Hitotsubashi Journal of Economics 59 (2018), pp.9-24. Ⓒ Hitotsubashi University

METAFRONTIER ANALYSIS OF THE HIGH-TECH INDUSTRY'S ENVIRONMENTAL EFFCIENCY IN JAPAN AND TAIWAN

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Received December 2016; Accepted December 2017

Abstract

This study reflects on environmental conservation and sustainable development via environmental efficiency by utilizing a one-stage model to measure the performances of decision-making units. Färe et al. (1989) propose the concept of undesirable output, distinguishing between output that is good and bad. O'Donnell et al. (2008) use metafrontier frameworks to compare the technical efficiency of firms and to distinguish different groups. Therefore, this study utilizes the concept of undesirable output and environmental efficiency and also combines metafrontier frameworks to evaluate and compare Japan's and Taiwan's high-tech industries. Findings show that Japan's performance is better than Taiwan's.

Keywords: metafrontier, environmental efficiency, directional distance function
JEL Classification Codes: D24, O57, Q53

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I. *Introduction*

While the Kyoto protocol was signed over ten years ago, many environmental warning signs still prevail, such as melting glaciers, rising sea-levels, carbon dioxide emissions caused by burning coal, and ecological destruction of tropical rainforests. Humans continue to repeat their disruptive behaviors toward the environment, and so far any beneficial manpower has not been able to slow down this natural destruction. Because it is impossible to change the current situation, some activities conducted through enterprises can at least be started, as they have enough power to affect everyone.

Many scholars in the past have researched efficiency by comparing decision-making units (DMUs) that operate under a variety of resources. Sometimes the same resources are being analyzed but in different DMUs, and their outputs may not even be the same. While efficiency is a measure of DMUs' operations, it can also be used in many other areas. Measuring efficiency generally involves data envelopment analysis and stochastic frontier analysis. Data envelopment analysis (DEA), previously used to measure industrial efficiency, has been applied to many issues such as environmental efficiency, resource efficiency, etc. However, conventional DEA assumes certain outputs are good, when in fact outputs may differ when used by industry in real life - for example, in the case of plant material transformed into coal, oil, and other fossil fuels. Moreover, power output, heat, carbon dioxide, sulfur dioxide, and other greenhouse gases also generate a negative output.

Färe et al. (1989) employ a non-linear programming method that looks at undesirable outputs and analyze actual side effects and the different forms these outputs may take in various. For instance, they include bad debts in banking, wastewater and solid waste in manufacturing, noise pollution in the airline industry, etc. A real assessment of efficiency must take the negative impacts of these undesirable side effects into account.

Kim et al. (2010) examine the causal relationship between economic growth and carbon dioxide emissions in South Korea, finding a significant positive relationship between carbon dioxide emissions and economic activity. Féres and Reynaud (2012) investigate the impacts from environmental and economic performances of Brazilian manufacturing firms. Bian and Yang (2010) use resource and environmental efficiencies in an analysis of 30 provinces in China, which has since become the second-largest energy user in the world. In fact, China's Gross National Product (GNP) increased 68-fold between 1978 and 2007, while Its industrial waste and greenhouse gas emissions tripled. Khanna and Kumar (2012) research corporate environmental management and environmental efficiency and find. This research takes into account environmental degradation as a result of emissions, wastewater, and similar undesirable outputs. However, some undesirable outputs, like wastewater and wastepaper, can be recycled or reused in beneficial ways. The variables of evaluation efficiency for the environment are labour and capital as the inputs and the emissions of CO_2, NO_2, and GNP and the added value of products as the outputs. The past literature has discussed undesirable outputs such as CO_2, evaluating and comparing DMUs that control or slow down CO_2 and explaining the result (Bowden and Payne, 2010; Gomes and Lins, 2007). In regards to their effect on industry, undesirable outputs that can be recycled or reused as new inputs should not be considered in the same way as undesirable outputs that cannot.

This study uses variables in the past literature and adds water consumption on the input side and the emissions of wastewater and waste on the output side. We utilize these variables in this study to analyze environmental efficiency, because every industry uses water and metals in their production process. If only CO_2 is considered in efficiency analysis, then the result will not be close to the real world . When a firm uses water and metals in its manufacturing process, then the firm, according to Newton's law of conservation of quality, discharges some desirable and undesirable outputs. In this case the undesirables outputs used in this study to evaluate environmental efficiency on the negative side are wastewater and waste (Bian and Yang, 2010).

In addition to undesirable outputs, firms usually employ different production technologies in different geographic locations and socioeconomic conditions. However, conventional DEA assumes that all observed firms meet the same production frontier (use the same production technology). Therefore, O'Donnell et al. (2008) utilize the metafrontier approach to analyze the technology gap, using DEA as the basis of evaluation to estimate the technical efficiency of the metafrontier and group frontiers, but they do not consider undesirable outputs. Aiming to address these issues, this study uses the directional distance function (DDF) and then integrates the metafrontier concept to evaluate the environmental efficiency of Japan's and Taiwan's high-tech industry.

