Performance Analysis of International Steel Manufacturers: A Benchmark Study for Steel Supply Chains

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***Abstract* — The authors present a benchmarking study on efficiencies or performance of various global manufacturers in the steel manufacturing supply chain using the analysis of DEA models. We select appropriate variables including costs of goods sold as an input variable for purchasing performance measure and net sales as an output for distribution performance measure to be used in our DEA analysis. Our analysis results from the selected five international steel manufacturers would help supply chain managers in steel manufacturing industry to evaluate and compare other large steel manufacturers for making possible strategic alliance decisions with publically available data. The contribution of this paper is to add a benchmarking analysis of global steel manufacturers with supply chain related variables for various DEA models with insights for their use of assets and expenses in evaluating their supply chain efficiency and performance.**

***Keywords*—*benchmarking, supply chain management (SCM), steel manufacturing, performance, efficiency, data envelopment analysis (DEA).*

1. Introduction

Heavy Industry flourished up to the second quarter of 2008 until it faced the critical recession. Like in other industries, the recession also negatively influenced the supply chain of steel manufacturing in terms of making it difficult for the other supply chain members to make a long term strategic alliance decision with manufacturers. Effective supply chain management stems from measuring supply chain performance. Measuring the right supply chain performance depends on what metrics to be used because difference metrics are needed for difference industries. In order to come up with the right metrics, variable selection to the desired model to be used for an analysis becomes critical. In this study, we present the widely used DEA (Data Envelopment Analysis) method with appropriately selected variables and apply it to the analysis of performance benchmarking of five large international steel production companies of interest which play important roles in global steel manufacturing supply chains.

The products produced by these companies are raw materials to other manufacturers such as auto makers, home appliance manufacturers, construction companies, ship builders, etc. Steel products are commoditized, and, as a result, competition is fierce in the market. In addition, the demands of these products are closely tied to the economy of the world. Accordingly, the performance benchmarking of these companies can be an interesting research topic to related firms and practitioners in steel supply chains.

The steel manufacturing industry has touch competition among global steel manufacturers. There is no outstanding company which is leading the market. Information such as market share, competitive pricing, production technology, or service quality is not transparent or not readily available for raw-material (iron ores) suppliers and buyers (end-product manufacturers) when they are to evaluate the performances of the steel manufacturers to make strategic alliancing decisions. In order for other supply chain members to search as much information as possible, some usually visit manufacturers, spy on competitors, or hire a third party agency to collect relevant information. In this paper, we present a way to compare performance or efficiencies of the global steel manufacturers by selecting appropriate variables from readily available public data and applying them to relevant DEA models.

We use three DEA models – CCR-I, BCC-I, and SBM-I-C which are described later in this paper. We analyzed in two aspects of efficiencies: one with the assets and the other with the expenses. The data we collected for the analysis spanned over a four year period.

2. Literature Review

DEA is a widely used technique to evaluate and analyze efficiency of Decision Making Units (DMUs). DEA was first developed by [3] based on production efficiency

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measurement theories proposed by [7]. They used a multiple-iteration, linear-programming (LP) based method to measure efficiency boundaries of DMUs to compare relative efficiency among them. DMUs are entities or objects that are being measured for efficiency. Since the seminal work by [3], several variations or improvements have been made by [2] (BCC model) and [11] (SBM or Slack-Based Measure model).

In terms of other benchmarking papers using DEA, [9] used the DEA model to evaluate industrial efficiencies in German foundries. According to their research, 12.5 percent of the foundries seem be technically efficient. The majority of the foundries have efficiency scores that range from 30 percent to 60 percent which are considered low. The study also shows that the median capacity utilization rate is also low at 74 percent. [4] evaluated ten plants and came up with an overall efficiency score of 96.6 percent. They show that some plants need to reevaluate and change some of the components of the operations in order to obtain the maximum efficiency with less waste. [14] analyzed Malaysian publically listed companies and found that the average overall efficiency score was not satisfactory. The study showed that the companies were wasting close to 50 percent of their outputs and needed to increase usage or decrease waste. Decreasing the waste would increase the profitability in this case. [13] studied ISO5000 iron-steel basic metal industry. Their DEA results of 14 industry firms showed that, using CCR model, three firms were efficient. However, when BCC model was used, triple the amount of firms, nine, were found to be efficient. The DEA results have helped the inefficient firms to increase their efficiencies.

