DEA Environmental Assessment on Industrial Sectors in the United States

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Abstract
To evaluate corporate sustainability, we should address not only operational performance but also environmental performance because people care more about environment protection than before. They prefer to purchase green products in nowadays. This study proposes "DEA environmental assessment" for measuring how to invest for eco-technology innovation to prevent industrial pollutions as a major research concern. The proposed approach incorporates the analytical capability on an occurrence of zero and negative values in a data set. We pay attention to both successful companies with positive net incomes and unsuccessful companies with negative net incomes in a short-term horizon. This study finds that US energy sectors may be not attractive in terms of a short-term horizon because of stricter governmental regulation on their operations and environment mitigations than other industrial sectors. Therefore, the energy sectors need a long-term horizon to attain a high level of corporate sustainability by investing eco-technology innovation for pollution mitigation.

Keywords: Energy, green technology innovation, corporate sustainability

Introduction

Climate change and global warming has been a major concern for all countries. In long-run consideration, environmental protection plays a more important role for sustainable development for all countries. Therefore, all corporates should pay attention to environment pollutions in their production lines. This study evaluates the operational and environmental performance of different industrial sectors in the United States. The evaluation results could be different in short-run and long-run consideration.

The US government conducts various regulation changes for prevent industrial pollutions. Also public people care more about the living conditions. Then, all companies should adjust their business strategies for sustainable development. Obviously, environmental protection requires a large investment and the companies cannot gain any direct benefit from the investment in short-run. However, the environmental investment will improve efficiency and competitiveness through innovation for companies. For example, TESLA is very popular in car industry due to "green" design without producing any emissions even though the price is high. This indicates that modern corporations in all industrial sectors have to consider the environmental protection to enhance the performance for sustainable development in short-run and long-run.

DEA environment assessment has been applied to many issues for social sustainability. The difficulty to analyze the corporate sustainability is the negative or zero values. Previous works only considered the successful companies, but the result cannot reflect the reality of the industrial sectors. This study applies the DEA approach, which can measure the data with positive, zero and negative values.

Applying the methodology to US industrial sector data, we find the fact that the technology innovation investment in the low-tech industries including energy sector can improve their unified performance as a short-run concern, but cannot improve the unified performance for high-tech industries. Also the energy firms may be not attractive in terms of net income in short-run because of strict governmental regulation and need to attain a high level of corporate value by investing technology innovation for pollution mitigation in long-run.

Literature review

A holistic methodology, or Data Envelopment Analysis (DEA) was used to evaluate the performance of companies for their corporate sustainability in many previous studies. For example, Sueyoshi and Wang, 2014a, Sueyoshi and Wang 2014b, Sueyoshi and Yuan, 2015a.

As mentioned above, the difficulty of analyzing corporate sustainability is handling the negative or zero values in data sets. Therefore, Wang et al. (2014) analyzed the corporate sustainability in U.S. industrial sectors only for successful companies with positive net incomes.

Technology innovation can solve various environmental problems so that we can obtain the corporate sustainability. See Sueyoshi and Yuan, 2016a, 2016b.

This study applies the advanced DEA methodology (see Sueyoshi and Yuan, 2015b) to handle negative or zero values in US industrial sectors for corporation sustainability.

Methodology and methods

This study considers that there are n DMUs (Decision Making Units: corresponding to an organization to be evaluated). The *j*-th DMU ($j = 1, .., n$) uses a column vector of inputs (X_j) in order to yield not only a column vector of desirable outputs (G_j) but also a column vector of undesirable outputs (B_j), where $X_j = (x_{1j}, x_{2j}, .., x_{mj})^T$, $G_j = (g_{1j}, g_{2j}, .., g_{sj})^T$ and $B_j = (b_{1j}, b_{2j}, .., b_{hj})^T$. Here, the superscript "*T*" indicates a vector transpose. These column vectors are referred to as "production factors" in this study. It is assumed that $X_j > 0$, $G_j > 0$ and $B_j > 0$ for all $j = 1, .. , n$, where all components of the three vectors are strictly positive.