II. *Literature Review*

1. Environmental Efficiency

The issue of damage to the environment has been studied for a long time, with the objective of environmental projection and related methods of analysis initially developed by Cooper and associates (Charnes et al., 1976; Charnes et al., 1952; Charnes et al., 1958). In order to evaluate firms' efficiency the emission issue has been researched in terms of undesirable outputs (Coli et al., 2011; Färe et al., 1989; Sözena et al., 2011; Sahoo et al., 2011; Sueyoshi and Goto, 2010, 2011). Zhou et al. (2008) provide a summary of approximately 100 studies on energy and environmental impacts that are of benefit to our study of this issue.

This study's DEA considers both desirable outputs (e.g., revenue) and undesirable outputs (e.g. CO_2, solid waste, and wastewater) from the inputs of energy, water, labour, and capital. Early on, DEA was applied to evaluate organizational efficiency in many industries, generally using multiple inputs and outputs. The strength of DEA is that it does not set the cost/production function in advance or utilize linear programming. These strengths have led to more effective energy and environmental research, such that many articles have introduced DEA as a research method in recent years.

Many researchers have followed in the initial vein of Färe et al. (1989), who first set up non-linear programming to handle undesirable outputs. Scheel (2001) indicates that production change at any level has different influences on desirable and undesirable outputs. Färe and Grosskopf (2004) utilize distance function-based DEA to evaluate the effect of undesirable outputs on environmental efficiency. Vencheh et al. (2005) employ DEA based on a mathematical model to calculate an efficiency value that considers both desirable and undesirable outputs. Reinhard et al. (2002) present environmental efficiency as a ratio of harmful inputs to lowest desirable outputs at a given technological and observation level. Zhang et al. (2008) note that if we only consider the environmental impact, then questions regarding energy use and efficiency are excluded. These latter two papers both consider the efficiency of energy use and waste emission - that is, environmental efficiency. Coli et al. (2011) develop an environmental efficiency index incorporating environmental harm as an input in order to minimize harm on a particular level KumarMandal and Madheswaran (2010) categorize greenhouse gases into two input-and-output-based models to compare cement industries in India. All of the above studies demonstrate the widely recognized importance of the issue of environmental efficiency.

2. Undesirable Factor

Many industries have undesirable outputs, including agriculture, aviation, electrical-power, animal husbandry, and cement (Atkinson and Dorfman, 2005; Chang and Yang, 2011; Oggioni et al., 2011; Sueyoshi and Goto, 2011; Yu, 2004). In addition to operational efficiency, environmental efficiency has been quickly adopted as an area of research interest. Early studies like Charnes et al. (1952) were followed by the adoption of DEA to evaluate energy, environment, and operational efficiencies on different decision-making units (DMUs) and industries. DEA is the only method that is able to construct an assessment and measure multiple inputs and outputs on every DMU (Charnes et al., 1976).

Unlike past DEA models including the model of CCR (constant returns to scale) or BCC (variable returns to scale), the present model herein does not assume outputs and inputs are desirable in the real production process. The motive for the undesirable output model was developed based on the global environmental projection, and thus every research defines pollutants as undesirable outputs (Bian and Yang, 2010; Liu et al., 2010; Pittman, 1983; Sahoo et al., 2011; Tyteca, 1996; Zhou et al., 2008). The traditional DEA model assumes easily disposable outputs, no overuse of inputs, and input congestion, and that outputs are expected by DMUs. It appears that input congestion and not economic level leads to a decrease in what. However, the addition of further desirable outputs might produce undesirable outputs as a byproduct.

3. Metafrontier Analysis

In practice one generally uses production frontiers to evaluate the efficiency of firms. The value of efficiency changes when firms operate under different technology situations. Battese and Rao (2002) propose a framework concept to define the metafrontier as a frontier that consists of a technology set, which is unrestricted. Group-frontier consists of a technology set, which is restricted. Whether unrestricted or restricted, the metafrontier always envelops the group frontier. Battese et al. (2004) correct the model of Battese and Rao (2002) and note that the unit of evaluation will have different random production frontiers for different technologies. Battese et al. (2004) not only use the metafrontier, but also add stochastic frontier analysis (SFA) to technology efficiency to assess and compare the distance from the metafrontier to the group frontier. This distance is called the technology gap ratio (TGR). Metafrontier analysis combines different methods of evaluating efficiency to assess firms' operating performance. Based on the charateristics of the research sample, metafrontier analysis distinguishes different groups and compares the gap in production technology among different firms in the area of operation technology. However, metafrontier is more suited to application in a cross country comparison.

III. *Research Method*

Employing the conventional DEA approach for efficiency assessment usually assumes that all producers possess the same level of production technology. However, the assessed DMUs usually reflect different production technologies owing to differences in geographical location, national policy, and socio-economic conditions. Therefore, O'Donnell et al. (2008) apply the metafrontier concept in the estimation of DEA efficiency, gauge a metafrontier through the use of group samples, divide the DMU, and estimate the group frontiers of each group.

