Regional Electricity Demand and Economic Transition in China

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Abstract

China's economy is going through a major transition, characterized by a slower growth rate, a structural shift to the tertiary (service) sector, and industrial deleveraging—a process to reduce overcapacity that has built up in key industrial sectors over the past decades. Given the uncertainties that China is facing during its current economic transition, it is important to examine whether future electricity consumption will continue to grow rapidly or grow more slowly in the medium term. This analysis examines the relationship between electricity consumption, gross domestic product (GDP), economic structure, and overcapacity in heavy industries in China, using provincial-level data from 1995–2015. The results provide valuable insight on the trend in future electricity demand, given that key features in China's economic transition are likely to continue in the foreseeable future.

Keywords: Electricity consumption, economic structure, overcapacity, China, panel analysis

1. Introduction

After 35 years of rapid growth, China's economy is going through a major transition, characterized by a slower growth rate, a structural shift to the tertiary (service) sector, and industrial deleveraging—a process to reduce overcapacity that has built up in key industrial sectors over the past decades. China's gross domestic product (GDP) growth rate was 7.3 percent in 2014, 6.9 percent in 2015, and 6.7 percent in 2016 [1]. Contribution of the tertiary sector to total GDP has exceeded 50 percent since 2015 and grew to 51.6 percent in 2016 [1]. The growth of the six energy-intensive industries (i.e., processing of petroleum, coking, and processing of nuclear fuel; manufacture of raw chemical materials and chemical products; manufacture of non-metallic mineral products; smelting and pressing of ferrous metals; smelting and pressing of non-ferrous metals; and production and supply of electric power and heat) decreased from 7.5 percent in 2014 to 6.3 percent in 2015, and further decreased to 5.2 percent in 2016 [1–3].

All of these factors have a profound impact on China's energy demand and electricity consumption. As a result of rapid expansion over the past three decades, China has the largest electric power system in the world, with an installed power generation capacity of 1,650 gigawatts (GW) and a total generation of 5,990 terawatt-hour (TWh) in 2016 [4]. However, the rapid growth in China's electricity use has slowed significantly in recent years. Electricity growth slowed to 3 percent in 2014 [5] and to 0.96 percent in 2015 [6]; however, it bounced back to 5 percent in 2016 [4].

Projection on future electricity consumption is indispensable for power system planning and for making sound investment decisions. Many studies by Chinese and international institutions before 2015 projected fast growth in electricity use [7–11]. The newly released National 13th Five-Year Plan (FYP) for Electricity Development forecast future electricity consumption reaching 6,800 TWh to 7,200 TWh by 2020, with a projected annual growth rate of 3.6 percent to 4.8 percent [12]. Given China's current trend of economic transition, it is important to examine whether future electricity consumption will remain at a high growth or the existing slowdown in electricity use represent a pivot in China's energy and economic dynamics. Our hypothesis is that the recent slowdown in China's electricity use reflects a fundamental shift in China's evolving economic transition, characterized by the following:

(1) an economic slowdown from an average of 10 percent growth for the past three decades to a sub-7 percent growth rate in 2015;

(2) the growth of the tertiary (services) sector, which is less energy-intensive, as China moves from an investment-based economy to a consumption- and services-based economy; and

(3) a decline in the output of heavy industrial products, due to excess capacity and slowdown in demand for such products.

This analysis examines the relationship between electricity consumption and GDP, economic structure, and industrial deleveraging in light of China's economic transition.

We argue that these trends in economic transition are likely to continue in the foreseeable future; therefore, their influence on electricity use is likely to remain negative going forward and result in slower growth of electricity consumption in the future. Our research can be used to help policy-makers make informed, scientifically based decisions on power system planning and investment in China.

This paper is organized as follows: Section 2 reviews previous studies on forces driving electricity consumption and electricity demand forecasting. Section 3 describes the econometric models used in this study to examine the impact factors of electricity consumption in China since 1995, and includes the data set. Section 4 presents results and an electricity demand forecast for China in 2020 using the models discussed in Section 3. The final section provides our conclusions.

