Modeling and Forecasting the Energy Efficiency and Consumption in China: A Fixed-Effect Panel Stochastic Frontier Approach

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Introduction

As China's economy has achieved great success by expanding more than four folds during the past three decades, two extraordinary phenomena in China's energy economy were also observed. First, China has become the world's largest consumer of energy products with its primary energy consumption reaching 3.5 trillion TCE in 2010 and global share accounting for over 20% of world's total consumption. Second, energy consumption per unit of GDP, which is known as the energy intensity, has declined from 15.7 TCE/10,000 RMB to 4.2TCE/10,000 RMB (in 1995 price), indicating a dramatic improvement in energy efficiency.

These two phenomena are closely related to two groups of empirical studies of China's energy economy. The first group of studies is to estimate the short-run and long-run income and price elasticities of energy demand and provide the future energy demand forecast. Most of these studies employ the time series techniques, including vector error correction model(Chan and Lee, 1997; Lin, 2003; Lee and Chang, 2008), vector autoregression (Crompton and Wu, 2005), cointegration analysis and Granger-causality analysis (Soytas and Sari, 2006, Zou and Chau, 2006). Other methods include dynamic OLS (Masih and Masih, 1996), Energy Balance Model (Adams and Shachmurove, 2007), spatial econometrics (Cattaneo et al., 2011).Almost all the estimated income elasticities are less than unity, range from ? to ?.

The second group of studies analyzes the factors that are responsible for the energy intensity decline (or improved energy efficiency). Most of these studies employ the decomposition analysis which decomposes the change of energy intensity into two components, one due to individual industrial energy intensity and the other due to its output share. A few studies adopt other methods including input-output model or econometric analysis to identify the roles of more fundamental factors such as income and energy prices.

To have a good forecast of future energy demand, it is important to take into account the changing energy efficiency in addition to have good estimates of income and price elasticities. In the standard energy demand econometric estimation efficiency change is usually not explicitly taken into account but rather embodied in the technological change as well as in the error term. Filippini and Hunt (2011) innovatively use a stochastic demand frontier approach to model the energy demand and energy efficiency simultaneously for a panel of OECD countries in which the energy efficiency is measured as the difference between the observed energy use and the frontier (i.e., the best performance energy use).

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The aim of this paper is to forecast the energy consumption of China by explicitly accounting for the energy efficiency improvement. A "frontier" function of energy consumptions for Chinese provinces is first econometrically estimated using a panel dataset over the period 1995 to 2011. The factors which may affect the energy demand as well as the energy (in)efficiency are identified. The "frontier" gives the minimum level of energy consumption necessary for an economy to produce a given level of energy service. The difference between the observed energy use and the "frontier" (i.e., the best performance energy use) represents the inefficiency level. The model is then used to forecast the energy consumption between 2012 and 2020.

Three contributions are made to the existing literature. First,

Second, use the provincial level data.

Third, extend the Filippini and Hunt (2011)

The paper is organized as following.

Method and Data

From the standard production theory the energy demand is a derived demand which is a function of output and energy price along with other shifters. Following Filippini and Hunt (2011, 2012), we use the stochastic frontier function to model the aggregate energy demand which explicitly take into account the effect of energy efficiency. Specifically, the energy demand function is specified as follows,

$$y_{it} = \alpha_i + x_{it}\beta + \varepsilon_{it} \quad (1) \qquad \varepsilon_{it} = v_{it} + u_{it} \quad (2)$$

$$v_{it} \sim N(0, \sigma_v^2) \quad (3) \qquad u_{it} = h_{it} u_i^* \quad (4)$$

$$h_{it} = f(z_{it}\delta) \quad (5) \qquad u_i^* \sim N^+(\mu, \sigma_\mu^2) \quad (6)$$

$$i = 1, \ldots N, t = 1, \ldots T.$$

where the dependent variable (y_{it}) is the natural logarithm of aggregate energy consumption and x_{it} is the vector of explanatory variables including the time trend (a proxy for the technological progress), the GDP, the energy price and population, the shares of value added of industrial and service sectors, all of which are expressed in natural logarithm. Furthermore, the error term in equation (1) is composed of two independent parts. v_{it} is the usual error term capturing the effect of noise and follows a normal distribution. The other part of the error term is u_{it} , which can be interpreted as indicator of inefficient use of energy, that is, the "wasted energy".

