the mechanism through which the reform impacts the on-grid prices of thermal generation, and Section 6 draws

[5] In absolute terms, supply interruptions in the northeast provinces have increased by over 12 hours per household on an annual basis.

[6] Note the SPGC covers the Guangdong province which is the largest and the most economically successful province in China but faces relatively high final electricity prices for residential and most industrial and commercial customers and is a net importer of electricity from other provinces (Pollitt, 2020).

[7] SGCC supplies electricity to 26 provinces, and its main objectives are to support the national economy and to guarantee supply security. SGCC has an international presence in different countries (e.g., it owns a 41% stake in ElectraNet, and a 19.9% stake in AusNet Services in Australia. SPGC supplies five provinces in southern China and was established in 2002 to break the monopoly of electricity supply in China held by SGCC.

main conclusions and provides some policy implications for future reform.

2 Data and Methodology

2.1 Data Description

The data used in this paper is mainly from the China Electricity Yearbook (CEY), 2003 to 2018.[8] The average retail prices in 2017 and 2018 are from the China National Energy Bureau.[9] The benchmark on-grid prices for thermal generation are from Pingan Securities.[10] The source of coal price indexes at the provincial level is the Inner Mongolia Coal Exchange Center.[11] Other control variables are either directly sourced from the China Economic Internet (CEInet) or are calculated from the CEInet data. We deflate the nominal values of GDP per capita by the consumer price index (CPI) using 2003 as the base year. *Industrialization* is measured as the percentage of the secondary sector in the GDP in a given province, and *urbanization rate* is measured by the ratio of urban to total population in a province.

Table 1 contains the descriptive statistics for the selected variables. Table 1 shows that the average on-grid price for the electricity generated from thermal energy is around 390 RMB per MWh, whereas the on-grid price for hydroelectricity is 330 RMB per MWh. In contrast, the on-grid prices for gas-, wind- and solar-generated electricity are much higher, reflecting the scarcity of gas in China and the high fixed investment costs of wind and solar energy generation. The number of observations for solar and gas is lower than those from other sources, reflecting the fact that they are not available in every province. The average retail price of electricity is higher than the average retail price for households reflecting the existing cross-subsidy mechanism.[12] The differences between the minimum and maximum of the various electricity price variables (i.e., *average retail price* and *average retail price for households*) mirror the vast socio-economic realities across different provinces in China. This heterogeneity in regional economic development has been captured in the analysis below by controlling for GDP per capita, urbanization rate, and level of industrialization.

The variable *running hours* measures the running hours of generators in each year, which reflects the technical characteristics of different types of generators. For instance, *running hours* of thermal generators is considerably higher than that of hydro generators, as the latter are limited in their annual hours due to rainfall availability. In contrast, while thermal generators

[8]Our data is available from 1993 to 2018. To remove the effect of the electricity reform launched in 2002, we only use the data after 2003.

[9]Note that the retail prices pre-2016 (inclusive) are from the China Electricity Yearbook (CEY). Since CEY 2019 (containing data up to 2017) is unavailable to date, the more recent (post-2016) data are from the National Energy Bureau (NEB). The NEB data pre-2016 (inclusive) are consistent with the pre-2016 CEY data. Moreover, the retail prices given in both CEY and NEB are the averages exclusive of market-based electricity prices and administrative fees (the additional fees charged to fund various government programs).

[10]Please see `http://pdf.dfcfw.com/pdf/H3_AP201904251322714397_1.pdf`.

[11]Available at `http://www.imcec.cn/zgdm`.

[12]Under the existing system, the prices that households pay for electricity are much lower than those in other middle-income countries, while prices paid by the industrial and commercial sectors are relatively higher.

Table 1: Descriptive Statistics

Variables (unit)	Obs.	Mean	Std. Err	Min.	Max.
Dependent variables					
ECONOMIC PERFORMANCE (RMB/MWh)					
On-grid price: thermal	178	398.621	76.843	205.39	606.78
On-grid price: gas	76	680.929	144.12	267.28	977.44
On-grid price: hydro	143	337.278	110.168	192.2	831.38
On-grid price: wind	168	610.407	105.352	423.76	1059.11
On-grid price: solar	129	976.545	311.766	345.41	2184
Average retail price	168	592.492	117.882	346.31	777.24
Average retail price for households	168	532.733	55.920	399.99	666.25
Benchmark price: thermal	149	365.258	56.198	232.5	503
TECHNICAL PERFORMANCE					
Coal burned per KWh (g)	676	344.919	44.849	204	554
Line loss rate (%)	436	7.243	2.146	1.42	19.88
SUPPLY RELIABILITY					
Reliability (%)	147	99.834	0.1297	99.22	99.977
Supply interruptions (hours/household)	148	18.0069	42.071	2.01	509
Independent variables					
2015 electricity reform	806	0.1538	0.361	0	1
Generator running hours: thermal (hours)	698	4885.32	1116.39	4	7732
Generator running hours: hydro (hours)	600	2737.23	1214.48	0	6134
GDP per capita (RMB)	496	28180	18378	3701	101274
Urbanization rate (%)	434	0.526	0.146	0.207	0.896
Industrialization (%)	806	0.442	0.086	0.147	0.664
Total Electricity Consumption (10^8KWh)	611	1133.282	1072.198	13	5958.97
Installed Capacity: thermal (10^4KW)	679	1733.389	1851.986	1	10335
Electricity Generation: thermal (10^8KWh)	647	800.376	800.557	0 .01	4253.7
Population (10^6)	606	42.905	27.104	2.58	11.346
Fixed Investment (10^8RMB)	434	685.76	562.31	12.74	3382.51

are in some instances dispatched to meet peak load, the very high costs of starting up, ramping up and ramping down, imply that most thermal generators remain in running status throughout the day as base loaders.

The variable *coal burned per KWh* is the number of grams of coal burned per KWh of thermal generation using generators over 600 MW. The *line loss rate* is the percentage of electricity lost in the process of T&D, defined as (on-grid electricity – electricity sales)/on-grid electricity. *Reliability* is calculated as the ratio of total effective electricity supply hours of 10 KV distribution utilities and the total hours per period. *Supply interruptions* refers to the average number of power outage hours during a particular period, calculated as $\sum$ (power outage hours per time $\times$ number of power outage users per time)/total number of electricity users. The technical and supply reliability variables are from the China Electricity Yearbook. The *fixed investment* variable reflects the value in RMB invested in the energy sectors.[13] The key policy variable is represented in the form of a dummy variable, denoted by 2015 *Electricity reform*, which takes the value of 1 from 2015 onwards, and zero otherwise.

