Electricity Policy Research Group

UNIVERSITY OF CAMBRIDGE

Efficiency Analysis of Chinese coal-fired power plants: Incorporating both the undesirable and uncontrollable variables in DEA

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- Traditional efficiency research and DEA
- Research motivations
- Research methodology
- Data collection and coverage
- Results and Implications

Traditional efficiency research and DEA (1)

Why efficiency research?

■ The relationship between efficiency and market design may have helpful policy implications to electricity restructuring.

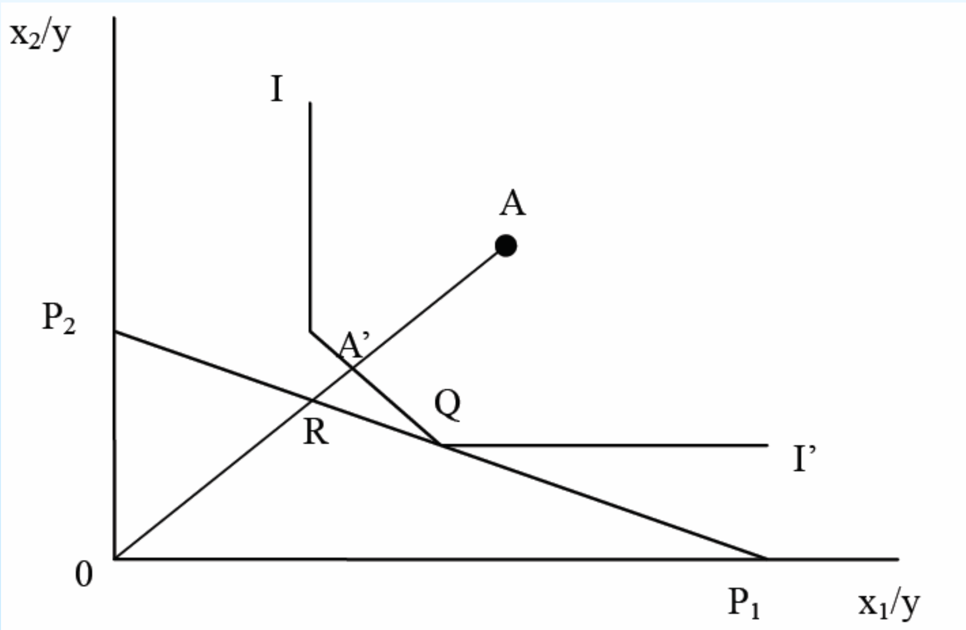
■A properly designed electricity market can promote long-run efficiency gains through competition (Chao and Huntington, 1998).

■ International practices show that privatisation in generation sector is nominated the highest priority of reform (Rothwell and Gomez, 2003).

Traditional efficiency research and DEA (2)

Traditional Efficiency Research:

- Conventional inputs modelled to produce desirable or marketable outputs;
- Techniques for model construction: DEA, SFA, etc.
- Data envelopment analysis (DEA): Widely used since Charnes et al(1978);



$$
\begin{aligned}
& Min_{\theta,\lambda}\theta \\
s.t.\quad & -y_i + Y\lambda \geq 0, \\
& \theta x_i - X\lambda \geq 0, \\
& \lambda \geq 0
\end{aligned}
$$

Research motivations (1)

Two difficulties in doing an objective efficiency evaluation:

(1) How to treat the undesirable output (emissions): Ignorance of undesirable outputs might produce misleading results.

- Fare et al (1989): decision making units' (DMUs') performance rankings were very sensitive to whether undesirable outputs were included.
- In power generation, similar results were found in Fare et al (1989, 1996), Yaisawarng and Klein (1994), Tytecan (1996, 1997), and Korhonen and Luptacik (2004).
- **What we should do:** credit a DMU for its provision of desirable outputs, and penalize it for its provision of undesirable outputs.