[1] used the constant return to scale (CRS) DEA model (For the detailed characteristics of CRS-DEA, refer [5]) to evaluate the total efficiency of the safety performance in thirty Indian firms in three industries: construction, refractory, and steel. CRS model showed the mean efficiency score of 89.9 percent. It means that the occupational safety needs to be improved in the Indian industries. According to [12], the Chinese iron and steel industry had a mean technical efficiency of 66.2 percent which was better than the original estimate of 62.3 percent. The study reports that the higher-than-expected efficiency is due to the positive attributes such as age, agglomeration, profit, and product being added to the model. [10] analyzed the fourteen top manufacturing companies in Pakistan using the CCR and BCC DEA models. The results of the analysis showed that the average overall technical efficiencies of these companies varied from 64 to 99 percent. Only one company had the superior performance than the others in all the years that were evaluated.

The contribution of this paper is to add a benchmarking analysis of global steel manufacturers with supply chain related variables for various DEA models with insights for their use of assets and expenses in evaluating their supply chain efficiency and performance. The rest of the paper is followed by literature review, method and data analysis, results and discussions, and conclusion.

3. Method and Data Analysis

We used DEA models because DEA models are effective in measuring the relative efficiencies of a homogenous set of DMUs. DEA models also measure relative efficiency using multiple inputs and multiple outputs among similar DMUs.

To briefly present the mathematical representation of DEA as in [8], let E_0 be an efficiency score for the base DMU *0*, then:

$$Max\ E_0 = \frac{\{\sum_{r=1}^{R} u_{r0} y_{ro}\}}{\{\sum_{i=1}^{I} v_{i0} x_{i0}\}} \tag{1}$$

subject to:

$$\frac{\{\sum_{r=1}^{R} u_{r0} y_{rk}\}}{\{\sum_{i=1}^{I} v_{i0} x_{ik}\}} \leq 1\ for\ all\ k \tag{2}$$

$$u_{r0}, v_{i0}\ \geq\ \delta\ for\ all\ r, i, \tag{3}$$

where:

y_{rk} is the observed quantity of output *r* generated by unit *k*=1,2, …, *N*.

x_{ik} is the observed quantity of output *i* generated by unit *k*=1,2, …, *N*.

u_{r0} is the weight to be computed given to output *r* by the base unit *0*.

v_{r0} is the weight to be computed given to output *i* by the base unit *0*.

δ is a very small positive number.

The formulation above can be converted to a system of LP models that can be analyzed in an iterated manner using a software package. In addition, depending on how the frontiers of the efficiency space are set, there are several variations of techniques that have been developed by multiple researchers such as CCR, BCC, and SBM [5] with CRS (constant-returns-to-scale, [3]) or VRS (variable-returns-to-scale, [3]) options. We use the three aforementioned DEA models for this study: CCR, BCC, and SBM. The first one, Charnes, Cooper, and Rhodes (CCR) model, measures efficiency scores by technical efficiency (TE) which means economic efficiency. It uses CRS where returns-to-scale is constant. The second one, Banker, Charnes, and Cooper (BCC) model, measures efficiency scores by pure technical efficiency (PTE) which is a scaled-up measure from CCR by SE (scale efficiency) – see Eq. (4) below for the relationship between TE, PTE and SE. This is due to the fact that BCC assumes returns-to-scale is variable (VRS). Therefore, scale efficiency (SE) represents the efficiency due to the scale difference between CRS and VRS. The last model, Slack Based Measure (SBM) model, which minimizes the input and output slacks and evaluates ways to reduce the costs, shows efficiency scores that incorporate mix efficiency (MIX), which help explain efficiency variance due to the excessive use of resources or inputs. The mathematical relationships among these efficiency scores can be summarized as follows:

