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23 May 2015

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Abstract

This study estimates the environmental efficiency of international listed firms in 10 worldwide sectors from 2007-2013 by applying an order-m method, a non-parametric approach based on free disposal hull with subsampling bootstrapping. Using a conventional output of gross profit and two conventional inputs of labor and capital, this study examines the order-m environmental efficiency accounting for the presence of each of 10 undesirable inputs/outputs and measures the shadow prices of each undesirable input and output. The results show that there is greater potential for the reduction of undesirable inputs rather than bad outputs. On average, total energy, electricity, or water usage has the potential to be reduced by 50%. The median shadow prices of undesirable inputs, however, are much higher than the surveyed representative market prices. Approximately 10% of the firms in the sample appear to be potential sellers or production reducers in terms of undesirable inputs/outputs, which implies that the price of each item at the current level has little impact on most of the firms. Moreover, this study shows that the environmental, social, and governance activities of a firm do not considerably affect environmental efficiency.

Key words: Data envelopment analysis; Environmental efficiency; Shadow price; Free disposal hull; Linear programming
JEL classification: C14, D24, Q50

## 1. Introduction

When addressing the environmental problems facing firms or implementing new environmental policies, it is important to understand how firms operate their business in terms of the environment and efficiency. In the environmental performance analysis literature, both parametric and non-parametric approaches are used to estimate environmental efficiency in empirical studies. In particular, two of the main non-parametric methods are data envelopment analysis (DEA) and free disposal hull (FDH), which have been used in many publications (Cazals et al., 2002; Cherchye et al., 2001; De Witte and Marques, 2010; Färe et al., 1996, 2005; Lee et al., 2002; Ishinabe et al., 2013).

Both DEA and FDH are characterized by a lack of assumptions about the particular functional form of the production frontier and can estimate a best-practice frontier from observed data. However, a problem with DEA/FDH is that the best-practice frontier could be sensitive to super-efficient outliers (Cazals et al., 2002; Daraio and Simar, 2007; Tauchmann, 2011). In other words, when sample size is sufficiently large, a best-practice frontier estimated by DEA/FDH could be overestimated due to super-efficient peer decision making units (DMUs). Therefore, DEA/FDH efficiency scores that lack a deep examination of super-efficient DMUs, as in many publications, show just the upper limit of the score on the potential production frontier (for a review of treatment of outliers within the Journal of Environmental Management, see Supplementary material S1). The same is true for environmental efficiency analysis that uses DEA/FDH without considering super-efficient DMUs because the estimated score tends to be too efficient to be operational for most DMUs.

This suggests that a sensibility analysis should be conducted on DEA/FDH. To avoid the problem of outliers, Cazals et al. (2002), Daraio and Simar (2007), and Tauchmann (2011) propose the order-m method, which is based on FDH using subsampling bootstrapping to create peer DMUs and enables sensitive analysis of FDH.

The aim of this study is to develop a sensitivity analysis method for efficiency estimates, and to apply the proposed method to evaluate current situation of environmental efficiency among listed firms worldwide in 2007-2013. This study first examines the order-m method to technically evaluate environmental efficiency among DMUs, and develops a method of shadow price estimation to economically evaluate DMUs. We consider the development of order-m in the directional distance function in this paper is the most important contribution into the existing literature. From the viewpoint of empirical study, this study then evaluates the environmental efficiency of listed firms worldwide technically (order-m) and economically (shadow price estimation). In addition, this study provides insights into the characteristics of technically efficient firms, as a second step analysis, using a regression model.

The primary motive of this study is to examine the environmental efficiency of international listed firms by adopting the order-m method of the directional distance function. This study considers each of ten undesirable inputs/outputs in ten respective models. Using an output (i.e., gross profit, which is sales minus the cost of goods sold) and two inputs (labor and capital), we consider each of the following items to be undesirable inputs/outputs. Total energy consumption, electricity use, water use, and paper consumption are considered to be undesirable inputs (energy and material uses); Scope 1, Scope 1 + 2, Scope 1 + 2 + 3, sulfur oxides (SOx), nitrogen oxides (NOx), and volatile organic compounds (VOC) are undesirable outputs (emissions). Note that, Scope 1, 2, and 3, which are greenhouse gas (GHG) emission categories, are defined in

GHG Protocol (see World Resources Institute and World Business Council for Sustainable Development, 2011, p.140) as follows: "(Scope 1) emissions from operations that are owned or controlled by the reporting company; (Scope 2) emissions from the generation of purchased or acquired electricity, steam, heating or cooling consumed by the reporting company; (Scope 3) all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions."

In examining the environmental efficiency of the order-m method, this study analyzes two additional topics. One is the calculation of the shadow prices, which indicate the maximum acceptable prices for certain firms/plants if markets exist, for each of the ten input/output items. Another topic is the examination of which activities affect the firms' environmental efficiency using a regression model as a second step. Regarding the former topic, the shadow prices indicate the opportunity costs for the firms/plants to reduce each item by one unit. To address environmental problems, policy makers are often required to create markets or impose heavier taxes on environmental resources/emission credits. If a market is created for undesirable inputs and outputs to be traded or an environmental tax rate is increased, the shadow price will hint at how many firms/plants will be potential buyers or sellers of the item and indicate the potential effect of creating such markets as emission trading scheme or policy implementation. In other words, comparing the shadow prices to the actual market price could indicate a gap between a buyer (i.e., a production expander) and seller (i.e., production reducer).

This study applies two methods for calculating shadow prices, which are called order-m specification and parametric liner programming (LP) specification in this study.

Regarding order-m specification, this study derives the relative shadow prices from the estimated solutions to the dual problem of order-m estimation. Although this method is often used in DEA, it faces the challenge that dual variables (i.e., shadow prices in the dual DEA/FDH problem) often take a value of zero, which results in positive infinity shadow prices (for a similar case of FDH relative prices, see Kuosmanen et al., 2006). To overcome this challenge, this study simply uses values without rounding close-to-zero values to zero to avoid the problem by force. In a more sophisticated way, the appendix shows a procedure for estimating the upper and lower bounds of the shadow price. In addition, in a more indirect manner, this study uses parametric LP specification (Chambers, 2002; Fukuyama and Weber, 2008), which restores the convexity with a quadratic production function. The parametric LP specification smooths the values on the order-m production frontier over a quadratic production function and estimates the partial derivatives of the order-m score.

To examine what characteristics of firms affect calculated environmental performance, this study aims to find empirical evidence on the relationship between the environmental, social, and governance (ESG) activities of firms and efficiency levels. If ESG activities improve efficiency, investment in the activities can be interpreted as generating a return. On the other hand, if the ESG activities reduce efficiency, investment in these activities is interpreted as causing a loss.

The structure of this study is as follows: Section 2 presents our model and the method for estimating shadow prices; Section 3 explains the dataset used in this study; Section 4 presents the estimated results, and section 5 concludes.

## 2. Model

2.1 Preliminary construction

Suppose that there are $N$ DMUs, and a certain DMU, $i$, belongs to a set of DMUs, $S$: $i \in S$. Let $x \in R_{+}^{J}$, $y \in R_{+}^{K}$, and $b \in R_{+}^{L}$ denote the vectors of inputs, desirable outputs and focal undesirable (i.e., environmentally bad) inputs/outputs, respectively, in the Euclidean space, $R_{+}^{J+K+L}$. $b$ consists of bad inputs, $b^{in}$, and/or bad outputs, $b^{out}$, and could also be expressed as $b \in \{b^{in}, b^{out}\}$. The true technology production set, $T$, in this study is defined in the Euclidean space, $R_{+}^{J+K+L}$, as follows:

$$T = \left\{ (x, y, b) \in R_{+}^{J+K+L} \middle| (x, b^{in}) \text{ can produce } (y, b^{out}) \right\} \qquad (1)$$

where $b \in \{b^{in}, b^{out}\}$.

Following Deprins et al. (1984) and Cherchye et al. (2001), this study adopts FDH approximation to estimate the true technology set, $T$, by the observed DMUs. FDH is originally based on two minimal assumptions: the technology set, $T$, should envelop all observed data, and all inputs ($x$, $b_{in}$) and outputs ($y$) are freely (or strongly) disposable.

In adopting environmentally undesirable outputs, $b^{out}$, earlier DEA studies often assume weak disposability of undesirable outputs (e.g., Färe et al., 1996). Under weak disposability, the desirable and undesirable outputs ($y$, $b^{out}$) are both assumed to be weakly disposable as follows: if $(x, y, b^{in}, b_0^{out}) \in T$, then $(x, \alpha y, b^{in}, \alpha b_0^{out}) \in T$ where $0 < \alpha < 1$. On the other hand, weak disposability is seldom assumed in FDH approximation because FDH analysis is based on free (strong) disposability. Following Ray and Mukherjee (2007) and De Witte and Marques (2010), this study instead assumes reverse disposability of undesirable outputs, which is similar to the assumption of free disposability. A certain level of desirable outputs, which is associated with a lower level of undesirable outputs, could be generated with a higher level of undesirable outputs. This assumption could be specifically represented as follows: if $\left(x,y,b^{in},b_0^{out}\right) \in T$ and $b_1^{out} \geq b_0^{out}$, then $\left(x,y,b^{in},b_1^{out}\right) \in T$.

Based on the two minimal assumptions and reverse disposability described above, we consider empirical approximation of FDH in the directional distance function form of primal/dual problems using LP. The empirical approximation of FDH was originally developed by Deprins et al. (1984). Recent studies, such as Cherchye et al. (2001), derive the FDH approximation directional distance function. The construction of the primal/dual problems of FDH approximation has been proposed in the literature (see Leleu, 2009). The primal problem is a maximum problem of how many times ($h$) a certain DMU can extend a set of efficiency directional vectors $\left(g_x, g_y, g_b\right)$ towards the production frontier. It indicates the degree to which that DMU can improve efficiency. On the other hand, the dual problem is a minimization problem of the difference between the shadow profits (i.e., dual profits) of a certain DMU and a reference peer DMU on the frontier (denoted by $\pi$) given a set of arbitrary shadow prices ($v$, $u$, $q$) that correspond, respectively, to $x$, $y$, and $b$. Given the efficiency direction vector, it indicates how much of a loss the certain DMU takes compared to the nearest referenced DMU on the frontier. It also implies that, given the efficiency direction vector, the number of shadow prices ($v$, $u$, $q$) that the DMU adopts. Following Kuosmanen et al. (2006) and Leleu (2009) regarding the dual DEA and FDH problems, note that the difference between them appears as the difference in the arbitrary shadow prices (i.e., dual variables). In the dual DEA problem, shadow prices are generic (i.e., the same) for all of the observed DMUs. On the other hand, the shadow prices in the dual FDH problem are specific (i.e., different) among the different observed DMUs ($n$). Therefore, by using the generic shadow prices (i.e., making shadow prices same among DMUs) instead of the specific prices, the FDH problems in this study can be easily rewritten to the DEA problems.

Following Leleu (2009), the directional distance function for FDH approximation under variable returns to scale (VRS) can be calculated by the following pair of primal/dual LP problems. Note that this study also adopts VRS because the original FDH approximation introduced by Deprins et al. (1984) corresponds to VRS above the primal/dual problems. The primal problem for a certain DMU, $i$, is represented as follows:

$$\delta_i^{FDH-P}\left(x_i, y_i, b_i; g_x, g_y, g_b\right) = \max_{x_i, y_i, b_i} \sum_{n=1} h_n \tag{2}$$

$$\text{s.t.} \quad z_n\left(y_n^k - y_i^k\right) \geq h_n g_y^k \quad \forall k \in K, \forall n \in S \tag{3}$$

$$z_n\left(x_n^j - x_i^j\right) \leq -h_n g_x^j \quad \forall j \in J, \forall n \in S \tag{4}$$

$$z_n\left(b_n^j - b_i^j\right) \leq -h_n g_b^l \quad \forall l \in L, \forall n \in S \tag{5}$$

$$\sum_{n=1} z_n = 1 \tag{6}$$

$$z_n \geq 0 \ \forall n \in S \tag{7}$$

where $z$ denotes a set of weights to determine relative efficiency. The corresponding dual problem $\delta_i^{FDH-D}\left(x_i, y_i, b_i; g_x, g_y, g_b\right)$ under VRS could be expressed as follows:

$$
\begin{aligned}
&\delta_i^{FDH-D}\left(x_i, y_i, b_i; g_x, g_y, g_b\right) \\
&= \sum_{k=1}^{K} u_{i^{ref}}^{k}\left(x_i, y_i, b_i; g_x, g_y, g_b\right)\cdot\left(y_{i^{ref}}^{k} - y_i^{k}\right) - \sum_{j=1}^{J} v_{i^{ref}}^{j}\left(x_i, y_i, b_i; g_x, g_y, g_b\right)\cdot\left(x_{i^{ref}}^{j} - x_i^{j}\right) \\
&-\sum_{l=1}^{L} q_{i^{ref}}^{l}\left(x_i, y_i, b_i; g_x, g_y, g_b\right)\cdot\left(b_{i^{ref}}^{l} - b_i^{l}\right) \\
&= \min_{v_s^j, u_s^k, q_s^l, \pi} \pi
\end{aligned}
\tag{8}
$$

$$
\text{s.t.} \sum_{k=1}^{K} u_n^k\left(y_n^k - y_i^k\right) - \sum_{j=1}^{J} v_n^j\left(x_n^j - x_i^j\right) - \sum_{l=1}^{L} q_n^l\left(b_n^l - b_i^l\right) \le \pi \;\; \forall n \in S \tag{9}
$$

$$
\sum_{k=1}^{K} u_n^k g_y^k - \sum_{j=1}^{J} v_n^j g_x^j - \sum_{l=1}^{L} q_n^l g_b^l = 1 \;\; \forall n \in S \tag{10}
$$

$$
u_n^k \ge 0 \;\; \forall k \in K, \forall n \in S \tag{11}
$$

$$
v_n^j \ge 0 \;\; \forall j \in J, \forall n \in S \tag{12}
$$

$$
q_n^l \ge 0 \;\; \forall l \in L, \forall n \in S \tag{13}
$$

where $i^{ref}$ denotes the referenced peer DMU (on the frontier) of DMU *i*. (*v*, *u*, *q*) denote a set of arbitrary shadow prices (dual variables) corresponding, respectively, to (*x*, *y*, *b*). $\pi$ denotes the relative shadow profit, and the dual problem minimizes $\pi$ by allowing for specific shadow prices ($v_n$, $u_n$, $q_n$) compared with other peer DMUs.

2.2 Order-m of the directional distance function

Following Cazals et al. (2002), Daraio and Simar (2007), and Tauchmann (2011), the order-m efficiency score is calculated by averaging the FDH scores with subsampling bootstrapping *D* times. In each subsampling event, order-m assesses a certain DMU by expected best performance from a sample of *m* peers. Original order-m takes the following four steps: 1) In the *d*-th subsampling (*d* = 1,..., *D*), a sample of *m* peer DMUs is randomly drawn with replacement from *S*. Let $S_d$ denote a set of *m* peer DMUs in the *d*-th subsampling. 2) The pseudo FDH efficiency $\delta_{mi}^{FDH_d}\left(x_i, y_i, b_i; g_x, g_y, g_b\right)$ is calculated using this artificial reference sample. 3) Steps 1 and 2 are repeated *D* times. 4) The order-m efficiency $\delta_{mi}^{OM}$ is calculated as the average of the pseudo FDH scores:

$$\delta_{mi}^{OM} = \frac{1}{D}\sum_{d=1}^{D}\delta_{mi}^{FDH_d} \tag{14}$$

Note that if there is no solution in certain *d*-th iteration, this study considers the order-m efficiency score to be $\delta_{mi}^{FDH_d}$, which is on the frontier and equals zero.