The data ranges for adjustment are determined by the upper and lower bounds on inputs and those of desirable and undesirable outputs. These upper and lower bounds are specified by

$$R_i^x = (m+s+h)^{-1}\left(max\left\{x_{ij} \mid j = 1,\cdots,n\right\} - min\left\{x_{ij} \mid j = 1,\cdots,n\right\}\right)^{-1}$$

$$R_r^g = (m+s+h)^{-1}\left(max\left\{g_{rj} \mid j = 1,\cdots,n\right\} - min\left\{g_{rj} \mid j = 1,\cdots,n\right\}\right)^{-1} \text{ and}$$

$$R_f^b = (m+s+h)^{-1}\left(max\left\{b_{fj} \mid j = 1,\cdots,n\right\} - min\left\{b_{fj} \mid j = 1,\cdots,n\right\}\right)^{-1}.$$

<u>Unified Efficiency under natural and managerial disposability (UENM)</u>

UENM is used as methodology considering both operational performance and environmental performance.

UENM under variable RTS and DTS (UENM$_v$): the radial formulation under natural and managerial disposability leads to model (1) as below:

$$
\begin{aligned}
& Maximize\ \xi + \varepsilon_s [\sum_{i=1}^{m^-} R_i^x d_i^{x-} + \sum_{q=1}^{m^+} R_q^x d_q^{x+} + \sum_{r=1}^{s} R_r^g (d_r^{g+} + d_r^{g-}) + \sum_{f=1}^{h} R_f^b d_f^b \\
& s.t. \quad \sum_{j=1}^{n} x_{ij}^- \lambda_j + d_i^{x-} = x_{ik}^- \quad (i = 1, .., m^-), \\
& \sum_{j=1}^{n} x_{qj}^+ \lambda_j - d_q^{x+} = x_{qk}^+ \quad (q = 1, .., m^+), \\
& \sum_{j=1}^{n} g_{rj}^+ \lambda_j - d_r^{g+} - \xi g_{rk}^+ = g_{rk}^+ \quad (r = 1, .., s), \\
& \sum_{j=1}^{n} g_{rj}^- \lambda_j + d_r^{g-} = g_{rk}^- \quad (r = 1, .., s), \qquad (1) \\
& \sum_{j=1}^{n} b_{fj} \lambda_j + d_f^b + \xi b_{fk} = b_{fk} \quad (f = 1, .., h), \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j \geq 0\ (j = 1, .., n),\ \xi : URS,\ d_i^{x-} \geq 0\ (i = 1,..,m^-),\ d_q^{x+} \geq 0\ (q = 1,..,m^+), \\
& d_r^{g+} \geq 0\ (r = 1,..,s), d_r^{g+} \geq 0\ (r = 1,..,s)\ \&\ d_f^b \geq 0\ (f = 1,..,h).
\end{aligned}
$$

The level of unified efficiency of the k-th DMU under managerial disposability as follows:

$$
UENM_v = 1 - \left\{ \xi^* + \varepsilon_s \left[\sum_{i=1}^{m^-} R_i^x d_i^{x-*} + \sum_{q=1}^{m^+} R_q^x d_q^{x+*} + \sum_{r=1}^{s} R_r^g (d_r^{g+*} + d_r^{g-*}) + \sum_{f=1}^{h} R_f^b d_f^{b*} \right] \right\}, \qquad (2)
$$

where the inefficiency measure and all slack variables are identified on the optimality of Model (1). The equation within the parenthesis, obtained from Model (1), indicates the level of unified inefficiency. The UENM is obtained by subtracting the level of inefficiency from unity.

UENM under constant RTS and DTS ($UENM_c$): To attain the status of constant RTS and DTS, this study drops the condition ($\sum_{j=1}^{n} \lambda_j = 1$) from Model (1) and measures the level of unified efficiency by

$$
UENM_c^* = Equation\ (2),
$$

(3)

where the optimal solution is obtained from Model (1) without $\sum_{j=1}^{n} \lambda_j = 1$.

Scale Efficiency Measure under Natural and Managerial Disposability ($SENM$): To examine how each DMU carefully manages its operational size under natural and managerial disposability, this study measures the degree of its scale efficiency by

$$
SENM^* = UENM_c^* / UENM_v^*. \qquad (4)
$$

Since $UENM_c^* \leq UENM_v^*$, the scale efficiency is less than or equals unity. The higher score in $SENM^*$ indicates the better scale management under managerial disposability.