$$TE = PTE \times SE \quad (4)$$

$$SBM = PTE \times SE \times MIX = TE \times MIX \quad (5)$$

Because SE and MIX are less than or equal to one, using the relationships in Eq. (4) and Eq. (5), the magnitudes of the measures will be:

$$\text{SBM scores} \leq TE \leq PTE \quad (6)$$

SE and MIX are derived values from using the equations (4) and (5) after running CCR, BCC, and SBM models of DEA program.

For our analysis, we have chosen five large international steel roll manufacturers who are competing in the market. The five companies are as follows: one from the United States (Ampco-Pittsburg), two from China (First Heavy Industries and National Erzhong Group), and one each from Japan and Korea (Hitachi Metals Ltd. and Doosan Heavy Industries). Other than two Chinese companies that are government owned, the rest of the companies are publicly held corporations. The oldest company is Ampco-Pittsburgh which was formed in 1897. Doosan is the youngest company who joined the industry about 65 years later. These companies manufacture heavy steel rolls by either forging or casting. These steel rolls are then sent to other manufacturing companies to be used in their large-production machines for mass production of everyday products from assembly lines.

We use input-based DEA models instead of output-based DEA models since the input variables have more information pertaining to the companies of interest for this research. We focus on the financial reports for the assets and the expenses for the input-based model. For the assets model, we use the following items as input variables: 1) cash and cash equivalents, 2) inventory, and 3) property, plant and equipment (PPnE). For the expenses model, we use the following items as input variables: 1) cost of goods sold, 2) selling and administrative costs, and 3) depreciation cost. Net sales are used as the output for both of the assets and expenses models. We then take these models and analyze them with three DEA models: CCR-I, BCC-I, and SBM-I-C. Also, in order to observe some degree of longitudinal results, we have collected four years of financial report data from year 2008 to 2011. Along with the above endogenous factors, we looked at the scrap price for the same period of 2008 and 2011 to take into account the global steel manufacturing market as an exogenous factor.

By analyzing the three DEA models, we have obtained scale efficiency (SE) and company mix efficiency (MIX) factors along with individual manufacturer's efficiency for a further discussion in the following section. We also present the proposed improvements based on the projected efficiencies from the analysis. Finally, we compare the companies' efficiencies with the global economic trends to see if the global economy played a role in companies' inefficiencies that we evaluated.

4. Results and Discussions

We ran the following DEA models for assets and expenses: CCR-I, BCC-I, and SBM-I-C. The letter *I* represents 'Input' based models with which the models analyze/optimize efficiencies based on input values; whereas 'output' based models are run based on the output values of interest. The letter *C* at the end of SBM-I-C represents 'Constant Returns-to-scale' which can be further referred by [5]. Table 1 presents the efficiencies on assets from the aforementioned three DEA models along with scale efficiencies (SE) and mix efficiencies (MIX) of the five companies over the period of four years between 2008 and 2010 below:

Table 1. Efficiencies from Asset focused DEA models.

Company	CCR-I	BCC-I	SBM-I-C	SE	MIX
	TE	PTE			
Ampco Pittsburgh 2011	40%	100%	37%	40%	92%
Ampco Pittsburgh 2010	38%	99%	35%	39%	92%
Ampco Pittsburgh 2009	39%	100%	34%	39%	89%
Ampco Pittsburgh 2008	50%	100%	43%	50%	87%
First Heavy Industries 2011	39%	40%	26%	97%	67%
First Heavy Industries 2010	49%	51%	30%	97%	60%
First Heavy Industries 2009	63%	65%	40%	98%	64%
First Heavy Industries 2008	100%	100%	100%	100%	100%
National Erzhong Group 2011	36%	37%	24%	96%	67%