The primal/dual problems of the order-m form are represented as the *D*-times simple average of equations (2) to (7) (i.e., the primal problem) and equations (8) to (13) (i.e., the dual problem) in each subsampling, $S_d$. The order-m primal problem as a directional distance function is expressed as follows:

$$\delta_{mi}^{OM}\left(x_i, y_i, b_i; g_x, g_y, g_b\right) = \frac{1}{D}\sum_{d=1}^{D}\delta_{mi}^{FDH-P_d}\left(x_i, y_i, b_i; g_x, g_y, g_b\right) \tag{15}$$

where $\delta_{mi}^{FDH-P_d}\left(x_i, y_i, b_i; g_x, g_y, g_b\right)$ is calculated by equations (2) to (7) in the *d*-th iteration using sub-sampling size *m*. The corresponding order-m dual problem as a directional distance function is expressed as follows:

$$
\begin{aligned}
&\delta_{mi}^{OM}\left(x_i, y_i, b_i; g_x, g_y, g_b\right) \\
&= \frac{1}{D}\sum_{d=1}^{D}\delta_{mi}^{FDH-D_d}\left(x_i, y_i, b_i; g_x, g_y, g_b\right) \\
&= \frac{1}{D}\sum_{d=1}^{D}\left\{\sum_{k=1}^{K}u_{i^{ref}d}^{k}\left(y_{i^{ref}d}^{k}-y_i^k\right)-\sum_{j=1}^{J}v_{i^{ref}d}^{j}\left(x_{i^{ref}d}^{j}-x_i^j\right)-\sum_{l=1}^{L}q_{i^{ref}d}^{l}\left(b_{i^{ref}d}^{l}-b_i^l\right)\right\} \\
&= \sum_{k=1}^{K}\overline{u_{i^{ref}}^{k}}\cdot\left(\frac{\sum_{d=1}^{D}u_{i^{ref}d}^{k}y_{i^{ref}d}^{k}}{\sum_{d=1}^{D}u_{i^{ref}d}^{k}}-y_i^k\right)-\sum_{j=1}^{J}\overline{v_{i^{ref}}^{j}}\cdot\left(\frac{\sum_{d=1}^{D}v_{i^{ref}d}^{j}x_{i^{ref}d}^{j}}{\sum_{d=1}^{D}v_{i^{ref}d}^{j}}-x_i^j\right) \\
&-\sum_{l=1}^{L}\overline{q_{i^{ref}}^{l}}\cdot\left(\frac{\sum_{d=1}^{D}q_{i^{ref}d}^{l}b_{i^{ref}d}^{l}}{\sum_{d=1}^{D}q_{i^{ref}d}^{l}}-b_i^l\right) \\
&= \frac{1}{D}\sum_{d=1}^{D}\min_{v_s^k,u_s^j,q_s^l,\pi}\pi_d
\end{aligned}
\tag{16}
$$

where minimizing $\pi_d$ is calculated by equations (8) to (13) in the *d*-th sub-sampling iteration using sub-sampling size *m*. $i^{ref}d$ denotes the referenced peer DMU of a certain DMU, *i*, in the *d*-th iteration. Values with an overbar in equation (16) denote the average value of the *D* iterations. $\sum_{d=1}^{D}u_{i^{ref}d}^{k}y_{i^{ref}d}^{k}\Big/\sum_{d=1}^{D}u_{i^{ref}d}^{k}$ , $\sum_{d=1}^{D}v_{i^{ref}d}^{j}x_{i^{ref}d}^{j}\Big/\sum_{d=1}^{D}v_{i^{ref}d}^{j}$ , and $\sum_{d=1}^{D}q_{i^{ref}d}^{l}b_{i^{ref}d}^{l}\Big/\sum_{d=1}^{D}q_{i^{ref}d}^{l}$ in equation (16) denote a set of (*x*,*y*,*b*) of a *D*-times weight-averaged reference DMU (i.e., a pseudo-reference DMU) for a certain DMU, *i*.

## 2.3 Shadow price

### 2.3.1 Order-m specification of shadow price

In the literature, the derivations of shadow prices for undesirable inputs/outputs are performed with nonparametric approaches, such as DEA, and the profit-maximization problem is often constructed with constraints to production technology. This problem is often solved by the Lagrange multiplier method, and this study follows this method for deriving shadow prices. Following Kumbhakar (1996), Lee et al. (2002), Färe et al. (2005), and Fukuyama and Weber (2008), the profit-maximization problem (i.e., maximal revenue function) with a set of production constraints is represented as follows:

$$\underset{x,y,b}{Max}\ p_y y_i - p_x x_i - p_b b_i \tag{17}$$

$$\text{s.t.}\ \ \overset{OM}{\delta_{mi}}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right) = 0 \tag{18}$$

where

$$\overline{\sigma_i^{xj}} = 1 - \frac{\overset{OM}{\delta_{mi}}\left(x_i, y_i, b_i; g^x, g^y, g^b\right)\cdot g_x^j}{x_i^j}\quad \forall j \in J \tag{19}$$

$$\overline{\sigma_i^{yk}} = 1 + \frac{\overset{OM}{\delta_{mi}}\left(x_i, y_i, b_i; g^x, g^y, g^b\right)\cdot g_y^k}{y_i^k}\quad \forall k \in K \tag{20}$$

$$\overline{\sigma_i^{bl}} = 1 - \frac{\overset{OM}{\delta_{mi}}\left(x_i, y_i, b_i; g^x, g^y, g^b\right)\cdot g_b^l}{b_i^l}\quad \forall l \in L. \tag{21}$$

($p_x$, $p_y$, $p_b$) denotes the respective price vectors in terms of input, output, and environmentally undesirable input/output prices. $\overset{OM}{\delta_{mi}}$ denotes the order-m directional distance function, which represents the production technology for DMU $i$. $\left(\overline{\sigma_i^x}, \overline{\sigma_i^y}, \overline{\sigma_i^b}\right)$

denotes the average inefficiency factors of input, output, and undesirable input/output, respectively, through $D$ iterations. Equation (18) denotes order-m technology, $\delta_{mi}^{OM}$ , on the frontier (i.e., $\delta_{mi}^{OM}$ is equal to zero) given a set of frontier values $\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i\right)$.

Assuming that $\delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right)$ is differentiable into $\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i\right)$, the Lagrangian of equations (17) and (18) could be represented as follows:

$$\underset{x,y,b,\Lambda}{Max}\, p_y y_i - p_x x_i - p_b b_i + \Lambda\left[\delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right)\right]. \tag{22}$$

The first-order conditions (FOCs) of the above profit-maximization problem are as follows:

$$p_y + \Lambda \cdot \frac{\partial \delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right)}{\partial \overline{\sigma_i^y} y_i} \cdot \overline{\sigma_i^y} = 0 \tag{23}$$

$$-p_b + \Lambda \cdot \frac{\partial \delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right)}{\partial \overline{\sigma_i^b} b_i} \cdot \overline{\sigma_i^b} = 0 \tag{24}$$

$$-p_x + \Lambda \cdot \frac{\partial \delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right)}{\partial \overline{\sigma_i^x} x_i} \cdot \overline{\sigma_i^x} = 0 \tag{25}$$

$$\delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right) = 0 \tag{26}$$

From equations (22) and (26), we can calculate the relative shadow price of a focal *l*-th undesirable input/output toward the price of a *k*-th good output as follows:

$$\frac{p_b^l}{p_y^k} = -\frac{\partial \delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right) \Big/ \partial \overline{\sigma_i^{bl}} b_i^l}{\partial \delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right) \Big/ \partial \overline{\sigma_i^{yk}} y_i^k} \cdot \frac{\overline{\sigma_i^{bl}}}{\overline{\sigma_i^{yk}}}. \tag{27}$$

The relative price (left hand side of equation (27)) of *b* (bad input/output) over *y* (good output) is represented as the ratio of the partial differentiations of *b* and *y* multiplied by the ratio of the inefficiencies of *b* and *y* ($\overline{\sigma_i^{bl}} / \overline{\sigma_i^{yk}}$). If DMU *i* is on the frontier, $\overline{\sigma_i^{bl}} / \overline{\sigma_i^{yk}}$ equals one. If DMU *i* is not on the frontier and is less efficient or super-efficient, $\overline{\sigma_i^{bl}} / \overline{\sigma_i^{yk}}$ will vary depending on the directional vectors $(g_x, g_y, g_b)$. For example, if $g_y$ and $g_b$ are more than zero, $\overline{\sigma_i^{bl}} / \overline{\sigma_i^{yk}}$ of a less efficient DMU is less than one and is zero at minimum. In a similar way, $\overline{\sigma_i^{bl}} / \overline{\sigma_i^{yk}}$ of a super-efficient DMU should be more than one. We can directly estimate the relative shadow price between output (*y*) and an undesirable input/output (*b*) as follows (we call this method order-m specification). Each model in this study considers four dimensions of (*x*, *y*, *b*): labor ($j$ = 1) and capital ($j$ = 2) as input *x*, gross profit ($k$ = 1) as output *y*, and each undesirable input/output ($l$ = 1). Following the shadow prices in the dual order-m problem and equation (27), the relative price of a bad input/output ($b_1$) over gross profit ($y_1$) can be rewritten as follows:

$$\begin{aligned}\frac{p_b^1}{p_y^1} &= -\frac{\partial\delta_{mi}^{OM}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)\Big/\partial\overline{\sigma_i^{b1}}b_i^1}{\partial\delta_{mi}^{OM}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)\Big/\partial\overline{\sigma_i^{y1}}y_i^1}\cdot\frac{\overline{\sigma_i^{b1}}}{\overline{\sigma_i^{y1}}} \\ &= \frac{\overline{q_{i^{ref}}^1}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)}{\overline{u_{i^{ref}}^1}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)}\cdot\frac{\overline{\sigma_i^{b1}}}{\overline{\sigma_i^{y1}}}\end{aligned} \quad . \tag{28}$$

Because the price of gross profit ($y_1$) should be one (i.e., \$1), $p_b^1 / p_y^1$ will be equal to $p_b^l$. Note that the negative sign in equation (28) is cancelled out, which is unlike Lee et al. (2002) and Fukuyama and Weber (2008) because their signs for the bad input/output dual variables are opposite to those used in this study.

In calculating equation (28), the constraints are that the two denominators, $\overline{\sigma_i^{y1}}$ and $\overline{u_{i^{ref}}^1}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)$, should not be equal to zero. The former constraint, $\left(\overline{\sigma_i^{y1}}\neq 0\right)$, should be easily satisfied when a set of observed data ($x$, $y$, $b$) and directional vectors ($g^x$, $g^y$, $g^b$) are all positive and all non-negative, respectively, for all DMUs as well as the setting. An immediate problem is avoiding $\overline{u_{i^{ref}}^1}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)$ being zero, but there should be multiple solutions. Simply, this study uses an interior point solution that gives the solutions without rounding close-to-zero values to zero and avoids the problem by force. In a more sophisticated way, Fukuyama and Weber (2008) provide a procedure for estimating the upper and lower bounds of the shadow price (the Appendix shows an application of their procedure to the order-m method).

2.3.2 Parametric LP specification

In an indirect manner, this study smooths values on the order-m production frontier over a quadratic production function following Chambers (2002) and Fukuyama and Weber (2008) (we call this parametric LP specification). This specification requires three steps. First, to estimate value sets of inputs, an output, and bad inputs/outputs on the frontier (i.e., to remove the super-efficient value sets), we estimate inefficiency scores using the order-m method (i.e., ($\overline{\sigma_i^x}, \overline{\sigma_i^y}, \overline{\sigma_i^b}$) in equation (19), (20), and (21)). Note that because the direction should be same among the DMUs in this specification, we set $\left(g_x, g_y, g_b\right)$ = (0, 1000, 1).

Using the frontier value sets ($\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i$) for all DMUs, we then estimate the directional output distance function on the frontier assuming convexity. Suppose that $\phi$ denotes a sum of two effects: inefficiency due to convexity and estimation error, and $\phi \geq 0$. Then, the efficiency of LP specification, $\delta_i^{LP}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right)$, is represented as follows:

$$\begin{aligned} \delta_i^{LP}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right) &= \delta_{mi}^{OM}\left(\overline{\sigma_i^x} x_i, \overline{\sigma_i^y} y_i, \overline{\sigma_i^b} b_i; g^x, g^y, g^b\right) + \phi_i \\ &= \phi_i \end{aligned} . \quad (29)$$

In particular, this study adopts $\delta_i^{LP}$ in a quadratic functional form following Chambers (2002) and Fukuyama and Weber (2008) as follows:

$$
\begin{aligned}
&\delta_i^{LP}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)\\
&=\alpha+\sum_{j=1}^{J}\alpha_j\overline{\sigma_{ji}^x}x_{ji}+\sum_{k=1}^{K}\beta_k\overline{\sigma_{ki}^y}y_{ki}+\sum_{l=1}^{L}\gamma_l\overline{\sigma_{li}^b}b_{li}\\
&+\frac{1}{2}\sum_{j=1}^{J}\sum_{j'=1}^{J}\alpha_{jj'}\overline{\sigma_{ji}^x}x_{ji}\overline{\sigma_{j'i}^x}x_{j'i}+\frac{1}{2}\sum_{k=1}^{K}\sum_{k'=1}^{K}\beta_{kk'}\overline{\sigma_{ki}^y}y_{ki}\overline{\sigma_{k'i}^y}y_{k'i}+\frac{1}{2}\sum_{l=1}^{L}\sum_{l'=1}^{L}\gamma_{ll'}\overline{\sigma_{li}^b}b_{li}\overline{\sigma_{l'i}^b}b_{l'i}\\
&+\sum_{j=1}^{J}\sum_{k=1}^{K}\varepsilon_{jk}\overline{\sigma_{ji}^x}x_{ji}\overline{\sigma_{ki}^y}y_{ki}+\sum_{j=1}^{J}\sum_{l=1}^{L}\eta_{jl}\overline{\sigma_{ji}^x}x_{ji}\overline{\sigma_{li}^b}b_{li}+\sum_{k=1}^{K}\sum_{l=1}^{L}\rho_{kl}\overline{\sigma_{ki}^y}y_{ki}\overline{\sigma_{li}^b}b_{li}
\end{aligned}
\quad . \tag{30}
$$

Here, following Chambers (2002) and Fukuyama and Weber (2008), conditions of symmetry on the second order terms and the translation property of the directional distance function are imposed in equation (30) as follows:

$$\alpha_{jj'}=\alpha_{j'j},\, j\neq j';\beta_{kk'}=\beta_{k'k},k\neq k';\gamma_{ll'}=\gamma_{l'l},l\neq l' \tag{31}$$

$$
\begin{aligned}
&\sum_{k=1}^{K}\beta_k y_{ki}-\sum_{l=1}^{L}\gamma_l b_{li}=-1;\sum_{k'=1}^{K}\beta_{kk'}g_y^{k'}-\sum_{l=1}^{L}\rho_{kl}g_b^{l}=0\ \forall k;\\
&\sum_{l'=1}^{L}\gamma_{ll'}g_b^{l'}-\sum_{k=1}^{K}\rho_{kl}g_y^{k}=0\ \forall l;\sum_{k=1}^{K}\varepsilon_{jk}g_y^{k}-\sum_{l=1}^{L}\eta_{jl}g_b^{l}=0\ \forall j
\end{aligned}
\tag{32}
$$

Then, following Färe et al. (2005) and Fukuyama and Weber (2008), two additional restrictions are imposed:

$$\delta_i^{LP}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)\geq 0\ \forall i \tag{33}$$

$$\partial\delta_i^{LP}\left(\overline{\sigma_i^x}x_i,\overline{\sigma_i^y}y_i,\overline{\sigma_i^b}b_i;g^x,g^y,g^b\right)\Big/\partial\overline{\sigma_{ki}^y}y_{ki}\leq 0\ \forall k,\forall i\,. \tag{34}$$

To estimate the parameters of equation (30), we adopt the deterministic LP procedure of Aigner and Chu (1968) and Fukuyama and Weber (2008). This procedure minimizes the sum of the DMU deviations between the LP specification efficiency, $\delta_i^{LP}\left(\overline{\sigma_i^x}x_i, \overline{\sigma_i^y}y_i, \overline{\sigma_i^b}b_i; g^x, g^y, g^b\right)$, and the frontier value (i.e., zero) as follows:

$$\begin{aligned} &\min \sum_i \left\{ \delta_i^{LP}\left(\overline{\sigma_i^x}x_i, \overline{\sigma_i^y}y_i, \overline{\sigma_i^b}b_i; g^x, g^y, g^b\right) - 0 \right\} \\ &= \min \sum_i \phi_i \end{aligned} . \tag{35}$$

To estimate shadow price, we use the estimated efficiency, $\delta_i^{LP}$, adopting the Lagrangian as in equation (22) as follows:

$$\underset{x,y,b,\Lambda}{Max}\ p_y y_i - p_x x_i - p_b b_i + \Lambda\left[\delta_i^{LP}\left(\overline{\sigma_i^x}x_i, \overline{\sigma_i^y}y_i, \overline{\sigma_i^b}b_i; g^x, g^y, g^b\right)\right]. \tag{36}$$

As in the order-m specification, from equation (36), the relative price of certain $b$ over certain $y$ can be estimated (see Supplementary material S2). Note again that each model in this study considers the following four dimensions of ($x$, $y$, $b$): labor ($j$ = 1) and capital ($j$ = 2) as input $x$, gross profit ($k$ = 1) as output $y$, and each undesirable input/output ($l$ = 1). Then, using equation (36), the relative price of a bad input/output ($l$ = 1) over a good output ($k$ = 1) can be rewritten as follows:

$$\frac{p_b^1}{p_y^1} = -\frac{\partial\delta_i^{LP}\left(\overline{\sigma_i^x}x_i, \overline{\sigma_i^y}y_i, \overline{\sigma_i^b}b_i; g^x, g^y, g^b\right) \Big/ \partial\overline{\sigma_{1i}^b}b_{1i}}{\partial\delta_i^{LP}\left(\overline{\sigma_i^x}x_i, \overline{\sigma_i^y}y_i, \overline{\sigma_i^b}b_i; g^x, g^y, g^b\right) \Big/ \partial\overline{\sigma_{1i}^y}y_{1i}} \cdot \frac{\overline{\sigma_{1i}^b}}{\overline{\sigma_{1i}^y}}$$

$$= -\frac{\gamma_1 + \gamma_{11}\overline{\sigma_{1i}^b}b_{1i} + \sum_{j=1}^{2}\eta_{j1}\overline{\sigma_{ji}^x}x_{ji} + \rho_{11}\overline{\sigma_{1i}^y}y_{1i}}{\beta_1 + \beta_{11}\overline{\sigma_{1i}^y}y_{1i} + \sum_{j=1}^{2}\varepsilon_{j1}\overline{\sigma_{ji}^x}x_{ji} + \rho_{11}\overline{\sigma_{1i}^b}b_{1i}} \cdot \frac{\overline{\sigma_{1i}^b}}{\overline{\sigma_{1i}^y}} \quad . \tag{37}$$

Here, because the price of gross profit ($p_y^1$) should be one (i.e., \$1), $p_b^1/p_y^1$ will be equal to $p_b^1$.