UENM with Desirable Congestion: UENM (DC)

In order to incorporate an occurrence of DC, or technology innovation for pollution mitigation, this study reformulates Model (1) so that it can measure the unified efficiency with a possible occurrence of DC. The reformulated model becomes as follows;

$$
\begin{aligned}
&Maximize\ \xi + \varepsilon_s [\sum_{i=1}^{m^-} R_i^x d_i^{x-} + \sum_{q=1}^{m^+} R_q^x d_q^{x+} + \sum_{f=1}^{h} R_f^b d_f^b] \\
&s.t.\quad \sum_{j=1}^{n} x_{ij}^- \lambda_j + d_i^{x-} = x_{ik}^- \ (i = 1, .., m^-), \\
&\sum_{j=1}^{n} x_{qj}^+ \lambda_j - d_q^{x+} = x_{qk}^+ \ (q = 1, .., m^+), \\
&\sum_{j=1}^{n} g_{rj}^+ \lambda_j + \xi g_{rk}^+ = g_{rk}^+ \ (r = 1, .., s), \\
&\sum_{j=1}^{n} g_{rj}^- \lambda_j = g_{rk}^- \ (r = 1, .., s), \\
&\sum_{j=1}^{n} b_{fj} \lambda_j - d_f^b = b_{fk} \ (f = 1, .., h), \\
&\sum_{j=1}^{n} \lambda_j = 1, \\
&\lambda_j \geq 0 \ (j = 1, .., n),\ \xi: URS, \\
&d_i^{x-} \geq 0 \ (i = 1,..,m^-),\ d_r^{x+} \geq 0 \ (r = 1,..,m^+), \&\ d_f^b \geq 0 \ (f = 1,..,h),
\end{aligned}
\tag{5}
$$

The level of unified inefficiency of the k-th DMU under natural and managerial disposability as follows:

$$
UENM(DC)_v = 1 - \left\{ \xi^* + \varepsilon_s \left[\sum_{i=1}^{m^-} R_i^x d_i^{x-*} + \sum_{q=1}^{m+} R_q^x d_q^{x+*} + \sum_{f=1}^{h} R_f^b d_f^{b*} \right] \right\}, \tag{6}
$$

where the inefficiency score and all slack variables are identified on the optimality of Model (5). The equation within the parenthesis, obtained from Model (5), indicates the level of unified inefficiency with a possible occurrence of DC. The level of UENM(DC) is obtained by subtracting the level of inefficiency from unity.

The dual formulation becomes as follows:

$$\text{Minimize} \sum_{i=1}^{m^-} v_i x_{ik}^- - \sum_{q=1}^{m^+} z_q x_{qk}^+ + \sum_{r=1}^{s} u_r^+ g_{rk}^+ + \sum_{r=1}^{s} u_r^- g_{rk}^- - \sum_{f=1}^{h} w_f b_{fk} + \sigma$$

$$\begin{aligned} s.t. \quad & \sum_{i=1}^{m^-} v_i x_{ij}^- - \sum_{q=1}^{m^+} z_q x_{qj}^+ + \sum_{r=1}^{s} u_r^+ g_{rj}^+ + \sum_{r=1}^{s} u_r^- g_{rj}^- - \sum_{f=1}^{h} w_f b_{fj} + \sigma \ge 0 && (j = 1, .., n), \\ & \sum_{r=1}^{s} u_r^+ g_{rk}^+ = 1, && \\ & v_i \ge \varepsilon_s R_i^x && (i = 1, .., m^-), \\ & z_q \ge \varepsilon_s R_q^x && (q = 1, .., m^+), \\ & u_r^+ \ \& \ u_r^- : URS && (r = 1, .., s), \\ & w_f \ge \varepsilon_s R_f^b && (f = 1, .., h) \ \& \\ & \sigma : URS. && \end{aligned} \tag{7}$$

UENM under constant RTS and DTS ($UENM(DC)_c$): To attain the status of constant RTS and DTS, this study drops the condition ($\sum_{j=1}^{n} \lambda_j = 1$) from Model (5) and measures the level of unified efficiency by

$$UENM(DC)_c^* = \text{Equation (6)}, \tag{8}$$

where the optimal solution is obtained from Model (5) without $\sum_{j=1}^{n} \lambda_j = 1$.

