

The Efficiency Improvement in Low-carbon Technology Innovation of Chinese Enterprises under CDM: An Empirical Study based on DEA Assessments

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Abstract The Clean Development Mechanism (CDM) with financial incentives and technical transfer brings about potential improvement in the efficiency of Chinese enterprises' low-carbon technology innovation. Based on DEA models and data of industrial enterprises, we assess the efficiencies and their improvement under CDM. We then estimate the effects of CDM on the probability of efficiency improvement using a logit model. The effects of CDM on the improvement rate are also estimated. It is found that the undertaking of CDM would benefit Chinese enterprises to achieve more significant efficiency improvement in their low-carbon technology innovation, by raising not only the probability but also the rate of efficiency improvement.

Keywords: *clean development mechanism (CDM), low-carbon technology innovation, efficiency improvement, DEA*

Cite This Article: Kun LUO, and Rendao YE, "The Efficiency Improvement in Low-carbon Technology Innovation of Chinese Enterprises under CDM: An Empirical Study based on DEA Assessments." *Journal of Finance and Economics*, vol. 5, no. 6 (2017): 310-315. doi: 10.12691/jfe-5-6-7.

1. Introduction

The sustainable development of China is confronted with an increasingly crucial challenge by massive energy consumption and intensive carbon emission. Economic growth, energy saving and emission reduction have to be coordinated, which is the very nature of low-carbon economy. To this end, it is essential that Chinese enterprises keep performing efficient innovation and application of low-carbon technology. However, due to highly significant sunk costs as well as risks of R&D and spillovers, enterprises are often found to be inactive and inefficient in low-carbon technology innovation activities. It is urgent to introduce new mechanisms with a view of improving Chinese enterprises' low-carbon technology innovation efficiencies.

The Clean Development Mechanism (CDM) provides an option. This flexible mechanism under the Kyoto Protocol allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits with some sort of support from industrialized countries. These CERs can then be traded among those countries, thus giving industrialized countries some flexibility in how they meet their emission reduction limitation targets, while rewarding developing countries with financial and technical gains. This mechanism therefore helps to stimulate emission reduction on a

win-win foundation between both sides of the emission market. Still, further evidences are needed before we can decide whether or not these potential impacts on emission reduction in developing countries are achieved in reality [1,2,3]. A key question lies in whether the low-carbon technology innovation efficiencies in developing countries can be improved under this mechanism. It is argued that CDM is capable of stimulating low-carbon technology innovation, since barriers to technical diffusion can be bypassed under financial incentives and information flow [4,5]. On the contrary, [6,7,8,9,10,11,12] found that such stimulation effects are subject to several factors, including the scales of CDM transactions, types of the technology being transferred, transaction costs, and government behaviors in host countries. With China being one of the largest host countries, there are studies about CDM practices in China and their impacts on low-carbon technology innovation [13].

In this paper, we focus on the innovation efficiency, an essential problem in low-carbon technology innovation, and study the impacts of CDM on the efficiency improvement. Based on DEA models and data of industrial enterprises in 30 provinces of China, we assess Chinese enterprises' low-carbon technology innovation efficiencies and their improvement under CDM. We then estimate the effects of CDM on the probability of efficiency improvement using a logit model. The effects of CDM on the rate of efficiency improvement are also estimated for further conclusions.

2. Low-carbon Technology Innovation Efficiency

Generally, efficiencies of economic activities are considered from an input-output perspective, and we herein define low-carbon technology innovation efficiency by the ratio of output with regard to input in low carbon technology innovation activities. As in Table 1, input is indicated by enterprises' low-carbon technology R&D personnel and expenditures, while output is indicated by the rates of reduction in energy consumption intensity and CO₂ emission intensity.

Table 1. Input and Output Indicators of the Efficiency

Input	X ₁	Low-carbon technology R&D personnel full-time equivalent (man-year)
	X ₂	Low-carbon technology R&D expenditures (10 thousand Yuan)
Output	Y ₁	Rate of reduction in industrial energy consumption intensity, namely rate of reduction in tons of SCE (standard coal equivalent) consumption per 10 thousand Yuan of industrial value-added (%)
	Y ₂	Rate of reduction in industrial CO ₂ emission intensity, namely rate of reduction in tons of CO ₂ emission per 10 thousand Yuan of industrial value-added (%)

Note: Calculate reductions compared to last year. See also [14].