2.4 Regression model

The previous subsections detail the efficiency analysis model used in this study as a first step. This subsection describes the regression model used as a second step. The aim of this regression is to examine the correlation between present (i.e., 2007-2013) ESG activities and the inefficiency of using and/or outputting undesirable materials. In the regression model, the independent variable is each order-m score, and the dependent variable is the degree to which ESG activities are practiced. The regression model as a second step is expressed as follows:

$$\delta_{mi}^{OM}\left(x_i, y_i, b_i; g^x, g^y, g^b\right) = \beta_0 + \beta_1' ESG + e \tag{38}$$

where *e* denotes an error term, and *ESG* denotes the degree of ESG activities.

The coefficient of *ESG,* $\beta_1$, in equation (38) would explain how the efficiency is affected by ESG activities. When $\beta_1$ of certain ESG activities is significantly different from zero and positive, it implies that more activities are performed by less efficient firms to use and/or output environmentally undesirable items. Here, the practice of ESG activities is also interpreted as an investment. Therefore, a positive $\beta_1$ implies that the investment of certain ESG activities causes a loss in efficiency. On the other hand, when $\beta_1$ of certain ESG activities is significantly negative, the interpretation should be the opposite. A negative $\beta_1$ implies that activities are practiced to a greater degree by more efficient firms for the use and/or output of environmentally undesirable items or that the investment of certain ESG activities generates a return in the form of improved efficiency.

## 2.5 Settings

To estimate the order-m approximation, study adopts the directional vectors, $\left(g_x, g_y, g_b\right)$ = (0, $y$, $b$), and VRS. These vectors seek the simultaneous maximum reduction in undesirable inputs/outputs and expansion in good outputs (Färe et al., 2005). It also considers that it is often more difficult to adjust production capability such as capital and labor in the short run than outputs and intermediate inputs. For $D$ and $m$, which are the number of iterations and the size of the subsampling peer DMUs, respectively, this study sets 1,000 as $D$ and 100% of the original peer DMUs as $m$. In addition, to set the peer DMUs, we first divide the industries into 10 sectors based on the Global Industry Classification Standard (GICS) for sector identification (see Supplementary material Table S.1). The peer DMUs for each DMU, $i$, are collected within a certain sector to which $i$ belongs. Therefore, DMU $i$ may refer to other past or future DMUs within the dataset.

In the parametric LP specification for estimating shadow price, this study adopts $\left(g_x, g_y, g_b\right)$ = (0, 1000, 1). We follow Färe et al. (2005) and Fukuyama and Weber (2008), which set $g_y$ = 1 and $g_b$ =1; however, because digit number of *y* in this study is considerably larger than *b*, we adjust digits by setting $g_y$ = 1000. As with the order-m specification, *D* is set as 1,000, and 100% of the original peer DMUs is set for *m*. As with the order-m specification as well, we consider firms within the same sector (see Table S.1) to be peer DMUs.

For the regression analysis in equation (38), it is supposed that the relationship between ESG activities and inefficiency could be clustered by industrial classification. Therefore, this study uses the GICS subindustry classifications (see Table S.1) as clusters and estimates cluster-robust standard errors to assess the significance level of the coefficient.

## 3. Data

The information used in this study comes from Bloomberg Professional service and consists of data from between 2007 and 2013 for listed firms in 10 sectors around the world (unbalanced panel data). The Bloomberg Professional service (also known as Bloomberg Terminal), which is provided by Bloomberg Limited Partnership (where its headquarters is in New York City, New York, U.S.), provides market information such as real-time financial market data, market news, and price quotes, and enables to place trades on the electronic trading platform, through online access to the proprietary computer system. We obtain firm-level data via market screening of the Bloomberg Professional service. The number of total and net observations (obs) are 7,396 and 1,735, respectively (see Supplementary material Table S.2), and the 10 sectors are as follows: energy (#10; 339 obs), materials (#15; 1334 obs), industrial (#20; 1764 obs), consumer discretionary (#25; 1141 obs), consumer staples (#30; 881 obs), health care (#35; 466 obs), financial (#40; 199 obs), information technology (#45; 918 obs), telecommunication services (#50; 142 obs), and utilities (#55; 185 obs) (see Supplementary material Table S.3 for the number of observations in each sector for each model). Table 1 and Supplementary material Table S.4, respectively show the descriptive statistics for all sectors combined and for each sector individually, and Supplementary material Table S.5 shows the representative correlations. For output, $y$, we use gross profit (i.e., sales minus the cost of goods sold) at the nominal price (U.S. dollars). In terms of inputs, $x$, we use the number of employees (persons) and capital stock as surrogate variables of labor and capital, respectively. The capital stock is calculated with the benchmark-year method (base year: 2005) as follows: $K(t) = K(t-1) + I(t) - R(t)$ where $K$, $I$, and $R$ denote capital stock, new investment, and retirement cost, respectively. We use net fixed assets as new investments and retirement cost as depreciable fixed assets. $t$ represents time (years). The base year is assumed to be 2005, and the 2005 capital stock is the net fixed assets. If a capital stock value for a certain firm is missing in 2005, the first available value after 2005 is used as the base year for that firm.

For undesirable inputs ($b^{in}$), we use four items: energy consumption (MWh), electricity use (MWh), water use (cubic meter), and paper consumption (metric ton). For undesirable outputs ($b^{out}$), we use six items: Scope 1, Scope 1+2, Scope 1+2+3, SOx, NOx, and VOC (metric ton). Note that in each estimation of the efficiency, we use each of the undesirable inputs/outputs, $b$, above along with inputs, $x$, and an output, $y$, to ensure enough observations for each estimation. This is because, unlike financial data, there are many missing values for the undesirable inputs/outputs, $b$.

To assess the estimated shadow prices based on actual prices, Table 2 shows a list of representative market prices for emissions/resource use in recent years. Note that this survey is limited because the prices are only from certain parts of the world, and there is no representative market price for total energy consumption and VOC. However, the table provides an indication of whether the estimated shadow prices are relatively expensive. The average retail electricity prices from 28 OECD countries reported by the International Energy Agency (IEA) (2013), which include price data for both industries and households, were nominally $128.3 (U.S. dollars) and $213.2 for industries and households, respectively. For water use, the average water tariff charged to households in 29 OECD countries was $2.05 in 2008. Regarding paper use, the price of wood pulp in the global commodity market was $823.1 per metric ton in 2013. Regarding GHGs, the price per ton of phase 2 in the European Union Emission Trading Scheme (EU ETS) ranged from below 10 Euros to 30 Euros from 2008-2012. For SOx, SOx allowance prices in the U.S. ranged between $0.56 to more than $1,200 per ton from 1994-2012 (Schmalensee and Stavins, 2013). Finally, regarding NOx, the NOx allowance prices in the U.S. ranged between $80 and a few thousand U.S. dollars per ton from 2001-2012.

In the second step regression model, we use eight dummy variables related to ESG activities from Bloomberg dataset for the ESG activities (see Supplementary material Table S.6 for description). Energy efficiency policy (EEPol) indicates whether the company has implemented any initiatives to make its use of energy more efficient. Environmental quality management (EQM) indicates whether the company has introduced any type of environmental quality management and/or environmental management system to help reduce the environmental footprint of its operations. Green building policy (GBPol) indicates whether the company has taken any steps towards using environmental technologies and/or environmental principles in the design and construction of its buildings. Sustainable packaging (SPack) indicates whether the company has taken any steps to make its packaging more environmentally friendly, which might include efforts to improve the recyclability of its packaging and the use of less environmentally damaging materials in its packaging, among others. Environmental supply chain policy (ESCPol) indicates whether the company has implemented any initiatives to reduce the environmental footprint of its supply chain. Waste reduction policy (WastePol) indicates whether the company has implemented any initiatives to reduce the waste generated during the course of its operations. GHG reduction initiative (GHGIni) indicates whether the company has implemented any initiatives to reduce its air emissions. GHG reduction policy (GHGPol) indicates whether the company has outlined its intention to help reduce global GHG emissions, which cause climate change, through its ongoing operations and/or the use of its products and services. Note that because there are missing values for the ESG dummy variables, the estimate from each regression might be smaller than the order-m estimation.

## 4. Results and discussions

### 4.1 Order-m and FDH scores

Table 3 shows the results of the efficiency analysis, order-m (upper part) and FDH (lower part). Each row denotes efficiency scores in each percentile (10th-90th), average values and standard deviations. Each column denotes the result using each type of undesirable inputs/outputs along with gross profit ($y$), labor, and capital ($x$). The efficiency score denotes the percentage to which a certain firm can increase gross profit ($y$) and decrease each undesirable input/output ($b$).

For the undesirable inputs (columns 1, 2, 3, and 4), the respective median order-m and FDH values are 0.475 and 0.543 for energy consumption, 0.488 and 0.565 for electricity use, 0.525 and 0.604 for water use, and −0.014 and 0.000 for paper consumption. Regarding the undesirable outputs (columns 5, 6, 7, 8, 9, and 10), the median order-m and FDH values are 0.167 and 0.227 for Scope 1, 0.184 and 0.258 for Scope 1+2, 0.000 and 0.017 for Scope 1+2+3, −0.072 and 0.125 for SOx, 0.215 and 0.273 for NOx, and 0.000 and 0.006 for VOC.

In setting D (1000) and *m* (100% of the original sample size), the difference between the order-m and FDH scores is not large, but it is measurable. The difference is about five percent on average, and the minimum and maximum values of the differences are 0.006 for VOC efficiency and 0.079 for water use efficiency, respectively.

This result shows that there is more potential for a reduction in undesirable inputs (except for paper use) than for undesirable output reduction. In particular, it implies that total energy consumption, electricity use, or water use have the potential for an approximately 50% reduction on average. Regarding undesirable output reduction, while the efficiencies of Scope 1 and Scope 1+2 indicate a median potential for improvement of less than 20%, the efficiency of Scope 1+2+3 implies no reduction potential at present (0.0%). For other emissions, while the efficiency of SOx and NOx show a certain degree of improvement potential (7.2% and 21.5%, respectively), VOC emission shows no reduction potential (0.0%).[1]

Table 4 shows the median order-m scores in each sector. Considering undesirable inputs as a whole, industrials (#20), consumer discretionary (#25), and

[1] We need to note that by reducing the consumption of energy that contains more emissions and/or by using other types of energy of less polluting emission, environmental efficiency would improve in both dimensions of undesirable inputs and undesirable outputs; however, this topic is not the focus of this paper and presents an interesting and more practically question for future research.

telecommunication services (#50) are inclined to be less efficient than the other sectors whereas energy (#10), materials (#15), and consumer staples (#30) show average inefficiency (i.e., near the median). On the other hand, for the order-m scores of undesirable outputs as a whole, the result shows the different propensities of the GHGs (Scope 1, 1+2, 1+2+3) and the other emissions (SOx, NOx, and VOC). While the inefficiency scores of the GHGs (Scope 1, 1+2, 1+2+3) tend to be higher than the median (i.e., less efficient) in industrials (#20), consumer discretionary (#25), consumer staples (#30), and information technology (#45), the inefficiency scores of the other emissions (SOx, NOx, and VOC) tend to be higher (i.e., less efficient) in energy (#10), materials (#15), and telecommunication services (#50).

4.2 Shadow prices

Table 5 shows the percentiles of the shadow prices estimated by order-m specification (order-m) and parametric LP specification (LP). Each column denotes the results for each type of undesirable inputs/outputs (*b*) along with gross output (*y*), labor, and capital (*x*). Each row represents representative percentiles of the estimated shadow prices (from 10th to 90th). Supplementary material Table S.7 shows the coefficients from the parametric LP specifications.

Comparing order-m with LP, the result shows that the number of digits (of shadow prices) is similar in both specifications, but the difference in estimated values is measurable. Regarding undesirable input (columns 1, 2, 3, and 4), the median order-m and LP values of the shadow prices are $1,260,000 and $1,699,798 for total energy consumption (MWh), $4,974 and $8,242 for electricity use (MWh), $447,435 and $361,900 for water use (cubic meter), and $1,440,000,000 and $70,300,000 for paper consumption (ton). On the other hand, considering undesirable outputs (columns 5, 6, 7, 8, 9, and 10), the median order-m and FDH values of the shadow prices are $9,065 and $11,326 for Scope 1 (ton), $3,725 and $5,713 for Scope 1+2 (ton), $4,462 and $6,202 for Scope 1+2+3 (ton), $3,598,447 and $808,779 for SOx (ton), $2,072,486 and $647,261 for NOx (ton), and $2,180,000,000 and $588,000,000 for VOC (ton).

Table 6 shows the median shadow prices (order-m and LP) in each sector. As a whole, the shadow prices for the undesirable inputs tend to be higher in consumer discretionary (#25), health care (#35), information technology (#45), and telecommunication services (#50) than the median (columns 1, 2, 3, and 4). In addition to undesirable inputs, the shadow prices of undesirable outputs tend to be above the median in health care (#35) and information technology (#45) (columns 5, 6, 7, 8, 9, and 10).

The result shows that the median shadow prices of undesirable inputs/outputs are much higher than the surveyed representative market prices (Table 2)[2]. If the surveyed representative market prices are mandated worldwide, the result indicates that less than 10% of the sample firms should be potential sellers or production reducers of all undesirable inputs/outputs, except for total energy consumption and VOC.

Note that the distribution of the shadow prices for Scope 1, Scope 1+2, and Scope 1+2+3 are similar to the estimate for GHGs in Ishinabe et al. (2013). Using a dataset of 1,024 international companies worldwide, their result shows that the shadow prices for GHGs are less than $100 per ton in 10% of the sampled firms, between $100 and $1,000 in 18% of the firms, and between $1,001 and $10,000 in 42% of the firms.

[2] However, there is no representative market price for total energy consumption and VOC.

### 4.3 Regression result

Table 7 shows the result of the second step regression model. Overall, there are only a few variables that are statistically different from zero. The overall implication is that ESG activities do not considerably affect environmental efficiency. We detected the following statistically significant variables. Green building policy (GBPol) is statistically different from zero and positively correlated with the order-m (inefficiency) scores of Scope 1 (column 5) and significantly negatively correlated with the inefficiency of VOC (column 10). This indicates that an investment in a green building policy is correlated with a low return and/or a large amount of GHG emissions but also with a high return and/or reduced amount of VOC emissions. GHG reduction policy (GHGPol) has significant negative relationship with the inefficiency of Scope 1 (column 5), which indicates that a GHG reduction policy investment currently achieves a profit and/or Scope 1 (GHG) reduction.

### 4.4. Conclusions and implications

This study measures the environmental efficiency of international listed firms worldwide (from 2007-2013) using the order-m method, which is a non-parametric approach based on FDH with subsampling bootstrapping. Along with a conventional output (gross output) and two conventional inputs (labor and capital), we consider 10 undesirable inputs/outputs in each sector and sub-industry studied as follows: total energy consumption, electricity use, water use, and paper consumption as undesirable inputs; Scope 1, Scope 1 + 2, Scope 1 + 2 + 3, SOx, NOx, and VOC as undesirable outputs. In addition, to examine the environmental efficiency of order-m, this study analyzes two additional topics: the estimation of shadow prices and a regression model as a second analytical step that incorporates ESG activities as explanatory variables.

This study has important policy implications. The results suggest that even if a market exists to trade environmentally undesirable inputs/outputs between firms or if the environmental taxes are higher than the current level, many firms would still be willing to purchase allowances to expand their production. Therefore, the current price does not considerably influence firms. However, because there are many potential buyers, the result also implies that the market price of the allowances or credits could jump depending on the circumstances and result in a buoyant market.