Let us assume that there are N peer DMUs, each with M inputs, S desirable outputs, and B undesirable outputs. The set of undesirable outputs is decomposed into (Y^{b}) and (Y^{sb}), where Y^{b} and Y^{sb} denote the bad outputs and separable bad outputs, respectively. We use inputs $x \in R_{+}^{M}$ to produce desirable outputs $y \in R_{+}^{S}$ and undesirable outputs $y^{u} = (y^{b}, \mu y^{sb}, (1-\mu) y^{sb}) \in R_{+}^{B}$ in the production process, where μ is the proportion of the shared separable bad outputs $y^{sb} \in R_{+}^{B-C}$. We can separate Y^{sb} into good outputs μy^{sb} and bad outputs $(1-\mu) y^{sb}$.

We assume that the production possibility set (PPS) of inputs and outputs is weak disposal. Chambers et al. (1996) propose the directional technology function, which allows for desirable outputs to be proportionately increased and undesirable outputs to be proportionately decreased at the same time. The meta-technology set can be represented as follows:

$$T^{m} = \{(x, y, y^{b}, y^{sb}) : x \mathrm{canproduce} y,\ y^{b} \mathrm{and}\ y^{sb}\} \tag{1}$$

The directional meta-distance function is defined as follows:

$$\begin{aligned} &\vec{D}^{meta}(x, y, y^{b}, y^{sb}; g_{y}, g_{y^{b}}, g_{y^{sb}}) = \\ &\sup\{\theta^{m} : (y + \theta^{m} g_{y}, y^{b} - \theta^{m} g_{y^{b}}, y^{sb} - \theta^{m} g_{y^{sb}}) \in T^{m}(x, y, y^{b}, y^{sb})\} \end{aligned} \tag{2}$$

We divide the industry into K technology sets (sub-groups) due to differences in geographical location and socio-economic conditions. The meta-technology set envelops the K group technology set, and then $T^{m} = \{T^{1} \cup T^{2} \cup \ldots \cup T^{K}\}$. The group technology set is represented as follows:

$$T^{k} = \left\{ \begin{array}{l} (x, y, y^{b}, y^{sb}) : x \text{ can be used by DMU sin group } k \\ \text{to produce } y,\ y^{b} \text{and } y^{sb} \end{array} \right\},\ k = 1, 2, \ldots, K \tag{3}$$

The K group DDF is defined as follows:

$$\begin{aligned} &\vec{D}^{k}(x, y, y^{b}, y^{sb}; g_{y}, g_{y^{b}}, g_{y^{sb}}) = \\ &\sup\{\phi^{k} : (y + \phi^{k} g_{y}, y^{b} - \phi^{k} g_{y^{b}}, y^{sb} - \phi^{k} g_{y^{sb}}) \in T^{m}(x, y, y^{b}, y^{sb})\},\ k = 1, 2, \ldots, K \end{aligned} \tag{4}$$

Due to $T^{m} = \{T^{1} \cup T^{2} \cup \ldots \cup T^{K}\}$, the technical efficiency measured on the basis of the metafrontier is therefore less than those of the group frontiers, as shown by $TE^{m}(x, y, y^{b}, y^{sb}) \leq TE^{k}(x, y, y^{b}, y^{sb})$. Additionally, the difference between the technical efficiency of the metafrontier and the group frontiers is referred to as the TGR^{k} and can be described as:

$$0 \leq TGR^k(x, y, y^b, y^{sb}) = \frac{TE^m(x, y, y^b, y^{sb})}{TE^k(x, y, y^b, y^{sb})} \leq 1 \tag{5}$$

The closer TGR is to 1, the smaller the gap is, which means the technical efficiency of the group frontiers is closer to the technical efficiency of the metafrontier. In order to calculate the directional meta-distance function and K group DDF, we need to solve the following two linear programs:

$$\begin{aligned}
&Max\vec{D}^{meta}(x_{io}, y_{ro}, y^b_{co}, y^{sb}_{do}; g) = \theta^m_o \\
&s.t. \sum_{j=1}^{N} \lambda_j x_{ij} \leq x_{io}, && i = 1,...,M, \\
&\quad \sum_{j=1}^{N} \lambda_j y_{rj} \geq (1+\theta^m_o) y_{ro}, && r = 1,...,S, \\
&\quad \sum_{j=1}^{N} \lambda_j y^b_{cj} = (1-\theta^m_o) y^b_{co}, && c = 1,...,C, \\
&\quad \sum_{j=1}^{N} \mu_{dj} \lambda_j y^{sb}_{dj} = \mu_{do} y^{sb}_{do}, && d = 1,...,B-C, \\
&\quad \sum_{j=1}^{N} (1-\mu_{dj}) \lambda_j y^{sb}_{dj} = (1-\mu_{do})(1-\theta^m_o) y^{sb}_{do}, && d = 1,...,B-C, \\
&\quad \lambda_j \geq 0, && j = 1,...,N,
\end{aligned} \tag{6}$$