3. Efficiency Improvement of Low-carbon Technology Innovation under CDM

Financial incentives and technical transfer under CDM would affect respectively the input and output of Chinese enterprises' low-carbon technology innovation, indicating potential improvement in the efficiency of such innovation.

3.1. Financial Incentives

China has been a most important host country ever since CDM comes into effect. As in Figure 1, up till October 2017, 56.6% of all CERs are issued under Chinese projects. These CERs, each equivalent to one tonne of CO₂, are allowed to be sold to the industrialized contract partners at certain prices. Figure 2 gives the CER prices of Chinese registered projects, ranging from US\$1.3 to US\$124.4 per tonne of CO₂, with the median being US\$11.3 per tonne of CO₂. Calculating the CER revenues of all the 1222 Chinese registered projects with available data of price and issuance amount, we find those Chinese enterprises selling CERs under CDM are able to gain 4.6 billion US\$ in total within the contract periods, ranging from 5 to 20 years. As Figure 3 shows, the median revenue of a CDM transaction could amount to 2 million US\$. A project in the province of Shanxi even enables the Chinese trader to sell 23.3 million tonnes of CO₂ and gain a total revenue of 193.5 million US\$ within the contract period of 10 years starting from 2009.

Note that these considerable CDM revenues come from sales of issued CERs. Chinese enterprises need to achieve emission reduction targets before they can sell those worthy credits. It is obvious that financial revenues under CDM contribute to generate and strengthen enterprises' incentives in low-carbon technology innovation activities. Consequently, inputs as in Table 1 expand, which at the present efficiency

level would most likely lead to larger outputs and better performance of low-carbon technology innovation. Moreover, as we will argue next, outputs could be further expanded via technical transfer under CDM, leading to improved efficiencies of low-carbon technology innovation.

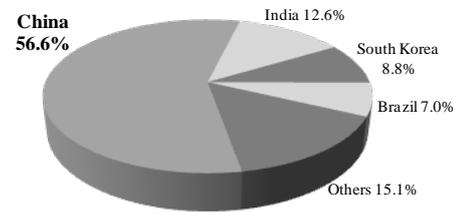


Figure 1. Share of issued CERs by host countries (Source: UNEP DTU Partnership).

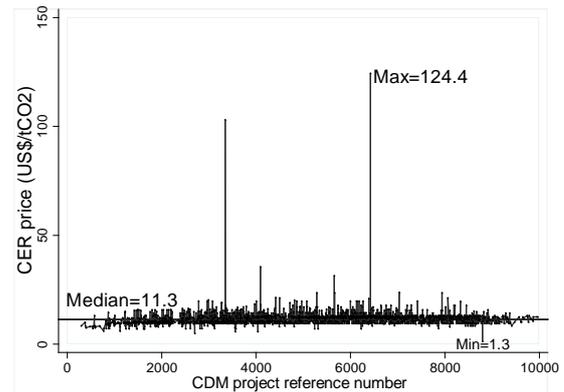


Figure 2. CER prices of Chinese registered CDM projects (Source: UNEP DTU Partnership).

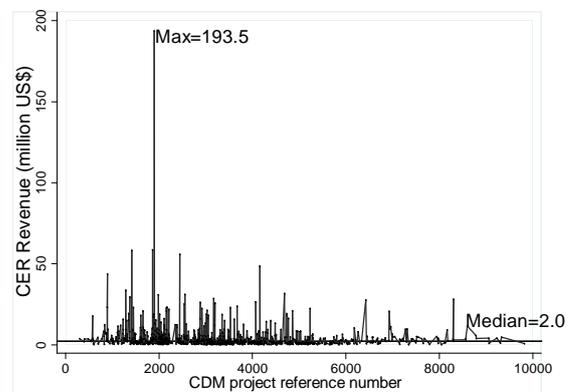


Figure 3. CER revenues of Chinese registered CDM projects (Source: UNEP DTU Partnership).