2.2 Econometric Model Specification

We estimate the following equation using a fixed effect (FE) model:

$$Y_{it} = \alpha + \beta Reform_{it} + \delta X_{it} + \gamma_t + \lambda_i + \mu_{it}$$

where Y_{it} is the dependent variable, with $i = province$ and $t = time$.[14] $Reform_{it}$ is the dummy variable capturing the electricity sector reform, and β is the associated coefficient. X_{it} represents a vector of control variables, including GDP per capita, urbanization rate, industrialization, total electricity consumption, installed capacity and running hours of thermal generators, generation from thermal energy and fixed investment to energy sectors. δ denotes the coefficients for the control variables, γ_t is the year dummy variable that controls the variables that are constant across provinces but vary over time (i.e., time fixed effects), λ_i is the dummy variable for provinces that controls the unobserved time-invariant individual effect (i.e., individual fixed effects), and μit is the error term. We use the natural logarithm of the variables, except for the variable indicating the reform, to directly investigate the impacts of the reform on the change rate of the dependent variables.

As the performance of the electricity sector may affect the reform implementation, there is a potential endogeneity problem that can lead to inconsistent estimates and incorrect inferences. We apply the general method of moments (GMM) that includes lagged dependent variables as the instrumental variables to deal with the potential endogeneity problem and specify the GMM model as follows:

$$Y_{it} = \alpha + \rho_1 Y_{it-1} + \rho_2 Y_{it-2} + ... + \rho_p Y_{it-p} + \beta Reform_{it} + \delta X_{it} + \mu_{it}$$

where Y_{it-p} is the p periods lagged value of dependent variable Y_{it}.[15]

Additionally, in dynamic unbalanced panel-data models with a small number of cross-sections, the estimates generated using the standard within-group estimators for dynamic models with fixed individual effects differ from those obtained with least-squares dummy variable (LSDV) models leading to biased and inconsistent estimates (Nickell, 1981). To account for

[13] As data on investment in the electricity sector are unavailable, we use the fixed investment in the energy sectors as a control variable. The fixed investment measures the investment in the mining, production and supply of coal, gas, oil, electricity and heating.

[14] As it is well known, in a random effect (RE) model, the individual-specific effects are uncorrelated with the independent variables, and thus the RE estimator is more efficient than the FE estimator. However, in practice it is unlikely that the random effect assumption holds. In FE models, unobserved time invariant heterogeneity can be removed through measures such as taking a first difference.

[15] Specifically, this paper uses the System GMM rather than the difference GMM, as the lagged levels are often rather poor instruments for first differenced variables, especially if the variables are close to a random walk. The System GMM addresses this potential weakness by including lagged level as well as lagged differences.

this, we also compute bias-corrected LSDV estimators (LSDVC) in addition to the FE and GMM estimators.[16]

3 Results and Discussion

This section presents our estimates of the impact of the 2015 electricity reform on economic and technical performance, and supply reliability of China's electricity sector. In the baseline models described below, we run the regression with the full sample.

3.1 Impacts of Reforms on Economic Performance

This subsection examines the reform impact on on-grid prices and electricity retail prices.

Table 2: Impacts on the On-grid Prices of Thermal Electricity

Variables	**Unconditional**	**FE**	**GMM**	**LSDVC**
2015 Reform	-0.1247***	-0.1421**	-0.0012	-0.0079
	(0.0270)	(0.0590)	(0.0304)	(0.1136)
Coal price	0.0002	0.0003	0.0004*	0.0003
	(0.0002)	(0.0003)	(0.0002)	(0.0006)
Total electricity consumption		0.2789	-0.0968	0.1552
		(0.4162)	(0.2521)	(1.1063)
GDP per capita		0.0900	0.0730	0.1114
		(0.1448)	(0.2048)	(0.8242)
Population		-3.1952**	0.0875	-2.5380
		(1.4001)	(0.1437)	(7.3989)
Urbanization rate		0.1191	-0.9564**	-0.6225
		(0.6538)	(0.4849)	(2.5939)
Fixed investment		-0.0384	0.0220	-0.0169
		(0.0389)	(0.0383)	(0.1693)
L.on-grid thermal price			0.7282***	0.6049***
			(0.2775)	(0.1852)
Constant	5.9491***	29.5067***	-0.0597	
	(0.1083)	(10.0627)	(3.4670)	
R^2	0.5188	0.5806		
Observations	145	116	116	116
Time fixed effects	Yes	Yes	No	No
Individual fixed effects	Yes	Yes	No	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

Table 2 reports the results of the impact on on-grid prices of thermal generation, with the second to the fifth column being the estimates obtained using unconditional regression, FE model, GMM model and LSDVC model, respectively. According to our preferred (FE) model,

[16]The Stata routine for this method is xtlsdvc. For more details refer to Bruno (2005).

the 2015 electricity reform has statistically significantly reduced the on-grid prices of thermal electricity by 12.2 percent. We note that apart from population, and the lagged thermal electricity price, other economic variables (including coal prices) have no explanatory power. These results are consistent with the highly centralized nature of the electricity sector, where prices are decided based on political and social considerations, and not on economic fundamentals.

The estimates of the reform's impacts on on-grid prices of the electricity generated from other types of energy are given in Table 3.[17] The lack of explanatory power of economic variables, including the reform, again relates to the on-grid price setting processes. In particular, the prices of wind and solar are set with reference to benchmarks determined by the central government based on the endowment of wind or solar energy in different regions. The prices for hydroelectricity are set according to the average on-grid electricity prices in each province, and those for gas electricity are set based on benchmark prices (which are, at most, 350 RMB/MWh higher than thermal electricity) in each place and fuel costs (i.e., gas prices).While Table 3 reports the results from the FE models, they are consistent with those with GMM and LSDVC models, as shown in the Appendix.

Table 3: Impacts on the On-grid Prices of Electricity Generated from Other Sources

Variables	**Hydro**	**Gas**	**Wind**	**Solar**
2015 Reform	-0.2131*	0.0451	-0.0202	0.2194
	(0.1190)	(0.3395)	(0.0715)	(0.3259)
Total electricity consumption	0.7210*	2.0687	0.1745	0.1009
	(0.3644)	(1.3256)	(0.2869)	(0.5772)
GDP per-capita	1.4360***	-1.6468	-0.0280	0.7789
	(0.4943)	(1.3079)	(0.1958)	(0.6481)
Population	-2.6321	-1.2147	-2.1428	-1.2331
	(2.5102)	(5.8782)	(1.3863)	(4.8358)
Urbanization rate	-1.3114	0.1379	-0.4782	-4.5424
	(1.3815)	(2.3464)	(0.6317)	(3.3490)
Fixed investment	-0.0239	-0.1407	0.0148	-0.0502
	(0.0883)	(0.1281)	(0.0334)	(0.1572)
Constant	6.6603	19.6910	22.5906**	5.6489
	(18.2718)	(50.7802)	(10.0093)	(37.9298)
R^2	0.2767	0.3522	0.2012	0.1756
Observations	119	62	139	102
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01.