$$\begin{aligned}
&Max\vec{D}^{k}(x_{io}, y_{ro}, y^b_{co}, y^{sb}_{do}; g) = \phi^k_o \\
&s.t. \sum_{j=1}^{N} \lambda_j x_{ij} \leq x_{io}, && i = 1,...,M, \\
&\quad \sum_{j=1}^{N} \lambda_j y_{rj} \geq (1+\phi^k_o) y_{ro}, && r = 1,...,S, \\
&\quad \sum_{j=1}^{N} \lambda_j y^b_{cj} = (1-\phi^k_o) y^b_{co}, && c = 1,...,C, \\
&\quad \sum_{j=1}^{N} \mu_{dj} \lambda_j y^{sb}_{dj} = \mu_{do} y^{sb}_{do}, && d = 1,...,B-C, \\
&\quad \sum_{j=1}^{N} (1-\mu_{dj}) \lambda_j y^{sb}_{dj} = (1-\mu_{do})(1-\phi^k_o) y^{sb}_{do}, && d = 1,...,B-C, \\
&\quad \lambda_j \geq 0, && j = 1,...,N,
\end{aligned} \tag{7}$$

Here, λ_j represents the intensity variables corresponding to the production process. We measure the technical efficiency of DMU_0 on the basis of the metafrontier and the group frontiers as $TE^m = 1 - \theta^m_k$ and $TE^k = 1 - \phi^k_o$, if the efficiency is equal to unity, indicating DMU_0 is efficient in the production process of the meta-technology set and group technology set; otherwise, the efficiency could be less than unity, which means DMU_0 is inefficient.

IV. *Empirical Result*

This research analyses manufacturing emissions comprised of undesirable outputs from two related countries, Japan and Taiwan, as these emissions could affect environmental efficiency performance. This research not only adopts the DDF model to evaluate the efficiency value of DMUs recycling their emissions, but also uses the concept of metafrontier analysis for the different groups.

1. Data Resources and Variables

Our empirical research focuses on the relative environmental efficiency and estimation of cross-country TGR for the period from 2007 to 2010 using data obtained from the Climate Analysis Indicators Tool (CAIT) of the World Resource Institute (WRI). Initially, data search showed 205 observations in Asia, including those from Japan, China, South Korea, and Taiwan. In the second screening of data for the period from 2007 to 2010, 68 observations remained and the last screening for the high-tech manufacturing industry produced 48 observations. We include data for only two countries, Japan and Taiwan. Based on the classification of Iyer et al. (2005), Japan is regarded as a high-income country (average annual per capita income is higher than US$ 11,456) among the four East Asian countries and Taiwan as a lower middle-income country. Samples for this empirical research have been taken from 7 enterprises in Japan and 5 in Taiwan covering the 4-year period from 2007 to 2010 (n = 48).

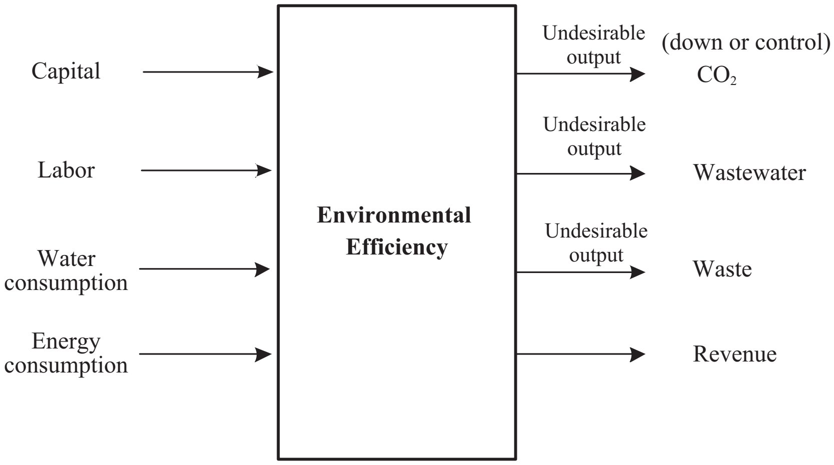
According to World Bank statistics, the high-tech manufacturing industry produces the largest amount of greenhouse gas emissions, causing the so-called greenhouse effect. Japan has an excellent environmental protection policy and its environmental performance is much better compared to other Asian countries such as South Korea, China, and Russia. Resource and environmental efficiencies are Taiwan's most important issues as it has few natural resources. The industrial proportion of high-tech manufacturing in Taiwan is 10.5%. Since the high-tech industry has high economic value and pollution, research effort is needed to find solutions to environmental problems.

