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Eco-efficiency Evaluation of Construction Industry with Pollution Output: a DEA Approach

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We propose the efficiency evaluation framework of construction industry on the basis of taking advantage of eco-efficiency concept and employing DEA approach. When doing DEA analysis, we consider their influence on environment and treat the carbon dioxide emission as pollution output so that it is able to improve the science of efficiency evaluation of construction industry and the usefulness of decision-making. Based on the DEA model with pollution output considered and the related data of construction industry from 2008 to 2013, we measured the eco-efficiency, economic efficiency and environmental efficiency of construction industry in each region and tested the correlation of these three kinds of efficiency. The results show the highest efficiency of construction industry is eco-efficiency, followed by economic efficiency and environmental efficiency, and there is much room for the improvement of environmental efficiency. The efficiency of construction industry in different regions are obviously different, and the average value of efficiency in eastern area is higher than that of central and western area.

1. Introduction

Construction industry has been experiencing a rapid development in China due to the rapid development of real estate industry. Construction industry thus plays an ever increasing important role on Chinese economy. Construction industry is a resource-intensive industry, which can consume a lot of resources. The large volume consumption of resources needs the environment to bear the impacts they cause. In other words, it means construction industry can cause great environmental impacts. According to National Bureau of Statistics of China (2014), the amount of total energy consumption of construction industry in 2013 (7017 tce) was 3.18 times that of 2000. However, comparing with other industrial sectors, the direct resources consumption and the direct pollutants in construction industry are still not so obvious. It is therefore the environmental impacts that construction industry causes have not been fully emphasized. Most of prior studies focused on the evaluation of its economic efficiency. There are only few studies that take the environmental impacts into consideration when evaluating the performance of construction industry (Liu and Zhang, 2014).
The aim of this study tries to propose a proper framework to evaluate the performance of construction industry. Eco-efficiency, which is an effective instrument for sustainable analysis, can be used in the evaluation of construction industry's eco-efficiency. The integrated concept of eco-efficiency was first proposed by Schaltegger and Sturm, they defined eco-efficiency as a "business link to sustainable development" (Schaltegger and Sturm, 1990). This concept became popular when the World Business Council for Sustainable Development (WBSCD) introduced it in 1992. Eco-efficiency can be expressed as the ratio of economic value added to environmental impacts or the ratio of environmental impacts to economic value (Keffer and Shimp, 1999). Through the concept of eco-efficiency, we can find that it cares not only about economic value added but also about environmental impacts. It is suitable we can take advantage of this concept to evaluate the performance of construction industry. In this sense, the environmental impacts that have been neglected by previous researches can be incorporated in the evaluation framework so that it can be more reasonable. However, if we use the concept of eco-efficiency to evaluate the performance directly, it can cause an inevitable problem. When we calculate whichever economic value added or environmental impacts, we need to assign weights to each indicator. For instance, economic value added are due to the sales of different kinds of goods or services. If the goods sold do not make same contribution for a certain

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company, then we have to assign weights to different products. In this regard, it may need the subjective judgments from leadership or other methods, which may not consistent with the truth.

In order to overcome this problem, we can try an alternative approach. Data envelopment analysis (DEA) is widely used in measuring the relative efficiency of a set of independent decision making units (DMUs) with multiple inputs and multiple outputs (Charnes et al., 1978). It also can be regarded as the solution for derivation of weights and subjective valuation of weights through aggregating different environmental pressures to construct complete eco-efficiency indicators. On the basis of eco-efficiency concept, we can employ DEA approach to evaluate its performance and take its environmental impacts into consideration. For construction industry, the construction process exerts a relative limited influence on environment (Liu and Zhang, 2014). But as highlighted earlier, it can consume a lot of resources. We thus need to measure its environmental impacts not only its direct energy consumption but also its indirect consumption. It is a little difficult to calculate the environmental impacts directly, but we can calculate the carbon dioxide emission by construction industry through its energy consumption. Carbon dioxide emission can be regarded as the environmental impacts. In DEA analysis, we can use it as the pollution output.