Table 4 shows that overall retail prices have decreased from approximately 2 percent to 5 percent across the three models. However, the impact on prices faced by households is

[17] Given the degrees of freedom and the small number of samples in this estimation, we did not consider individual provinces fixed effects. We follow this approach in the subsequent estimations where the number of observations is less than 100.

very small and statistically insignificant. That is, the reduction in price mostly benefited non-households, which is consistent with the Chinese government's focus on reducing costs to businesses to foster economic growth. The lack of statistical significance for the impact on household prices has a simple explanation. These prices are regulated with broader objectives (e.g., inflation control) (Davidson and Pérez-Arriaga, 2020) rather than just cost-reflectiveness.

Table 4: Impacts on the Retail Prices of Electricity

Variables	**Average Retail Price (Overall)**			**Average Retail Price (HH)**		
	FE	**GMM**	**LSDVC**	**FE**	**GMM**	**LSDVC**
	(1)	(2)	(3)	(4)	(5)	(6)
2015 Reform	-0.0422*	-0.0503***	-0.0204*	0.0004	0.0041	0.0097
	(0.0240)	(0.0100)	(0.0120)	(0.0178)	(0.0082)	(0.0098)
Elec. consum.	0.0852	0.0900	0.0351	0.0897	0.0806	0.0205
	(0.1263)	(0.0823)	(0.1069)	(0.0659)	(0.0577)	(0.0987)
GDP per-capita	-0.0916	0.0617	0.0751	-0.0830	-0.1161	-0.0587
	(0.0745)	(0.0808)	(0.0918)	(0.0554)	(0.0736)	(0.2309)
Population	-0.1415	0.1945*	-1.8272***	-0.0821	-0.0688	-0.3107
	(0.7025)	(0.1132)	(0.6646)	(0.4500)	(0.0479)	(1.6707)
L.dependent variab		1.0677***	0.4076**		1.0677***	0.4076**
		(0.4049)	(0.1861)		(0.4049)	(0.1861)
Constant	7.1552*	0.7632		7.1552*	0.7632	
	(3.7676)	(2.8510)		(3.7676)	(2.8510)	
R^2	0.5091			0.0736		
Observations	140	112	112	140	112	112
Time FE	Yes	No	No	Yes	No	No
Individual FE	Yes	No	No	Yes	No	No

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01. Columns (1) to (3) presents the estimation results of China's 2015 electricity reform on the average retail prices of electricity, and columns (4) to (6) report the estimates of the reform on the average retail electricity prices for households. "Elec. consum." is the abbreviation of "total electricity consumption", and "FE" is the abbreviation of fixed effects.

3.2 Impacts of Reforms on Technical Performance

This subsection presents and discusses the estimates of the 2015 reform's effects on the technical performance of China's electricity sector, as measured by the coal burned per KWh of thermal generation with units over 600 MW, and the line loss rate in transmission and distribution.

The estimated results are given in Table 5, which shows that the reform has significantly reduced the coal burned per KWh in thermal generation, whereas its impact on the line loss rate is not statistically significant.[18] A possible explanation for the lack of impact of the 2015 reform on line loss rate is that losses can also be reduced by upgrading infrastructure. Moreover,

[18]Note that in Table 5 we only present the estimates derived through FE models and GMM models, as in the LSDVC models the number of observations is not sufficient to carry out the command request.

the ongoing effort to upgrade T&D infrastructure in China is largely independent of the 2015 reform, although both aim to improve the efficiency of the electricity sector. Another possible explanation is that the energy efficiency in China's electricity T&D sector has been relatively advanced already (Menezes and Zheng, 2018), leaving limited scope for further improvements. To (partly) test this hypothesis, we estimate the impact of the reform on absolute values. The results confirm the hypothesis and are reported in the appendix in Table 18.[19]

Table 5: Impacts on the Technical Performance of Electricity Generation and T&D

Variables	**Coal Burned per KWh**		**Line Loss Rate**	
	FE	**GMM**	**FE**	**GMM**
2015 Reform	-0.209***	-0.019***	-0.201	-0.165**
	(0.053)	(0.006)	(0.208)	(0.065)
Installed capacity (thermal)	-0.070*	-0.001	0.172	0.266
	(0.038)	(0.024)	(0.293)	(0.417)
Generation (thermal)	0.036	-0.011	-0.297	-0.153
	(0.037)	(0.022)	(0.287)	(0.376)
Running hours (thermal)	-0.063***	-0.016	0.146	0.388
	(0.022)	(0.015)	(0.319)	(0.465)
Fixed investment	0.029***	-0.003	-0.012	-0.350***
	(0.010)	(0.008)	(0.109)	(0.123)
L.coal burned per KWh		0.566***		
		(0.043)		
L.line loss rate				-0.038
				(0.142)
Constant	6.514***	2.723***	1.425	-0.132
	(0.246)	(0.321)	(2.918)	(4.216)
R^2	0.784		0.387	
Observations	351	319	136	109
Time fixed effects	Yes	No	Yes	No
Individual fixed effects	Yes	No	Yes	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

3.3 Impacts of Reforms on Electricity Supply Reliability

This subsection provides the estimates of the impact of the reform on reliability and supply interruptions, which are reported in Table 6.[20] In particular, the impact on these two variables is statistically significant, with a small, almost negligible decrease in reliability, and a substantial

[19]To further ensure that the finding that the 2015 electricity does not significantly affect the technical performance in terms of line loss rate, we collected data from another database (i.e., the Wind Economic Database) that encompasses the data up to 2019. The estimation results obtained with at least 274 observations reveal that the insignificant impacts are not likely to be caused by the failure of capturing policy effects. The related estimation results are given in Table 20 in Appendix 3.

[20]Note that the estimation results reported in Table 6 represent percentage changes in percentage. The estimates in absolute levels are given in the appendix in Table 19.

increase in supply interruptions (over 50% in all three estimation models). It is not surprising that a reduction in prices may lead to lower quality, in an environment where regulation is not sufficiently effective and there is no competition.