Scale Efficiency Measure ($SENM$): To examine how each DMU carefully manages its operational size under natural and managerial disposability, this study measures the degree of its scale efficiency by

$$SENM(DC)^* = UENM(DC)_c^* / UENM(DC)_v^*. \tag{9}$$

Since $UENM(DC)_c^* \le UENM(DC)_v^*$, the scale efficiency is less than or equals unity. The higher score in $SENM(DC)^*$ indicates the better scale management under natural and managerial disposability. The scale efficiency considers a possible occurrence of DC, or technology innovation on industrial pollution.

Investment Rule

After solving Model (7), this study can identify an occurrence of DC, or technology innovation for pollution mitigation, by the following rule along with the assumption on a unique optimal solution (Sueyoshi and Goto, 2014):

(a) if $u_r^{+*} = 0$ for some (at least one) r, then "zero DTR" occurs on the k-th DMU,
(b) if $u_r^{+*} < 0$ for some (at least one) r, then "negative DTR" occurs on the k-th DMU and
(c) if $u_r^{+*} > 0$ for all r, then "positive DTR" occurs on the k-th DMU.

Note that if $u_r^{+*} < 0$ for some r and $u_{r'}^{+*} = 0$ for the other r', then this study considers that the negative DTR (Damages to Scale) occurs on the k-th DMU, indicating a status of DC, or technology innovation for pollution mitigation.

It is indeed true that $u_r^{+*} < 0$ for all r is the best case because an increase in any desirable output always decreases an amount of undesirable outputs. Meanwhile, if $u_r^{+*} < 0$ is identified for some r, then it indicates that there is a chance to reduce an amount of undesirable output(s). Therefore, this study also considers the second case as an investment opportunity because we want to reduce an amount of industrial pollution as much as possible.

Under an occurrence of negative DTR (i.e., $u_r^{+*} < 0$ for at least one r), the effect of investment on undesirable outputs is determined by the following rule:

(a) if $z_q^* > \varepsilon_s R_q^x$ for q in Model (7), then the q-th input for investment under managerial disposability can effectively decrease an amount of undesirable outputs and
(b) if $z_q^* = \varepsilon_s R_q^x$ for q in Model (7), then the q-th input for investment has a limited effect on decreasing an amount of undesirable outputs.

The investment on inputs under managerial disposability is not recommended in the other two cases (i.e., positive and zero DTR) as depicted in the right hand side of Figure 1. Furthermore, this study uses "a limited effect" in the second case. The term implies that if this study drops the data range on the q-th input in Model (7), then there is a high likelihood that z_q^* may become zero. Moreover, $z_q^* > \varepsilon_s R_q^x$ are required for some q, but not necessary for all q.

Finally, it is important to note that the proposed investment classification needs at least two desirable outputs because Model (7) has $ug_k = 1$ in the case of a single desirable output. Even if u is unrestricted, Model (7) cannot produce a negative value on the dual variable, so being unable to identify an investment opportunity. Thus, the investment rule discussed in this study needs multiple desirable outputs.

Results

This study obtains a data set on S&P companies in 2012 and 2013 from the proceeding study of Sueyoshi and Wang (2014) for Carbon Disclosure Project (CDP) and COMPUSTAT. It includes the companies' direct and indirect GHG emission, the investment in carbon mitigation and the corresponding total estimated GHG saving. The data set consists of two desirable outputs: net income and estimated annual CO_2 saving, two undesirable outputs: direct and indirect CO_2 emissions, three inputs under natural disposability: number of employees, working capital and total assets and two inputs under managerial disposability: investment in CO_2 abatement and R&D expense.

