An Empirical Analysis on Regional Technical Efficiency of Chinese Steel Sector Based on Network DEA Method

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June, 2014

Outline

Background

- Chinese steel sector played an important role in the development of China's economy, and the total production climbed up very quickly.
- The excess capacity phenomenon in Chinese steel industry has emerged since the period of Tenth Five-Year Plan, and the capacity utilization of China's steel is low.
- The difference of steel sector between different regions is obvious such as production technology, product structure and market demand.
- Regional technical efficiency characteristics can help us analyze regional differences and its influencing factors, and provide some policy implications.

Existing Research Content

These existing study issues can be divided into two categories:

- research from the perspective of steel-making technology.
- research from the perspective of productivity and efficiency performance.

For the study of productivity and efficiency performance in Chinese steel sector:

- productive and technical efficiency has been studied based on firm-level data sets, and few uses regional data sets.
- technical efficiency measures the maximum possible expansion of the outputs for a given level of the inputs and technology, i.e. the ability of a production unit to produce as much outputs as the inputs allow.

Existing Research Method

Data Envelopment Analysis (DEA) is a nonparametric approach developed by Charnes et al. (1978) as a technique to assess the performance of DMUs.

- Advantages: measure the relative efficiency under the situations in which there are multiple inputs and outputs.
- Shortcomings: deal with the internal production process as a black box when measuring the efficiency and ignores the information on the production process.
- Can we have a greater insight in the DMU production process by Network DEA method?

Therefore, this paper will study the technical efficiency of steel sector based on regional data sets by Network DEA methods.

Outline

Traditional DEA

Now we consider a production system with n DMUs, and each DMU has three factors: input indicators, intermediate product indicators and output indicators, as represented by three vectors: $x \in \mathbb{R}^m$, $z \in \mathbb{R}^p$, $y \in \mathbb{R}^l$. We define the matrices as follows:

$$\text{Input matrix: } X = [x_1, x_2, \cdots, x_n] \in \mathbb{R}^{m \times n}$$

$$\text{Intermediate matrix: } Z = [z_1, z_2, \cdots, z_n] \in \mathbb{R}^{p \times n}$$

$$\text{Output matrix: } Y = [y_1, y_2, \cdots, y_n] \in \mathbb{R}^{l \times n}$$

Notation:

- Traditional DEA methodology considers intermediate products as inputs or outputs by different researchers.
- The choice of input-oriented or output-oriented DEA methods

Traditional DEA

Input-oriented DEA:

$$\rho^* = \min \theta_0$$

$$s.t. \quad \begin{cases} \theta_0 x_0 \geq X\lambda \\ y_0 \leq Y\lambda \\ \sum_{j=1}^{n} \lambda_j = 1, \lambda \geq 0, 0 \leq \theta_0 \leq 1 \end{cases}$$

Output-oriented DEA:

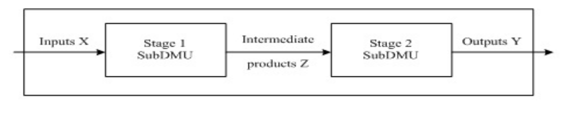
$$\rho^* = \min \theta_0$$

$$s.t. \quad \begin{cases} x_0 \geq X\lambda \\ \theta_0 y_0 \leq Y\lambda \\ \sum_{j=1}^{n} \lambda_j = 1, \lambda \geq 0, 0 \leq \theta_0 \leq 1 \end{cases}$$

Network DEA

How the network DEA method works?

- In the network DEA framework, the production process can be divided into two or more sub-DMUs production processes, and part of the inputs (or outputs) for one sub-DMU are produced (or consumed) by other sub-DMUs.
- For simplicity, we consider a two-stage network DEA model as shown in the following figure:



- The production possibility set (P) is defined by

$$P = \{(x, z, y) | x \geq X\lambda, z = Z\lambda, y \leq Y\lambda, \lambda \geq 0\}$$

Network DEA

For evaluating $DMU_0(x_0, z_0, y_0)$, the two-stage network DEA model can be formulated as follows.

Unoriented two-stage network DEA:

$$\rho^* = \min \theta_0$$

$$s.t. \quad \begin{cases} \theta_0 x_0 = X\lambda + S^x \\ z_0 = Z\lambda \\ \varepsilon_0 y_0 = Y\lambda - S^y \\ S^x \geq 0, S^y \geq 0, \lambda \geq 0, \sum_{j=1}^{n} \lambda_j = 1 \\ \theta_0 + \varepsilon_0 = 2, 0 \leq \theta_0 \leq 1, \varepsilon_0 \geq 1 \end{cases}$$

where $S = (S^x, S^y)$ corresponds to the slack variables in inputs and outputs.