National Erzhong Group 2010	45%	47%	26%	96%	58%
National Erzhong Group 2009	56%	58%	32%	96%	58%
National Erzhong Group 2008	70%	72%	39%	97%	55%
Hitachi Metals Ltd. 2011	100%	100%	100%	100%	100%
Hitachi Metals Ltd. 2010	94%	94%	87%	100%	93%
Hitachi Metals Ltd. 2009	76%	76%	74%	100%	98%
Hitachi Metals Ltd. 2008	100%	100%	100%	100%	100%
Doosan Heavy Industries 2011	100%	100%	100%	100%	100%
Doosan Heavy Industries 2010	100%	100%	100%	100%	100%
Doosan Heavy Industries 2009	96%	100%	82%	96%	86%
Doosan Heavy Industries 2008	97%	100%	83%	97%	86%

Ampco Pittsburgh shows almost 100 percent on pure managerial efficiencies over the observation period, which is measured with a BCC model. However, its overall efficiencies measured with a SBM model are low due to mainly different operating environments or scale efficiency. It means that Ampco Pittsburgh's source of inefficiency lies on external factors. Meanwhile, First Heavy Industries and National Erzhong Group show relatively low efficiency cores on TE and SBM. Their inefficiencies are due to poor management and undesirable asset composition as indicated by PTE and MIX efficiencies. These companies can increase their efficiencies by improving management processes and asset structures, which will be discussed later in this section with projections on the variables, e.g., types of assets. Hitachi Metals and Doosan Heavy Industries demonstrate consistently high efficiency scores across three different DEA models. These companies can be benchmarks to other companies for improving or maintaining their performance. . The efficiency scores on expenses are presented in Table 2.

Table 2. Efficiencies from Expense focused DEA models.

Company	CCR-I	BCC-I	SBM-I-C	SE	MIX
	TE	PTE			
Ampco Pittsburgh 2011	92%	96%	54%	96%	59%
Ampco Pittsburgh 2010	76%	90%	42%	84%	56%
Ampco Pittsburgh 2009	100%	100%	100%	100%	100%
Ampco Pittsburgh 2008	100%	100%	75%	100%	75%
First Heavy Industries 2011	90%	90%	80%	100%	89%
First Heavy Industries 2010	100%	100%	100%	100%	100%
First Heavy Industries 2009	100%	100%	100%	100%	100%
First Heavy Industries 2008	99%	100%	96%	99%	97%
National Erzhong Group 2011	91%	91%	75%	100%	82%
National Erzhong Group 2010	97%	97%	86%	100%	89%
National Erzhong Group 2009	99%	99%	94%	100%	95%
National Erzhong Group 2008	100%	100%	100%	100%	100%
Hitachi Metals Ltd. 2011	100%	100%	100%	100%	100%
Hitachi Metals Ltd. 2010	100%	100%	96%	100%	96%
Hitachi Metals Ltd. 2009	95%	96%	61%	99%	65%
Hitachi Metals Ltd. 2008	95%	95%	66%	100%	70%
Doosan Heavy Industries 2011	100%	100%	100%	100%	100%
Doosan Heavy Industries 2010	87%	100%	52%	87%	59%
Doosan Heavy Industries 2009	81%	100%	47%	81%	58%
Doosan Heavy Industries 2008	85%	100%	49%	85%	58%

The efficiencies measured with expenses are similar across the companies and years. Especially, PTE scores that show pure management efficiency are 90 percent or higher for all companies during the observation period. Some companies such as Ampco Pittsburgh and Doosan Heavy Industries mark spotty inefficiencies on MIX efficiency scores. Based on these results, we can say that the expenses in the models do not have discriminant power for measuring performance of the companies in this study. However, it is somewhat surprising to us because we expected that Chinese companies, First Heavy Industries and National Erzhong Group, might incur low expenses, or more efficient, because they are usually considered to have less costly labor, utilities, properties, and so on. We speculate that it may be due to the ownership which is on Chinese Government - Government owned firms are often found to be inefficient for mega-scale industries such as power generation, telecommunication, and nationwide postal service.