2. Literature Review

Current literature on electricity consumption and economic growth mainly focuses on two categories: (1) the causal relationship between them, and (2) the influence of different economic variables and/or demographic variables on electricity consumption, as well as electricity forecasting. Although our analysis focuses on the second—the correlation between electricity consumption and economic growth—we conducted a literature review on both categories to present a whole picture of the current academic literature in this topic.

2.1 Forces driving electricity consumption

International studies found mixed results on the causal relationship between electricity consumption and economic growth. Acaravci and Ozturk (2010) examined the long-term relationship and causality between electricity consumption and economic growth in 15 European transition countries using the Pedroni panel cointegration technique for the period of 1990–2006 [13]. They found no causal relationship between electricity consumption and economic growth in any of these 15 countries. Wolde-Rufael (2014) reexamined the causal relationship in these countries using a bootstrap panel causality approach using data over the period of 1975–2010 and found that some countries have unidirectional causality, some have bidirectional causality, and some do not show causality in any direction[14]. Ciarreta and Zarraga (2010) examined the long-run and causal relationship between electricity consumption and GDP for 12 European countries using national-level data from 1970–2007 and found a unidirectional causal relationship from energy consumption to GDP [15]. Osman et al. (2016) investigated the relationship between electricity consumption and economic growth in the Gulf Corporation Council countries using panel data analysis with annual data from 1975 to 2012 and found bidirectional causality between economic growth and electricity consumption [16].

International studies that include analysis on China include Cowan et al. (2014), Chen et al. (2007), Karanfil and Li (2015)[17–19]. China-specific analysis include Shiu and Lam (2004), Yuan et al. (2007)and Cheng et al. (2013)[20–22]. Two studies found no causality relationship between electricity consumption and GDP in China [17,18], one found short-run or little unidirectional causality from GDP to electricity [19], and three found unidirectional causality from electricity consumption to GDP [20–22].

Table 1 shows a summary of results from the studies mentioned above. Zhang et al. (2017) [23] has a more comprehensive summary on different studies on causality studies between electricity consumption and economic growth. Based on the review of studies in China, they concluded that the causal relationship between electricity consumption and economic growth varies across provinces in China and electricity consumption reduction in China is the result of economic structural optimization and industrial transformation. They also believe that more quantitative empirical research is needed to study the relationship between electricity consumption and economic growth.

Table 1. Summary of literature results from causality tests between electricity consumption and GDP

Authors	Countries	Methodology	Causality relationship
Acaravci and Ozturk (2010) [13]	15 European transition countries	Pedroni panel cointegration	No long-term equilibrium relationship between electricity consumption per capita and real GDP per capita
Wolde-Rufael (2014) [14]	15 European transition countries	The Konya (2006) bootstrap panel Granger causality approach	Unidirectional Granger causality from electricity consumption to economic growth in two countries and the other way around in four countries; bidirectional causality in one country; no Granger causality in any direction in the rest of the countries
Ciarreta and Zarraga (2010) [15]	12 European countries	Panel unit root tests and panel cointegration tests, fully modified OLS, panel system GMM	Unidirectional and negative short-run and strong causal relation from energy consumption to GDP
Osman et al. (2016) [16]	Gulf Corporation Council countries	Dynamic panel data analysis: PMGE, demeaned PMG, AMG, MGE, and DFE	Bidirectional causality between economic growth and electricity consumption
Cowan et al (2014) [17]	BRICS countries	The Konya (2006) bootstrap panel Granger causality approach	Neither electricity consumption nor economic growth is sensitive to each other in Brazil, India, and China.
Chen et al. (2007) [18]	10 Asian developing countries	Error-correction model for a single country and panel Granger causality test	No causality relationship between electricity consumption and GDP were found in China for a single-country analysis; panel causality test found a bidirectional long-run causality and a unidirectional short-run causality from economic growth to electricity consumption.
Karanfil and Li (2015) [19]	160 countries	Panel unit root, cointegration, and causality tests	GDP and electricity consumption present only short-run or little causality for wealthy economies, whereas their relationship tends to be stronger in the long run for low-income economies.
Shiu and Lan (2004) [20]	China	Error-correction model	A unidirectional relationship running from electricity consumption to real GDP
Yuan et al. (2007) [22]	China	Co-integration test	There exists Granger causality running from electricity consumption to GDP, but