3.2. Technical Transfer

CDM provides the industrialized countries with more options in how they meet their emission reduction targets. Due to higher marginal costs of emission reduction, enterprises from developed countries would prefer trading CERs at certain prices with partners from developing countries, rather than endeavoring to reduce emission themselves. But before the transactions could be closed, advanced low-carbon technology need to be transferred to enterprises in developing countries for them to achieve emission reduction targets and obtain issued CERs.

We find evidences of technical transfer in the CDM projects hosted in China, although unfavorably not in most cases. Figure 4 gives the shares of projects with technical

transfer in all Chinese registered CDM projects, while Figure 5 gives the shares of annual emission reductions under such projects. Nearly 30% of all Chinese projects claim in the Project Design Documents to ensure technical transfer, which may take the forms of equipments delivery, techniques and knowhow exchange, or both. These projects generate over 70% of all annual emission reductions under CDM, much more than those without technical transfer. Provided that more endeavors were made to facilitate technical transfer, Chinese enterprises would manage to further expand their emission reduction outputs under CDM.

It is obvious that technical transfer plays an important role in achieving emission reduction targets for the Chinese enterprises, especially when it involves transfer of both equipments and techniques and knowhow. As Figure 4 and Figure 5 show, these projects, although accounting for only 15% of all projects, generate half of the annual emission reductions under CDM in China.

By virtue of the financial incentives and technical transfer mentioned above, the input and output of Chinese enterprises' low-carbon technology innovation tend to expand under CDM. Still, with expansions at both ends, further assessments and empirical results are needed before we can conclude that the efficiency does improve under CDM in reality.

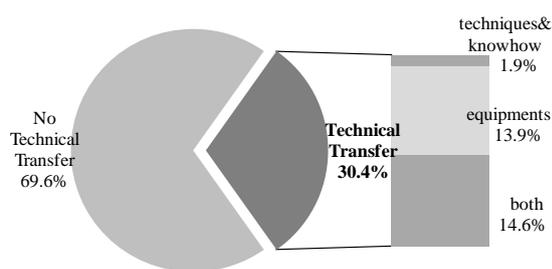


Figure 4. Share of Chinese projects with technical transfer (Source: UNFCCC CDM statistics).

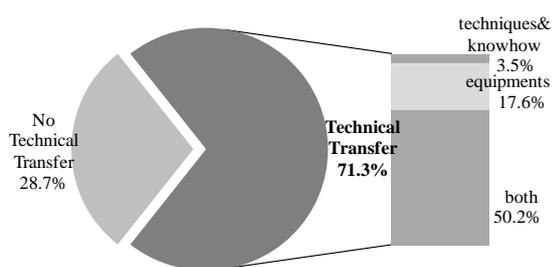


Figure 5. Share of Chinese annual emission reductions under projects with technical transfer (Source: UNFCCC CDM statistics).

4. Empirical Results based on DEA Assessments

4.1. DEA Assessments of the Efficiencies

The DEA methodology assesses the efficiency of a certain decision making unit (DMU) by calculating whether or not this DMU takes on the optimum efficiency value among all the DMUs in question, thus giving the relative efficiency value out of a pool of DMUs (See [15-20] for more about the DEA methodology). We herein

consider an enterprise's low-carbon technology innovation as a DMU. Using the CCR model and data of industrial enterprises above designated size in 30 provinces of China, we assess Chinese enterprises' low-carbon technology innovation efficiencies and their improvement under CDM.

Table 2 gives the assessed efficiency scores from 2011 to 2015. It is obvious that Chinese enterprises are critically inefficient in low-carbon technology innovation, with the mean and median scores remaining far away from the efficient frontiers throughout five years. To make matters worse, in quite a few cases enterprises even fail to achieve positive output in low-carbon technology innovation, showing no signs of reduction in energy consumption and emission intensities, and leaving low-carbon technology innovation totally inefficient.