Research motivations (2)

(2) **How to treat uncontrollable variables: Ignoring these factors might also produce misleading results**

Examples:

- efficiency of coal-fired power plants influenced by coal quality;
- electricity distribution networks influenced by population density and average customer size;
- labour intensive industry influenced by labour union power;
- firm's performance influenced by government regulations.

Very few published papers simultaneously consider both the undesirable outputs and the uncontrollable variables.

Research methodology (1)

A two-step approach:

(1) First step: a DEA model incorporating emissions (basic DEA model).

Assuming we have N (homogeneous) firms each producing *P* desirable outputs (y^d) and *S* undesirable outputs (y^u) while using *M* inputs. Then the input-oriented efficiency $F_j(X, Y^d, Y^u)$ is:

$$F_j(X, Y^d, Y^u) = Min\,\theta$$

$$s.t.$$

$$Y^d \lambda \geq y_j^d$$

$$Y^u \lambda \leq \theta \cdot y_j^u$$

$$X \lambda \leq \theta \cdot x_j$$

$$\lambda \geq 0,\ j = 1, \ldots, N$$

Research methodology (2)

(2) Second step: Incorporating the uncontrollable variables. The basic guideline is to level the playing ground for all 'players'.

Previous works of including the uncontrollable variables:

- Separation model: Charnes et al (1981), Banker and Morey (1986), Grosskopf and Valdmanis (1987), Banker et al (1990), etc.;
- One-stage model: Banker and Morey (1986), McCarty and Yaisawarng (1993);
- Two-stage model: McCarty and Yaisawarng (1993), Fried *et al* (1993);
- Three-stage model: Fried *et al* (2002);
- Four-stage model: Fried et al (1999);

Except separation model, which is discarded due to its apparent shortcomings, all other models are used and compared in the second step.

Data collection--- variables

- Traditional analysis data of power plants
  --- desirable output: ***annual electricity generation;***
  --- traditional inputs: ***installed capacity, number of employees, annual fuel consumption;***

- Undesirable outputs: emissions, which are calculated in terms of the *IPCC Reference Approach*, for example, ***SO_2 emission***.

- Uncontrollable variables: ***unit scale, calorific value of coal, vintage, and CHP (combined heat & power).***

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Data collection--- sample coverage