			not the other way around, from 1978 to 2004.
Cheng et al. (2013) [21]	China	Log-linear regression model	Growth in power generation led to GDP growth from 1953 to 2010, but not the other way around.

2.2 Electricity demand forecasting

Studies on impact factors in New Zealand and Italy found GDP, electricity price, and population all have effective impacts on electricity consumption, though the Italy study showed price elasticity of electricity consumption is limited [24,25]. Mohamed and Bodger (2005) applied multiple linear regression techniques to examine the impact of GDP, average price of electricity, and population on electricity consumption in New Zealand [24]. Using national-level data during the period 1965–1999, the study found the explanatory variables considered performed effectively in forecasting electricity consumption based on statistical tests. Bianco, Manca and Nardini (2009) also used multiple linear regression models to investigate the GDP, electricity price, and GDP per capita elasticities of domestic and non-domestic electricity consumption in Italy [25]. Using national-level data over the period of 1970–2007, the study found that price elasticity of electricity consumption is limited, but GDP and GDP-per-capita elasticities showed higher values. The study also developed different long-term forecasting models, which led to similar results on future electricity consumption among these models.

Our study reviewed two national, China-specific studies on the driving forces of electricity consumption. The driving forces examined were GDP, population, electricity price, structural change, energy efficiency, and heavy industry capacity elimination. Lin (2003) [26] applied a cointegration approach to evaluate the impacts of GDP, fuel price, population, economic structural change (total industrial output subtracting heavy industry output), and energy efficiency on electricity consumption using national level-data from 1952–2001. The study found that all the independent variables have long-term relationships with electricity consumption. Elasticities of GDP, fuel price, population, economic structural change, and energy efficiency on electricity consumption are 0.78, -0.016, 0.565, -0.527, and -0.332 for the period from 1978–2001, respectively. Song et al. (2017) [27] used a modified firefly algorithm to quantify the impact of heavy industry capacity elimination policies on electricity consumption in China and found that electricity demand increases with the growth of GDP, industry structure, and population, but it could be reduced with capacity elimination policies.

As the economic transition happens in China, two recent studies have explored the impacts of structural change on electricity consumption growth in a specific Chinese province. Ge et al. (2017) used multivariable regression to explore the reasons of the deviation between economic growth and electricity consumption in Anhui Province [28]. The analysis found that real GDP, industrial structure (the share of large industrial enterprises value-added as of total GDP), heating degree days, cooling degree days, and investment in fixed assets all have positive effects on electricity consumption, while energy intensity and financial development are negative factors. The analysis found that industrial structure is the major contributor to electricity consumption growth, and the reduction of energy intensity and the growth of the financial industry contribute to the deviation between the economic growth rate and electricity consumption. He et al. (2017) [29] quantified the impacts of the economic new normal in China on electricity consumption of Tianjin using econometric analysis for each sector, including the primary sector, sub-industrial sectors, sub-tertiary sectors, and residential living. This study includes the factors of the economic new normal by adding independent variables such as the Internet age, marketization reform, technological progress, and consciousness of energy conservation and emission reduction. The study found that under the new economic situation, the main driving force of electricity consumption growth is the tertiary industry and residential living (proportion of output value 73 percent, 2035–2040) instead of energy-intensive industries.