It is interesting that the efficiencies turn out to be rather low in the most developed regions in China including Beijing, Shanghai, Jiangsu, Zhejiang and Guangdong. The answer lies in their disproportionately large scale of inputs with regard to outputs in low-carbon technology innovation. As in Figure 6, enterprises in these regions input massive R&D expenditures, far beyond the median level, only to achieve outputs slightly outnumbering the median level. Take Jiangsu in 2014 for example. Enterprises here expended a total of 7 billion Yuan on low-carbon technology R&D, nearly 8 times the median expenditure, but only managed to attain a reduction rate of 3.3%, quite close to the median rate.

The results indicate that most enterprises in China would expect higher efficiencies in low-carbon technology innovation, provided that outputs were expanded significantly. As we argued above, CDM should help Chinese enterprises achieve more remarkable energy saving and emission reduction outputs. It could make a difference in the low-carbon technology innovation efficiencies if enterprises take good advantage of this mechanism. We further verify this difference and assess the impacts of CDM on the efficiencies in the next section.

Table 2. The Efficiency Scores of DEA Assessment

Region	2011	2012	2013	2014	2015	Region	2011	2012	2013	2014	2015
Beijing	0.06	0.05	0.14	0.06	-	Hubei	0.06	0.05	0.10	0.05	0.24
Tianjin	0.07	0.04	0.11	0.04	-	Hunan	0.09	0.06	0.14	0.06	0.06
Hebei	0.07	0.03	0.07	0.03	-	Guangdong	0.01	0.00	0.01	0.01	0.02
Shanxi	0.10	-	-	-	-	Guangxi	0.22	0.05	0.16	0.17	0.51
Inner Mongolia	0.16	0.07	0.33	-	-	Hainan	1.00	1.00	-	1.00	-
Liaoning	0.05	0.04	0.13	0.04	-	Chongqing	0.10	0.01	0.12	0.12	0.39
Jilin	0.14	0.26	0.37	0.31	0.00	Sichuan	0.08	0.09	0.16	-	-
Heilongjiang	0.05	-	0.07	-	-	Guizhou	0.18	0.55	1.00	1.00	1.00
Shanghai	0.03	-	0.00	0.06	-	Yunnan	0.11	0.25	0.51	-	-
Jiangsu	0.01	0.00	0.01	0.01	0.03	Shaanxi	0.10	0.11	0.13	0.02	-
Zhejiang	0.01	0.01	0.00	0.02	-	Gansu	0.19	-	0.01	0.14	-
Anhui	0.09	0.05	0.05	0.05	-	Qinghai	0.64	-	-	-	-
Fujian	0.04	0.04	0.06	0.02	0.15	Ningxia	0.63	0.22	0.17	0.17	-
Jiangxi	0.14	0.06	0.12	-	-	Xinjiang	0.13	-	-	-	-
Shandong	0.01	0.01	0.04	0.00	-	Mean	0.15	0.13	0.16	0.15	0.27
Henan	0.02	0.03	0.04	0.01	-	Median	0.09	0.05	0.11	0.05	0.15

Note: CCR model output-oriented. Negative output data, indicating increases in energy consumption and emission intensities, are inappropriate for the model and dropped in calculation, thus giving no results. Data source: Large and Medium-sized Industrial Enterprises' Independent Innovation Statistics; China Energy Statistical Yearbook.

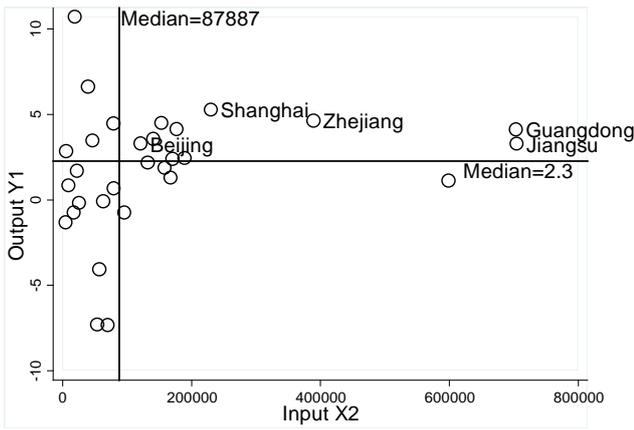


Figure 6. Output and input of low-carbon technology innovation in developed regions of China