Another implication is that there is much reduction potential for these efficiencies, especially of the undesirable inputs rather than the undesirable outputs. This means that when a production technology is adopted by a leader within a certain industry, the industry will experience a higher reduction rate in undesirable inputs than undesirable outputs. For example, the amount of energy consumption is highly correlated with the amount of GHG emissions (Scope 1, 2, 3) (Supplementary material Table S.5 shows a correlation table of this study), so from the standpoint of an environmental efficiency, reduced energy consumption should be considered over a reduction in GHG emissions. However, the result of this study does not mean that it is less expensive to reduce undesirable inputs, especially the use of energy and water, than to reduce undesirable outputs. This study shows there is great reduction potential for these efficiencies but does not address cost effectiveness.

In addition, it would be worth to have a deeper analysis of the ESG activities of global firms because the result shows that the impact of ESG activities on environmental efficiency is quite limited. This could imply that the representative ESG activities undertaken by listed firms worldwide are not presently directly connected with the main business and environmental efficiency. To improve environmental efficiency, it seems necessary to shift the production technology of the main business towards environmental friendliness rather than implement a set of ad-hoc ESG activities. Therefore, the empirical result might suggest that improving environmental efficiency could be more expensive than expected.

Note that data limitation remains a key issue. As described above, unlike financial data, access to environmental data is still limited. The environmental data used in this study lacks many variables, and due to this limitation, this study could only consider 10 undesirable inputs/outputs in each model and could not align the observations of each model. An examination of regional and country environmental efficiency characteristics is also required.

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Table 1. Descriptive statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Gross profit | 7,369 | 3,550,000,000 | 7,930,000,000 | 795,165 | 84,000,000,000 |
| Labor | 7,369 | 29,827 | 58,575 | 2 | 648,254 |
| Capital stock | 7,369 | 5,970,000,000 | 16,800,000,000 | 241,694 | 276,000,000,000 |
| Energy cons. | 6,059 | 9,252 | 60,985 | 0.1 | 3,936,340 |
| Electricity use | 5,006 | 1,175,007 | 7,182,663 | 0.7 | 251,000,000 |
| Water use | 5,377 | 76,548 | 640,602 | 0.2 | 36,500,000 |
| Paper cons. | 866 | 116 | 1,168 | 0.1 | 24,000 |
| Scope 1 | 2,267 | 3,514,233 | 13,200,000 | 1.8 | 203,000,000 |
| Scope 1+2 | 2,181 | 4,250,000,000 | 14,100,000,000 | 147,000.0 | 227,000,000,000 |
| Scope 1+2+3 | 1,049 | 13,800,000,000 | 76,100,000,000 | 536,500.0 | 775,000,000,000 |
| SOx | 1,702 | 23,087 | 204,681 | 0.1 | 3,189,997 |
| NOx | 2,459 | 40,684 | 499,631 | 0.1 | 11,200,000 |
| VOC | 890 | 19 | 287 | 0.1 | 8,500 |
| EEPol | 7,349 | 0.92 | 0.28 | 0 | 1 |
| EQM | 7,358 | 0.79 | 0.41 | 0 | 1 |
| GBPol | 7,354 | 0.16 | 0.37 | 0 | 1 |
| SPack | 7,355 | 0.25 | 0.44 | 0 | 1 |
| EnvSCPol | 7,352 | 0.63 | 0.48 | 0 | 1 |
| WastePol | 7,357 | 0.84 | 0.37 | 0 | 1 |
| GHGini | 7,355 | 0.89 | 0.31 | 0 | 1 |
| GHGPol | 7,357 | 0.69 | 0.46 | 0 | 1 |

Notes:

Gross profit denotes sales minus cost of goods sold (U.S. dollars at nominal price). Labor denotes the number of employees (persons). Capital stock is estimated by benchmark year method where bench mark year is 2005. Unit of energy consumption and electricity use is megawatt hour (MWh). Unit of water use is cubic meter. Units of paper consumption, scope 1/1+2/1+2+3, SOx, NOx, and VOC are metric ton. EEPol, EQM, GBPol, SPack, ESCPol, WRPol, GHGini, and GHGPol denote dummy variables of ESG activities (see Supplementary material Table S.6). Supplementary material Table S.4 shows descriptive statistics by sector.

Table 2. Survey for representative market prices

| Category | Unit | Representative market price | Source |
|---|---|---|---|
| Energy consumption | MWh | — | — |
| Electricity use | MWh | Average electricity retail prices are $128.3 (U.S. dollars) for industries and $213.2 for households in 28 OECD countries [a)] | IEA (2013) |
| Water use | cubic meter | Average water tariff charged to households in 29 OECD countries [b) c)] is $2.05 in 2008 | OECD (2010) |
| Paper use | ton | Price of wood pulp is $823.1 per metric ton in 2013 | World Bank DataBank [d)] |
| Scope 1, 2, 3 of GHG | ton | The price per ton of phase 2 in EU ETS ranged about below 10 Euros to 30 Euros in 2008-2012 | European Commission (2012) |
| SOx | ton | $SO_2$ allowance prices in the U.S. ranged between $0.56 and more than $1,200 per ton in 1994-2012 | Schmalensee and Stavins (2013) |
| NOx | ton | NOx allowance prices in the U.S. ranged between $80 and a few thousand U.S. dollars per ton in 2001-2012 | Burtraw and Szambelan (2009); Environmental Protection Agency Progress Report [e)] |
| VOC | ton | — | — |

Notes:

(a) The 28 OECD countries are Belgium, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Sweden, Switzerland, Turkey, United Kingdom, United States.

(b) Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

(c) This survey is carried out by Global Water Intelligence (http://www.globalwaterintel.com).

(d) World Bank DataBank: Global Economic Monitor Commodities of the World Bank (http://databank.worldbank.org/)

(e) http://www.epa.gov/airmarkets/progress/progress-reports.html

Table 3. Percentiles of order-m and FDH scores in all sectors

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Percentile | Energy Cons. | Electricity use | Water use | Paper cons. | Scope 1 | Scope 1+2 | Scope 1+2+3 | SOx | NOx | VOC |
| | | | | | order-m score | | | | | |
| 10th | −0.077 | −0.087 | −0.082 | −0.210 | −0.160 | −0.149 | −0.209 | −0.165 | −0.138 | −0.176 |
| 20th | −0.020 | −0.027 | −0.019 | −0.123 | −0.079 | −0.071 | −0.118 | −0.094 | −0.067 | −0.098 |
| 30th | 0.092 | 0.080 | 0.111 | −0.078 | −0.038 | −0.029 | −0.072 | −0.053 | −0.028 | −0.055 |
| 40th | 0.285 | 0.288 | 0.321 | −0.052 | 0.001 | 0.020 | −0.039 | −0.011 | 0.040 | −0.028 |
| 50th | 0.475 | 0.488 | 0.525 | −0.014 | 0.167 | 0.184 | 0.000 | 0.072 | 0.215 | 0.000 |
| 60th | 0.647 | 0.652 | 0.706 | 0.000 | 0.386 | 0.364 | 0.086 | 0.241 | 0.421 | 0.129 |
| 70th | 0.794 | 0.801 | 0.848 | 0.110 | 0.603 | 0.588 | 0.287 | 0.436 | 0.627 | 0.323 |
| 80th | 0.891 | 0.898 | 0.936 | 0.394 | 0.792 | 0.757 | 0.530 | 0.663 | 0.835 | 0.554 |
| 90th | 0.962 | 0.960 | 0.983 | 0.734 | 0.924 | 0.901 | 0.791 | 0.922 | 0.955 | 0.789 |
| Mean | 0.004 | −1.335 | −0.293 | −0.559 | 0.179 | 0.260 | 0.091 | −0.832 | 0.015 | 0.043 |
| Std. Dev. | 21.250 | 66.428 | 18.427 | 7.820 | 2.222 | 0.657 | 0.970 | 33.083 | 8.695 | 1.721 |
| | | | | | FDH score | | | | | |
| 10th | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 20th | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 30th | 0.133 | 0.125 | 0.160 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 40th | 0.344 | 0.345 | 0.394 | 0.000 | 0.039 | 0.065 | 0.000 | 0.000 | 0.076 | 0.000 |
| 50th | 0.543 | 0.565 | 0.604 | 0.000 | 0.227 | 0.258 | 0.017 | 0.125 | 0.273 | 0.006 |
| 60th | 0.713 | 0.740 | 0.786 | 0.000 | 0.489 | 0.458 | 0.135 | 0.308 | 0.512 | 0.185 |
| 70th | 0.839 | 0.859 | 0.907 | 0.165 | 0.697 | 0.671 | 0.375 | 0.528 | 0.720 | 0.400 |
| 80th | 0.920 | 0.936 | 0.965 | 0.473 | 0.863 | 0.819 | 0.622 | 0.775 | 0.906 | 0.659 |
| 90th | 0.974 | 0.983 | 0.991 | 0.800 | 0.968 | 0.934 | 0.829 | 0.979 | 0.984 | 0.838 |
| Mean | 0.497 | 0.506 | 0.531 | 0.192 | 0.379 | 0.370 | 0.248 | 0.323 | 0.396 | 0.256 |
| Std. Dev. | 0.383 | 0.391 | 0.397 | 0.319 | 0.391 | 0.375 | 0.334 | 0.376 | 0.396 | 0.337 |
| Obs | 6,059 | 5,006 | 5,377 | 866 | 2,267 | 2,181 | 1,049 | 1,702 | 2,459 | 890 |

Table 4. The median of order-m scores by sector

| | | Undesirable input $b^{in}$ | | | | Undesirable output $b^{out}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Percentile | Sector | Energy Cons. | Electricity use | Water use | Paper cons. | Scope 1 | Scope 1+2 | Scope 1+2+3 | SOx | NOx | VOC |
| 50th | 10 | 0.410 | −0.067 | 0.187 | −0.096 | 0.111 | 0.051 | −0.076 | 0.527 | 0.460 | 0.257 |
| 50th | 15 | 0.465 | 0.404 | 0.534 | −0.035 | 0.149 | 0.134 | −0.015 | 0.110 | 0.490 | 0.247 |
| 50th | 20 | 0.586 | 0.661 | 0.624 | 0.026 | 0.402 | 0.459 | 0.229 | 0.031 | 0.138 | −0.017 |
| 50th | 25 | 0.697 | 0.747 | 0.771 | −0.008 | 0.456 | 0.431 | 0.018 | 0.052 | 0.048 | −0.010 |
| 50th | 30 | 0.274 | 0.302 | 0.277 | −0.098 | 0.117 | 0.222 | 0.029 | 0.005 | −0.018 | −0.026 |
| 50th | 35 | 0.026 | 0.026 | 0.039 | −0.068 | −0.018 | −0.011 | −0.034 | −0.027 | 0.008 | −0.019 |
| 50th | 40 | −0.015 | −0.050 | 0.038 | −0.011 | 0.172 | 0.121 | −0.032 | 0.000 | −0.071 | −3.279 |
| 50th | 45 | 0.699 | 0.663 | 0.928 | −0.001 | 0.260 | 0.275 | 0.012 | 0.140 | 0.331 | −0.002 |
| 50th | 50 | 0.000 | −0.008 | −0.034 | −0.072 | −0.046 | −0.037 | −0.058 | n/a | 0.000 | n/a |
| 50th | 55 | 0.000 | −0.085 | −0.034 | −0.114 | −0.088 | −0.103 | −0.113 | −0.140 | −0.002 | −0.128 |
| 50th | All | 0.475 | 0.488 | 0.525 | −0.014 | 0.167 | 0.184 | 0.000 | 0.072 | 0.215 | 0.000 |
| Obs | | 6,059 | 5,006 | 5,377 | 866 | 2,267 | 2,181 | 1,049 | 1,702 | 2,459 | 890 |

Table 5. Percentiles of shadow prices in all sectors

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| Percentile | Energy Cons. (MWh) | Electricity use (MWh) | Water use (cubic meter) | Paper cons. (ton) | Scope 1 (ton) | Scope 1+2 | Scope 1+2+3 | SOx (ton) | NOx (ton) | VOC (ton) |
| Estimated by order-m specification | | | | | | | | | | |
| 10th | 1,530 | 27 | 184 | 914,583 | 18 | 16 | 29 | 24 | 843 | 5,022,230 |
| 20th | 24,110 | 247 | 5,007 | 27,800,000 | 222 | 151 | 208 | 16,396 | 24,974 | 125,000,000 |
| 30th | 124,064 | 899 | 30,881 | 119,000,000 | 872 | 555 | 770 | 161,742 | 127,532 | 344,000,000 |
| 40th | 426,492 | 2,221 | 128,492 | 426,000,000 | 3,153 | 1,558 | 2,269 | 715,389 | 542,506 | 838,000,000 |
| 50th | 1,260,000 | 4,974 | 447,435 | 1,440,000,000 | 9,065 | 3,725 | 4,462 | 3,598,447 | 2,072,486 | 2,180,000,000 |
| 60th | 3,139,771 | 10,999 | 1,288,696 | 2,600,000,000 | 24,370 | 8,239 | 7,809 | 17,800,000 | 7,102,320 | 4,460,000,000 |
| 70th | 9,027,860 | 23,673 | 3,758,059 | 5,830,000,000 | 71,186 | 19,384 | 13,885 | 67,400,000 | 20,000,000 | 8,570,000,000 |
| 80th | 31,500,000 | 73,487 | 20,900,000 | 14,700,000,000 | 226,519 | 53,449 | 33,059 | 288,000,000 | 76,500,000 | 29,400,000,000 |
| 90th | 83,800,000,000 | 164,000,000 | 12,400,000,000 | 56,100,000,000 | 1,836,562 | 388,050 | 132,354 | 2,120,000,000 | 535,000,000 | 105,000,000,000 |
| Estimated by parametric LP specification | | | | | | | | | | |
| 10th | 37,824 | 558 | 6,634 | 10,062 | 184 | 220 | 73 | 608 | 2,834 | 8,782 |
| 20th | 136,180 | 1,340 | 27,530 | 54,404 | 671 | 583 | 282 | 6,118 | 11,913 | 34,267 |
| 30th | 357,861 | 2,537 | 77,945 | 302,478 | 2,182 | 1,601 | 1,865 | 40,016 | 40,575 | 560,660 |
| 40th | 746,672 | 4,385 | 168,954 | 7,915,198 | 5,449 | 2,804 | 3,939 | 195,853 | 156,551 | 38,600,000 |
| 50th | 1,699,798 | 8,242 | 361,900 | 70,300,000 | 11,326 | 5,713 | 6,202 | 808,779 | 647,261 | 588,000,000 |
| 60th | 3,724,932 | 15,682 | 830,752 | 393,000,000 | 24,645 | 9,733 | 10,857 | 4,462,802 | 2,820,864 | 3,530,000,000 |
| 70th | 11,100,000 | 30,115 | 2,441,879 | 2,010,000,000 | 64,437 | 19,475 | 22,003 | 54,000,000 | 19,200,000 | 12,100,000,000 |
| 80th | 59,900,000 | 67,486 | 11,700,000 | 7,080,000,000 | 252,795 | 44,461 | 42,434 | 605,000,000 | 124,000,000 | 45,200,000,000 |
| 90th | 1,210,000,000 | 220,745 | 133,000,000 | 34,100,000,000 | 2,301,315 | 129,873 | 121,969 | 6,170,000,000 | 1,770,000,000 | 181,000,000,000 |
| Obs | 6,059 | 5,006 | 5,377 | 866 | 2,267 | 2,181 | 1,049 | 1,702 | 2,459 | 890 |

Note: Units of each percentile are U.S. dollars at nominal price.