Regarding electricity forecasting in China, many studies have projected electricity consumption in 2020 to be in the range of 6,500 terawatt-hours (TWh) to 7,800 TWh. Figure 1 provides the electricity projections of the estimations in the 13th FYP and four recent studies: the International Energy Agency's (IEA)*World Energy Outlook 2014* [10], the *2050 China Economic Development and Electricity Demand Study* by the Intelligent Laboratory for Economy-Energy-Electricity-Environment (ILE4) [7], the Energy Research Institute's China *2050 High Renewable Energy Penetration Scenario and Roadmap Study* (High RE) [11], and Lin et al. (2015) [31]. Xu et al. projected even higher electricity consumption in 2020, with over 10,000 TWh using an optimized hybrid grey projection model [30].

Figure 1. Electricity consumption in 2015 and its projection in 2020 in China

Note: S1, S2, and S3 are three scenarios presented by ILE4 [7]. The IEA and High RE reports only provide electricity generation; we subtract transmission and distribution losses (6 percent assumed) and import/export balances which are negligible in China [10,11]. Lin et al. (2015) has three functional forms: linear, polynomial, and logarithm [31]. Low 13th FYP and High 13th FYP are the two scenarios indicated in the 13th FYP [12].

Given the existing economic transition in China, this study examined the correlation between economic development and electricity consumption, considering structural change and heavy industry overcapacity reduction, to explain their impact on electricity consumption. We used provincial-level time series data to capture provincial differences, as the provinces are under different stages of economic development. Differing from the relatively high electricity growth projection of many studies in China, this study provides a perspective on future electricity consumption in 2020 that considers the economic transition happening in China.

It is unique among the electricity growth studies of China because it: (1) uses provincial panel data analysis in China to examine the relationship between electricity consumption and economic growth; and (2) captures both structural change and heavy industry overcapacity reduction to reflect the current economic transition in China.

3. Methods

3.1. Econometric model

As we focus on evaluating the relationship between economic growth and electricity consumption, we use linear and log-linear regressions, which are believed to be an effective way to deal with the relationship between variables [29]. We do not include electricity price in the model, as its elasticity on electricity consumption was found to be small in the literature [25,26].

We considered the following econometric model [24]:

$$y_{it} = Z_{it}\beta + \eta_i + \varepsilon_{it}$$

where y_{it} is total electricity consumption (***TotalETWh***) of province i in year t; Z_{it} is a vector of exogenous variables, including total GDP, industry composition, heavy industry capacity, and population; β is a vector of parameters; η_i represents the individual effect, capturing the idiosyncratic characters of each province; and ε_{it} is the error term.

We also estimated the elasticity of economic growth on electricity consumption [25,26]:

$$Lny_{it} = LnZ_{it}\beta + \eta_i + \varepsilon_{it}$$

The exogenous variables contained in the model are listed below:

Total GDP (denoted as ***TotalGDPReal***) is the total provincial GDP for a specific year that was deflated using a national GDP deflator from 2010 constant yuan. This variable describes the economic development, which pushes up the electricity consumption.

Population (denoted as ***Population***) is the total population for each province at a specific year. As an explanatory variable, the larger the population, the more electricity demand there will be. At the same time, it can control the size (weight) for different provinces.

Heavy industry capacity (denoted as ***CrudeSteelOutput***) is used to measure the overcapacity of heavy industry in China. We use crude steel output for each province as a proxy of the heavy industry capacity. We expect the heavy industry growth would drive the electricity consumption up.

Economic structure (denoted as ***TertiaryGDPShare***) affects electricity consumption through transformation of economic structure. In our analysis, we measured the effects of structural change by the share of tertiary industry total valued added as of total GDP.

3.2. Data sets

Total GDP, value-added of the tertiary industry, and population data of 30 provinces in China for 1995–2015 are from China Statistical Yearbooks, accessed from the China Data Online [32].

Total GDP and tertiary GDP were deflated using a national GDP deflator using 2005 constant yuan, from the World Bank [33]. Data for provincial total electricity consumption are extracted from the Energy Balance Sheet for each province in the China Energy Statistical Yearbooks [34]. Data for crude steel output at the provincial level are from the online database of the National Bureau of Statistics of China [32].