4.2. The Efficiency Improvement under CDM

Since the efficiency scores given by DEA models indicate the relative efficiency values among certain DMUs within the same time period, it won't make sense to compare the scores throughout different periods. However, it is reasonable to probe into the ranks, changes in which over periods indicate whether or not there exists any improvement. We calculate the improvement rates in efficiency ranks of the last period compared to the first period. We then correlate the improvement rates with numbers of registered CDM projects hosted in different regions, so as to see if there exists any evidence of relations between the efficiency improvement and the undertaking of CDM.

Figure 7 gives the results. Enterprises from the regions that host the most projects are found to achieve more significant improvement in efficiency ranks. Take Yunnan, Sichuan and Inner Mongolia in the upper-right corner of Figure 7 as examples of regions where CDM is progressing the most massively. Projects in these regions remarkably outnumber the median level, especially in Yunnan. There are currently 369 valid projects being hosted in this province, nearly 3.8 times the median. Meanwhile, enterprises here achieved the most significant efficiency improvement by the rate of 81.8%, ascending from Rank 11 to Rank 2. This is also the case in Sichuan. The efficiency ranks rose to 7 from 17 and improved by 58.8%, almost 2.4 times the median improvement rate.

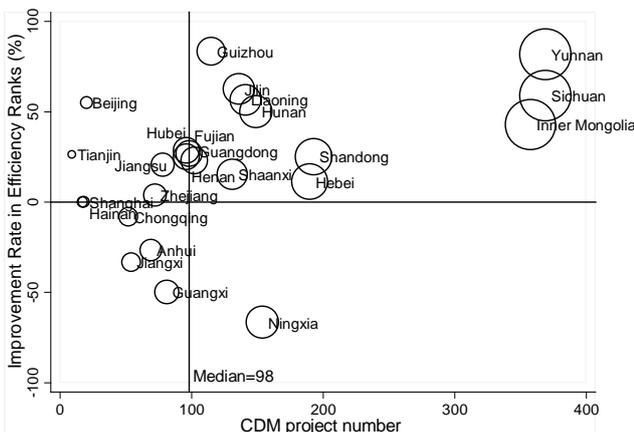


Figure 7. Improvement rate in efficiency ranks by CDM project numbers

Take Anhui, Jiangxi and Guangxi in the lower-left corner of Figure 7 as examples of regions where CDM is progressing the least massively. Efficiency ranks in these provinces dropped by 26.7%, 33.3% and 50% respectively, indicating deterioration instead of improvement in the efficiencies.

Relations between CDM project numbers and efficiency improvement rates are confirmed by the results of Spearman's rank correlation test. The correlation coefficient is 0.46, significant at the significance level of 5%. For further empirical results, we estimate the impacts of CDM on the probability and rate of efficiency improvement in the following section.

4.3. Effects of CDM on the Probability and Rate of Efficiency Improvement

Firstly we consider the effects of CDM on the probability of efficiency improvement. Define efficiency improvement by the binary variable *EI*, which takes the value of 1 when efficiency improvement occurs and the value of 0 otherwise. We then use the logit model as in

$$P(EI = 1 | x) = F(x\beta) \tag{1}$$

where $F(\cdot)$ follows the Logistic distribution, and x denotes the logarithm of project numbers and annual issued CERs in Regressions (i) and (ii) respectively.

Table 3 gives the regression results, and we calculate the marginal effects of project numbers and annual issued CERs respectively. It is found that the probability of efficiency improvement would rise by 18% as project numbers increase by 1%. Increases in annual issued CERs would have the same effects. The results confirm that the undertaking of CDM benefits Chinese enterprises in their low-carbon technology innovation by raising the probability of efficiency improvement. Seeing that the overall efficiencies are rather low throughout China currently, such positive effects would make a real difference in the performance of low-carbon technology innovation.