Table 6. The median of shadow price by sector

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentile | Sector | Energy Cons. (MWh) | Electricity use (MWh) | Water use (cubic meter) | Paper cons. (ton) | Scope 1 (ton) | Scope 1+2 | Scope 1+2+3 | SOx (ton) | NOx (ton) | VOC (ton) |
| Estimated by order-m specification | | | | | | | | | | | |
| 50th | 10 | 285,135 | 4,265 | 102,533 | 2,400,000,000 | 901 | 788 | 192 | 175,539 | 151,062 | 404,000,000 |
| 50th | 15 | 108,669 | 932 | 15,342 | 1,029,488 | 666 | 445 | 487 | 313,766 | 443,714 | 774,000,000 |
| 50th | 20 | 1,003,049 | 3,576 | 575,736 | 2,890,000,000 | 8,169 | 4,460 | 2,962 | 12,000,000 | 2,751,331 | 2,150,000,000 |
| 50th | 25 | 7,506,619 | 15,474 | 1,937,559 | 702,000,000 | 48,242 | 9,857 | 7,277 | 41,700,000 | 8,427,089 | 1,360,000,000 |
| 50th | 30 | 998,832 | 2,566 | 214,828 | 67,400,000 | 6,953 | 2,738 | 2,089 | 34,600,000 | 12,800,000 | 63,800,000,000 |
| 50th | 35 | 4,825,840 | 12,175 | 908,853 | 3,050,000,000 | 48,558 | 11,994 | 12,530 | 82,200,000 | 23,200,000 | 14,600,000,000 |
| 50th | 40 | 1,507,601 | 2,363 | 551,467 | 1,860,000,000 | 77,677 | 9,979 | 12,458 | 101,176 | 77,988 | −36,200,000,000 |
| 50th | 45 | 13,200,000 | 22,049 | 7,394,800 | 2,460,000,000 | 147,657 | 19,710 | 10,881 | 37,500,000 | 48,600,000 | 56,700,000,000 |
| 50th | 50 | 4,737,212 | 6,243 | 7,848,501 | 595,000,000 | 146,145 | 11,204 | 11,029 | n/a | 3,263,526 | n/a |
| 50th | 55 | 70,800 | 1,733 | 3,619 | 5,310,000,000 | 477 | 498 | 220 | 161,742 | 129,776 | 6,920,000,000 |
| 50th | All | 1,260,000 | 4,974 | 447,435 | 1,440,000,000 | 9,065 | 3,725 | 4,462 | 3,598,447 | 2,072,486 | 2,180,000,000 |
| Estimated by parametric LP specification | | | | | | | | | | | |
| 50th | 10 | 41,106 | 3,614 | 244,108 | 651,990 | 4,059 | 1,276 | 57 | 53,183 | 50,501 | 11,200,000 |
| 50th | 15 | 867,917 | 988 | 22,634 | 14,800,000 | 245 | 295 | 72 | 123,652 | 204,399 | 28,500,000 |
| 50th | 20 | 603,032 | 19,151 | 718,289 | 6,511,686 | 6,119 | 6,207 | 4,662 | 323,179 | 272,394 | 4,280,000,000 |
| 50th | 25 | 1,878,529 | 14,471 | 441,775 | 29,000,000 | 67,870 | 19,316 | 11,009 | 11,600,000 | 3,313,659 | 728,000,000 |
| 50th | 30 | 32,300,000 | 37,482 | 913,563 | 76,500,000 | 17,154 | 6,204 | 14,695 | 121,000,000 | 3,158,504 | 1,450,000,000 |
| 50th | 35 | 2,369,251 | 20,272 | 445,458 | 3,380,000,000 | 87,092 | 20,723 | 18,062 | 183,000,000 | 20,900,000 | 21,900,000,000 |
| 50th | 40 | 2,945,106 | 2,616 | 1,150,263 | 61,300,000 | 26,528 | 11,489 | 7,128 | Inf | 1,064 | 1.090E+24 |
| 50th | 45 | 5,019,440 | 7,551 | 575,848 | 69,600,000 | 418,361 | 17,164 | 26,809 | 44,300,000 | 79,400,000 | 11,000,000,000 |
| 50th | 50 | 4,164,004 | 9,709 | 14,300,000 | 1,190,000,000 | 99,155 | 27,014 | 26,022 | n/a | Inf | n/a |
| 50th | 55 | 151,174 | 1,388 | 22,459 | 9,635 | 1,645 | 1,100 | 101 | 353,882 | 104,504 | 936,000,000 |
| 50th | All | 1,699,798 | 8,242 | 361,900 | 70,300,000 | 11,326 | 5,713 | 6,202 | 808,779 | 647,261 | 588,000,000 |
| Obs | | 6,059 | 5,006 | 5,377 | 866 | 2,267 | 2,181 | 1,049 | 1,702 | 2,459 | 890 |

Notes: Unit of shadow prices is U.S. dollars at nominal price. n/a denotes there is no obs.

Table 7. Regression result

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| *b* | Energy Cons. | Electricity use | Water use | Paper cons. | Scope 1 | Scope 1+2 | Scope 1+2+3 | SOx | NOx | VOC |
| Indep. variable | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ | $\delta_{mi}^{OM}$ |
| EEPol | −3.230 | 9.933 | 0.552 | −2.768 | −0.128 | −0.027 | −0.352 | −3.345 | 0.087 | 0.541 |
| | (3.217) | (8.562) | (1.898) | (2.676) | (0.110) | (0.062) | (0.284) | (3.543) | (0.158) | (0.464) |
| EQM | −0.825 | 0.573 | −0.431 | −0.538 | −0.070 | 0.009 | −0.111 | 1.417 | −0.168 | −0.200 |
| | (0.851) | (2.158) | (0.464) | (0.601) | (0.054) | (0.035) | (0.111) | (1.469) | (0.151) | (0.151) |
| GBPol | 0.231 | 1.974 | 0.419 | −0.618 | 0.149** | 0.045 | −0.165 | 1.139 | 0.252 | −0.542* |
| | (0.290) | (1.275) | (0.489) | (0.794) | (0.074) | (0.040) | (0.127) | (1.195) | (0.226) | (0.283) |
| SPack | 0.496 | −2.744 | 0.588 | −0.322 | 0.106 | 0.028 | 0.049 | 0.355 | 0.423 | 0.134 |
| | (0.515) | (3.475) | (0.649) | (0.718) | (0.078) | (0.046) | (0.058) | (0.382) | (0.420) | (0.109) |
| EnvSCPol | −1.038 | 4.383 | 0.630 | 1.068 | 0.077 | 0.015 | 0.212 | 3.970 | −0.354 | −0.071 |
| | (0.956) | (4.083) | (0.641) | (1.189) | (0.122) | (0.036) | (0.128) | (4.209) | (0.375) | (0.185) |
| WastePol | −1.020 | 0.795 | −0.634 | 2.089 | 0.115 | 0.062 | 0.325 | −3.908 | 0.258 | 0.091 |
| | (1.010) | (1.714) | (1.145) | (1.633) | (0.134) | (0.063) | (0.197) | (4.125) | (0.455) | (0.095) |
| GHGini | 7.004 | −5.657 | 2.944 | 1.015 | 0.166 | 0.119 | 0.409 | −3.980 | −0.079 | 0.151 |
| | (6.631) | (6.133) | (2.017) | (1.347) | (0.103) | (0.087) | (0.326) | (4.461) | (0.157) | (0.156) |
| GHGPol | 0.320 | −0.802 | 0.206 | 0.313 | −0.158** | −0.040 | −0.127 | 6.211 | −0.217 | 0.013 |
| | (0.209) | (1.655) | (0.390) | (0.614) | (0.074) | (0.032) | (0.138) | (6.117) | (0.215) | (0.087) |
| Constant | −1.491 | −8.696 | −3.388 | −1.200 | 0.088 | 0.122* | −0.166 | 0.022 | 0.213 | −0.404 |
| | (1.584) | (7.007) | (2.633) | (1.186) | (0.108) | (0.073) | (0.132) | (0.746) | (0.260) | (0.550) |
| Obs | 6042 | 4998 | 5368 | 865 | 2256 | 2172 | 1047 | 1700 | 2452 | 888 |
| (# of clusters) | 134 | 131 | 130 | 75 | 130 | 128 | 109 | 68 | 85 | 56 |
| F value | 0.66 | 0.60 | 1.50 | 0.49 | 1.47 | 1.25 | 2.29** | 0.23 | 0.58 | 0.89 |
| R-squared | 0.0068 | 0.0024 | 0.0034 | 0.0103 | 0.0039 | 0.0092 | 0.0454 | 0.0072 | 0.0009 | 0.0206 |

Notes: All columns shows results of regression model. **, and * denote significances at the 5% and 10% level, respectively. Coefficients are without parentheses, and cluster-robust standard errors are in parentheses where GICS sub-industry classification is used as cluster (see Supplementary material Table S.1).

Appendix

Fukuyama and Weber (2008) claim that the supporting hyperplanes of dual variables in the DEA specification are not necessarily unique to an efficient observation, so there might be multiple supporting hyperplanes. They also provide a procedure to estimate the upper and lower bounds on the shadow price of the undesirable input/output by solving a series of fractional programming problems. In addition to DEA, there could be multiple supporting hyperplanes of dual variables (*u*,*v*,*q*) in the order-m method, and we apply their procedure to the order-m method in the following paragraphs.

From the solutions to equation (24), we obtain $\sum_{d=1}^{D} u^k_{i^{ref}d} y^k_{i^{ref}d} \Big/ \sum_{d=1}^{D} u^k_{i^{ref}d}$, $\sum_{d=1}^{D} v^j_{i^{ref}d} x^j_{i^{ref}d} \Big/ \sum_{d=1}^{D} v^j_{i^{ref}d}$, and $\sum_{d=1}^{D} q^l_{i^{ref}d} b^l_{i^{ref}d} \Big/ \sum_{d=1}^{D} q^l_{i^{ref}d}$, which are a set of (*x*,*y*,*b*) of a pseudo-reference DMU (i.e., a *D*-times weight-averaged reference DMU) for a certain DMU, *i*, and $\left(\overline{\sigma_i^{*x}}, \overline{\sigma_i^{*y}}, \overline{\sigma_i^{*b}}\right)$, which is a set of inefficiencies from equations (33), (34), and (35). We let $\left(x^*_{i^{ref}}, y^*_{i^{ref}}, b^*_{i^{ref}}\right)$ denote a set of (*x*,*y*,*b*) of a pseudo-reference DMU, and re-estimate a set of pseudo reference dual variables (i.e., $\overline{u_{i^{ref}}}$, $\overline{v_{i^{ref}}}$, $\overline{q_{i^{ref}}}$), given $\left(x^*_{i^{ref}}, y^*_{i^{ref}}, b^*_{i^{ref}}\right)$ and $\left(\overline{\sigma_i^{*x}}, \overline{\sigma_i^{*y}}, \overline{\sigma_i^{*b}}\right)$. Following Fukuyama and Weber (2008), the upper bound for the undesirable input/output shadow price is the solution to the following fractional programming problem:

$$p_b^{\max,1} = \max\left\{ \frac{\overline{q_{i^{ref}}^1}\left(\overline{\sigma_i^{*x}}x_i, \overline{\sigma_i^{*y}}y_i, \overline{\sigma_i^{*b}}b_i; g^x, g^y, g^b\right)}{\overline{u_{i^{ref}}^1}\left(\overline{\sigma_i^{*x}}x_i, \overline{\sigma_i^{*y}}y_i, \overline{\sigma_i^{*b}}b_i; g^x, g^y, g^b\right)} \cdot \frac{\overline{\sigma_i^{*b1}}}{\overline{\sigma_i^{*y1}}} \cdot p_y^1 \right\} \tag{A.1}$$

$$\text{s.t.} \sum_{k=1}^{K}\overline{u_{i^{ref}}^k}\left(y_{i^{ref}}^{*k} - \overline{\sigma_i^{*yk}}y_i^k\right) - \sum_{j=1}^{J}\overline{v_{i^{ref}}^j}\left(x_{i^{ref}}^{*j} - \overline{\sigma_i^{*xj}}x_i^j\right) - \sum_{l=1}^{L}\overline{q_{i^{ref}}^l}\left(b_{i^{ref}}^{*l} - \overline{\sigma_i^{*bl}}b_i^l\right) = 0 \tag{A.2}$$

$$\sum_{k=1}^{K}\overline{u_{i^{ref}}^k}g_y^k - \sum_{j=1}^{J}\overline{v_{i^{ref}}^j}g_x^j - \sum_{l=1}^{L}\overline{q_{i^{ref}}^l}g_b^l = 1 \tag{A.3}$$

$$\overline{u_{i^{ref}}^k} \geq 0 \ \forall k \in K \tag{A.4}$$

$$\overline{v_{i^{ref}}^j} \geq 0 \ \forall j \in J \tag{A.5}$$

$$\overline{q_{i^{ref}}^l} \geq 0 \ \forall l \in L \tag{A.6}$$

Applying the transformation procedure of Charnes and Cooper (1962), the fractional programming problem (equation (A.1)) could be converted to the LP problem. We restrict $\overline{u_{i^{ref}}^1}\left(\overline{\sigma_i^x}x_i, \overline{\sigma_i^y}y_i, \overline{\sigma_i^b}b_i; g^x, g^y, g^b\right) \neq 0$ and set the following variables:

$$\tau = \frac{1}{\overline{u_{i^{ref}}^1}\left(\overline{\sigma_i^{*x}}x_i, \overline{\sigma_i^{*y}}y_i, \overline{\sigma_i^{*b}}b_i; g^x, g^y, g^b\right)} \tag{A.7}$$

$$\overline{\mathbf{v}_{i^{ref}}^j} = \tau \cdot \overline{v_{i^{ref}}^j} \forall j \tag{A.8}$$

$$\overline{\mathbf{u}_{i^{ref}}^k} = \tau \cdot \overline{u_{i^{ref}}^k} \forall k \tag{A.9}$$

$$\overline{\mathbf{v}_{i^{ref}}^j} = \tau \cdot \overline{v_{i^{ref}}^j} \forall j \ . \tag{A.10}$$

The LP problem for equation (A.1) is expressed as follows:

$$p_b^{\max,1} = \max\left\{ \overline{\mathbf{q}_{i^{ref}}^{1}}\left(\overline{\sigma_i^{*x}}x_i, \overline{\sigma_i^{*y}}y_i, \overline{\sigma_i^{*b}}b_i; g^x, g^y, g^b\right) \cdot \frac{\overline{\sigma_i^{*b1}}}{\overline{\sigma_i^{*y1}}} \cdot p_y^1 \right\} \quad (A.11)$$

$$\text{s.t.} \quad \sum_{k=1}^{K} \overline{\mathbf{u}_{i^{ref}}^{k}}\left(y_{i^{ref}}^{*k} - \overline{\sigma_i^{*yk}}y_i^k\right) - \sum_{j=1}^{J} \overline{\mathbf{v}_{i^{ref}}^{j}}\left(x_{i^{ref}}^{*j} - \overline{\sigma_i^{*xj}}x_i^j\right) - \sum_{l=1}^{L} \overline{\mathbf{q}_{i^{ref}}^{l}}\left(b_{i^{ref}}^{*l} - \overline{\sigma_i^{*bl}}b_i^l\right) = 0 \quad (A.12)$$

$$\sum_{k=1}^{K} \overline{\mathbf{u}_{i^{ref}}^{k}} g_y^k - \sum_{j=1}^{J} \overline{\mathbf{v}_{i^{ref}}^{j}} g_x^j - \sum_{l=1}^{L} \overline{\mathbf{q}_{i^{ref}}^{l}} g_b^l = \tau \quad (A.13)$$

$$\tau > 0 \quad (A.14)$$

$$\overline{\mathbf{u}_{i^{ref}}^{1}} = 1 \quad (A.15)$$

$$\overline{\mathbf{u}_{i^{ref}}^{k}} \geq 0 \ \forall k \in K \quad (A.16)$$

$$\overline{\mathbf{v}_{i^{ref}}^{j}} \geq 0 \ \forall j \in J \quad (A.17)$$

$$\overline{\mathbf{q}_{i^{ref}}^{l}} \geq 0 \ \forall l \in L. \quad (A.18)$$

In a similar way, the lower bound of the shadow price is calculated in the following LP problem:

$$p_b^{\min,1} = \min\left\{ \overline{\mathbf{q}_{i^{ref}}^{1}}\left(\overline{\sigma_i^{*x}}x_i, \overline{\sigma_i^{*y}}y_i, \overline{\sigma_i^{*b}}b_i; g^x, g^y, g^b\right) \cdot \frac{\overline{\sigma_i^{*b1}}}{\overline{\sigma_i^{*y1}}} \cdot p_y^1 \right\} \quad (A.19)$$

$$\text{s.t.} \quad \sum_{k=1}^{K} \overline{\mathbf{u}_{i^{ref}}^{k}}\left(y_{i^{ref}}^{*k} - \overline{\sigma_i^{*yk}}y_i^k\right) - \sum_{j=1}^{J} \overline{\mathbf{v}_{i^{ref}}^{j}}\left(x_{i^{ref}}^{*j} - \overline{\sigma_i^{*xj}}x_i^j\right) - \sum_{l=1}^{L} \overline{\mathbf{q}_{i^{ref}}^{l}}\left(b_{i^{ref}}^{*l} - \overline{\sigma_i^{*bl}}b_i^l\right) = 0 \quad (A.20)$$

$$\sum_{k=1}^{K} \overline{\mathbf{u}_{i^{ref}}^{k}} g_y^k - \sum_{j=1}^{J} \overline{\mathbf{v}_{i^{ref}}^{j}} g_x^j - \sum_{l=1}^{L} \overline{\mathbf{q}_{i^{ref}}^{l}} g_b^l = \tau \quad (A.21)$$

$$\tau > 0 \quad (A.22)$$

$$\overline{\mathbf{u}_{i^{ref}}^{1}} = 1 \quad (A.23)$$

$$\overline{\mathbf{u}^{k}_{i^{ref}}} \geq 0 \ \forall k \in K \tag{A.24}$$

$$\overline{\mathbf{v}^{j}_{i^{ref}}} \geq 0 \ \forall j \in J \tag{A.25}$$

$$\overline{\mathbf{q}^{l}_{i^{ref}}} \geq 0 \ \forall l \in L. \tag{A.26}$$

Note that if $\overline{u^{1}_{i^{ref}}}\left(\overline{\sigma_i^{*x}}x_i, \overline{\sigma_i^{*y}}y_i, \overline{\sigma_i^{*b}}b_i; g^x, g^y, g^b\right) = 0$, either the upper bound equation (equation (A.11)) or the lower bound equation (equation (A.19)) could be infeasible. This would imply that the shadow price of $p_b^1$ is infinitely positive.