Total electricity consumption of each province for selected years are listed in Table 2. Significant consumption growth happened in all provinces.

Table 2. Total electricity consumption by province in 1995, 2000, 2005, 2010, and 2015

Province	Total Electricity Consumption (TWh)				
	1995	2000	2005	2010	2015
Anhui	26	34	58	100	154
Fujian	24	37	70	123	180
Jiangsu	64	91	202	360	492
Shanghai	38	53	87	123	133
Zhejiang	40	67	154	270	342
Beijing	24	35	53	78	89
Hebei	57	76	140	252	298
Inner Mongolia	19	26	67	154	254
Shandong	74	100	200	330	518
Shanxi	37	48	89	27	164
Tianjin	17	22	37	17	80
Chongqing		30	32	60	83
Henan	52	67	130	235	304
Hubei	37	50	80	133	177
Hunan	34	37	62	126	143
Jiangxi	17	20	38	65	102
Sichuan	54	48	85	140	184
Gansu	23	28	47	76	105
Ningxia	9		29	53	85
Qinghai	6	11	21	45	64
Shaanxi	22	29	49	80	122
Xinjiang	12	17	28	61	205
Guangdong	72	124	254	384	507
Guangxi	20	30	47	93	125
Guizhou	19	32	52	77	107
Hainan	3	4	8	15	26
Yunnan	21	29	51	93	132
Heilongjiang	41	38	53	75	87
Jilin	26	27	38	58	65
Liaoning	59	75	105	161	189

Some total electricity consumption and crude steel output data are missing; these are presented in Table 3.*

Table 3. A summary of missing data

Variables	Province	Year
Total electricity consumption	Chongqing	1995, 1996
Crude steel output	Chongqing	1995
	Hainan	2010–2013
	Ningxia	2001, 2008–2010

* Chongqing was part of Sichuan Province before 1997, so total electricity consumption in Chongqing for year 1995 and 1996 should be included in the data for Sichuan Province.

The descriptive statistics of the dependent and independent variables variables are summarized in Table 4.

Table 4. Descriptive statistics of variables

Variables	Definition	Units	Obser-vation	Mean	S.D.	Min	Max
TotalETWh	Total electricity consumption	TWh	628	92.09	90.02	2.8	518
TotalGDPReal	Total Real GDP	100 million 2005 yuan	630	7778	8086	222	49662
Population	Population	10,000 ppl	630	4,300	2,624	481	11,430
CrudeSteelOutput	Heavy industry capacity	10,000 tons	621	1,336	2,292	0.01	18,850
TertiaryGDPShare	Economic structure		630	0.4033	0.0772	0.2766	0.7965

4. Results and Discussion

4.1. Estimation results

We first regressed electricity consumption on total GDP, tertiary share, crude steel output, and population in a linear form using least squares with dummy variable (LSDV) to control for the unobserved heterogeneity for each province by introducing a province dummy. To control for common and exogenous shocks for all provinces, such as the entrance of China into the World Trade Organization (WTO) in 2001 and the global financial crisis in 2008, years were included in Model 1. Table 5 lists the regression results. All factors considered had significant and expected effects on electricity consumption.

In the LSDV Model, the degree of freedom was reduced by N variables of province dummy. To avoid introducing so many constraints in the regression model, we applied a fixed effects model (FE) which used within-group estimates to deal with individual fixed effects. As with the previous models, year variables were used to control time trend. We used fixed effects estimators or random effects estimators in Model 2. Hausman tests showed that fixed effects estimators are preferred for Model 2. Estimated parameters for all independent variables were the same, but the tertiary share did not have a significant negative effect on electricity consumption.

4.2 Elasticity estimation

We then used the log-log function form to test elasticity of electricity demand as of GDP, crude steel production, population, and tertiary GDP share†. Model 3 used LSDV to capture differences in provinces. Gross domestic product, crude steel production, and population all had significant positive effects on electricity consumption, while the tertiary share had a significant negative effect on electricity consumption. Model 4 can be estimated by the fixed effects estimator or the random effects estimator. The results of Hausman tests showed that fixed effects estimators are preferred for Model 4. All independent variables had significant effects on electricity consumption.