The most important aspect of the DEA approach is the choice of variables. The present study selects number of employees and capital as inputs because these variables are used in assessing the operational performance of a business (Bian and Yang, 2010; Coli et al., 2011; Sueyoshi and Goto, 2010, 2011; Watanabe and Tanaka, 2007). Water and energy consumption are used as the evaluation indictors of environmental efficiency (Bian and Yang, 2010; Chang and Yang, 2011; Gomes and Lins, 2007; Oggioni et al., 2011; Zhang et al., 2008). In terms of output variables, this study chooses revenue as a desirable output and CO_2 emissions, wastewater, and waste as undesirable outputs (Atkinson and Dorfman, 2005; Bian and Yang, 2010; Coli et al., 2011; Färe et al., 2004; Gomes and Lins, 2007; KumarMandal and Madheswaran, 2010; Oggioni et al., 2011; Shi et al., 2010; Sueyoshi and Goto, 2010, 2011; Zhang et al., 2008; Zhou and Ang, 2008). As shown in Table 1, four variables of data (labour, capital, water consumption, and energy consumption) are selected as input data, four variables of data (revenue, CO_2 emissions, wastewater, and waste) are the output data, and CO_2 emissions, wastewater, and waste are the undesirable output variables. Table 1 also lists the definitions of the input and output variables and the reference literature from which these variables were drawn. Figure 1 shows the research structure.

TABLE 1. DEFINITIONS AND SOURCE OF INPUTS AND OUTPUTS

	Variables	References
Inputs	■ Number of employees: includes part-time and full-time.	Coli et al. (2011); Färe et al. (2004)
	■ Capital (unit: $10,000): sum of current assets, fixed assets, other assets, and total shareholder equity.	Atkinson and Dorfman (2005); Sueyoshi and Goto (2011)
	■ Water consumption (unit: 10,000 tons): total water consumption by enterprise. [** same as above*]	Zhang et al. (2008); Bian and Yang (2010)
	■ Energy consumption (unit: kWh): total electricity consumption by enterprise.	Zhang et al. (2008); Shi et al. (2010); Zhou and Ang (2008)
Outputs	■ Revenue (unit: $10,000): including operating revenue and other revenue.	Bian and Yang (2010); Färe et al. (2004); Färe et al. (1989); Olerup (2010)
	■ CO_2 emissions (unit: tons): CO_2 emissions from business operations.	Balat (2010); Oggioni et al. (2011); Watanabe and Tanaka (2007); Zhang et al. (2008)
	■ Wastewater (unit: 1, 000 tons): total wastewater produced by enterprise operations.	Bian and Yang (2010)
	■ Waste (unit: tons): total waste produced by enterprise operations.	Bian and Yang (2010)

FIGURE 1. RESEARCH STRUCTURE: ENVIRONMENTAL EFFICIENCY OF THE HIGH-TECH MANUFACTURING INDUSTRIES



2. Empirical Results and Analysis

Table 2 presents the variables of descriptive statistics. Data for the research period (2007-2010) uses the concept of present value to assess consistency, avoiding any biases from time value. The unit is US$ million and the 2010 wholesale price index (WPI) is used as the benchmark deflator. In terms of capital, Taiwan has more sources of capital than Japan. The possible reason for this is that Japan’s business model has tended to be relatively conservative in recent years. In terms of labour, Japan is the highest, which is a really significant result. A possible reason is that our sample for Japan has 28 DMUs. Energy consumption is similar between the two countries, but a large difference exists in terms of water consumption. We theorise that enterprise size is large scale in Japan compared to Taiwan, and water usage is therefore greater in Japan.

Analysis of revenue also highlights some differences. Mean revenue in Taiwan is US$ 8.63 billion while that in Japan is US$ 18.563 billion. The economic situation in Japan is good for Taiwan. For undesirable emissions, Japan has the highest CO_2 emissions and this conforms to the research of Kim et al. (2010) who show that high growth is accompanied by higher CO_2 emissions. Japan has highest emissions from wastewater and water consumption is also high. The average ratio of recycling wastewater in Taiwan is 65.85%, which is better than 45.44% in Japan. The average ratio of recycling waste in Taiwan is 81.93%, or better than Japan’s ratio of 68.98%. It can be argued that geographical factors allow enterprises in Taiwan to be more focused on waste resource usage. Overall, Japan uses more natural resources such as energy and water, but its overall environmental performance is not ideal.

Table 3 shows the ratios of recycling waste and wastewater in the two countries. In Japan the mean of waste recycling is 68.98% and that of wastewater recycling is 45.44%. These amounts are less than in Taiwan where waste recycling is 82.80% and wastewater recycling is 63.08%. Both countries exhibit an uptrend in the recycling amount except during the recent economic crisis period. The amount of water recycled is less compared to waste recycled, because wastewater recycling allows enterprises to save a lot more on costs, whereas recycled water is more difficult to execute and firms may not have the relevant expertise to complete the work.