Supplementary material

## S1. A discussion about treatment of outliers within the Journal of Environmental Management

The issue of outliers in DEA/FDH has been discussed at least two decades ago in the environmental management literature such as in the Journal of Environmental Management. Tyteca (1996) reviews that this issue is well known in DEA/FDH, and that there are two solutions; by simply ignoring outliers and by replacing the best-practice frontier by another one. After Tyteca (1996), the JEM has published at least 11 papers examining environmental performance using usual DEA/FDH at firm or farm level, which is likely to have more indistinguishable outliers than at country or municipality level. Among them, 5 studies refer to and deal with outliers (or make sure there is no outlier) of their dataset (Frija et al., 2011; Gadanakis et al., 2015; Lundgren et al., 2013; Picazo-Tadeo and Prior, 2009; Van Meensel et al., 2010); 1 study only refers to the problem of outlier (Barnes, 2006); 5 studies do not refer to outliers (Barnes et al., 2009; Chen et al., 2012; De Koeijer et al., 2002; Oude Lansink and Bezlepkin, 2003; Picazo-Tadeo et al., 2011). As Tyteca mentions, the best practice frontier is not considerably suited for the value of the indicator in itself but rather as a means to rank DMUs; therefore, some may justify estimation with potential super-efficient outliers because ranking DMU itself is important as a measure to improve environmental efficiency in the actual business situation. However, it will be beneficial for the value of the indicator to have options for sensitive analysis.

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Supplementary material Table S.1. GICS Sector and sub-industry classification

| # | GICS Sector | obs | Cluster: GICS Sub-Industry (#) |
|---|---|---|---|
| 10 | Energy | 339 | Oil & Gas Drilling, Oil & Gas Equipment & Services, Integrated Oil & Gas, Oil & Gas Exploration & Production, Oil & Gas Refining & Marketing, Oil & Gas Storage & Transportation, Coal & Consumable Fuels (7) |
| 15 | Materials | 1334 | Commodity Chemicals, Diversified Chemicals, Fertilizers & Agricultural Chemicals, Industrial Gases, Specialty Chemicals, Construction Materials, Metal & Glass Containers, Paper Packaging, Aluminum, Diversified Metals & Mining, Gold, Precious Metals & Minerals, Silver, Steel, Forest Products, Paper Products (16) |
| 20 | Industrials | 1764 | Aerospace & Defense, Building Products, Construction & Engineering, Electrical Components & Equipment, Heavy Electrical Equipment, Industrial Conglomerates, Construction Machinery & Heavy Trucks, Agricultural & Farm Machinery, Industrial Machinery, Trading Companies & Distributors, Commercial Printing, Environmental & Facilities Services, Office Services & Supplies, Diversified Support Services, Security & Alarm Services, Human Resource & Employment Services, Research & Consulting Services, Air Freight & Logistics, Airlines, Marine, Railroads, Trucking, Airport Services, Highways & Railtracks, Marine Ports & Services (25) |
| 25 | Consumer Discretionary | 1141 | Auto Parts & Equipment, Tires & Rubber, Automobile Manufacturers, Motorcycle Manufacturers, Consumer Electronics, Home Furnishings, Homebuilding, Household Appliances, Housewares & Specialties, Leisure Products, Apparel, Accessories & Luxury Goods, Footwear, Textiles, Casinos & Gaming, Hotels, Resorts & Cruise Lines, Leisure Facilities, Restaurants, Education Services, Specialized Consumer Services, Advertising, Broadcasting, Cable & Satellite, Movies & Entertainment, Publishing, Distributors, Catalog Retail, Department Stores, General Merchandise Stores, Apparel Retail, Computer & Electronics Retail, Home Improvement Retail, Specialty Stores, Automotive Retail, Homefurnishing Retail |
| 30 | Consumer Staples | 881 | Drug Retail, Food Distributors, Food Retail, Hypermarkets & Super Centers, Brewers, Distillers & Vintners, Soft Drinks, Agricultural Products, Packaged Foods & Meats, Tobacco, Household Products, Personal Products (12) |
| 35 | Health Care | 466 | Health Care Equipment, Health Care Supplies, Health Care Distributors, Health Care Services, Health Care Facilities, Managed Health Care, Biotechnology, Pharmaceuticals, Life Sciences Tools & Services (9) |
| 40 | Financials | 199 | Diversified Banks, Regional Banks, Thrifts & Mortgage Finance, Other Diversified Financial Services, Multi-Sector Holdings, Specialized Finance, Consumer Finance, Asset Management & Custody Banks, Investment Banking & Brokerage, Diversified Capital Markets, Life & Health Insurance, Multi-line Insurance, Property & Casualty Insurance, Diversified REITs, Industrial REITs, Office REITs, Retail REITs, Specialized REITs, Diversified Real Estate Activities, Real Estate Operating Companies, Real Estate Development, Real Estate Services (22) |
| 45 | Information Technology | 918 | Internet Software & Services, IT Consulting & Other Services, Data Processing & Outsourced Services, Application Software, Systems Software, Home Entertainment Software, Communications Equipment, Technology Hardware, Storage & Peripherals, Electronic Equipment & Instruments, Electronic Components, Electronic Manufacturing Services, Technology Distributors, Semiconductor Equipment, Semiconductors (14) |
| 50 | Telecommunication Services | 142 | Alternative Carriers, Integrated Telecommunication Services, Wireless Telecommunication Services (3) |
| 55 | Utilities | 185 | Electric Utilities, Gas Utilities, Multi-Utilities, Water Utilities, Independent Power Producers & Energy Traders, Renewable Electricity (6) |
| | All sectors | 7369 | (148) |

Table S.2. Total number and net number of observations by sector and country in 2007-2013

| | Sector | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | Total |
| | Total number of obs | | | | | | | | | | |
| Saudi Arabia | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Argentina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| Australia | 18 | 43 | 12 | 1 | 10 | 7 | 7 | 0 | 7 | 0 | 105 |
| Austria | 6 | 3 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| Belgium | 0 | 9 | 0 | 5 | 10 | 7 | 0 | 0 | 9 | 0 | 40 |
| Botswana | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Bosnia and Herzegovina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| Brazil | 10 | 36 | 17 | 12 | 19 | 1 | 6 | 6 | 8 | 47 | 162 |
| Colombia | 5 | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 5 | 16 |
| China | 8 | 33 | 70 | 17 | 19 | 16 | 3 | 6 | 4 | 20 | 196 |
| Chile | 0 | 10 | 4 | 0 | 5 | 0 | 0 | 0 | 0 | 18 | 37 |
| Canada | 36 | 42 | 10 | 9 | 1 | 0 | 0 | 1 | 6 | 11 | 116 |
| Czech | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Croatia | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Denmark | 0 | 18 | 14 | 7 | 8 | 28 | 0 | 0 | 0 | 0 | 75 |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Finland | 0 | 16 | 18 | 6 | 12 | 6 | 0 | 15 | 0 | 0 | 73 |
| France | 7 | 10 | 69 | 67 | 41 | 15 | 0 | 21 | 6 | 6 | 242 |
| Greece | 10 | 17 | 14 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 47 |
| Germany | 0 | 38 | 25 | 42 | 25 | 21 | 0 | 7 | 6 | 0 | 164 |
| Hungary | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 6 | 0 | 10 |
| Hong Kong | 7 | 9 | 23 | 1 | 0 | 3 | 15 | 6 | 0 | 7 | 71 |
| Ireland | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| Indonesia | 4 | 19 | 0 | 6 | 3 | 0 | 0 | 0 | 0 | 3 | 35 |
| Italy | 0 | 0 | 7 | 12 | 0 | 0 | 0 | 6 | 0 | 1 | 26 |
| India | 0 | 2 | 4 | 1 | 0 | 0 | 4 | 15 | 0 | 2 | 28 |
| Israel | 0 | 3 | 5 | 0 | 4 | 0 | 0 | 0 | 1 | 0 | 13 |
| Japan | 59 | 616 | 993 | 579 | 366 | 172 | 49 | 491 | 14 | 5 | 3344 |
| Kenya | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| Korea | 0 | 19 | 7 | 4 | 3 | 0 | 0 | 5 | 0 | 1 | 39 |
| United Kingdom | 37 | 96 | 154 | 144 | 57 | 29 | 77 | 37 | 11 | 18 | 660 |
| Malaysia | 0 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 7 |
| Mexico | 0 | 15 | 9 | 2 | 23 | 0 | 0 | 0 | 4 | 0 | 53 |
| Netherlands | 1 | 26 | 9 | 16 | 18 | 0 | 0 | 6 | 0 | 0 | 76 |
| Norway | 11 | 1 | 9 | 0 | 6 | 0 | 0 | 0 | 0 | 3 | 30 |
| New Zealand | 0 | 1 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 1 | 8 |
| Pakistan | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| Portugal | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 6 | 9 |
| Philippine | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 1 | 6 | 19 |
| Poland | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 15 |
| Russia | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Romania | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| South Africa | 9 | 62 | 25 | 26 | 26 | 11 | 0 | 0 | 7 | 0 | 166 |
| Sri Lanka | 0 | 0 | 10 | 0 | 7 | 0 | 0 | 0 | 5 | 0 | 22 |
| Spain | 0 | 0 | 2 | 7 | 0 | 1 | 0 | 0 | 0 | 0 | 10 |
| Singapore | 0 | 0 | 6 | 0 | 2 | 0 | 10 | 0 | 4 | 0 | 22 |
| Sweden | 1 | 6 | 74 | 32 | 24 | 4 | 4 | 9 | 11 | 0 | 165 |
| Slovenia | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 2 |
| Switzerland | 0 | 0 | 16 | 1 | 6 | 17 | 0 | 6 | 0 | 0 | 46 |
| Thailand | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Turkey | 0 | 7 | 4 | 8 | 9 | 0 | 0 | 0 | 2 | 1 | 31 |
| Taiwan | 0 | 5 | 11 | 15 | 5 | 0 | 0 | 83 | 9 | 0 | 128 |
| Abu Dhabi | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| United States | 88 | 118 | 115 | 102 | 154 | 105 | 12 | 198 | 16 | 15 | 923 |
| Virt-x (Switzerland/UK) | 0 | 25 | 12 | 6 | 7 | 22 | 0 | 0 | 0 | 0 | 72 |
| Total | 339 | 1334 | 1764 | 1141 | 881 | 466 | 199 | 918 | 142 | 185 | 7369 |
| | Net number of obs | | | | | | | | | | |
| Saudi Arabia | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Argentina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Australia | 4 | 14 | 5 | 1 | 3 | 1 | 2 | 0 | 1 | 0 | 31 |
| Austria | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Belgium | 0 | 2 | 0 | 1 | 2 | 1 | 0 | 0 | 2 | 0 | 8 |
| Botswana | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Bosnia and Herzegovina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Brazil | 2 | 12 | 7 | 5 | 5 | 1 | 3 | 2 | 3 | 22 | 62 |
| Colombia | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 4 |
| China | 4 | 20 | 32 | 6 | 6 | 8 | 2 | 5 | 1 | 6 | 90 |
| Chile | 0 | 3 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 10 |
| Canada | 13 | 15 | 5 | 3 | 1 | 0 | 0 | 1 | 3 | 4 | 45 |
| Czech | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Croatia | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Denmark | 0 | 3 | 3 | 2 | 2 | 5 | 0 | 0 | 0 | 0 | 15 |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Finland | 0 | 4 | 4 | 1 | 2 | 1 | 0 | 3 | 0 | 0 | 15 |
| France | 2 | 2 | 12 | 13 | 8 | 3 | 0 | 7 | 1 | 1 | 49 |
| Greece | 2 | 5 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| Germany | 0 | 8 | 7 | 9 | 4 | 4 | 0 | 2 | 1 | 0 | 35 |
| Hungary | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 3 |
| Hong Kong | 2 | 5 | 9 | 1 | 0 | 1 | 6 | 1 | 0 | 2 | 27 |
| Ireland | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Indonesia | 1 | 5 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 9 |
| Italy | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 5 |
| India | 0 | 1 | 2 | 1 | 0 | 0 | 2 | 5 | 0 | 1 | 12 |
| Israel | 0 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 5 |
| Japan | 10 | 110 | 187 | 112 | 65 | 31 | 8 | 92 | 2 | 5 | 622 |
| Kenya | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Korea | 0 | 4 | 3 | 2 | 1 | 0 | 0 | 3 | 0 | 1 | 14 |
| United Kingdom | 8 | 23 | 35 | 32 | 14 | 6 | 17 | 10 | 4 | 3 | 152 |
| Malaysia | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| Mexico | 0 | 5 | 4 | 1 | 7 | 0 | 0 | 0 | 2 | 0 | 19 |
| Netherlands | 1 | 6 | 2 | 4 | 3 | 0 | 0 | 1 | 0 | 0 | 17 |
| Norway | 2 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 7 |
| New Zealand | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 4 |
| Pakistan | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Portugal | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 |
| Philippine | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 2 | 7 |
| Poland | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 |
| Russia | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Romania | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| South Africa | 2 | 17 | 8 | 9 | 6 | 3 | 0 | 0 | 2 | 0 | 47 |
| Sri Lanka | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 5 |
| Spain | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 3 |
| Singapore | 0 | 0 | 2 | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 6 |
| Sweden | 1 | 1 | 13 | 8 | 5 | 2 | 1 | 2 | 2 | 0 | 35 |
| Slovenia | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 2 |
| Switzerland | 0 | 0 | 3 | 1 | 2 | 4 | 0 | 1 | 0 | 0 | 11 |
| Thailand | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Turkey | 0 | 2 | 2 | 2 | 2 | 0 | 0 | 0 | 1 | 1 | 10 |
| Taiwan | 0 | 2 | 3 | 4 | 2 | 0 | 0 | 25 | 3 | 0 | 39 |
| Abu Dhabi | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| United States | 24 | 32 | 40 | 36 | 37 | 28 | 4 | 55 | 4 | 12 | 272 |
| Virt-x (Switzerland/UK) | 0 | 4 | 3 | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 13 |
| Total | 86 | 318 | 408 | 265 | 190 | 105 | 51 | 216 | 40 | 74 | 1753 |

Table S.3. The number of observations in each model

| | Undesirable input $b^{in}$ | | | | Undesirable output $b^{out}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Sector | Energy Cons. | Electricity use | Water use | Paper cons. | Scope 1 | Scope 1+2 | Scope 1+2+3 | SOx | NOx | VOC |
| 10 | 241 | 145 | 169 | 14 | 187 | 162 | 48 | 126 | 197 | 127 |
| 15 | 1,152 | 740 | 992 | 38 | 351 | 333 | 104 | 541 | 747 | 248 |
| 20 | 1,475 | 1,309 | 1,263 | 251 | 408 | 398 | 213 | 312 | 442 | 186 |
| 25 | 898 | 766 | 793 | 199 | 349 | 329 | 191 | 184 | 254 | 119 |
| 30 | 747 | 640 | 693 | 83 | 283 | 277 | 118 | 184 | 248 | 21 |
| 35 | 434 | 348 | 403 | 40 | 145 | 144 | 72 | 144 | 205 | 114 |
| 40 | 149 | 115 | 145 | 26 | 92 | 92 | 37 | 1 | 11 | 4 |
| 45 | 714 | 744 | 710 | 142 | 311 | 309 | 173 | 189 | 254 | 65 |
| 50 | 118 | 120 | 97 | 58 | 70 | 71 | 50 | 0 | 1 | 0 |
| 55 | 131 | 79 | 112 | 15 | 71 | 66 | 43 | 21 | 100 | 6 |
| All | 6,059 | 5,006 | 5,377 | 866 | 2,267 | 2,181 | 1,049 | 1,702 | 2,459 | 890 |