Till now, there are five main categories to evaluate the performance with undesirable factors (Bian et al, 2015). In this study, we followed Korhonen and Luptacik, and take undesirable output (carbon dioxide emission) as classical DEA input to evaluate eco-efficiency (Korhonen and Luptacik, 2004). Furthermore, we propose an evaluation framework of eco-efficiency, which includes three parts (economic efficiency, environmental efficiency then eco-efficiency). We divide eco-efficiency into three parts according to their natural connection. In this way, it can provide more information for us about how to further improve eco-efficiency of construction industry.

2. The methods needed for eco-efficiency evaluation of construction industry

The measurement model of carbon dioxide emission of construction industry. As mentioned above, we use carbon dioxide emission as the pollution output in eco-efficiency analysis so that we need to calculate the carbon dioxide emission by construction industry first. We follow the basic calculation principle proposed by Feng et al. (2014), which can be described as anyone should undertake what they have consumed (Feng et al, 2014). What's more, the carbon dioxide emission by construction industry include two parts: direct and indirect emission. The direct emission is caused by its own activities, while the indirect emission means the emission from other industries but induced by construction industry(Liu and Zhang, 2014). In the view of the practicability of the measurement model and the availability of data, we define the direct carbon dioxide emission by construction industry is due to the direct consumption of 9 kinds of energy (coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas and electricity), while the indirect carbon dioxide emission is due to the consumption of construction materials, such as cement, steel, glass, wood and aluminum products. As we know, consuming construction materials may not lead to carbon dioxide emission but producing these products can cause carbon dioxide emission undoubtedly. Follow the calculation method of carbon dioxide emission proposed by Intergovernmental Panel on Climate Change (IPCC), the measurement model is shown as follows.

$$E_{CO_2} = 44/12\left[\sum C_i \times \beta_i \times f_i + \sum G_i \times \varepsilon_i \times (1-\alpha_i)\right]$$

E_{CO_2} is the total carbon dioxide emission by construction industry, the unit is 10 thousand ton; C_i is the consumption amount of the ith energy, the unit is 10 thousand ton, except the unit of natural gas is 108 m3 and the unit of electricity is 108 kw/h; β_i is the convert coefficient of standard coal of the ith energy, the unit is tce/t, except the unit of natural gas is tce/104 m3 and the unit of electricity is tce/104 kw/h; f_i is the unit coefficient of carbon dioxide emission of the ith energy; G_i is the consumption amount of the ith construction materials, ε_i is the coefficient of carbon dioxide emission of the ith construction material; α_i is the recycle coefficient of the ith recycle construction material. The coefficients of carbon dioxide emission of construction materials and the recycle coefficient of the recycle construction materials that needed in the calculation are from the research results of Feng et al. (2014) and Li (2009) [1,8]. More details can be seen in their papers.

The DEA model of eco-efficiency analysis. Since the aim of eco-efficiency evaluation tries to reduce the environmental impacts but remain the outputs at the same time and the development of construction industry in each province are highly related to its economic development, we employ the input-oriented CCR model in our study.

The general linear programming of input-oriented CCR model can be represented as follows.

$$\min[\theta - \varepsilon E^T(s^- + s^+)]$$

$$\text{s.t.} \sum_{j=1}^{n} \lambda_j \times X_j + s^- = X_{j0} \times \theta$$

$$\sum_{j=1}^{n} \lambda_j \times Y_j - s^+ = Y_{j0}$$

$$s^- \geq 0, s^+ \geq 0, \lambda_j \geq 0, j = 1, \dots, n$$

Where θ is the overall efficient value of decision making unit (DMU); λ_j is the parameter vector of DMU; X_j is the input vector of the jth DMU; Y_j is the output vector of the jth DMU; s^- and s^+ are the flabby variables (remnant variables). ε is a positive non-Archimedean infinitesimal smaller than any positive real number and is used to prevent the weights from being zero.

When taking the pollution output into consideration, followed the general linear programming of input-oriented CCR model, the new model is as follows.

$$\min[\theta - \varepsilon E^T(s^b + s^g + s^-)]$$

$$\text{s.t.} \sum_{j=1}^{n} \lambda_j \times X_j + s^- = X_{j0} \times \theta$$

$$\sum_{j=1}^{n} \lambda_j \times Y_j^g - s^g = Y_{j0}^g$$

$$\sum_{j=1}^{n} \lambda_j \times Y_j^b + s^b = Y_{j0}^b$$

$$\lambda \geq 0, s^- \geq 0, s^g \geq 0, s^b \geq 0, \varepsilon > 0;\ j = 1, \dots, n$$

Where Y_j^g and Y_j^b denote the desirable and pollution outputs of jth DMU respectively; s^g expresses shortages in good outputs; s^b correspond to excesses in pollution outputs. The new model corresponds to a standard input-oriented CCR model provided that pollution outputs behave in the model like inputs. In this model, the DMU reduces simultaneously the inputs and pollution outputs in order to increase eco-efficiency.