Sha'anxi	36
Gansu	32
Xizang	1
Qinghai	3
Ningxia	14
Xinjiang	13

Beijing	18
Tianjin	21
Hebei	111
Shanxi	98
Inner Mongolia	27

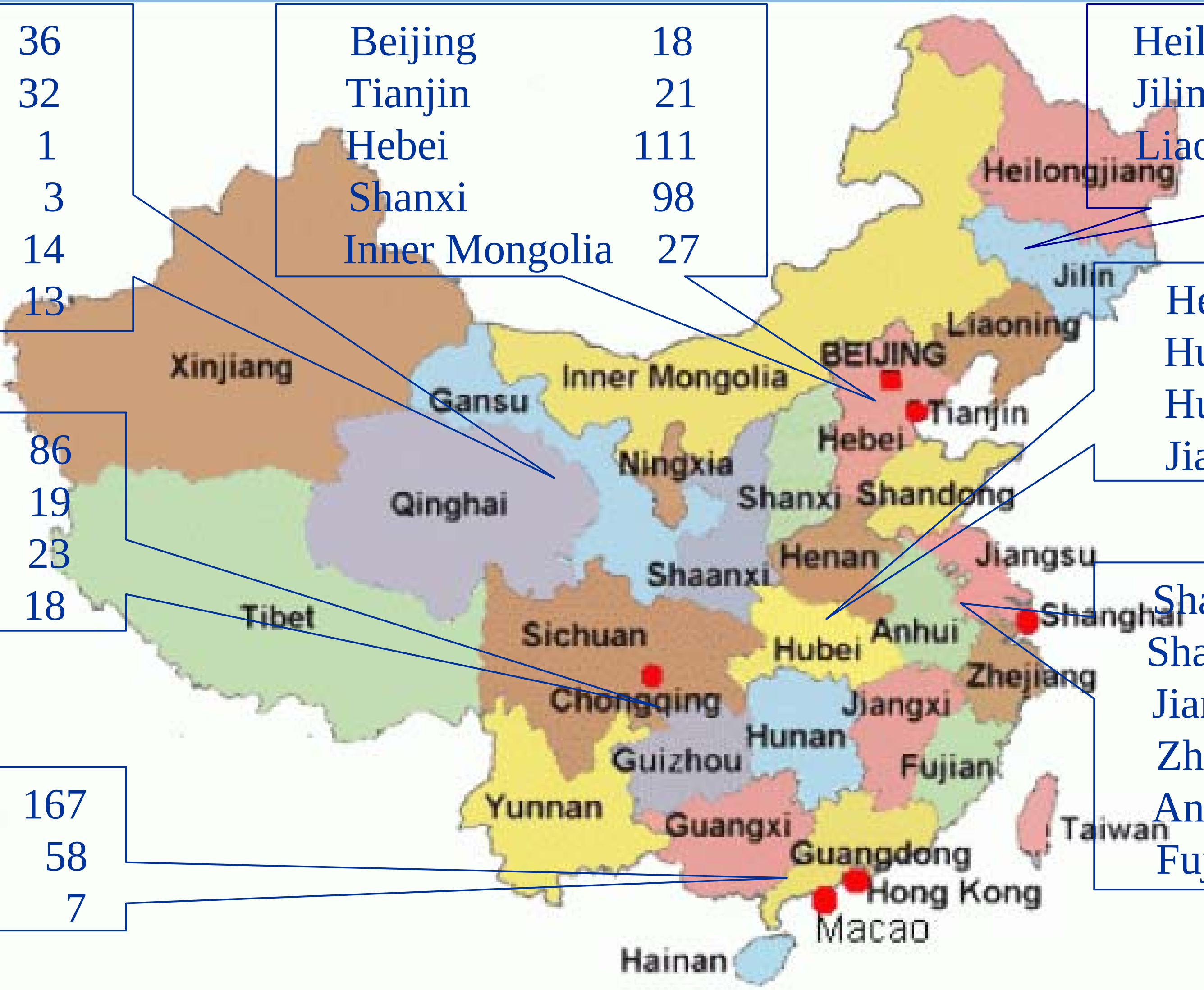
Heilongjiang	87
Jilin	65
Liaoning	104

Sichuan	86
Chongqing	19
Yunnan	23
Guizhou	18

Henan	138
Hubei	59
Hunan	38
Jiangxi	30

Shanghai	26
Shandong	141
Jiangsu	183
Zhejiang	38
Anhui	55
Fujian	25

Guangdong	167
Guangxi	58
Hainan	7



Data collection--- example data

Descriptive Statistics of Power Plants with uncontrollable variables

Variable	Unit	Mean	Maximum	Minimum	Std. Err.
Desirable output:					
Annual Generation	1000 MWh	2614.26	12422.77	59.85	2262.41
Inputs:					
Installed Capacity	MW	482.69	2400	12	407.27
Labour	no.	801	3674	136	645
Fuel	TJ	27073.73	124968	1121	22270.44
Undesirable output:					
SO_2 Emission	ton	24110.14	194595	461	27538.53
Uncontrollable variables:					
Vintage	Year	10.19	43	1	8.09
calorific value of coal	GJ / ton	22.86	28.68	12.49	2.43
Scale1		0.41	1	0	0.49
Scale2		0.52	1	0	0.50
Scale3		0.07	1	0	0.25
CHP		0.21	1	0	0.41

Note: sample size = 221

Application (1):

Application (1): A general survey on Chinese coal-fired power plants

- Research Data: all sample coal-fired power plants;
- Model used: step-one DEA model (incorporating SO_2 emissions);

Results:

- Very large variation in the technical efficiency across plants; in average, the technical efficiency is only 0.774;
- Large imbalance in development: All efficient plants are located in the east coastal areas. Mainly in Shanghai and Guangdong.
- The waste of resources in the industry is enormous.