Table 5. Regression results

	Model 1 LSDV	Model 2 FE	Model 3 LSDV	Model 4 FE
GDP	0.0095*** (0.0003)	0.0095*** (0.0006)	0.882*** (0.022)	0.882*** (0.050)
Tertiary Share	-64.96*** (22.25)	-64.96 (55.03)	-0.881*** (0.177)	-0.881** (0.388)
Crude Steel Output	0.0049*** (0.00039)	0.0049*** (0.0009)	0.056*** (0.012)	0.056** (0.021)
Population	0.0097*** (0.0019)	0.0097** (0.0036)	0.588*** (0.119)	0.588* (0.308)
Year	0.91*** (0.23)	0.91 (0.57)		
Province dummy	Yes		Yes	
Constant	-1856*** (457.6)	-1827 (1147)	-8.71*** (0.97)	-8.13*** (239)
R-squared	0.9684	0.9039	0.9777	0.7859
No. observations	620	620	620	620
Individuals		30		30
Estimation	LSDV	FE	LSDV	FE

Note: Robust standard errors are reported in parentheses. *, **, *** indicates significance at the 10%, 5%, and 1% level, respectively.

4.3. Discussions

We used models (model 1 and model 3) with provincial fixed effects to forecast future electricity consumption for each province in 2020, then the sum of electricity consumption in each province was the total electricity consumption for China. Assumptions for GDP growth rates, tertiary share and population at the provincial level were based on provincial 13th FYPs‡. Based on provincial level plans, in 2020, national GDP grows at an annual rate of 7.5%, much higher than the goal of 6.5% in the national 13^{th} FYP, and tertiary share is about 54%, lower than the national goal of 56%. For population, sum of provincial level population is approximately the same as the national goal of 1420 milion people in 2020. To compare with the electricity demand estimation

† Tertiary GDP share was not transformed into log form as the coefficient of it means one percent change in GDP share induces how much changes in electricity consumption.

‡ For provinces that couldn't find numbers, we kept them the same as the 2015 level for population and tertiary share, and assumed a 6.5% growth rate for GDP.

in the 13th FYP, we adjusted provincial level GDP, tertiary share, and population to be consistent with the national 13th FYP. GDP growth rate for each province was multiplied by a factor to slower down to the national goal of 6.5% annual growth rate. Similar adjustments were made to tertiary share so that national tertiary share reached 56%.

For crude steel production, there is litte reference for future production projection for each province. So we first kept crude steel production for each province stayed at the 2015 levels. Under this assumption and after adjustment of GDP, tertiary share and population, model 1 projects total electricity consumption to be 7328 TWh and model 3 projection is 6661 TWh, with annual growth rates 3.2% to 5.2%, respectively.

However, at the national level, total crude steel production was estimated to reduce to 725 million tons, about 10% reduction compared to the 2015 level [35]. This will further contribute to a 0.57% reduction to total electricity demand by 2020 based on model 3, assuming all provinces have the same percentage of reduction of crude steel production by 2020.

Figure 2 shows the contribution of GDP, tertiary share, crude steel output, and population to the total electricity demand. The growth of GDP contributes to 4.4 percent annual growth to electricity consumption by 2020. Adding the population growth, the annual growth rate of electricity consumption increases to 4.7 percent. A structure shift to the tertiary sector contributes to a 1.5 percent decrease of the growth rate. Including the 0.57 percent decrease resulting from the reduction of crude steel production, annual growth rate of electricity demand would be 3.1 percent.