TABLE 2. DESCRIPTIVE STATISTICS FOR ALL VARIABLES

		Input variable				Output variable			
						Desirable	Undesirable		
		Capital	Labour	Energy consumption	Water consumption	Revenue	CO_2 emissions	Wastewater	Waste
Japan	Mean	138,065	169,867	283,626	8,914,086	863,012	2,296,845	94,119	69,731
	Maxi	468,412	400,129	652,730	52,530,000	3,090,699	5,212,000	429,000	608,000
	Mini	26,985	2,869	112,500	1,707	50,831	43,528	1,430	2,349
Taiwan	Mean	349,919	18,509	228,752	11,380	1,856,345	1,340,704	7,636	25,903
	Maxi	2,046,611	43,385	420,700	24,810	10,901,383	4,005,224	17,700	75,200
	Mini	8,869	1,886	74,000	457	94,841	90	38	3,663
Overall	Mean	226,337	106,801	260,762	5,204,625	1,276,900	1,898,453	58,084	51,470
	Maxi	2,046,611	400,129	652,730	52,530,000	10,901,383	5,212,000	429,000	608,000
	Mini	8,869	1,886	74,000	457	50,831	90	38	2,349

In terms of waste, almost all enterprises have implemented recycling, which is easy to practice in daily life, just like recycling paper, PET bottles, kitchen waste, etc. However, the daily waste of enterprises accounts for just a small amount of overall waste. Most of the time, the recycled waste could be used in other relevant recycling industries.

The resources recovery will be found Japan has the best performance in recycling and

Taiwan is second. This result is testimony to our impression that Japan has focused on restructuring its policies to enable sustainable development with environmental conservation. Table 4 presents the empirical results from Equation 6. The third and eighth columns represent the technical efficiency of the metafrontier for these 48 high-tech manufacturing firms. When the metafrontier is regarded as the basis for evaluation, 31 of the 48 manufacturing firms are relatively efficient: Sharp (2008, 2009), Panasonic (2007, 2010), Casio (2007, 2008, 2009, 2010), Hitachi (2007, 2010), Fujitsu (2007, 2008, 2009, 2010), and Fujifilm (2007, 2008, 2009, 2010) in Japan; HannStar display (2007, 2008, 2009, 2010), TSMC (2007, 2008, 2009, 2010), Qisda (2009), and UMC (2007, 2010) in Taiwan. Further, 20 of these efficient enterprises are in Japan and 11 are in Taiwan, when the meta-technology set and group-specific technology set are regarded as the basis for evaluation. We found that 4 out of the 7 Japanese manufacturing

TABLE 3. RATIO OF RECYCLING

Corporation	Year	Recycling of waste	Recycling of wastewater	Corporation	Year	Recycling of waste	Recycling of wastewater
Sharp	2007	56.42%	7.28%	HannStar display	2007	95.00%	75.30%
	2008	64.35%	6.38%		2008	96.00%	79.00%
	2009	65.45%	5.75%		2009	95.00%	80.60%
	2010	54.55%	5.62%		2010	95.32%	86.39%
Panasonic	2007	89.00%	6.96%	AUO	2007	57.50%	23.26%
	2008	60.49%	6.96%		2008	59.68%	18.98%
	2009	51.58%	6.96%		2009	82.00%	21.48%
	2010	95.00%	6.96%		2010	84.54%	79.33%
NEC	2007	97.20%	69.58%	TSMC	2007	79.00%	80.10%
	2008	96.28%	69.58%		2008	85.00%	80.40%
	2009	99.67%	69.58%		2009	87.00%	83.40%
	2010	94.06%	69.58%		2010	89.00%	84.10%
Casio	2007	93.80%	9.69%	Qisda	2007	71.00%	75.00%
	2008	91.27%	8.06%		2008	78.00%	75.00%
	2009	93.41%	8.20%		2009	83.00%	75.00%
	2010	68.62%	8.74%		2010	81.40%	75.00%
Hitachi	2007	85.90%	64.69%	UMC	2007	66.67%	20.46%
	2008	61.11%	88.18%		2008	86.14%	20.00%
	2009	68.41%	88.06%		2009	84.69%	64.45%
	2010	76.32%	36.04%		2010	85.61%	64.44%
Fujitsu	2007	8.68%	69.58%				
	2008	9.68%	69.58%				
	2009	14.41%	69.58%				
	2010	12.04%	69.58%				
Fujifilm	2007	78.01%	92.74%				
	2008	82.83%	94.19%				
	2009	83.78%	97.48%				
	2010	79.16%	66.63%				
Mean	2007	72.72%	45.79%	Mean	2007	73.83%	54.82%
	2008	66.57%	48.99%		2008	80.96%	54.68%
	2009	68.10%	49.37%		2009	86.34%	64.99%
	2010	68.53%	37.59%		2010	87.17%	77.85%
	overall	68.98%	45.44%		overall	82.08%	63.08%

firms and 2 of the 5 Taiwanese manufacturing firms outperform the other manufacturing firms. This result shows that it is relatively easy for Japan's manufacturing firms to perform well.