The outcome that reforms exacerbate supply interruptions and reliability is also found in the growing literature on electricity sector liberalisation and blackouts (e.g., Jamasb et al., 2017). The reduction in supply reliability is also supported by economic theory. White (1972) adds quality to a simple model of competition and shows that the quality per unit that will be provided by a competitive industry subject to price regulation will be dependent on the price set by the regulator. The higher the price, the higher the quality per unit. Conversely, the lower the price, which is the usual outcome of electricity reform, the lower the quality. Indeed, quality of service regulation is common across countries that had reformed their electricity sector in the 1990s (e.g., Australia and the United Kingdom).

Table 6: Impacts on the Performance of Electricity Supply (Reliability and Supply Interruptions)

Variables	**Reliability**			**Supply Interruptions**		
	FE	**GMM**	**LSDVC**	**FE**	**GMM**	**LSDVC**
2015 Reform	-0.0004	-0.0009***	-0.0006***	0.8210***	0.6084***	0.5816*
	(0.000)	(0.000)	(0.000)	(0.214)	(0.156)	(0.308)
Elec. consum.	-0.0031*	0.0013	-0.0003	-0.6819	0.1477	0.3081
	(0.002)	(0.002)	(0.002)	(1.419)	(0.696)	(4.709)
GDP per-capita	0.0008	-0.0014	0.0011	-0.2507	0.0141	0.1015
	(0.001)	(0.001)	(0.002)	(0.741)	(1.290)	(3.306)
Population	-0.0109	-0.0015	-0.0287*	-6.8778	0.0168	3.5240
	(0.017)	(0.003)	(0.016)	(7.770)	(1.910)	(32.295)
Fixed investment	0.0005	0.0003	0.0003	0.0830	0.1224	-0.0070
	(0.000)	(0.000)	(0.000)	(0.156)	(0.292)	(0.549)
L.reliability		0.5827***	0.3907**			
		(0.117)	(0.177)			
L.supply-interpt.					0.1722	0.0467
					(0.166)	(0.184)
Constant	4.7030***	1.9368***		65.0294	-0.5441	
	(0.128)	(0.532)		(57.027)	(23.182)	
R^2	0.5035			0.3418		
Observations	147	114	114	148	115	115
Time FE	Yes	No	No	Yes	No	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$. "Elec. consum." is the abbreviation of "total electricity consumption", and "FE" is the abbreviation of fixed effects.

3.4 The Lagged Impact of the Reform

The potential lagged effect of the reform is captured by considering the lagged value of variables (values in the t +1 year) as our robustness tests for assessing lagged policy effect.

We first assume that the electricity reform was launched in 2016 rather than in 2015 and show the estimated outcomes in Table 7. We concentrate on the aspects on which the 2015 reform has generated statistically significant impacts in the above analysis, including on-grid prices of thermal generation, average retail prices of electricity, coal burned per kWh of generation and electricity reliability. Moreover, we focus on the estimates derived with GMM models in capturing the dynamic effects of the reform, and address the potential endogeneity issues in the model.

The coefficients of the reform (for the on-grid prices of thermal generation, average retail electricity prices and the reliability of electricity supply) become larger if we assume that the reform was implemented in 2016 rather than in 2015. This implies that the impacts are more apparent on certain aspects after the reform had been implemented for a period of time. Moreover, we find that the lagged values of on-grid prices and average retail prices have significant impacts on on-grid prices in the current period already, reflecting the path dependency of the setting of on-grid prices and retail prices. A similar result applies to the technical performance in terms of coal burned for thermal generation. In contrast, the reliability of electricity supply and supply interruptions have little to do with past performance.

Table 7: The Lagged Impacts of the Reform

	On-grid Price	**Retail Price**	**Coal Burned**	**Reliability**	**Supply Inter.**
Lagged Reform	-0.0973***	-0.0676***	-0.0180***	-0.0010***	0.5708***
	(0.0181)	(0.0070)	(0.0061)	(0.0002)	(0.1279)
L.lnOngrid price	0.4935***				
	(0.1722)				
L.lnRetail price		0.4745***			
		(0.0772)			
L.lnCoal burned			0.5804***		
			(0.0424)		
L.lnReliability				0.0289	
				(0.1341)	
L.lnSupply inter.					-0.0953
					(0.1040)
Constant	1.0959	-1.3121*	2.6245***	4.4523***	-7.4642
	(2.5643)	(0.6790)	(0.3178)	(0.6107)	(15.9978)
Observations	116	112	319	114	115

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01. "On-grid Price" delegates the on-grid prices for thermal generation, "Retail Price" represents the average retail prices of electricity, "Coal Burned" delegates the coal burned per KWh of thermal generation, and "Supply inter." is the supply interruptions.

4 Heterogeneity Analysis

This section analyzes the effects of heterogeneity from two perspectives. First, we focus on the impacts of regional heterogeneity, since China encloses a large territory and there is wide disparity in economic and social development across different regions. Second, we account for the heterogeneity of the provinces covered by the two different grid companies.[21] For simplicity, we will only present the estimates obtained via FE models.[22] Moreover, we focus on the generation from thermal energy when considering the impact on-grid prices.

4.1 Regional Heterogeneity

The estimates regarding the impacts of electricity reforms on economic performance, technical performance and supply reliability are given in Tables 8, 9 and 10, respectively.

Table 8: Impacts on the Electricity Prices: Regional Heterogeneity

	East	**Middle**	**West**	**Northeast**
Panel 1: On-grid Prices of Thermal Generation				
2015 Reform	-0.2584***	-0.2321	-0.2947	0.0379
	(0.0605)	(0.1669)	(0.1652)	(0.0458)
R^2	0.8742	0.8423	0.4836	0.9557
Observations	49	30	55	15
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No
Panel 2: Average prices (overall)				
2015 Reform	0.0357	-0.0435	-0.1503	0.2312
	(0.0394)	(0.0798)	(0.1215)	(0.2514)
R^2	0.1944	0.3144	0.2867	0.4219
Observations	138	115	30	25
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No
Panel 3: Average prices (households)				
2015 Reform	0.0626	-0.1197	-0.0995	0.0421
	(0.0468)	(0.0703)	(0.0558)	(0.0849)
R^2	0.6532	0.6776	0.7528	0.5036
Observations	45	30	50	15
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

We find that the on-grid tariffs for thermal generation have decreased by over 25% in the eastern regions as a result of the reform. This impact is considerably higher than the reduction estimated with the full sample. In contrast, the reform effect in other regions is not statistically significant. Although the estimates of the impact of the reform on the overall average retail

[21] Five provinces (Guangdong, Guangxi, Hainan, Yunnan and Guizhou) are covered by the Southern Power Grid Company, while the remaining provinces are covered by the State Grid Corporation of China.