As mentioned above, we evaluate not only the eco-efficiency, but also economic efficiency and environmental efficiency. We use the general linear model to evaluate economic and environmental efficiency, use the new model to evaluate eco-efficiency.

3. Eco-efficiency evaluation of construction industry in China

Regions, variables and data. Due to the lack of energy consumption data of Tibet, there are 30 regions considered in this study (provinces, autonomous regions and municipalities). According to the conventional classification method, we divide all regions into three main areas: eastern, central and western areas. The detail information of the regions is shown in Table 1.

Table 1: Regions information considered in this study

Areas	Regions
Eastern Area	Beijing, Tianjin, Shanghai, Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong and Hainan
Central Area	Heilongjiang, Jilin, Inner Mongolia, Henan, Shanxi, Anhui, Hubei, Hunan, Jiangxi and Guangxi
Western Area	Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Yunnan, Xinjiang, Sichuan and the Chongqing

With respect to the variables that used as inputs and outputs, we take construction industry its own specific features and the availability of data into consideration. As shown in Table 2, the inputs include energy consumption which has been converted into ton of standard coal equivalent (tce), capital (the total assets of construction industry), labor (the number of employees engaged in construction industry) and mechanical equipment (total power of construction mechanical equipment); the outputs include output value (the total output value of construction industry) and construction space (the floor space under construction); the pollution output includes carbon dioxide emission. The descriptive statistics of data are also presented in Table 2. We collect the required data from China Statistical Yearbook on Construction and China Energy Statistical Yearbook, time periods cover from 2008 to 2013.

Table 2: Descriptive statistics of the data set

Category	Variables	Unit	Min	Max	Mean	S.D.
Inputs	Capital	10K yuan	833386	136831634	29120058	26991305
	Labor	Person	63931	7824887	1518943	1427328
	Mech. Equi.	Kw	150726	48148108	7108187	7096643
	Energy	10K tce	9.4	323.71	103.91	66.67
Outputs	Output Value	10K yuan	1111837	219936099	36052304	36219511
	Construction Space	10K m2	404.5	196773.9	26644.36	33649.85
Undesir. output	Car. Diox. Emi.	10K tons	539.54	345533.3	21787.87	38785.14

Note: 1K is equal to 1000 thousand.

Economic efficiency of construction industry. In the stage of economic efficiency evaluation of construction industry, the inputs are energy, capital, labor and mechanical equipment, the outputs are the total output value of construction industry and the floor space under construction. The economic efficiency results of construction industry in each province are shown in Table 3. From the perspective of regional distribution, the average value of economic efficiency of construction industry in eastern area is significant higher than in central and western area. Seeing from the number of province that their efficient value is 1, the number remain almost unchanged during this period. Besides, eastern area has the highest number that their efficient is 1, followed by central and western area. According to these results, we can know that the regional distribution of economic efficiency is highly related with the economic development level in each area. Furthermore, Beijing, Jiangsu and Zhejiang all show a stable trend that their economic efficiency value are always 1 from 2008 to 2013, and the economic efficiency value of Heilongjiang, Jiangxi, Tianjin and Shanghai is quite close to 1, except in 2012 and 2013, the others all fluctuate slightly during this period.

Environmental efficiency of construction industry. In the stage of environmental efficiency evaluation, we consider the environmental impacts. The input is the pollution output (carbon dioxide emission by construction industry) and the outputs are the total output value of construction industry and the floor space under construction. The results of environmental efficiency are also presented in Table 3. Compared with the results of economic efficiency, the regional distribution results of environmental efficiency are consistent with economic efficiency, but the calculation results of environmental efficiency are much lower. Moreover, there is only one province that its environmental efficiency can be 1 each year. Shanghai is the province that its environmental efficiency is usually 1 during this period, except in 2012. For Guangzhou, its environmental efficiency reaches 1 in 2012, which is the highest in this year. The calculation results demonstrate that environmental efficiency show a fluctuation trend and there is much room for the improvement of environmental efficiency.