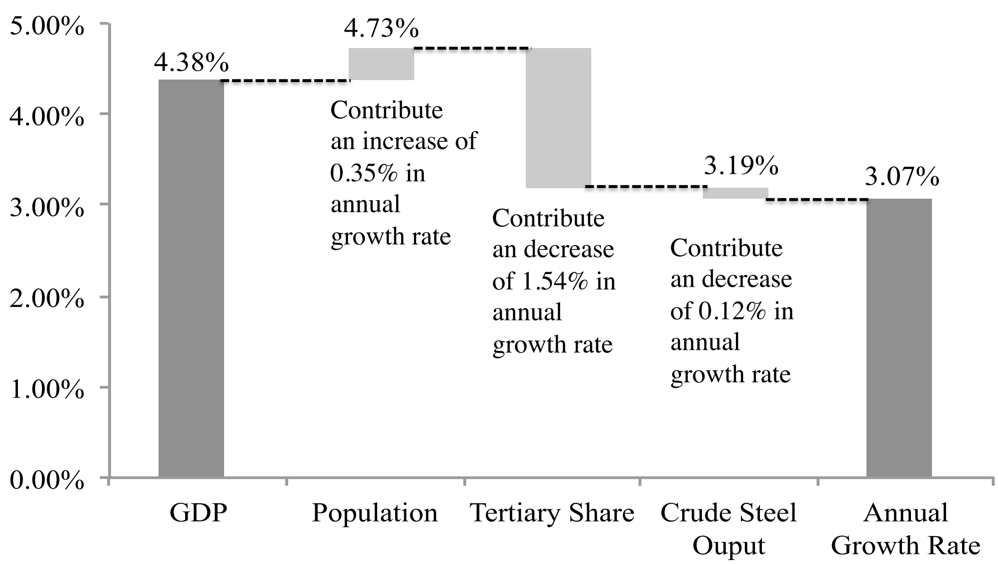

Figure 2 Contribution of GDP, structural change, overcapacity, and population to electricity demand

5. Conclusions

After 35 years of rapid growth, China's economy is going through a major transition, characterized by a slower growth rate, a structural shift to the tertiary sector, and industrial deleveraging—a process to reduce overcapacity that has built up in key industrial sectors over the past decades. All these trends have contributed to a significant slowdown in demand growth for electricity in China in recent years.

At the same time, China's power sector is also going through profound regulatory and technological changes, driven in part by China's commitment to clean energy targets under the Paris Agreement, i.e., achieving 20 percent of its energy from non-fossil energy sources by 2030, most of which would be in the form of non-fossil generation in the power sector. While China leads the world in investing in renewable electricity sources, there is also a widespread overcapacity for coal-fire power plants, and significant curtailment of wind, solar, and hydro power. A careful integrated resource planning process and methodology is essential to avoid such pitfalls and achieve the multiple objectives of economic efficiency, power systems reliability, and environmental goals.

Understanding the trend in demand growth is a fundamental part of this planning process. Our hypothesis is that demand growth in electricity is plateauing due to ongoing economic transition and restructuring. The results of our regression analysis show that GDP, population, economic structural change, and industrial capacity all have statistically significant influence on electricity demand.

Among the leading factors affecting electricity demand growth, GDP continues to be the most significant driver for demand growth for power, followed by economic structural change, population growth and industrial de-leveraging. Our results on GDP elasticity, structural shift elasticity and population elasticity on electricity consumption are consistent with those results from Lin (2003), who used national data with earlier years. These results suggest that electricity demand growth is likely to slow down in the near future due to the ongoing economic strucutual change.

In addition, continued technological progress will improve the efficiency of energy use, which tends to further dampen demand growth. On the other hand, electrification of end-use energy could stimulate great use of electricity. Such factors deserve further analysis in future studies.

The difference of future electricity projection between the linear model and the log-linear model, along with the huge variance on electricity consumption of other studies, indicates significant uncertainty in the future electricity growth. Such uncertainty implies great risks in investing in new generating and transmission capacity, especially under the condition of excess generating capacity in China today. To manage such risks, a more transparent, robust, and dynamic planning methodology and process is essential. In addition, China should consider other market instruments to help guide its investment in the power sector.

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