Outline

Indicators Data

For the indicators used in the network DEA model:

- Input indicators:
  (1) investment in fixed assets in steel industry
  (2) the number of employed persons at the end of each year
- intermediate indicaror: pig iron
- final output indicators: crude steel and finished steel

Data

- panel data of the Mainland China's 26 provinces, autonomous regions or municipalities
- period: 2006 to 2010

Descriptive statistics

Table 1. Descriptive statistics of input, intermediate and output indicators

	Input indicators		Intermediate indicator	Output indicators	
Variables	Capital C	Labor L	Pig iron P	Crude steel CS	Finished steel FS
	Billion-yuan	Ten-thousand people	Million-tons	Million-tons	Million-tons
Mean	11.666	7.308	19.468	20.250	24.140
Median	8.108	5.718	12.125	12.428	16.452
Maximum	61.843	22.388	148.177	144.588	171.135
Minimum	0.138	1.750	2.338	3.047	2.785
Std.Dev	12.032	5.378	24.207	24.187	27.396
Skewness	2.142	1.530	3.157	3.124	2.882
Kurtosis	8.142	4.371	14.552	14.132	12.890

There is a larger number in standard deviation (Std.Dev) for all indicators, which means the great regional differences.

Correlation coefficient between indicators

Table 2. Pearson correlation coefficients between production indicators

Index	C	L	P	CS	FS
C	1.0000	0.7705***	0.8291***	0.8308***	0.7877***
L		1.0000	0.7512***	0.7280***	0.6658***
P			1.0000	0.9898***	0.9460***
CS				1.0000	0.9735***
FS					1.0000

Note: "*"、"**"、"***" represent their significance levels of 10%, 5% and 1% respectively.

There is a significantly positive correlation between output and input indicators at the significance level of 1%, which meets the isotonic condition in the DEA methodology framework.

Area division

Table 3. Three areas division of the Mainland China

	The provinces in the corresponding area
Eastern area	Liaoning, Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong
Central area	Jilin, Heilongjiang, Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan
Western area	Inner Mongolia, Guangxi, Guizhou, Yunnan, Shaanxi, Gansu, Xinjiang, Sichuan

These three areas have significant differences in many aspects:

- GDP contribution and economic development in eastern area are obviously higher
- steel industry in eastern area has the advantages of port transportation and market demand
- central area is the base of agriculture, and western area is least developed

Outline

Comparison results between In-DEA and Out-DEA models

Table 4. Comparison analysis of technical efficiency by traditional In-DEA and Out-DEA models

Input-oriented: Test for equality of means			Output-oriented: Test for equality of means		
Test Method	Value	Probability	Test Method	Value	Probability
t-test	5.1523	0.0000	t-test	7.8753	0.0000
Welch F-test	26.5457	0.0000	Welch F-test	62.0206	0.0000
Input-oriented: Test for equality of medians			Output-oriented: Test for equality of medians		
Test Method	Value	Probability	Test Method	Value	Probability
Wilcoxon/Mann-Whitney	4.3882	0.0000	Wilcoxon/Mann-Whitney	6.2851	0.0000
Med.Chi-square	7.4462	0.0064	Med.Chi-square	23.4014	0.0000
Input-oriented: Test for equality of variances			Output-oriented: Test for equality of variances		
Test Method	Value	Probability	Test Method	Value	Probability
F-test	2.1520	0.0000	F-test	2.9066	0.0000
Siegel-Tukey	4.0157	0.0001	Siegel-Tukey	5.7178	0.0000

- efficiency scores produced from In-DEA and Out-DEA are significantly different (mean, median and variance)
- comparison results are robust for different test methods
- treat pig iron as input or output will affect the efficiency scores

Comparison results

We will consider a unifying framework by the network DEA to avoid this dilemma

Table 5. Correlations of the technical efficiency scores between different models

	Input-oriented			Output-oriented		
Pearson correlations	In-DEA	Out-DEA	Network DEA	In-DEA	Out-DEA	Network DEA
In-DEA	1.0000	0.7198	0.9434	1.0000	0.6660	0.8970
Out-DEA	-	1.0000	0.8379	-	1.0000	0.8118
Network DEA	-	-	1.0000	-	-	1.0000
Spearman rank correlations	In-DEA	Out-DEA	Network DEA	In-DEA	Out-DEA	Network DEA
In-DEA	1.0000	0.7323	0.9477	1.0000	0.6619	0.9065
Out-DEA	-	1.0000	0.8507	-	1.0000	0.8199
Network DEA	-	-	1.0000	-	-	1.0000

The correlations between efficiency scores produced from In-DEA or Out-DEA and those produced from Network DEA are higher than that from In-DEA and Out-DEA.

Provincial efficiency results

Based on the above comparison analysis, in the following we measure the efficiency by network DEA model.