[22] We obtain similar results when we estimate using LSDVC models, and these are available from the authors upon request.

prices of electricity are statistically significant with the full sample, they are not significant in any region. While the estimates are not statistically significant, they point to remarkably diverse impacts, both in terms of magnitude and sign, across the different regions.

Technical performance, as measured by the amount of coal burned for each unit of generation, has improved significantly across all regions, except in the eastern provinces, as observed from Table 9. The reduction in coal burned per KWh is both statistically and economically significant, with reductions ranging from 21% to 33% over the period. The lack of the statistical significance of the impact of reform on eastern provinces can be explained by the high levels of technical performance prior to the reform. The number of grams of coal burned per KWH was on average 333.5 g/KWh in the East prior to reform, which is around 19.0 g/KWh higher than the national average level.[23]

Table 9: Impacts on the Technical Performance: Regional Heterogeneity

	East	**Middle**	**West**	**Northeast**
Panel 1: Coal Burned per KWh				
2015 Reform	-0.0923	-0.2347*	-0.2133*	-0.3291**
	(0.0725)	(0.1107)	(0.0990)	(0.0132)
R^2	0.7967	0.9219	0.7312	0.9919
Observations	120	72	135	24
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No
Panel 2: Rate of Line Loss				
2015 Reform	-0.4213	0.0566	0.2247	-1.2848***
	(0.3359)	(0.7692)	(0.7044)	(0.0579)
R^2	0.6074	0.2908	0.6299	0.8642
Observations	46	30	45	15
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

In contrast, the technical performance in terms of line loss rate of T&D has been reduced only in northeastern provinces. It has been reduced by a large magnitude, over 100% at the one percent level. This might reflect the development slowdown in northeastern China where the operation efficiency of state-owned companies is very low, which leaves much space for these provinces to catch up.[24]

The policy treatment effect of the 2015 electricity reform on reliability is also heterogeneous across different regions both statistically and economically. The reliability has increased by

[23]The average level of coal burned for each KWh of generation before 2015 was 351.7, 369.6, and 354.2 grams in the middle, west and northeast China, respectively.

[24]The northeast provinces, with abundant natural resources, powered the early economic development in the decades after the establishment of the People's Republic of China. However, economic performance in these provinces has lagged behind the rest of the country over the last few decades. This decline in performance has been attributed to the difficulties in implementing reform in the region due to vested interest groups (Wang and Feng, 2014; Zheng et al., 2019).

around 0.14% in the west, while northeast regions have experienced reduced levels of electricity supply reliability.

Table 10: Impacts on the Supply Reliability: Regional Heterogeneity

	East	**Middle**	**West**	**Northeast**
Panel 1: Reliability				
2015 Reform	-0.0016	0.0003	0.0014*	-0.0014**
	(0.0009)	(0.0005)	(0.0008)	(0.0003)
R^2	0.5506	0.6048	0.6949	0.9870
Observations	50	29	54	14
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No
Panel 2: Supply Interruptions				
2015 Reform	1.5656**	2.4448	0.6904	1.0444***
	(0.6824)	(2.0348)	(0.5171)	(0.0241)
R^2	0.7085	0.1866	0.5396	0.9984
Observations	50	29	55	14
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

In contrast, the reform has increased the instances of supply interruptions across all regions, but such an increase also differs statistically and economically. The more developed provinces in the East experienced an increase of approximately 160% in supply interruptions, while interruptions in the northeastern provinces increased by approximately 104%. The policy effect on the other two regions is not statistically significant. This finding is consistent with the report of the State Council of China in 2018, which showed that, of the 52 major cities in China, the two cities that suffered the most supply interruptions in the first half of 2018 were Shenyang (10.44 hours per household) and Changchun (8.39 hours per household), both located in the Northeast. The larger increase in supply interruptions in eastern provinces ought to be seen in a context where the number of average supply interruption hours in this region before the 2015 reform was nearly one-third of that of the rest of the country (6.37 hours against a national average of 17.11 hours).

4.2 Grid Coverage Heterogeneity

The Chinese national grid in China was split into two grid companies, SGCC and SPGC, as part of the 2002 electricity sector reform. In addition to examining the impact across regions, as reported in the previous subsection, we examine below the impact of the reform across the coverage areas of these two grid companies, which have distinct characteristics.

Our estimates of the impact of the reform on economic performance, technical performance and supply reliability are reported, respectively, in Tables 11, 12 and 13. We note that on-grid prices of thermal energy were significantly affected by the 2015 reform. The impact, however, is highly asymmetric, with a reduction of 11% in the SGCC area, and an increase of 73% in the SPGC area. These results seem counter-intuitive at first glance. However, we note that the reduction of on-grid prices of thermal generation in the SGCC area is likely explained by the significant increase in wind and solar generation, as we discuss later in this subsection. Moreover, a closer look at the raw data on on-grid prices can help to contextualize the increase in the SPGC area, which covers the following five provinces: Guangdong, Guangxi, Hainan, Guizhou and Yunnan. The data show that on-grid prices for thermal generation saw a continuous decline in Guangdong, but prices for the other four provinces have shown a high degree of variability, reaching their lowest level in 2016, and increasing subsequently. Given that the coefficients reflect the average treatment, and measure relative rather than absolute changes, the results are consistent with the raw data.

In addition, the impact of the reform on the average retail prices of electricity (either overall or for households) for the two different areas is not statistically significant. The results are broadly consistent with what has been found in the above sections.[25]

Table 11: Impacts on the Electricity Prices: Grid Coverage Heterogeneity

Variables	**On-grid Prices**		**Retail Prices (overall)**		**Retail Prices (hh)**	
	SGCC	SPGC	SGCC	SPGC	SGCC	SPGC
2015 Reform	-0.112**	0.726*	-0.035	-0.110	0.007	-0.164
	(0.048)	(0.272)	(0.022)	(0.086)	(0.017)	(0.165)
R^2	0.7316	0.8383	0.4996	0.8972	0.1285	0.3739
Observations	124	25	115	25	115	25
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	No	No	No	No	No	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

The reform affected the different dimensions of technical efficiency differently across the two grid coverage areas. The impact on coal burned per unit of thermal generation was similar across the two areas, with a reduction of approximately 20%. These estimates are in line with the results for the full sample. The impact on line loss rates, however, is heterogeneous across the two different areas. The line loss rate has been significantly reduced in the SPGC area, while the impact in the SGCC area is not statistically significant. These results are also broadly consistent with our estimates for the full sample given that SPGC covers only five of China's 31 provinces.