Table 1: Unified efficiency measures of industry sectors

Sector	Company type	UENMv	UENMc	SENM	DMUs
Consumer discretionary	Automobiles & Components	0.7463	0.5042	0.7483	6
	Consumer Durables & Apparel	0.5645	0.3034	0.4502	5
	Retailing	0.5532	0.0107	0.0439	2
	Overall	0.6466	0.3510	0.5253	13
Consumer staples	Food, Beverage & Tobacco	0.3259	0.2467	0.6358	9
	Household & Personal Products	0.6096	0.0929	0.2483	4
	Overall	0.4132	0.1994	0.5166	13
Energy	Energy equipment & services	0.5772	0.4855	0.7915	4
	Oil & gas	0.6501	0.4904	0.7895	10
	Overall	0.6293	0.4890	0.7900	14
Health care	Health Care Equipment &	1.0000	0.9161	0.9161	2
	Biotechnology & Life Sciences	0.4176	0.3542	0.8545	11
	Pharmaceuticals	0.6674	0.5553	0.8250	14
	Overall	0.5903	0.5001	0.8438	27
Industrials	Capital Goods	0.7970	0.7757	0.9751	18
	Commercial & Professional	0.1401	0.1360	0.9847	2
	Overall	0.7313	0.7117	0.9761	20
Information technology	Semiconductors & Equipment	0.7127	0.7088	0.9920	20
	Software & Services	0.7703	0.7659	0.9897	19
	Technology Hardware &	0.7481	0.7414	0.9889	12
	Overall	0.7425	0.7378	0.9904	51
Materials	Chemicals	0.9530	0.9525	0.9995	13
	Containers & Packaging	0.9046	0.8961	0.9886	4
	Metals & Mining	0.9133	0.9133	1.0000	2
	Paper & Forest Products	0.9714	0.9714	1.0000	4
	Overall	0.9443	0.9426	0.9977	23

Source: Sueyoshi & Yuan (2015b).

Table 1 summarizes the same unified efficiency scores of the seven industrial sectors, all of which are measured by Model (1). Combining their unified (operational and environmental) performance, for example, the consumer staples industry is inefficient at the level of UENMv (0.4132) on average. The efficiency levels of energy industry are UENMv (0.6293) and UENMc (0.4890). The highest efficiency measures, or UENMv (0.9443) and UENMc (0.9426), can be found in the materials industry. The materials, information technology and industrials sectors consist of the high-ranked group. The health care and energy sectors belong to the middle-ranked group. The consumer directory and consumer staples sectors belong to the low-ranked group. The ranking position of the industrial sectors is consistent with their scale efficiency measures. For example, the materials, information technology and industrials sectors have high SENM measures (0.9977, 0.9904 and 0.9761), respectively.

Table 2 summarizes the unified efficiency scores of UENM(DC)v, UENM(DC)c, SENM(DC) of the seven industrial sectors, all of which are measured by Model (5). The most important feature of the three UENM measures is that they incorporate a possible occurrence of DC, or technology innovation for pollution mitigation. The three efficiency measures increase drastically in consumer discretionary, consumer staples and energy industry sectors in comparing them with the ones of Table 1. Therefore, the unified performance of these industries can be improved significantly by technology innovation. In particular, the unified efficiency measures of the consumer discretionary industry are increased to unity, indicating the status of full efficiency. In contrast, All efficiency scores UENM(DC)v, UENM(DC)c, SENM(DC) decrease in the top four industrial sectors (i.e., materials, information technology, industrials and health care) of Table 1. An exception may be found in SENM(DC) of the material industry in the manner that the SENM is 0.9977 and SENM(DC) is 0.9983.

Table 2: Unified efficiency measures of industry sectors

Sector	Company type	UENM(DC)v	UENM(DC)c	SENM(DC)	DMUs
Consumer discretionary	Automobiles & Components	1.0000	1.0000	1.0000	6
	Consumer Durables & Apparel	1.0000	1.0000	1.0000	5
	Retailing	1.0000	1.0000	1.0000	2
	Overall	1.0000	1.0000	1.0000	13
Consumer staples	Food, Beverage & Tobacco	0.8180	0.7384	0.8977	9
	Household & Personal Products	0.8173	0.7920	0.9658	4
	Overall	0.8177	0.7549	0.9187	13
Energy	Energy equipment & services	0.8251	0.7858	0.8690	4
	Oil & gas	0.7835	0.6915	0.8507	10
	Overall	0.7954	0.7184	0.8559	14
Health care	Health Care Equipment &	0.8280	0.7888	0.9402	2
	Biotechnology & Life Sciences	0.4650	0.3288	0.6829	11
	Pharmaceuticals	0.5204	0.4138	0.7238	14
	Overall	0.5206	0.4069	0.7231	27
Industrials	Capital Goods	0.5186	0.4788	0.8883	18
	Commercial & Professional	0.6374	0.5762	0.7774	2
	Overall	0.5305	0.4885	0.8772	20
Information technology	Semiconductors & Equipment	0.4151	0.3924	0.9102	20
	Software & Services	0.6608	0.6506	0.9573	19
	Technology Hardware &	0.4181	0.4146	0.9802	12
	Overall	0.5074	0.4938	0.9443	51
Materials	Chemicals	0.7345	0.7342	0.9970	13
	Containers & Packaging	0.6363	0.6362	0.9998	4
	Metals & Mining	0.6054	0.6054	1.0000	2
	Paper & Forest Products	0.9554	0.9554	1.0000	4
	Overall	0.7446	0.7444	0.9983	23