Table 6. Technical efficiency of steel sector in different provinces from 2006 to 2010

	2006	2007	2008	2009	2010	Mean	Std.dev.
Beijing	0.8435	0.6800	0.9432	0.9879	1.0000	0.8909	0.1330
Tianjin	0.7676	0.8112	0.8733	0.9551	0.9971	0.8809	0.0959
Hebei	0.9880	0.9660	0.9473	1.0000	1.0000	0.9803	0.0231
Shanxi	0.6854	0.7460	0.6513	0.8173	0.8957	0.7591	0.0991
Inner Mongolia	0.3754	0.4962	0.6187	0.5606	0.5345	0.5171	0.0909
Liaoning	0.7083	0.7666	0.7190	0.7251	0.7906	0.7419	0.0351
Jilin	0.8053	0.7958	0.7553	0.8320	0.7465	0.7870	0.0356
Heilongjiang	1.0000	0.9451	1.0000	1.0000	0.9613	0.9813	0.0263
Shanghai	0.7770	0.7845	0.7779	0.8489	0.9511	0.8279	0.0752
Jiangsu	0.9616	1.0000	1.0000	1.0000	1.0000	0.9923	0.0172
Zhejiang	1.0000	1.0000	1.0000	0.9404	1.0000	0.9881	0.0267

Provincial efficiency results

Anhui	0.6622	0.7095	0.7548	0.7930	0.7102	0.7259	0.0498
Jiangxi	0.9920	0.9916	0.9961	1.0000	1.0000	0.9959	0.0041
Fujian	1.0000	0.8381	0.6967	0.8925	0.8804	0.8615	0.1098
Shandong	0.8309	1.0000	1.0000	0.9170	1.0000	0.9496	0.0755
Henan	0.7618	0.8162	0.9232	0.7258	0.7743	0.8003	0.0759
Hubei	0.6516	0.6762	0.7384	0.8397	0.9753	0.7762	0.1329
Hunan	0.7007	0.7094	0.6915	0.6362	0.6518	0.6779	0.0321
Guangdong	0.8760	1.0000	0.9684	0.9334	1.0000	0.9556	0.0523
Guangxi	0.8114	0.8635	0.7427	0.6762	0.7582	0.7704	0.0710
Sichuan	0.6555	0.7225	0.6966	0.5946	0.6451	0.6629	0.0493
Guizhou	0.7951	0.8708	0.8440	0.6396	0.6048	0.7509	0.1212
Yunnan	0.7473	0.8197	0.7244	0.7853	0.7145	0.7582	0.0438
Shaanxi	1.0000	1.0000	1.0000	0.9823	0.8739	0.9712	0.0550
Gansu	0.7136	0.7612	0.7196	0.7928	0.7640	0.7502	0.0332
Xinjiang	1.0000	1.0000	0.9620	1.0000	1.0000	0.9924	0.0170
Average value	0.8119	0.8373	0.8363	0.8414	0.8550	-	-

Provincial efficiency results

Findings:

- there is a steady rise of technical efficiency from 2006 to 2010 (Eleventh Five-Year plan)
- the technical efficiency of most provinces has an obvious fall in the years of 2007 and 2008, when the sub-prime financial crisis has happened (consumption expectation–export).
- the technical efficiency of some provinces has larger fluctuations
- the province of Inner Mongolia has the lowest technical efficiency (low value-added products)

Need further statistical test to explain these phenomenons!!!

Regional efficiency results

Table 7. Technical efficiency of steel sector in three areas from 2006 to 2010

year	2006	2007	2008	2009	2010	Average
Eastern Area	0.8753	0.8846	0.8926	0.9200	0.9619	0.9069
Central Area	0.7824	0.7987	0.8138	0.8305	0.8394	0.8130
Western Area	0.7623	0.8167	0.7885	0.7539	0.7369	0.7717
Overall Area	0.8067	0.8333	0.8316	0.8348	0.8461	0.8305

Note: The value of Overall Area is the average efficiency score of Eastern Aera, Central Aera and Western Aera.

- technical efficiency of steel sector in three areas increases from west to east (coastal location, level of economic development and market demand)
- central area is better than west area in efficiency increasing rate

Outline

Conclusions

- Assesse the performance of regional technical efficiency of Chinese steel sector by a network DEA method.
- Give a comparative analysis on efficiency differences between traditional DEA method and network DEA method, and demonstrate the advantages of network DEA method.
- The empirical results provide some evidence on the development tendency and characteristics of regional technical efficiency of Chinese steel sector.
- Policy implications: optimize the steel industrial layout according to inland and coastal region characteristics, adjust the steel product structure.

Further research

This paper is a try to measure and analyze the technical efficiency of Chinese steel sector based on the network DEA method, and a promising area of future research is probably:

- For avoiding the finite sample basis, we can study the bootstrap technique corresponding with network DEA model
- The convergence technique (similar with economic growth theory) can help us to carry out an in-depth analysis of regional efficiency (development characteristics, differences)
- explore the possible impact factors of the technical efficiency in Chinese steel industry (economy scale, product structure, industry characteristics and regional location)

Thanks & Questions!