Eco-efficiency of construction industry. In the final stage, we evaluate eco-efficiency. The outputs are the same, but the inputs include the traditional inputs used in economic efficiency evaluation and the pollution output used in environmental efficiency evaluation. Table 3 also presents the results of eco-efficiency. Seeing from the results, the average value of eco-efficiency is much higher than economic efficiency and environmental efficiency. The number of province that their eco-efficiency can reach 1 is also higher, compared with the other two.

Although the eco-efficiency seems well in construction industry, there are still existing some potential problems behind this surface basing on the results of economic and environmental efficiency analyzed earlier.

Table 3: The results of three efficiencies.

Region	Economic efficiency						Environmental Efficiency						Eco-efficiency					
	2008	2009	2010	2011	2012	2013	2008	2009	2010	2011	2012	2013	2008	2009	2010	2011	2012	2013
Beijing	1	1	1	1	1	1	0.954	0.777	0.744	0.885	0.452	1	1	1	1	1	1	1
Tianjin	1	1	1	1	0.994	0.873	0.649	0.567	0.67	0.589	0.274	0.442	1	1	1	1	1	0.93
Shanghai	1	1	1	1	0.904	0.925	1	1	1	1	0.494	1	1	1	1	1	1	1
Liaoning	0.769	0.784	0.789	0.789	0.964	0.997	0.459	0.431	0.421	0.326	0.2	0.237	0.918	0.885	0.848	0.861	0.981	1
Hebei	0.751	0.882	0.966	0.899	1	1	0.437	0.471	0.197	0.055	0.023	0.143	0.827	0.902	0.966	0.899	1	1
Shandong	0.65	0.699	0.692	0.723	0.733	0.743	0.68	0.635	0.564	0.642	0.104	0.504	0.846	0.798	0.775	0.893	0.743	0.777
Jiangsu	1	1	1	1	1	1	0.706	0.773	0.7	0.202	0.188	0.633	1	1	1	1	1	1
Zhejiang	1	1	1	1	1	1	0.567	0.623	0.554	0.53	0.194	0.424	1	1	1	1	1	1
Fujian	0.759	0.769	0.852	0.898	0.868	0.85	0.574	0.506	0.459	0.576	0.184	0.352	0.877	0.809	0.852	0.977	0.923	0.853
Guangdong	0.881	0.888	0.877	0.858	0.878	0.86	0.976	0.861	0.635	0.439	1	0.56	1	1	0.877	0.861	1	0.907
Hainan	0.7	0.775	1	1	1	1	0.656	0.663	0.689	0.74	0.216	0.362	0.904	0.919	1	1	1	1
Mean	0.865	0.891	0.925	0.924	0.94	0.932	0.696	0.664	0.603	0.544	0.303	0.514	0.943	0.938	0.938	0.954	0.968	0.952
Heilongjiang	1	1	1	1	1	0.973	0.6	0.654	0.682	0.636	0.343	0.683	1	1	1	1	1	1
Jilin	0.777	0.944	0.952	0.822	0.847	0.927	0.537	0.423	0.47	0.514	0.004	0.137	1	1	0.97	1	0.847	0.927
Inner Mongolia	0.675	0.679	0.681	0.582	0.583	0.668	0.238	0.428	0.457	0.537	0.241	0.514	0.685	0.795	0.71	0.802	0.755	0.809
Henan	0.978	0.905	0.883	0.867	0.951	0.842	0.52	0.481	0.395	0.446	0.147	0.385	0.978	0.909	0.886	0.913	0.956	0.848
Shanxi	0.774	0.867	0.776	0.671	0.73	0.678	0.283	0.348	0.248	0.401	0.188	0.413	0.774	0.873	0.776	0.743	0.767	0.765
Anhui	0.691	0.756	0.784	0.809	0.832	0.802	0.702	0.683	0.536	0.596	0.248	0.477	0.927	0.885	0.83	0.917	0.971	0.842
Hubei	0.872	0.909	0.929	0.771	0.995	1	0.647	0.621	0.662	0.364	0.097	0.254	0.966	0.949	0.986	0.821	1	1
Hunan	0.842	0.874	0.926	0.945	0.919	0.88	0.542	0.476	0.473	0.603	0.198	0.488	0.923	0.888	0.926	1	0.972	0.968
Jiangxi	1	1	1	1	1	0.99	0.8	0.775	0.677	0.474	0.2	0.412	1	1	1	1	1	0.99
Guangxi	0.846	0.882	0.975	0.985	1	1	0.857	0.704	0.61	0.638	0.188	0.711	1	0.951	0.975	1	1	1
Mean	0.846	0.882	0.891	0.845	0.886	0.876	0.573	0.559	0.521	0.521	0.185	0.447	0.925	0.925	0.906	0.92	0.927	0.915
Chongqing	0.676	0.756	0.889	0.807	0.848	0.918	0.68	0.717	0.406	0.447	0.201	0.422	0.906	0.903	0.889	0.896	0.922	0.966
Sichuan	0.659	0.717	0.781	0.789	0.84	0.856	0.68	0.603	0.269	0.256	0.069	0.169	0.884	0.863	0.781	0.789	0.84	0.856
Guizhou	0.702	0.75	0.843	0.723	0.804	0.979	0.636	0.498	0.781	0.544	0.195	0.353	0.825	0.753	1	0.782	0.822	0.979
Yunan	0.644	0.737	0.74	0.633	0.712	0.744	0.556	0.554	0.4	0.557	0.225	0.224	0.75	0.814	0.751	0.872	0.83	0.752
Shaanxi	0.842	0.925	1	1	0.955	0.854	0.326	0.391	0.439	0.268	0.191	0.394	0.887	0.925	1	1	0.966	0.893
Gansu	0.572	0.616	0.701	0.701	0.748	0.788	0.326	0.534	0.579	0.29	0.229	0.396	0.646	0.792	0.808	0.727	0.864	0.848
Qinghai	0.639	0.738	0.803	0.725	0.641	0.723	0.315	0.292	0.256	0.565	0.224	0.535	0.671	0.752	0.803	0.931	0.735	0.876
Ningxia	0.55	0.603	0.643	0.615	0.655	0.739	0.612	0.679	0.601	0.596	0.248	0.491	0.733	0.832	0.804	0.847	0.865	0.83
Xinjiang	0.746	0.794	0.735	0.748	0.777	0.765	0.582	0.709	0.637	0.257	0.216	0.619	0.887	0.957	0.867	0.748	0.879	0.954
Mean	0.67	0.737	0.793	0.749	0.776	0.818	0.524	0.553	0.485	0.42	0.2	0.400	0.799	0.843	0.856	0.844	0.858	0.884