The scores indicate that the results of both assets based DEA and expenses based DEA show the scores of Hitachi Metals Ltd. and Doosan Heavy Industries are better than the other three companies across the years. Furthermore, Hitachi Metals Ltd. show better scores, except PTE, than Doosan Heavy Industries on the results of expenses based analysis (see Table 2), but Doosan Heavy Industries show better performance on the results of assets based evaluation (see Table 1). From the results of CCR-I, BCC-I and SBM-I-C, we back-calculated scale efficiency (SE) and mix efficiency (MIX) using the relationships described in the previous section and present in Table 1 and Table 2 as well. The time-average DEA scores are summarized in Table 3 and Table 4 below:

Table 3. Average DEA Scores for Asset model

Company (Four year Avg.)	Asset				
	TE	PTE	SBM-I-C	SE	MIX
Ampco Pittsburgh	42%	100%	37%	42%	90%
First Heavy Industries	63%	64%	49%	98%	73%
National Erzhong Group	52%	54%	30%	96%	60%
Hitachi Metals Ltd.	93%	93%	90%	100%	98%
Doosan Heavy Industries	98%	100%	91%	98%	93%
Average	69%	82%	60%	87%	83%

Table 4. Average DEA Scores for Expense model

Company (Four year Avg.)	Expense				
	TE	PTE	SBM-I-C	SE	MIX
Ampco Pittsburgh	92%	97%	68%	95%	73%
First Heavy Industries	97%	98%	94%	100%	97%
National Erzhong Group	97%	97%	89%	100%	92%
Hitachi Metals Ltd.	98%	98%	81%	100%	83%
Doosan Heavy Industries	88%	100%	62%	88%	69%
Average	94%	98%	79%	97%	82%

We analyze the projections or potential improvements for the input variables in order to approach the input efficiencies at a micro level and present the results in Table 5 below:

Table 5. Projected Improvements (percent) for Asset-Based DEA

Company	Cash and Cash Equivalents	Inventory	Property, Plant, and Equipemnt (net)
Ampco Pittsburgh 2011	-54.51%	-72.92%	-62.57%
Ampco Pittsburgh 2010	-56.96%	-74.42%	-62.69%
Ampco Pittsburgh 2009	-58.48%	-76.94%	-61.23%
Ampco Pittsburgh 2008	-55.43%	-66.08%	-48.87%
First Heavy Industries 2011	-71.49%	-93.55%	-56.15%
First Heavy Industries 2010	-77.86%	-91.49%	-41.55%
First Heavy Industries 2009	-63.00%	-90.38%	-26.20%
First Heavy Industries 2008	0.00%	0.00%	0.00%
National Erzhong Group 2011	-75.58%	-92.71%	-59.90%
National Erzhong Group 2010	-83.50%	-92.82%	-46.28%
National Erzhong Group 2009	-78.79%	-89.95%	-34.39%
National Erzhong Group 2008	-79.90%	-90.71%	-12.98%
Hitachi Metals Ltd. 2011	0.00%	0.00%	0.00%
Hitachi Metals Ltd. 2010	-9.78%	-27.95%	0.00%
Hitachi Metals Ltd. 2009	-42.54%	-13.73%	-20.45%
Hitachi Metals Ltd. 2008	0.00%	0.00%	0.00%
Doosan Heavy Industries 2011	0.00%	0.00%	0.00%
Doosan Heavy Industries 2010	0.00%	0.00%	0.00%
Doosan Heavy Industries 2009	-11.76%	-40.68%	-0.90%
Doosan Heavy Industries 2008	0.00%	-49.31%	-0.27%

Because the efficiency scores on the expenses are similar across the companies, we present the projections on assets only. In terms the projected improvements shown in Table 5, we do not focused on the output, net sales, because we learned that increasing this output is very susceptible in the commoditized steel market. When we look at the projections in Table 5, the inefficient companies in the assets focused models, First Heavy Industries and National Erzhong Group, can improve two variables, Cash and Cash Equivalent and Inventory relatively immediately. However, taking action on Property, Plant and Equipment would take time or need strategic plans.