This study is based on a balanced panel dataset for a sample of 27 Chinese provinces over the period 1995 to 2010. All the data are taken from China's Statistical Yearbook or

China Compendium of Statistics (1949-2008) except the marketization index, which is taken from Fan et al. (2011).

Table 1. Data Description and Summary Statistics

Dependent Variable	**Name**	Mean	Std Dev	Min.	Max.
Energy consumption (in 1000 TCE)	E	378 7162	4970	688	32225
Energy Demand Frontier function					
GDP (in 100 million 1995RMB)	GDP	378 4363	3879	168	24207
Energy price	price	378 117.47	23.20	84.42	234.4
Population in 10000	Pop	378 4618	2698	481	11625
Share of industrial sector in % of GDP	ssh	378 46.52	6.19	25.70	61.50
Share of service sector in % of GDP	ish	378 37.31	6.69	24.60	73.20
Capital labor ratio	KL	378 1.62	2.11	0.08	11.40
Efficiency function					
ratio of investment to total capital	IK	378 0.77	0.43	0.18	2.72
ratio of urban population	Urban	378 0.41	0.15	0.08	0.89
Share of FDI in the investment	FDI	378 0.09	0.09	0.00	0.52
the ratio of export to GDP	Open	378 0.27	0.37	0.00	2.05
Indicator of marketilization level	Market Index	378 3.61	1.88	0.40	9.67

Table 2. Estimation Results

	Battese and Coelli (1995)		Wang and Ho (2010)	
	Coefficient	P-value	Coefficient	P-value
Frontier function				
Constant	-1.817*	0.101		
Price	0.472**	0.026	-0.020	0.846
GDP	0.440***	0.005	0.848***	0
Pop	0.302**	0.039	0.325	0.179
SSH	0.009	0.17	0.0005	0.954
ISH	0.024***	0.003	0.006	0.156
KL ratio	0.015	0.374	-0.032**	0.029
Trend	0.045**	0.039	-0.202***	0
Efficiency function				
Constant	1.04	4.34		
IK ratio	-0.2	-2.4	-0.504**	0.02
Urban	0.25	1.55	-1.2	0.11
FDI	-0.9	-2.3	-0	0.98

Open	-0.1	-0.7	0.84	0.22
Market Index	-0	-1.6	-0.192***	0
Trend	-0.1	-3.3	-0.046***	0

Table 3. Energy Efficiency: Efficiency Score *vs.* Energy Intensity

	Energy Score	**Ranking**	**Energy Intensity**	**Ranking**
Beijing	**0.958**	**1**	**0.58**	**1**
Tianjin	**0.913**	**5**	**0.89**	**7**
Hebei	**0.550**	**20**	**1.6**	**22**
Shanxi	**0.921**	**4**	**2.15**	**27**
Inner Mongolia	**0.484**	**24**	**1.69**	**24**
Liaoning	**0.786**	**9**	**1.48**	**19**
Jilin	**0.924**	**3**	**1.14**	**17**
Heilongjiang	**0.948**	**2**	**0.98**	**10**
Shanghai	**0.474**	**26**	**0.77**	**5**
Jiangsu	**0.655**	**16**	**0.69**	**4**
Zhejiang	**0.560**	**19**	**0.6**	**2**
Anhui	**0.794**	**8**	**0.91**	**8**
Fujian	**0.48**	**25**	**0.77**	**6**
Jiangxi	**0.7**	**15**	**1.04**	**12**
Shandong	**0.05**	**27**	**0.93**	**9**
Henan	**0.58**	**18**	**1.1**	**15**
Hubei	**0.7**	**14**	**1.2**	**18**
Hunan	**0.74**	**12**	**1.09**	**14**
Guangdong	**0.77**	**10**	**0.65**	**3**
Guangxi	**0.54**	**22**	**1.12**	**16**
Sichuan	**0.59**	**17**	**1.08**	**13**
Guizhou	**0.72**	**13**	**1.92**	**25**
Yunnan	**0.55**	**21**	**1.56**	**21**
Shaanxi	**0.89**	**6**	**1**	**11**
Gansu	**0.8**	**7**	**1.5**	**20**
Qinghai	**0.53**	**23**	**2.07**	**26**
Xinjiang	**0.76**	**11**	**1.68**	**23**