Table 4 also presents the empirical results from Equation 7. The fourth and ninth columns represent the technical efficiency of the group frontiers for these 48 high-tech manufacturing firms. When the group frontiers are regarded as the basis of evaluation, 36 of the 48 manufacturing firms are relatively environmentally efficient: Sharp (2008, 2009, 2010), Panasonic (2007, 2008, 2010), NEC (2007, 2008, 2009, 2010), Casio (2007, 2008, 2009, 2010), Hitachi (2007, 2008, 2009, 2010), Fujitsu (2007, 2008, 2009, 2010), and Fujifilm (2007, 2008, 2009, 2010) in Japan; HannStar display (2007, 2008, 2009, 2010), TSMC (2007, 2008, 2009, 2010), Qisda (2007, 2008, 2009, 2010), and UMC (2007, 2010) in Taiwan. Further, 26 of these efficient enterprises are in Japan and 14 are in Taiwan.

Further, we conducted a Wilcoxon matched-pairs signed-ranks test to verify the different

Table 4. Measurement of Corporate Technology Effciency (2007-2010)

Corporation	Year	MTE	GTE	TGR	Corporation	Year	MTE	GTE	TGR
Sharp	2007	0.3772	0.3772	1	HannStar display	2007	1	1	1
	2008	1	1	1		2008	1	1	1
	2009	1	1	1		2009	1	1	1
	2010	0.7629	1	0.7629		2010	1	1	1
Panasonic	2007	1	1	1	AUO	2007	0.243	0.2541	0.9564
	2008	0.177	1	0.177		2008	0.0981	0.158	0.6207
	2009	0.373	0.373	1		2009	0.1185	0.1692	0.7001
	2010	1	1	1		2010	0.3485	0.3485	1
NEC	2007	0.143	1	0.143	TSMC	2007	1	1	1
	2008	0.2133	1	0.2133		2008	1	1	1
	2009	0.2552	1	0.2552		2009	1	1	1
	2010	0.3066	1	0.3066		2010	1	1	1
Casio	2007	1	1	1	Qisda	2007	0.7205	1	0.7205
	2008	1	1	1		2008	0.6318	1	0.6318
	2009	1	1	1		2009	1	1	1
	2010	1	1	1		2010	0.5078	1	0.5078
Hitachi	2007	1	1	1	UMC	2007	1	1	1
	2008	1	1	1		2008	0.2067	0.389	0.5314
	2009	1	1	1		2009	0.0285	0.1673	0.1703
	2010	1	1	1		2010	1	1	1
Fujitsu	2007	1	1	1					
	2008	1	1	1					
	2009	1	1	1					
	2010	1	1	1					
Fujifilm	2007	1	1	1					
	2008	1	1	1					
	2009	1	1	1					
	2010	1	1	1					
Mean	2007	0.7886	0.9110	0.8776	Mean	2007	0.7927	0.8508	0.9354
	2008	0.7700	1	0.7700		2008	0.5873	0.7094	0.7568
	2009	0.8040	0.9104	0.8936		2009	0.6294	0.6673	0.7741
	2010	0.8671	1	0.8671		2010	0.7713	0.8697	0.9016
	overall	0.8074	0.9554	0.8521		overall	0.6952	0.7743	0.8420

efficiency scores between the Japanese and Taiwanese high-tech industries. Table 5 shows that the Wilcoxon matched-pairs signed-ranks test values are -2.649 and -2.191, respectively, when the meta-frontier and group frontiers are regarded as the basis for evaluation. This states that the average MTE and GTE (0.8074, 0.9554) in Japan is larger than the average MTE and GTE (0.6952, 0.7743) in Taiwan, showing that Japan respects environmental efficiency more than Taiwan in a confidence interval of 5%. Figures 2 and 3 also illustrate the significant differences. The results show that Japanese firms remain environmentally efficient given their existing production technology; it is possible for them to use the current input level to reach the output level. However, in this regard, Japan still has a relatively better environmental performance than Taiwan.

In terms of TGR, Japan has the smallest technology gap between the meta-frontier and group frontiers as shown in Figure 4. This phenomenon shows that the meta-frontier is composed mainly of Japanese enterprises, since the meta-frontier efficiency and group frontier efficiency in Japan are both similar. Given the same conditions, enterprises in Japan recycle less wastewater, but their efficiency value is better than that of Taiwanese firms. The reason could be that enterprises in Taiwan have the best revenue performance and, thus, do not focus on recycling efficiency. This phenomenon results in the growth of Taiwan's national policies that pursue economic efficiency, while ignoring environmental projects.

V. *Conclusions*

In recent years, public concern about the drastic global climate change has increased. The

TABLE 5. WILCOXON-MANN-WHITNEY TEST OF HIGH-TECH INDUSTRIES IN JAPAN AND TAIWAN

	MTE	GTE
Mann–Whitney U value	158	212
Wilcoxon W-value	564	422
Z-value	-2.649	-2.191
P-value	0.008***	0.028**

Note: ** Significance at the 5% level; *** Significance at the 1% level.