The reform has had a negative impact on reliability, but the impact is small, and the impact

[25]The SGCC area covers the middle and northeastern regions, all eastern provinces except Guangdong and Hainan and all western provinces except Guangxi, Guizhou and Yunnan. The overall insignificant effect on the SGCC area is best understood when we consider that the sign of the impact of the reform on the middle region is opposite to that of the northeastern region, and that it is the same case for the east and the west. In a similar vein, the SPGC covers part of the eastern region (Guangdong and Hainan) and part of the western region (Guangxi, Guizhou and Yunnan), which have been affected by the reform in opposite ways.

Table 12: Impacts on Technical Performance: Grid Coverage Heterogeneity

Variables	**Coal Burned per KWh**		**Line Loss Rate**	
	SGCC	SPGC	SGCC	SPGC
2015 Reform	-0.207***	-0.192**	-0.049	-1.846*
	(0.0574)	(0.0557)	(0.1981)	(0.7715)
R^2	0.7881	0.8068	0.3572	0.8319
Observations	292	59	117	19
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01.

Table 13: Impacts on Reliability and Supply Interruptions: Grid Coverage Heterogeneity

Variables	**Reliability**		**Supply Interruptions**	
	SGCC	SPGC	SGCC	SPGC
2015 Reform	-0.0004	-0.0020*	0.8669***	-0.1643
	(0.0003)	(0.0008)	(0.2252)	(0.7637)
R^2	0.5447	0.5640	0.3002	0.7758
Observations	123	24	124	24
Time fixed effects	Yes	Yes	Yes	Yes
Individual fixed effects	No	No	No	No

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01.

is only statistically significant in the SPGC area. These results are consistent with the FE estimates for the full sample reported in Table 6. In contrast, the impact on supply interruptions is very heterogenous, with SGCC provinces experiencing an increase of 87% in interruptions (compared to less than 82% with the full sample), whereas the impact on SPGC areas is not statistically significant. In summary, while supply interruptions have increased markedly within the SGCC provinces, reliability has experienced a small reduction in the SPGC provinces. In summary, while supply interruptions have increased markedly within the SGCC provinces, reliability has experienced a small reduction in the SPGC provinces.

The heterogeneous impact of the reform on supply interruptions ought to be understood in the context of the different share of generation from intermittent energy (such as wind energy and solar energy) across the two grids. In particular, wind and solar generation accounts for around 1.6% of total generation in the SGCC between 2003 and 2008, and around 6.7% in 2015 - 2018. During the same periods, wind and solar generation accounted for 0.6% and 2.4% respectively, in the SPGC. Given the difference in intermittent energy generation in the two grids, it is unsurprising that supply interruptions have increased more markedly in the SGCC area.

5 Possible Mechanisms

In this paper, we have provided evidence that the 2015 reform has already had an impact on economic and technical efficiency and on reliability. The analysis above, however, is silent on the mechanisms through which the reform impacted the different variables. In this section, we posit and test two potential mechanisms through which the reform may have impacted the on-grid prices of thermal generation.[26]

5.1 Impact through Benchmark Tariffs Adjustment

Benchmark tariffs are the prices set annually based on the average costs of electricity generation in each province. They are province-specific and are usually determined by the performance of advanced generation units. Benchmark tariffs were introduced to attract investment in electricity generation at an early stage and then to provide incentives for electricity generators to control costs. On-grid prices of electricity generation by different generators are set with reference to benchmark tariffs and are adjusted according to their performance in various aspects (e.g., energy efficiency and emissions). To the extent that the reform has led to changes in benchmark prices, such change would be reflected on on-grid prices of electricity, including those for thermal generation.

In order to test the plausibility of this mechanism, we apply a two-stage least squares (2SLS) regression as follows:

$$BenchmarkP_{it} = \alpha_0 + \alpha_1 Reform_{it} + \alpha_2 X_{it} + \gamma_t + \lambda_i + \mu_{it} \tag{1}$$

$$OngridP_{it} = \beta_0 + \beta_1 BenchmarkP_{it} + \beta_2 Z_{it} + \gamma_t + \lambda_i + \mu_{it} \tag{2}$$

where i and t represent province and time, respectively. *BenchmarkP* and *OngridP* are the benchmark prices for thermal electricity set by the government and the on-grid prices of thermal electricity generation, respectively. X_{it} and Z_{it} are the array of control variables in the two equations, respectively. Equation (1) and (2) denote the regressions in the first and the second stage, respectively.

The estimation results of the 2SLS are presented in Table 14. Column (1) presents the outcomes obtained through unconditional regression. Columns (2) and (3) demonstrate the estimates with additional control variables controlled. The difference between the regressions in columns (2) and (3) is whether individual fixed effects have been considered or not.[27]

The first stage estimation results show that the 2015 reform has reduced the benchmark on-grid prices for thermal generation by over 8%. The estimates in the second stage suggest that a 1% change in benchmark tariffs leads to a 1.09% - 1.24% change in on-grid prices of thermal generation. Overall, we can see that the 2015 reform has negatively affected the benchmark

[26] We thank a thoughtful referee for suggesting potential mechanisms.

[27] When both time fixed effects and individual fixed effects are considered, the policy variable was dropped due to col-linearity in the first-stage regression. We only present the estimates without controlling for time fixed effects.

tariffs of thermal generation and that the coefficients of benchmark tariffs on on-grid prices are positive, both significant at the 1% level. With the benchmark price as an instrument in the 2SLS, we can verify the impacts of the 2015 reform on on-grid thermal electricity prices through the setting of benchmark tariffs.