Average input slacks per MW capacity in 2002

	Installed capacity (MW)	Labour	Fuel (TJ)
Input slacks / MW	0.21	1.37	10.99
Slack /total input	21%	55%	19%

Application (2) : Models

Application (2): Incorporating both undesirable and uncontrollable variables in DEA

Overview of models and variables

	Basic model	One stage	Two stage model: Tobit (3)	Two stage model: Logistic	Three-stage model (5)	Four-stage model
Desirable output:						
Annual generation	√	√	√	√	√	√
Inputs:						
Installed capacity	√	√	√	√	√	√
Labour	√	√	√	√	√	√
Fuel	√	√	√	√	√	√
Undesirable output:						
SO2 emission	√	√	√	√	√	√
Uncontrollable variables:						
Vintage		√			√	√
Vintage squared			√	√	√	√
Calorific value of coal		√	√	√	√	√
Scale1			√	√	√	√
Scale2			√	√	√	√
Scale3			√	√	√	√
CHP			√	√	√	√

Application (2): efficiency scores

Average efficiency scores in terms of uncontrollable variables

(a) In terms of vintage

Vintage (year)	No. of power plants	Basic model (1)	One-stage model (2)	Two-stage model Tobit (3)	Two-stage Logistic model (4)	Three-stage model (5)	Four-stage model (6)	Model average (2)-(6)
0-10	136	0.894	0.904	0.881	0.876	0.966	0.910	0.907
11-20	58	0.884	0.907	0.887	0.897	0.959	0.892	0.908
21-30	21	0.852	0.943	0.903	0.935	0.942	0.886	0.922
31-	6	0.766	0.946	0.866	0.962	0.880	0.816	0.894

(b) In terms of 'CHP' dummy variable

Calorific value (TJ/ton)	No. of power plants	Basic model (1)	One-stage model (2)	Two-stage model Tobit (3)	Two-stage Logistic model (4)	Three-stage model (5)	Four-stage model (6)	Model average (2)-(6)
CHP (=1)	46	0.874	0.936	0.886	0.903	0.945	0.875	0.909
CHP (=0)	175	0.887	0.903	0.884	0.886	0.963	0.907	0.909

Applications (2): results

- The impact of uncontrollable variables on the performance of coal-fired power plants is fairly stable;

- At least some power plants that had a relatively low efficiency scores in the traditional models did so in part due to their relatively unfavourable operating environments;

- The three-stage model, which is able to differentiate the managerial inefficiency from the statistical noise, can help us understand the mechanism of firm’s inefficiency.

Multilevel Implications (1)

(1) Implications for methodology

- Incorporating both the uncontrollable variable and undesirable output in DEA is feasible.

- Among the above models, the three-stage and four-stage model show their superiority over other models. Because the three-stage model is able to differentiate the managerial inefficiency from the statistical noise, therefore, it is more preferable.

Multilevel Implications (2)

(2) Policy Implications

- To evaluate the performance of coal-fired power plants, it is necessary to consider both the influence of the uncontrollable variables and the effects of undesirable outputs.
- Current literature underestimates the performance of those power plants operating in relatively unfavourable environments. This may endanger the selection of correct regulation policy.
- Efficiency analysis research can provide meaningful information on building an efficient industry.

Multilevel Implications (3)

(3) Economical or managerial implications

- The impact of selected uncontrollable variables is relatively significant in coal-fired power plants;
- Efficiency analysis can help find out the way to save input resources;
- The above methodology can also be used in other production systems in any countries, not only for coal-fired generation sector and not only for China.

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Questions and suggestions ?