FIGURE 2. AVERAGE MTE FROM 2007 TO 2010

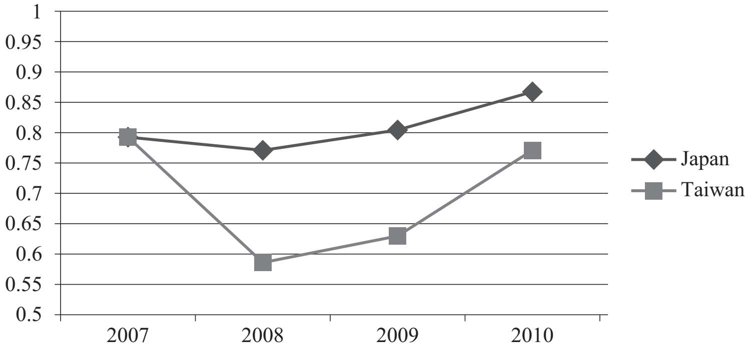


Figure 3. Average GTE from 2007 to 2010

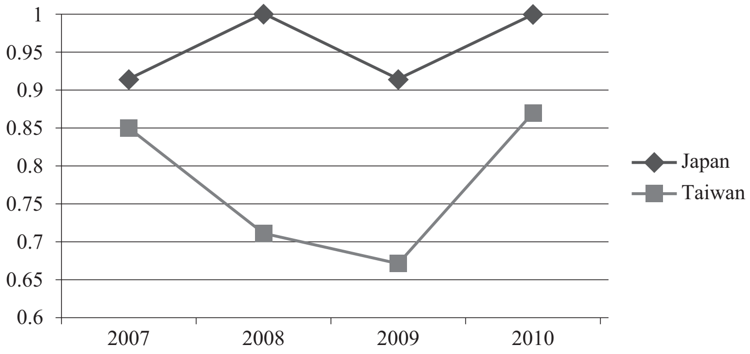
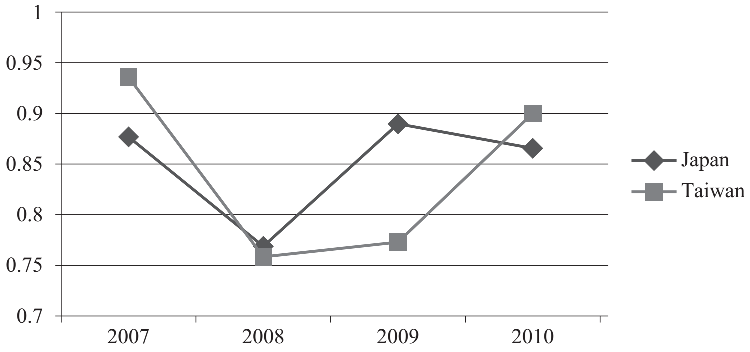


Figure 4. Average TGR from 2007 to 2010



majority of environmental literature has found a significant positive relationship between CO_2 emissions and economic activity (Kim et al., 2010). Besides, due to the perceived trade-off between economic development and CO_2 emissions reduction, many countries remain non-committal about the latter. However, these studies have ignored the impact of wastewater and solid waste on environmental efficiency. As a result, this paper has employed the concept of undesirable outputs into the directional distance function to assess the environmental efficiencies of Japan and Taiwan.

This research has selected number of employees, capital, water consumption, and energy consumption as inputs, revenue as a desirable output, and CO_2 emissions, wastewater, and solid waste as undesirable outputs to measure the environmental efficiency of 11 enterprises between 2007 and 2010. From the empirical results, it is apparent that the mean environmental efficiency of Japan is superior to that of Taiwan and the standard deviation of environmental efficiency of Japan is the lowest when the technology set is used as the basis for evaluation. The results show that Japanese enterprises have a relatively better environmental performance than Taiwanese firms. In addition, the paper recommends that enterprises in Japan and Taiwan should avoid wasting undesirable outputs by improving environmental efficiency. In this study, we adopted a variable that is different from the previous research to assess environmental efficiency. With this, we could accurately reflect the operational efficiency instead of the performance indicators of high economic growth. Social costs are also included in enterprise operational efficiency as the negative impact. Thus, we can reflect the real situation and remind countries to focus on environmental issues.

There is resurgence of public interest and concern about environmental problems because the current sources of energy will deplete and the need is to find alternative and efficient energy systems. Moreover, many scholars have discussed the lack of energy, greenhouse effect, and how to solve or control this problem. In the near future, CO_2 trading markets will not only control CO_2 emissions but also supply many economic transactions of carbon rights. Some countries can then improve their economic income through carbon trading and mergers will not discharge undesirable outputs. Finally, a limitation to this research is that the sample size is too small because the data are complex and difficult to collect. Therefore, this research just compares the high-tech manufacturing industries of Japan and Taiwan.

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