5.2 Impact through Market Segmentation

The second mechanism through which reform could have impacted on-grid prices of thermal generation is through market segmentation, as measured by price dispersion between

Table 14: Impacts through the Adjustment of Benchmark Tariffs for Thermal Generation

Variables	**2SLS** (1)	**2SLS** (2)	**2SLS** (3)
Panel A: First stage	Benchmark Prices: thermal generation		
2015 Reform	-0.1068***	-0.0858***	-0.1018***
	(0.0260)	(0.0152)	(0.0146)
Panel B: Second stage	On-grid Prices: thermal generation		
Benchmark prices: thermal	1.0867***	1.2399***	1.1052***
	(0.2418)	(0.3501)	(0.1795)
Coal price		-0.0004*	-0.0002**
		(0.0002)	(0.0001)
Electricity consumption		0.0029	0.1293
		(0.0387)	(0.2271)
GDP per capita		0.1624	0.1952*
		(0.0994)	(0.1126)
Population		-0.0289	-3.5052***
		(0.0696)	(1.0416)
Urbanization rate		-0.2496	0.2386
		(0.2003)	(0.5180)
Fixed investment		0.0557	-0.0036
		(0.0396)	(0.0292)
Constant	7.0887***	5.4213***	31.4926***
	(0.2458)	(1.0975)	(7.1419)
R^2	0.4092	0.5037	0.9322
KP rk LM statistic	15.050	20.499	52.638
LM p-value	(0.0000)	(0.0000)	(0.0000)
KP rk Wald F statistic	16.854	31.755	68.765
Time fixed effects	No	No	No
Individual fixed effects	No	No	Yes
Observations	148	116	116

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

regions. In China, market segmentation arises from local governments' protectionism policies in the context of China's current political promotion system.[28] With market segmentation, inter-provincial barriers are imposed.

Theoretically, in competitive markets, a higher degree of market segmentation is often associated with market power and thus higher prices.[29] However, in China, provincial market segmentation allows local officials to pursue development policies, such as building thermal power plants, which increased supply and reduced prices, or adjusting benchmark tariffs as analyzed in Section 5.1. Ultimately, the impact of market segmentation on prices will depend on the trade-off between being able to set higher prices as a result of market power and the incentives for local officials to pursue policies that lead to an increase in supply with the view to promote economic development.

We create a market segmentation index in each province by calculating the dispersion of the relative electricity price variation compared to the national level or to neighboring provinces. To be more specific, we use the first-order difference of the logarithmic price ratio to measure the relative prices, where the difference in electricity price between provinces i and j can be expressed as follows:

$$\Delta Q_{ij,t} = |ln(p_{it}/p_{jt}) - ln(p_{it-1}/p_{jt-1})| = |ln(p_{it}/p_{it-1}) - ln(p_{jt}/p_{jt-1})|$$

$$Marketseg_{it} = Var(\Delta Q_{ij,t}) \times 1000$$

in which $Marketseg_{it}$ is the market segmentation index of the electricity industry in province i in year t, indicating the dispersion degree of relative price variation.[30] The greater the variance of the relative price in the province, the greater are the market barriers in the province. The data used to calculate market segmentation index in each province is the provincial *Fuel and Electricity Prices* from the China Statistical Yearbook.[31]

To test the impact mechanism of the 2015 reform through market segmentation, we apply the 2SLS regression as follows:

$$MarketSeg_{it} = \alpha_0 + \alpha_1 Reform_{it} + \alpha_2 X_{it} + \gamma_t + \lambda_i + \mu_{it} \tag{3}$$

$$OngridP_{it} = \beta_0 + \beta_1 MarketSeg_{it} + \beta_2 Z_{it} + \gamma_t + \lambda_i + \mu_{it} \tag{4}$$

where i and t represent province and time, respectively. X_{it} and Z_{it} are the vectors of control variables in the two equations, respectively. Equation (3) and (4) denote the regression in the first and the second stage.

The related estimation results are reported in Table 15. From the first stage regression,

[28]Under the current promotion tournament of China's political system, local officials have the incentive to focus on the development of the local economy and exert protectionism to local firms.

[29]With market segmentation, outside competitors are impeded and thus the competition level is reduced, leading to higher prices.

[30]We obtain the market segmentation index $segm_{it}$ by multiplying 1000, since the absolute value of $Var(\Delta Q_{ij,t})$ is extremely minor.

[31]The values in some provinces Xinjiang and Tibet are absent, as there is no *Fuel and Electricity Prices* variable in these places.

we can see that the 2015 electricity reform has substantially increased market segmentation (whether the index is calculated at the national level or measured based on neighboring provinces). The second stage estimation results show that the market segmentation, measured at both levels, has negatively affected the on-grid prices of thermal generation, by over 6% at 1% significance level. The estimates in Table 15 confirm that market segmentation has led to a decrease in on-grid prices for thermal generation. The results reinforce the view that government, in this case in the form of local officials who increase barriers to trade and promote local supply, likely remain more important than markets in shaping electricity sector outcomes.

Table 15: Impacts through Changing Market Segmentation

Variables	**2SLS** (1)	**2SLS** (2)	**2SLS** (3)	**2SLS** (3)
Panel A: First stage	Market segmentation: national		Market segmentation: neighbor	
2015 Reform	1.5066***	1.8530***	0.4996***	0.6896***
	(0.2357)	(0.2902)	(0.1245)	(0.1912)
Panel B: Second stage	On-grid Prices: thermal generation			
Market segmentation: national	-0.0751***	-0.0604***		
	(0.0220)	(0.0208)		
Market segmentation: neighbor			-0.2238***	-0.1542**
			(0.0866)	(0.0685)
Coal price		-0.0007**		-0.0003
		(0.0003)		(0.0003)
Electricity consumption		-0.0984		-0.1722**
		(0.0795)		(0.0816)
GDP per capita		0.4225**		0.3704*
		(0.1688)		(0.1926)
Population		0.2120***		0.2936***
		(0.0759)		(0.0744)
Urbanization rate		-0.6195*		-0.5389
		(0.3475)		(0.4270)
Fixed investment		-0.0930**		-0.0464
		(0.0455)		(0.0547)
Constant	6.1483***	1.2864	6.1115***	1.1778
	(0.0374)	(1.7531)	(0.0482)	(2.0594)
R^2	0.1135	0.2254	0.0485	0.1233
Kleibergen-Paap rk LM statistic	30.254	22.803	14.359	11.660
LM p-value	(0.0000)	(0.0000)	(0.0002)	(0.0006)
Kleibergen-Paap rk Wald F	40.863	40.768	16.115	13.010
Time fixed effects	No	No	No	No
Individual fixed effects	No	No	No	No
Observations	166	108	178	116

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

6 Conclusions and Policy Implications

Our study empirically examined the impact of the 2015 reform of China's electricity sector on economic and technical performance, and on supply reliability.

We show that the reform has led to a significant reduction in the on-grid prices of thermal energy generation, and in average retail prices. Retail prices faced by households, however, have not been impacted. Technical performance, as measured by coal burned per KWh of generation, was positively impacted, while the impact on the line loss rate of electricity transmission and distribution was negligible. Consistent with the literature on the effects of electricity reform on quality, the 2015 reform has negatively and significantly reduced supply reliability and increased supply interruptions. These empirical findings, which are robust to different specifications, highlight the need to liberalize retail prices for households, and to adopt quality of service regulation to mitigate any negative impact on supply reliability.