Table S.4. Descriptive statistics by sector

| Sector | Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| 10 | Gross profit | 339 | 8,960,000,000 | 16,700,000,000 | 10,800,000 | 84,000,000,000 |
| 10 | Labor | 339 | 20,173 | 27,127 | 18 | 118,000 |
| 10 | Capital stock | 339 | 29,300,000,000 | 49,900,000,000 | 17,600,000 | 276,000,000,000 |
| 10 | Energy cons. | 241 | 50,491 | 90,658 | 6.2 | 430,556 |
| 10 | Electricity use | 145 | 1,463,979 | 2,626,808 | 904.7 | 10,400,000 |
| 10 | Water use | 169 | 128,043 | 293,021 | 20.1 | 1,370,400 |
| 10 | Paper cons. | 14 | 1 | 1 | 0.1 | 2 |
| 10 | Scope 1 | 187 | 20,700,000 | 30,900,000 | 3,064.0 | 141,000,000 |
| 10 | Scope 1+2 | 162 | 21,700,000,000 | 32,700,000,000 | 25,700,000.0 | 150,000,000,000 |
| 10 | Scope 1+2+3 | 48 | 200,000,000,000 | 285,000,000,000 | 30,300,000.0 | 775,000,000,000 |
| 10 | SOx | 126 | 40,562 | 62,898 | 1.0 | 241,000 |
| 10 | NOx | 197 | 51,065 | 75,724 | 10.0 | 468,000 |
| 10 | VOC | 127 | 51 | 81 | 0.1 | 310 |
| 15 | Gross profit | 1,334 | 1,630,000,000 | 3,010,000,000 | 2,155,520 | 35,700,000,000 |
| 15 | Labor | 1,334 | 15,255 | 27,665 | 9 | 315,867 |
| 15 | Capital stock | 1,334 | 4,720,000,000 | 9,230,000,000 | 1,582,198 | 79,900,000,000 |
| 15 | Energy cons. | 1,152 | 17,074 | 48,445 | 0.5 | 712,500 |
| 15 | Electricity use | 740 | 2,936,481 | 11,300,000 | 119.0 | 251,000,000 |
| 15 | Water use | 992 | 206,653 | 601,270 | 6.8 | 5,839,923 |
| 15 | Paper cons. | 38 | 1,626 | 5,193 | 0.1 | 24,000 |
| 15 | Scope 1 | 351 | 6,679,200 | 17,800,000 | 6,908.0 | 203,000,000 |
| 15 | Scope 1+2 | 333 | 9,710,000,000 | 21,500,000,000 | 12,100,000.0 | 227,000,000,000 |
| 15 | Scope 1+2+3 | 104 | 26,900,000,000 | 62,300,000,000 | 18,100,000.0 | 326,000,000,000 |
| 15 | SOx | 541 | 48,454 | 355,262 | 0.1 | 3,189,997 |
| 15 | NOx | 747 | 99,899 | 900,013 | 0.5 | 11,200,000 |
| 15 | VOC | 248 | 38 | 540 | 0.1 | 8,500 |
| 20 | Gross profit | 1,764 | 1,900,000,000 | 4,610,000,000 | 2,003,072 | 69,700,000,000 |
| 20 | Labor | 1,764 | 27,838 | 60,122 | 22 | 648,254 |
| 20 | Capital stock | 1,764 | 3,230,000,000 | 8,220,000,000 | 2,377,873 | 95,000,000,000 |
| 20 | Energy cons. | 1,475 | 3,178 | 9,915 | 0.2 | 75,512 |
| 20 | Electricity use | 1,309 | 450,474 | 1,329,287 | 0.7 | 13,900,000 |
| 20 | Water use | 1,263 | 9,392 | 65,940 | 3.7 | 1,163,000 |
| 20 | Paper cons. | 251 | 85 | 537 | 0.1 | 6,835 |
| 20 | Scope 1 | 408 | 1,092,675 | 3,368,441 | 7.0 | 25,500,000 |
| 20 | Scope 1+2 | 398 | 1,370,000,000 | 3,680,000,000 | 1,627,200.0 | 25,600,000,000 |
| 20 | Scope 1+2+3 | 213 | 1,560,000,000 | 3,720,000,000 | 9,250,000.0 | 22,500,000,000 |
| 20 | SOx | 312 | 21,698 | 76,783 | 0.1 | 519,000 |
| 20 | NOx | 442 | 23,019 | 86,258 | 0.1 | 561,049 |
| 20 | VOC | 186 | 2 | 5 | 0.1 | 41 |
| 25 | Gross profit | 1,141 | 3,720,000,000 | 6,250,000,000 | 20,300,000 | 45,000,000,000 |
| 25 | Labor | 1,141 | 42,647 | 73,355 | 122 | 549,763 |
| 25 | Capital stock | 1,141 | 5,660,000,000 | 13,500,000,000 | 241,694 | 125,000,000,000 |
| 25 | Energy cons. | 898 | 2,608 | 8,702 | 1.1 | 115,376 |
| 25 | Electricity use | 766 | 1,136,203 | 11,200,000 | 79.3 | 222,000,000 |
| 25 | Water use | 793 | 19,945 | 181,033 | 0.6 | 3,026,185 |
| 25 | Paper cons. | 199 | 24 | 52 | 0.1 | 300 |
| 25 | Scope 1 | 349 | 193,749 | 479,453 | 87.0 | 6,876,984 |
| 25 | Scope 1+2 | 329 | 647,000,000 | 1,120,000,000 | 302,000.0 | 7,990,000,000 |
| 25 | Scope 1+2+3 | 191 | 1,510,000,000 | 4,370,000,000 | 1,316,000.0 | 33,900,000,000 |
| 25 | SOx | 184 | 1,715 | 7,980 | 0.1 | 59,735 |
| 25 | NOx | 254 | 9,922 | 49,033 | 0.1 | 361,220 |
| 25 | VOC | 119 | 4 | 7 | 0.1 | 35 |
| 30 | Gross profit | 881 | 4,700,000,000 | 7,800,000,000 | 6,962,204 | 53,100,000,000 |
| 30 | Labor | 881 | 42,110 | 74,837 | 106 | 495,287 |
| 30 | Capital stock | 881 | 3,850,000,000 | 6,500,000,000 | 7,270,000 | 49,200,000,000 |
| 30 | Energy cons. | 747 | 3,287 | 6,947 | 0.6 | 76,854 |
| 30 | Electricity use | 640 | 1,018,291 | 2,472,756 | 86.8 | 22,600,000 |
| 30 | Water use | 693 | 17,334 | 40,338 | 2.1 | 313,000 |
| 30 | Paper cons. | 83 | 37 | 64 | 0.1 | 271 |
| 30 | Scope 1 | 283 | 712,211 | 955,155 | 38.0 | 4,130,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 30 | Scope 1+2 | 277 | 1,590,000,000 | 1,960,000,000 | 147,000.0 | 7,800,000,000 |
| 30 | Scope 1+2+3 | 118 | 2,900,000,000 | 5,700,000,000 | 9,300,000.0 | 29,800,000,000 |
| 30 | SOx | 184 | 1,058 | 3,220 | 0.1 | 21,400 |
| 30 | NOx | 248 | 801 | 1,484 | 0.1 | 7,087 |
| 30 | VOC | 21 | 0.2 | 0.1 | 0.1 | 1 |
| 35 | Gross profit | 466 | 6,470,000,000 | 10,100,000,000 | 31,000,000 | 53,200,000,000 |
| 35 | Labor | 466 | 23,696 | 32,411 | 498 | 178,337 |
| 35 | Capital stock | 466 | 3,570,000,000 | 5,620,000,000 | 42,600,000 | 25,200,000,000 |
| 35 | Energy cons. | 434 | 1,403 | 3,367 | 1.8 | 32,622 |
| 35 | Electricity use | 348 | 498,161 | 1,052,162 | 882.8 | 7,273,056 |
| 35 | Water use | 403 | 14,563 | 53,979 | 2.9 | 474,000 |
| 35 | Paper cons. | 40 | 63 | 213 | 0.1 | 802 |
| 35 | Scope 1 | 145 | 445,369 | 959,841 | 547.0 | 5,590,000 |
| 35 | Scope 1+2 | 144 | 907,000,000 | 1,730,000,000 | 3,046,000.0 | 9,300,000,000 |
| 35 | Scope 1+2+3 | 72 | 1,120,000,000 | 1,170,000,000 | 15,200,000.0 | 4,700,000,000 |
| 35 | SOx | 144 | 253 | 679 | 0.1 | 3,600 |
| 35 | NOx | 205 | 274 | 635 | 0.2 | 4,000 |
| 35 | VOC | 114 | 1 | 1 | 0.1 | 5 |
| 40 | Gross profit | 199 | 925,000,000 | 1,050,000,000 | 795,165 | 5,030,000,000 |
| 40 | Labor | 199 | 9,750 | 19,642 | 2 | 125,000 |
| 40 | Capital stock | 199 | 6,430,000,000 | 7,600,000,000 | 1,357,376 | 30,000,000,000 |
| 40 | Energy cons. | 149 | 4,310 | 13,322 | 0.1 | 68,609 |
| 40 | Electricity use | 115 | 384,208 | 570,955 | 76.1 | 3,339,252 |
| 40 | Water use | 145 | 5,584 | 25,033 | 2.5 | 213,371 |
| 40 | Paper cons. | 26 | 1 | 0.4 | 0.1 | 1 |
| 40 | Scope 1 | 92 | 1,061,766 | 3,809,192 | 1.8 | 16,400,000 |
| 40 | Scope 1+2 | 92 | 1,170,000,000 | 3,920,000,000 | 396,000.0 | 16,900,000,000 |
| 40 | Scope 1+2+3 | 37 | 78,500,000 | 102,000,000 | 536,500.0 | 306,000,000 |
| 40 | SOx | 1 | 3,963 | . | 3,963.4 | 3,963 |
| 40 | NOx | 11 | 1,246 | 2,169 | 0.8 | 7,346 |
| 40 | VOC | 4 | 2 | 3 | 0.3 | 7 |
| 45 | Gross profit | 918 | 3,440,000,000 | 7,640,000,000 | 1,817,664 | 69,200,000,000 |
| 45 | Labor | 918 | 35,234 | 62,564 | 349 | 434,246 |
| 45 | Capital stock | 918 | 2,800,000,000 | 6,560,000,000 | 1,011,812 | 91,600,000,000 |
| 45 | Energy cons. | 714 | 7,057 | 147,328 | 0.5 | 3,936,340 |
| 45 | Electricity use | 744 | 640,611 | 1,311,795 | 169.9 | 15,000,000 |
| 45 | Water use | 710 | 8,566 | 27,793 | 0.2 | 280,027 |
| 45 | Paper cons. | 142 | 14 | 47 | 0.1 | 320 |
| 45 | Scope 1 | 311 | 147,324 | 403,417 | 3.7 | 4,045,000 |
| 45 | Scope 1+2 | 309 | 576,000,000 | 1,130,000,000 | 1,465,300.0 | 11,300,000,000 |
| 45 | Scope 1+2+3 | 173 | 1,690,000,000 | 6,930,000,000 | 2,876,500.0 | 78,700,000,000 |
| 45 | SOx | 189 | 143 | 338 | 0.1 | 2,300 |
| 45 | NOx | 254 | 682 | 2,422 | 0.1 | 16,550 |
| 45 | VOC | 65 | 0.4 | 0.4 | 0.1 | 2 |
| 50 | Gross profit | 142 | 17,100,000,000 | 21,500,000,000 | 121,000,000 | 77,500,000,000 |
| 50 | Labor | 142 | 63,978 | 83,560 | 1,244 | 281,000 |
| 50 | Capital stock | 142 | 35,500,000,000 | 49,500,000,000 | 573,000,000 | 234,000,000,000 |
| 50 | Energy cons. | 118 | 3,037 | 6,870 | 17.9 | 66,775 |
| 50 | Electricity use | 120 | 2,592,257 | 3,678,631 | 7.9 | 14,600,000 |
| 50 | Water use | 97 | 2,980 | 5,526 | 34.7 | 26,390 |
| 50 | Paper cons. | 58 | 84 | 517 | 0.1 | 3,948 |
| 50 | Scope 1 | 70 | 135,994 | 269,585 | 620.0 | 1,170,232 |
| 50 | Scope 1+2 | 71 | 1,040,000,000 | 2,130,000,000 | 2,650,000.0 | 9,080,000,000 |
| 50 | Scope 1+2+3 | 50 | 1,130,000,000 | 2,500,000,000 | 4,310,000.0 | 9,140,000,000 |
| 50 | SOx | 0 | | | | |
| 50 | NOx | 1 | 3,290 | . | 3,290.0 | 3,290 |
| 50 | VOC | 0 | | | | |
| 55 | Gross profit | 185 | 2,480,000,000 | 2,920,000,000 | 39,100,000 | 17,500,000,000 |
| 55 | Labor | 185 | 17,981 | 50,965 | 40 | 336,013 |
| 55 | Capital stock | 185 | 9,160,000,000 | 10,300,000,000 | 15,800,000 | 76,800,000,000 |
| 55 | Energy cons. | 131 | 61,729 | 91,786 | 0.5 | 610,841 |
| 55 | Electricity use | 79 | 4,808,531 | 26,200,000 | 20.6 | 229,000,000 |
| 55 | Water use | 112 | 1,180,556 | 3,830,388 | 12.2 | 36,500,000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 55 | Paper cons. | 15 | 0.4 | 0.3 | 0.1 | 1 |
| 55 | Scope 1 | 71 | 11,600,000 | 16,400,000 | 1,634.4 | 60,000,000 |
| 55 | Scope 1+2 | 66 | 12,600,000,000 | 17,700,000,000 | 2,614,800.0 | 60,200,000,000 |
| 55 | Scope 1+2+3 | 43 | 15,400,000,000 | 19,300,000,000 | 3,352,000.0 | 60,200,000,000 |
| 55 | SOx | 21 | 29,668 | 38,775 | 1.1 | 121,239 |
| 55 | NOx | 100 | 22,175 | 30,558 | 1.9 | 246,562 |
| 55 | VOC | 6 | 0.3 | 0.3 | 0.1 | 1 |

Notes:

Gross profit denotes sales minus cost of goods sold (U.S. dollars at nominal price). Labor denotes the number of employees (persons). Capital stock is estimated by benchmark year method where bench mark year is 2005. Unit of energy consumption and electricity use is megawatt hour (MWh). Unit of water use is cubic meter. Units of paper consumption, scope 1/1+2/1+2+3, SOx, NOx, and VOC are metric ton. EEPol, EQM, GBPol, SPack, ESCPol, WRPol, GHGini, and GHGPol denote dummy variables of ESG activities (see Supplementary material Table S.6). Table 1 shows descriptive statistics in all sectors.

Table S.5. Correlation table of all sectors

| | Gross profit | Labor | Capital stock | Energy cons. | Elec. use | Water use | Paper cons. | Scope 1 | Scope 1+2 | Scope 1+2+3 | SOx | NOx | VOC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gross profit | 1.000 | | | | | | | | | | | | |
| Labor | 0.617 | 1.000 | | | | | | | | | | | |
| Capital stock | 0.752 | 0.415 | 1.000 | | | | | | | | | | |
| Energy cons. | 0.180 | 0.113 | 0.309 | 1.000 | | | | | | | | | |
| Elec. use | 0.150 | 0.149 | 0.176 | 0.162 | 1.000 | | | | | | | | |
| Water use | 0.052 | 0.081 | 0.100 | 0.174 | 0.248 | 1.000 | | | | | | | |
| Paper cons. | -0.019 | -0.011 | -0.009 | -0.010 | 0.048 | 0.112 | 1.000 | | | | | | |
| Scope 1 | 0.437 | 0.114 | 0.681 | 0.959 | 0.437 | 0.412 | -0.026 | 1.000 | | | | | |
| Scope 1+2 | 0.402 | 0.144 | 0.661 | 0.959 | 0.578 | 0.410 | -0.006 | 0.992 | 1.000 | | | | |
| Scope 1+2+3 | 0.565 | 0.077 | 0.805 | 0.702 | 0.410 | 0.586 | 0.092 | 0.701 | 0.708 | 1.000 | | | |
| SOx | 0.051 | 0.031 | 0.148 | 0.037 | 0.036 | 0.554 | -0.042 | 0.632 | 0.581 | 0.502 | 1.000 | | |
| NOx | 0.031 | 0.035 | 0.098 | 0.029 | 0.032 | 0.213 | -0.021 | 0.724 | 0.688 | 0.856 | 0.953 | 1.000 | |
| VOC | 0.051 | -0.010 | 0.087 | 0.784 | 0.093 | 0.001 | 0.953 | 0.828 | 0.778 | 0.947 | 0.717 | 0.762 | 1.000 |