Forecast of Energy Consumption between 2009 and 2015

Based on our model estimation, the predicted energy consumption for *ith* province in time $T+h$ can be calculated as

$$E(E_{iT+h}) = \hat{\alpha}_i + \hat{\beta}_y y_{iT+h} + \hat{\beta}_p p_{iT+h} + \hat{\beta}_{pop} pop_{iT+h} + \hat{\beta}_I ISH_{iT+h} + \hat{\beta}_S SSH_{iT+h} + E(u_{iT+h})$$

where $E(u_{iT+h})$ is computed as

$$E(u_{iT+h}) = \exp(\hat{\delta}_i ik_{iT+h} + \hat{\delta}_o open_{iT+h} + \hat{\delta}_m marketindex_{iT+h} + \hat{\delta}_f FDI_{iT+h} + \hat{\delta}_u urban_{iT+h}) * \hat{u}_i^*$$

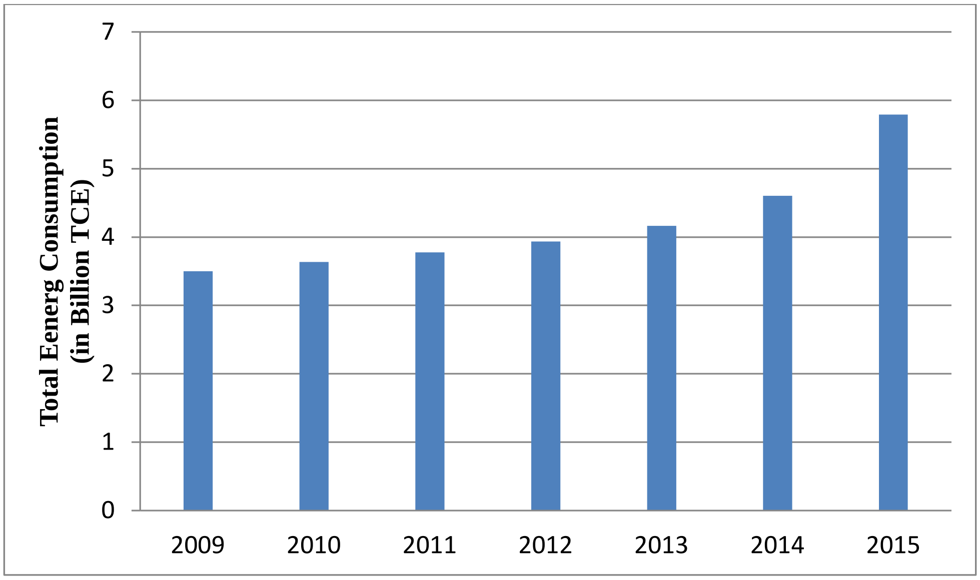
The future values of the explanatory variables need to be computed at provincial level for 7 years ahead. We take a naïve approach, assuming variables increase at fixed growth rates. The growth rates for GDP and urbanization are taken from 12th Five Year Plans announced by the provincial government. Other variables such as capital, labor, FDI, export etc are assumed to increase at the average growth rate of the sample years (1995-2008).