We also show that the results are heterogenous across different regions. In particular, we found that on-grid prices of thermal generation were reduced only in the most economically developed eastern regions, while the technical performance in terms of coal burned per unit of generation has significantly improved in all other regions but the east. Moreover, we show that in the northeast, reliability has been significantly reduced and supply interruptions have significantly increased.

Results are also heterogenous across the different areas covered by the two grid companies. In this case, we found that on-grid prices of thermal generation have been significantly reduced in the SGCC area, but increased in the provinces covered by the SPGC. We also show that reliability in the SPGC area has declined as a result of the reform, while supply interruptions in the SGCC area have increased significantly markedly.

The heterogeneous impact of the reform across regions and grid coverage areas underscores the importance of paying attention to the specific circumstances of each region. Our empirical findings suggest that the success or failure of reforms in any reforming economy such as China's is a complicated function of context specific economic as well as institutional factors. It follows that simply replicating successful reforms from elsewhere is not a guarantee of reform success unless it adequately caters for local conditions.

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Appendices

Appendix 1: Estimates with GMM and LSDVC Models

Table 16: Impacts on the On-grid Tariffs of Electricity Generated from Other Energy (GMM)

Variables	**Hydro**	**Gas**	**Wind**	**Solar**
2015 Reform	0.0434	-0.0677	0.0011	-0.1169
	(0.0439)	(0.0729)	(0.0255)	(0.0715)
L.On-grid prices: hydro	-0.0100			
	(0.1307)			
L.On-grid prices: gas		0.5688*		
		(0.2936)		
L.On-grid prices: wind			-0.0802	
			(0.1778)	
L.On-grid prices: solar				0.2057
				(0.2593)
R^2				
Observations	94	47	109	74

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01.

Table 17: Impacts on the On-grid Tariffs of Electricity Generated from Other Energy (LSDVC)

Variables	**Hydro**	**Gas**	**Wind**	**Solar**
2015 Reform	0.0712	-0.0619	0.0193	-0.0171
	(0.2445)	(0.1282)	(0.1881)	(0.2468)
L.On-grid prices: hydro	0.0175			
	(0.2056)			
L.On-grid prices: gas		0.3707		
		(0.2317)		
L.On-grid prices: wind			-0.1410	
			(0.1851)	
L.On-grid prices: solar				0.0740
				(0.2337)
R^2				
Observations	94	47	109	74

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01.

Appendix 2: Estimates with Absolute Values

Table 18: Impacts on the Technical Performance (Estimation with Absolute Values)

Variables	**Coal Burned per KWh**		**Line Loss Rate**	
	FE	**GMM**	**FE**	**GMM**
2015 Reform	-63.461***	-5.328***	-1.917	-0.608**
	(19.500)	(1.863)	(1.317)	(0.253)
Installed capacity (thermal)	-25.545*	-3.485	1.766	1.567
	(13.676)	(7.633)	(1.559)	(1.586)
Generation (thermal)l	12.636	-0.535	-2.765**	-1.505
	(12.504)	(6.815)	(1.349)	(1.368)
Running hours (thermal)	-20.794**	-5.823	1.061	3.298*
	(7.551)	(4.670)	(1.729)	(1.852)
Fixed investment	8.687**	-0.802	0.303	-0.687
	(3.322)	(2.624)	(0.539)	(0.511)
L.standard coal use		0.488***		
		(0.041)		
L.line loss rate				0.033
				(0.120)
Constant	584.308***	244.153***	1.529	-19.045
	(89.858)	(50.485)	(15.309)	(16.944)
R^2	0.784		0.441	
Observations	351	319	136	109
Time fixed effects	Yes	No	Yes	No
Individual fixed effects	Yes	No	Yes	No

Note: $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

Table 19: Impacts on the Performance of Electricity Supply (Estimation with Absolute Values)

Variables	**Reliability**			**Supply Interruptions**		
	FE	**GMM**	**LSDVC**	**FE**	**GMM**	**LSDVC**
2015 Reform	-0.038	-0.087***	-0.064***	13.030***	-10.827	-13.248
	(0.032)	(0.019)	(0.025)	(4.125)	(10.931)	(14.325)
Elec. Consum.	-0.309*	0.133	-0.029	-10.798	-1.594	40.658
	(0.174)	(0.248)	(0.219)	(24.977)	(71.889)	(138.363)
GDP per-capita	0.082	-0.135	0.112	-30.780	-12.538	-49.794
	(0.113)	(0.118)	(0.160)	(33.667)	(98.335)	(94.742)
Population	-1.078	-0.151	-2.856*	34.395	-11.155	224.093
	(1.660)	(0.296)	(1.628)	(162.300)	(46.886)	(971.364)
Fixed investment	0.048	0.027	0.029	1.520	4.940	-1.023
	(0.038)	(0.044)	(0.040)	(5.817)	(22.177)	(23.449)
L.reliability		0.582***	0.390**			
		(0.117)	(0.176)			
L.supply-interpt.					0.002	-0.083
					(0.075)	(0.168)
Constant	109.703***	43.317***		118.603	229.345	
	(12.754)	(10.959)		(1164.945)	(770.494)	
R^2	0.504			0.023		
Observations	147	114	114	148	115	115
Time FE	Yes	No	No	Yes	No	No

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01. "Elec. consum." is the abbreviation of "total electricity consumption", and "FE" is the abbreviation of fixed effects.

Appendix 3: Estimates with Data from the Wind Database

Table 20: Impacts on Line Loss Rate: Robustness Check Using the Wind Economic Database

Variables	**FE**	**GMM**	**LSDVC**
2015 Reform	-0.023	0.008	0.007
	(0.101)	(0.049)	(0.372)
Installed capacity: thermal	-0.152	-0.059	-0.077
	(0.175)	(0.181)	(0.426)
Generation: thermal	0.195*	0.021	0.144
	(0.096)	(0.165)	(0.445)
Running hours: thermal	-0.057	-0.011	-0.055
	(0.062)	(0.186)	(0.225)
L.line loss rate		0.430***	0.551**
		(0.057)	(0.234)
Time fixed effects	Yes	No	No
Individual fixed effects	No	No	No
Observations	306	274	274

Note: $*$ p < 0.1, $**$ p < 0.05, $***$ p < 0.01.