We have collected the scrap metal price index as presented in Figure 1 and found that the net sales are correlated with the market scrap metal price. The scrap metal price fluctuates a lot although the production efficiencies of several companies reached 100%. The global demand influences the product price which results in a floating price trend by Figure 1. Therefore, it is not considered to be efficient by just emphasizing on maximizing the output which is influenced by the market condition. The companies of interest in this study had experienced the financial crisis in 2008 and were impacted on the inventory part because many customers had cancelled the contracts or postpone the delivery time, which caused the inventory to reach higher than usual levels. The product's delivery in 2008 can be confirmed to be around three to five years - these impacts do not seem to influence the results in 2009 or even 2010.

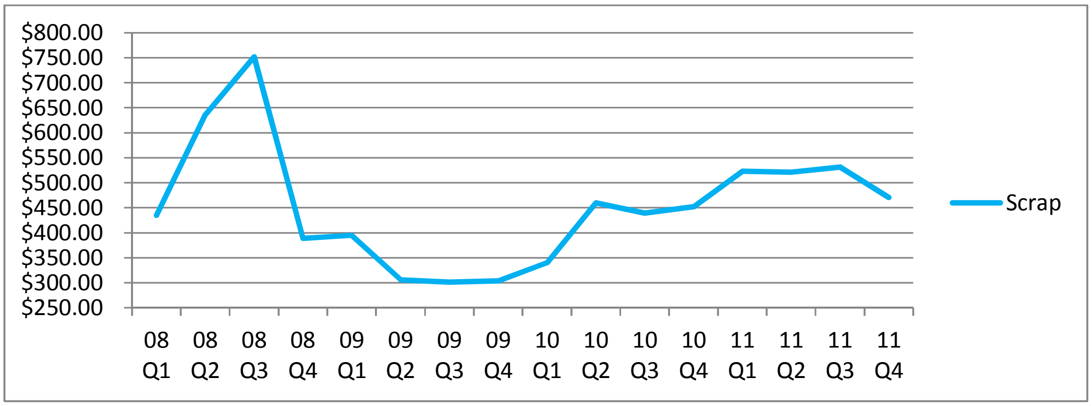

Figure 1. Scrap Metal Price Index between 2008 and 2011

The limitations of this study would be the use of only financial data that is publicly available and use of limited number of companies. For example, financial measurements on PP&E can be problematic because they are net financial values after depreciation. Regardless depreciation, the capacities of the companies should remain the same. Future studies need to address these issues by obtaining non-financial variables and additional companies, e.g. European countries.

5. Conclusion

This study explores the performance and efficiencies of the five global/international steel manufacturers by using Data Envelopment Analysis Models for the period of from 2008 to 2011 in order to help other supply chain members of steel manufacturing to evaluate across various companies using publically available data. We found from the assets DEA model that Ampco Pittsburgh has high pure managerial efficiency, but lower scale efficiency due to various operating or external environments. The Chinese government owned companies, First Heavy Industries and National Erzhong Group, have low efficiency in all measures due to inefficient management and undesirable asset composition. Hitach Metals Ltd. and Doosan Heavy Industries have overall high efficiency in assets model.

In expenses model, all companies have high efficiency although we would have liked to see even higher-than-others efficiency with Chinese steel manufacturers due to low cost structure, which did not happen due to inefficient government-based management. We recommend based on projections that Ampco Pittsburgh, Firt Heavy Industries, and National Erzhong Group improve Cash and Cash Equivalent and Inventory immediately while plan for a long term strategic improvement on PPnE. Furthermore, we compared the operation efficiency with the metal pricing index to compare which companies have better performance despite the market fluctuations. This study would help supply chain managers in steel manufacturing in terms of evaluating large not-so-transparent companies as either a supplier or a buyer for their strategic alliance decisions.

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