Table 3. Effects of CDM on the Probability of Efficiency Improvement

	Regression (i)		Regression (ii)	
	Coefficient	Marginal Effect	Coefficient	Marginal Effect
constant	-3.25**	-	-14.58**	-
log(project number)	0.97*	0.18*	-	-
log(annual issued CER)	-	-	0.99*	0.18*
LR χ^2	3.78*	-	5.12*	-
Pseudo R^2	0.13	-	0.17	-
Log likelihood	-12.93	-	-12.26	-

Note: *, ** Significant at the significance level of 5% and 10% respectively.

We then estimate the effects of CDM on the rate of efficiency improvement, using the model as in

$$IR = \alpha + \beta \log(x) + \varepsilon \tag{2}$$

where *IR* denotes the improvement rate in efficiency ranks, and x denotes project numbers and annual issued CERs respectively.

Table 4 gives the results. The improvement rate in efficiency ranks would rise by 4.85 units as project numbers increase by 1%. Similarly, an increase in annual issued CERs by 1% would result in an increase in the improvement rate by 1.34 units. Take Tianjin which hosts the least CDM projects for example. At present, enterprises here rank 14 in low-carbon technology innovation efficiency. Provided they manage to encourage the development of CDM and expand project numbers by 1%, they would get to improve efficiency ranks by the rate of 31.2%. In addition, provided they manage to expand annual issued CERs by 1%, they would further improve efficiency ranks by the rate of 32.5%. That means enterprises here could rise to Rank 9 or 10 in low-carbon technology innovation efficiency by virtue of CDM.

Take Shanghai, Jiangsu, Zhejiang and Guangdong for another example. As shown in Table 2, enterprises from these developed regions are significantly inefficient in low-carbon technology innovation. They input massive R&D personnel and expenditures, only to achieve moderate or even worse in some years negative outputs. Provided that they manage to expand project numbers and annual issued CERs by 1%, they would improve efficiency ranks by the rates ranging from 6.2% up to 32.9%. Better use of CDM would definitely benefit enterprises in similar situations to achieve more energy saving and emission reduction outputs, especially when technical transfer is involved, and therefore improve the efficiencies of low-carbon technology innovation.

Table 4. Effects of CDM on the Rate of Efficiency Improvement

	Coefficient	Coefficient
log(project number)	4.85*	-
log(annual issued CER)	-	1.34*
F	9.03*	8.02*
R ²	0.27	0.25
Adjusted R ²	0.24	0.22

Note: * Significant at the significance level of 1%.

5. Conclusions

Considering the mechanism design of CDM, Chinese enterprises should benefit from this mechanism and improve their efficiencies in low-carbon technology innovation, by virtue of financial incentives and technical transfer. For empirical evidences of these potential impacts, we use the DEA methodology and assess Chinese enterprises' low-carbon technology innovation efficiencies and their improvement under CDM. It is found that currently enterprises in most regions of China, including the most developed regions, are critically inefficient in low-carbon technology innovation. There exist some cases, however, in which the efficiencies turn out to improve over years. We then calculate the improvement rates in efficiency ranks, and correlate the improvement rates with CDM projects numbers. Evidence confirms about the relations between the efficiency improvement and the undertaking of CDM.

For further empirical results, we estimate the effects of CDM on the probability of efficiency improvement using

a logit model. Calculating the marginal effects, we find the probability of efficiency improvement would rise by 18% as project numbers or annual issued CERs increase by 1%. The results confirm that the undertaking of CDM benefits Chinese enterprises in their low-carbon technology innovation activities by raising the probability of efficiency improvement.

The effects of CDM on the rate of efficiency improvement are also estimated. It is found that the improvement rate in efficiency ranks would rise by 4.85 or 1.34 units as project numbers or annual issued CERs increase by 1% respectively. Better use of CDM would definitely benefit Chinese enterprises to achieve more significant improvement in the efficiencies of low-carbon technology innovation.

Acknowledgements

This research was supported by National Social Science Foundation (Grant No. 12CJY012), and Zhijiang Social Science Scholars Project of Zhejiang Province (Grant No. G115).

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