Table 4. Forecast of Energy Consumption at Provincial Level (in 1000 TCE)

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Beijing	**7101**	**7071**	**6930**	**6664**	**6271**	**5758**	**5148**
Tianjin	**6033**	**6124**	**6108**	**5970**	**5702**	**5311**	**4820**
Hebei	**24286**	**24731**	**25096**	**25401**	**25728**	**26255**	**27353**
Shanxi	**15481**	**16253**	**16802**	**17047**	**16928**	**16408**	**15492**
Inner Mongolia	**16128**	**16672**	**17169**	**17653**	**18213**	**19038**	**20538**
Liaoning	**20208**	**21169**	**21948**	**22498**	**22798**	**22876**	**22842**
Jilin	**8106**	**8312**	**8395**	**8327**	**8090**	**7680**	**7117**
Heilongjiang	**10105**	**10867**	**11526**	**12022**	**12298**	**12308**	**12029**
Shanghai	**9550**	**9461**	**9309**	**9154**	**9009**	**8948**	**9108**
Jiangsu	**21601**	**22227**	**22693**	**23018**	**23249**	**23507**	**24055**
Zhejiang	**14938**	**15176**	**15336**	**15457**	**15589**	**15832**	**16402**
Anhui	**9589**	**10400**	**11171**	**11870**	**12469**	**12962**	**13387**
Fujian	**8656**	**9312**	**10024**	**10859**	**11930**	**13476**	**16048**
Jiangxi	**5993**	**6278**	**6522**	**6717**	**6862**	**6974**	**7097**
Shandong	**39391**	**41117**	**45105**	**53230**	**70005**	**108555**	**218324**
Henan	**19389**	**19895**	**20334**	**20719**	**21105**	**21623**	**22556**
Hubei	**13076**	**13600**	**14031**	**14353**	**14573**	**14731**	**14938**
Hunan	**15321**	**15938**	**16424**	**16747**	**16894**	**16885**	**16795**
Guangdong	**22348**	**22939**	**23310**	**23452**	**23375**	**23141**	**22904**
Guangxi	**6791**	**7071**	**7350**	**7642**	**7984**	**8451**	**9205**
Sichuan	**15531**	**16421**	**17308**	**18209**	**19192**	**20414**	**22233**

Guizhou	**9662**	**10460**	**11241**	**11984**	**12685**	**13372**	**14142**
Yunnan	**7293**	**7804**	**8339**	**8916**	**9578**	**10424**	**11682**
Shaanxi	**8071**	**8458**	**8742**	**8889**	**8872**	**8676**	**8308**
Gansu	**5721**	**6013**	**6245**	**6399**	**6460**	**6423**	**6302**
Qinghai	**2426**	**2536**	**2635**	**2724**	**2809**	**2908**	**3062**
Xinjiang	**7413**	**7575**	**7650**	**7632**	**7531**	**7378**	

Figure 1. Forecast of Aggregate Energy Consumption Preliminary Results



Since the energy demand function is expressed in log-log form, the estimated coefficient can be interpreted as elasticities. The preliminary estimation results show that the income and price elasticities are 0.8 and -0.02 respectively. Population, larger share of industrial and service sectors all increase the energy consumption. With regard to the factors explaining the energy efficiency, a quick turnover of the existing capital and more competitive market can improve the energy efficiency. Other factors such as FDI, the openness of the economy, urbanization are not statistically significant.

The energy efficiency scores which lie between zero and one are calculated for each province in each year. Similar to the energy intensity, the changes of the energy scores show that almost all provinces experience efficiency improvement during the study period. However, the relative performance among provinces indicated by the respective ranking of these two efficiency indicators is not the same. For some provinces, the rankings are quite different. This implies that the change of energy intensity may not be a good indicator of energy efficiency.

Finally, we forecast the energy efficiency scores and energy consumption for provinces between 2011 and 2020. The preliminary results show that China's energy consumption is expected to continue increasing rapidly in spite that energy efficiency of all provinces keeps improving.

Reference

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