Source: Sueyoshi & Yuan (2015b).

Table 2 indicates that technology innovation may not improve the performance of firms in health care, industrials, information technology, and materials sectors, which have already reached a high level of technology development through spending much money on their engineering capabilities. Therefore, redundant investment on technology innovation cannot continuously improve companies' performance. Hence, the balanced investment on different part of business should be emphasized and promoted. On the other hand, the technology innovation investment can improve the high-tech companies' performance. Because the UENM(DC)v of two company types which are related with high technology (eg, biotechnology & life science, commercial & professional services) increase comparing to UENM in Table 1.

Discussion

Comparing between Tables 1 and 2, two important business implications are indicated. First, the technology innovation investment in the low-tech industries can improve their unified performance if desirable outputs are measured by net income and an amount of CO_2 emission reduction because these industries are the largest emitter among the seven sectors examined in this study and they historically paid more attention on operational performance rather than environment performance. The green investment may increase the amount of net income by enhancing a good corporate image in a short-term horizon. Second, balanced investment on technology innovation should be promoted. The high-tech industries, including health care, industrials, information technology and materials, already paid more attention on environment than economic performance in scale management. Therefore, the investment on technology innovation cannot attain best performance. This green investment on technology innovation may absorb the resources on other parts of business in the companies and it cannot lead to the immediate enhancement of their net incomes. However, technology innovation is a key factor of some sub-industries such as biotechnology and professional services, the green investment on technology innovation is necessary.

Table 3: Investment strategy on industry sectors

Company Name	# of effective investments	Percentage (%)	# of limited investments	Percentage (%)
Consumer discretionary	2	15.38	0	0.00
Consumer staples	2	15.38	0	0.00
Energy	2	14.29	0	0.00
Health care	4	14.81	0	0.00
Industrials	2	10.00	1	5.00
Information technology	11	21.57	2	3.92
Materials	8	34.78	1	4.35
Overall	31	19.25	4	2.48

Source: Sueyoshi & Yuan (2015b).

Table 3 lists effective and limited investment opportunities on the seven industrial sectors. On overall average, 31 observations (19.25%) are rated as effective investments and 4 observations (2.48%) are rated as limited investments in terms of developing corporate sustainability. The energy sector has the fraction (14.29%) of effective investments, rated as the sixth among the seven industrial sectors. This indicates that the energy sector does not exhibit an attractive investment opportunity for developing corporate sustainability in short-run, compared with the other six industrial sectors.

Conclusion

This study has paid attention to both successful companies with positive net incomes and unsuccessful companies with negative net incomes. The analytical capability on an occurrence of zero and negative values was incorporated. Finally, we have obtained the following empirical findings. First, the technology innovation investment in the low-tech industries including energy sector can improve their unified performance as a short-run concern if desirable outputs are measured by net income and an amount of CO_2 emission reduction. Second, balanced investment on technology innovation should be promoted for high-tech industries.

Specifically for energy sector, the energy firms may be not attractive in terms of net income in short-run because of strict governmental regulation on their operations and environment mitigations. The energy sector needs to attain a high level of corporate value by investing technology innovation for pollution mitigation in long-run.

In conclusion, it is important to note that this article is based upon the work of Sueyoshi & Yuan (2015b). It is hoped that this study makes a contribution in DEA environmental assessment. We look forward to seeing future extensions as discussed in this study.

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