Note: the first, the second and the third mean are the average values of three efficiencies in eastern, central and western area respectively.

Firstly, only Beijing and Shanghai can realize all their economic efficiency, environmental efficiency and eco-efficiency are 1 at the same time. For some other provinces, their economic efficiency and eco-efficiency may have already reached 1, but their environmental cannot. Hence, the improvement of environmental efficiency is the key for realizing all three efficiencies are 1 at the same time. Secondly, the results of economic efficiency of construction industry in each province are much higher than the results of environmental efficiency except Shandong. This result may provide evidence that in construction industry, each province also pays much attention to economic development and pay less attention to protect environment. Lastly, whichever economic efficiency, environmental efficiency or eco-efficiency, the average value of these results are much higher than that in central and western area. As we know, eastern area is much well developed than the other two areas. Thus, the results in construction industry are highly in line with the developing level of area economics.

4. Conclusion

In this paper, we propose an evaluation framework of eco-efficiency of construction industry using DEA approach. The evaluation of eco-efficiency includes three stage: economic efficiency, environmental efficiency then eco-efficiency. In the process of evaluation, we take the pollution output (carbon dioxide emission) into consideration. The measurement of carbon dioxide emission by construction industry is basing on its direct emission of energy consumption and its indirect emission of construction materials consumption. We collect the required data from related yearbooks and time periods cover from 2008 to 2013. The DEA results show there is still much room for the improvement of environmental efficiency, though eco-efficiency seems well. We need to make a better balance between economic development and environmental protection. At the same time, the average level of three kinds efficiencies in eastern area are much better than the other two areas. It is important for policy-makers that we still need to give more support such as capital, human resource and technologies to central and western area. We may then realize a balanced development in all areas.

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