Table S.6. Description of variable for the second step

| Long name | Name | Description |
|---|---|---|
| **For energy use** | | |
| Energy efficiency policy | EEPol | Indicates whether the company has implemented any initiatives to make its use of energy more efficient. |
| **For environmental quality** | | |
| Env. quality management | EQM | Indicates whether the company has introduced any kind of environmental quality management and/or environmental management system to help reduce the environmental footprint of its operations. |
| Green building policy | GBPol | Indicates whether the company has taken any steps towards using environmental technologies and/or environmental principles in the design and construction of its buildings. |
| Sustainable packaging | SPack | Indicates whether the company has taken any steps to make its packaging more environmentally friendly. This might include efforts to improve the recyclability of packaging, to use less environmentally damaging materials in packaging etc. |
| Env. supply chain policy | EnvSCPol | Indicates whether the company has implemented any initiatives to reduce the environmental footprint of its supply chain. Environmental footprint reductions could be achieved by reducing waste, by reducing resource use, by reducing environmental emissions, by insisting on the introduction of environmental management systems etc. in the supply chain. |
| Waste reduction policy | WastePol | Indicates whether the company has implemented any initiatives to reduce the waste generated during the course of its operations. |
| **For GHG emissions** | | |
| GHG reduction initiatives | GHGIni | Indicates whether the company has implemented any initiatives to reduce its environmental emissions to air. |
| GHG reduction policy | GHGPol | Indicates whether the company has outlined its intention to help reduce global emissions of the GHGs that cause climate change through its ongoing operations and/or the use of its products and services. Examples might include efforts to reduce GHG emissions, efforts to improve energy efficiency, efforts to derive energy from cleaner fuel sources, investment in product development to reduce emissions generated or energy consumed in the use of the company's products etc. |

Table S.7. Result of coefficient in parametric LP specification

| | (1) Energy consumption | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1.1) | (1.2) | (1.3) | (1.4) | (1.5) | (1.6) | (1.7) | (1.8) | (1.9) | (1.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 8.59E+07 | 5.52E+07 | 7.63E+07 | 6.67E+07 | 9.32E+07 | 7.93E+07 | 8.54E+06 | 8.37E+07 | 7.77E+07 | 2.23E+07 |
| Constant ($\alpha$) | 2.16E+04 | −1.36E+01 | −1.30E+01 | 3.44E+00 | −5.85E−01 | −2.18E+02 | −3.69E+00 | −4.38E+00 | 1.35E+04 | 2.23E+03 |
| $\alpha_1$ | 2.65E−01 | −2.02E−02 | 3.41E−02 | 8.40E−04 | 1.28E−03 | 3.35E−01 | 4.84E−01 | 3.34E−03 | −1.70E−01 | −2.68E−01 |
| $\alpha_2$ | 4.05E−06 | 3.38E−07 | 4.17E−07 | 5.97E−08 | −1.48E−09 | 2.38E−06 | 4.90E−07 | 1.71E−07 | 1.07E−05 | −1.42E−07 |
| $\beta_1$ | −1.35E−05 | −4.19E−09 | 3.98E−09 | −4.34E−08 | −1.90E−09 | −2.10E−06 | −1.51E−06 | −1.24E−08 | −1.68E−05 | 2.59E−07 |
| $\gamma_1$ | 9.86E−01 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 9.98E−01 | 9.98E−01 | 1.00E+00 | 9.83E−01 | 1.00E+00 |
| $\alpha_{11}$ | −3.40E−05 | 8.85E−08 | −1.82E−07 | −4.97E−08 | −2.27E−08 | −2.76E−05 | −8.35E−06 | −7.14E−08 | −6.42E−05 | −3.17E−05 |
| $\alpha_{12}$ | 6.61E−11 | 4.96E−13 | 1.99E−11 | 5.08E−14 | 4.54E−13 | 1.46E−10 | 1.39E−11 | 1.64E−12 | 1.09E−10 | 3.19E−10 |
| $\alpha_{21}$ | 6.61E−11 | 4.96E−13 | 1.99E−11 | 5.08E−14 | 4.54E−13 | 1.46E−10 | 1.39E−11 | 1.64E−12 | 1.09E−10 | 3.19E−10 |
| $\alpha_{22}$ | −1.14E−16 | −7.87E−18 | −8.90E−18 | 1.23E−18 | −6.92E−18 | −1.27E−15 | −7.51E−18 | −1.39E−17 | −3.52E−16 | −9.28E−17 |
| $\beta_{11}$ | −1.52E−15 | −2.08E−16 | −1.38E−16 | −7.38E−18 | −6.79E−18 | −6.24E−16 | 4.17E−16 | −1.86E−17 | −2.63E−16 | −8.09E−15 |
| $\gamma_{11}$ | −1.52E−09 | −2.08E−10 | −1.38E−10 | −7.38E−12 | −6.79E−12 | −6.24E−10 | 4.17E−10 | −1.86E−11 | −2.63E−10 | −8.09E−09 |
| $\varepsilon_{11}$ | 1.59E−10 | 2.65E−12 | 8.15E−13 | 8.06E−13 | −2.14E−13 | 7.05E−11 | 1.92E−11 | −2.80E−13 | 6.18E−11 | 1.98E−10 |
| $\varepsilon_{21}$ | 2.57E−16 | −3.13E−17 | −2.45E−16 | −6.99E−18 | 2.80E−18 | 2.50E−16 | −8.13E−16 | 1.83E−18 | 5.87E−17 | −1.97E−17 |
| $\eta_{11}$ | 1.59E−07 | 2.65E−09 | 8.15E−10 | 8.06E−10 | −2.14E−10 | 7.05E−08 | 1.92E−08 | −2.80E−10 | 6.18E−08 | 1.98E−07 |
| $\eta_{21}$ | 2.57E−13 | −3.13E−14 | −2.45E−13 | −6.99E−15 | 2.80E−15 | 2.50E−13 | −8.13E−13 | 1.83E−15 | 5.87E−14 | −1.97E−14 |
| $\rho_{11}$ | −1.52E−12 | −2.08E−13 | −1.38E−13 | −7.38E−15 | −6.79E−15 | −6.24E−13 | 4.17E−13 | −1.86E−14 | −2.63E−13 | −8.09E−12 |
| obs | 241 | 1152 | 1475 | 898 | 747 | 434 | 149 | 714 | 118 | 131 |
| | (2) Electricity use | | | | | | | | | |
| | (2.1) | (2.2) | (2.3) | (2.4) | (2.5) | (2.6) | (2.7) | (2.8) | (2.9) | (2.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 1.40E+08 | 8.43E+08 | 1.91E+08 | 1.94E+08 | 2.86E+08 | 9.67E+07 | 1.76E+07 | 1.35E+08 | 1.07E+08 | 5.60E+07 |
| Constant ($\alpha$) | 4.82E+04 | −3.52E+03 | −5.30E+02 | −2.90E+03 | −1.38E+03 | −1.01E+03 | −8.55E+02 | −5.86E+01 | 3.80E+04 | 4.86E+05 |
| $\alpha_1$ | 2.96E+01 | 4.72E+01 | 3.47E−01 | 1.84E+00 | 1.12E+01 | 1.92E+00 | 2.48E+01 | 1.33E−01 | 2.49E+01 | −1.47E+01 |
| $\alpha_2$ | 3.99E−05 | −1.85E−05 | 4.17E−06 | 4.66E−05 | −2.11E−05 | 2.20E−05 | 3.36E−07 | 1.53E−05 | −1.31E−05 | 3.91E−05 |
| $\beta_1$ | −2.64E−04 | −2.20E−04 | −1.01E−08 | −1.80E−07 | −1.33E−07 | −3.10E−05 | −1.20E−04 | −1.82E−05 | −8.26E−05 | −4.34E−04 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\gamma_{1}$ | 7.36E−01 | 7.80E−01 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 9.69E−01 | 8.80E−01 | 9.82E−01 | 9.17E−01 | 5.66E−01 |
| $\alpha_{11}$ | −7.30E−04 | −1.10E−03 | −1.50E−06 | −1.03E−05 | 2.79E−05 | −1.87E−04 | −1.18E−03 | −1.67E−06 | −2.34E−04 | −5.31E−04 |
| $\alpha_{12}$ | 1.08E−09 | 1.37E−09 | 2.70E−11 | −5.72E−11 | −3.62E−10 | 2.12E−09 | −1.67E−10 | 4.14E−11 | 2.55E−10 | 8.70E−09 |
| $\alpha_{21}$ | 1.08E−09 | 1.37E−09 | 2.70E−11 | −5.72E−11 | −3.62E−10 | 2.12E−09 | −1.67E−10 | 4.14E−11 | 2.55E−10 | 8.70E−09 |
| $\alpha_{22}$ | −2.26E−15 | 8.31E−15 | 3.00E−16 | −1.44E−15 | 3.11E−15 | −2.86E−14 | 1.05E−15 | −1.43E−15 | −3.14E−16 | −5.25E−15 |
| $\beta_{11}$ | −2.16E−14 | −6.10E−15 | −4.96E−15 | −8.76E−15 | −2.06E−15 | −6.07E−15 | −1.18E−13 | −1.57E−15 | −8.20E−16 | −4.95E−15 |
| $\gamma_{11}$ | −2.16E−08 | −6.10E−09 | −4.96E−09 | −8.76E−09 | −2.06E−09 | −6.07E−09 | −1.18E−07 | −1.57E−09 | −8.20E−10 | −4.95E−09 |
| $\varepsilon_{11}$ | −7.99E−10 | 1.13E−09 | 2.51E−11 | 6.98E−11 | −6.13E−10 | −2.74E−10 | 7.02E−09 | −3.42E−11 | −4.55E−10 | −1.04E−10 |
| $\varepsilon_{21}$ | 6.18E−15 | −1.06E−14 | −2.48E−15 | 1.24E−15 | 1.31E−15 | 8.98E−15 | −6.96E−15 | 9.34E−16 | 3.15E−16 | 1.13E−15 |
| $\eta_{11}$ | −7.99E−07 | 1.13E−06 | 2.51E−08 | 6.98E−08 | −6.13E−07 | −2.74E−07 | 7.02E−06 | −3.42E−08 | −4.55E−07 | −1.04E−07 |
| $\eta_{21}$ | 6.18E−12 | −1.06E−11 | −2.48E−12 | 1.24E−12 | 1.31E−12 | 8.98E−12 | −6.96E−12 | 9.34E−13 | 3.15E−13 | 1.13E−12 |
| $\rho_{11}$ | −2.16E−11 | −6.10E−12 | −4.96E−12 | −8.76E−12 | −2.06E−12 | −6.07E−12 | −1.18E−10 | −1.57E−12 | −8.20E−13 | −4.95E−12 |
| obs | 145 | 740 | 1309 | 766 | 640 | 348 | 115 | 744 | 120 | 79 |
| (3) Water use | | | | | | | | | | |
| | (3.1) | (3.2) | (3.3) | (3.4) | (3.5) | (3.6) | (3.7) | (3.8) | (3.9) | (3.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 3.70E+07 | 1.05E+08 | 4.01E+07 | 6.20E+07 | 9.69E+07 | 7.29E+07 | 7.92E+06 | 6.49E+07 | 8.40E+07 | 5.33E+07 |
| Constant ($\alpha$) | −1.88E+03 | −2.73E+02 | −9.51E+00 | −1.63E+01 | −2.96E+00 | 5.70E+02 | −8.75E+01 | 6.07E−01 | −2.72E+03 | 4.65E+04 |
| $\alpha_{1}$ | 1.18E+00 | 1.20E+00 | 1.68E−02 | 4.54E−02 | 3.25E−02 | 5.45E−01 | 3.48E−01 | −2.35E−04 | 2.70E+00 | −7.65E+00 |
| $\alpha_{2}$ | 1.19E−06 | 9.58E−07 | 1.39E−07 | −2.58E−08 | 3.26E−07 | 4.03E−06 | 4.62E−07 | 8.52E−08 | 1.51E−05 | −1.56E−05 |
| $\beta_{1}$ | −1.17E−06 | −7.72E−07 | −3.96E−08 | −2.48E−08 | −7.33E−08 | −3.96E−06 | −1.12E−06 | −9.63E−09 | −3.03E−05 | 8.01E−06 |
| $\gamma_{1}$ | 9.99E−01 | 9.99E−01 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 9.96E−01 | 9.99E−01 | 1.00E+00 | 9.70E−01 | 1.01E+00 |
| $\alpha_{11}$ | −3.49E−05 | −3.10E−05 | −4.61E−07 | −2.24E−07 | −9.02E−07 | −3.00E−05 | −6.05E−06 | 6.96E−09 | −1.02E−04 | −1.28E−04 |
| $\alpha_{12}$ | 3.85E−11 | 9.06E−11 | 5.83E−12 | 2.64E−13 | 1.39E−11 | 2.93E−10 | 1.07E−11 | 3.41E−13 | 1.13E−10 | 4.99E−09 |
| $\alpha_{21}$ | 3.85E−11 | 9.06E−11 | 5.83E−12 | 2.64E−13 | 1.39E−11 | 2.93E−10 | 1.07E−11 | 3.41E−13 | 1.13E−10 | 4.99E−09 |
| $\alpha_{22}$ | −4.67E−17 | −1.44E−16 | −2.66E−18 | −1.77E−18 | −1.63E−16 | −3.07E−15 | −1.48E−17 | −4.99E−18 | −3.71E−16 | −2.45E−15 |
| $\beta_{11}$ | −1.89E−15 | −5.17E−15 | −1.27E−17 | −9.02E−17 | −1.72E−16 | −6.66E−16 | 3.12E−16 | −1.03E−17 | −3.51E−16 | −4.24E−14 |
| $\gamma_{11}$ | −1.89E−09 | −5.17E−09 | −1.27E−11 | −9.02E−11 | −1.72E−10 | −6.66E−10 | 3.12E−10 | −1.03E−11 | −3.51E−10 | −4.24E−08 |
| $\varepsilon_{11}$ | 2.62E−11 | 2.60E−11 | 9.39E−13 | 7.98E−13 | −5.50E−13 | −8.59E−12 | 1.44E−11 | −3.06E−13 | 1.40E−10 | −2.04E−09 |
| $\varepsilon_{21}$ | 1.46E−16 | 4.85E−18 | −1.00E−16 | 5.08E−18 | 3.55E−17 | 8.38E−16 | −6.21E−16 | 1.65E−18 | 3.58E−17 | 3.11E−15 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\eta_{11}$ | 2.62E−08 | 2.60E−08 | 9.39E−10 | 7.98E−10 | −5.50E−10 | −8.59E−09 | 1.44E−08 | −3.06E−10 | 1.40E−07 | −2.04E−06 |
| $\eta_{21}$ | 1.46E−13 | 4.85E−15 | −1.00E−13 | 5.08E−15 | 3.55E−14 | 8.38E−13 | −6.21E−13 | 1.65E−15 | 3.58E−14 | 3.11E−12 |
| $\rho_{11}$ | −1.89E−12 | −5.17E−12 | −1.27E−14 | −9.02E−14 | −1.72E−13 | −6.66E−13 | 3.12E−13 | −1.03E−14 | −3.51E−13 | −4.24E−11 |
| obs | 169 | 992 | 1263 | 793 | 693 | 403 | 145 | 710 | 97 | 112 |
| (4) Paper consumption | | | | | | | | | | |
| | (4.1) | (4.2) | (4.3) | (4.4) | (4.5) | (4.6) | (4.7) | (4.8) | (4.9) | (4.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 3.38E+05 | 1.81E+06 | 1.36E+07 | 2.95E+07 | 2.15E+07 | 5.17E+06 | 9.07E+05 | 1.92E+07 | 4.21E+07 | 3.76E+05 |
| Constant ($\alpha$) | 3.82E+05 | 5.44E+04 | −6.00E+02 | −3.80E+02 | −6.62E+03 | 7.41E+04 | −4.32E+04 | −7.63E+02 | 3.97E+04 | 3.69E+05 |
| $\alpha_1$ | −3.24E+01 | −1.75E+01 | 1.23E+00 | 7.05E−01 | 1.54E+01 | −5.56E+01 | 5.29E+01 | 9.42E−01 | 2.74E+00 | −8.16E+00 |
| $\alpha_2$ | 8.51E−05 | −1.69E−05 | 1.38E−06 | 2.76E−06 | 8.84E−05 | 1.19E−04 | 5.89E−05 | 7.23E−06 | 1.90E−05 | −1.36E−04 |
| $\beta_1$ | −6.74E−04 | −3.86E−06 | 7.10E−08 | −4.48E−07 | −1.03E−04 | 1.91E−05 | −3.74E−04 | −1.65E−06 | −3.25E−05 | −2.37E−04 |
| $\gamma_1$ | 3.26E−01 | 9.96E−01 | 1.00E+00 | 1.00E+00 | 8.97E−01 | 1.02E+00 | 6.26E−01 | 9.98E−01 | 9.67E−01 | 7.63E−01 |
| $\alpha_{11}$ | 4.49E−03 | 1.59E−03 | 7.66E−06 | 1.89E−05 | 2.11E−04 | 4.29E−03 | −4.22E−03 | −8.83E−06 | −1.89E−04 | −3.94E−03 |
| $\alpha_{12}$ | 8.90E−09 | 2.13E−09 | 5.00E−11 | −2.26E−10 | −1.33E−09 | 3.24E−08 | 3.95E−09 | −4.22E−11 | −6.56E−10 | −1.18E−08 |
| $\alpha_{21}$ | 8.90E−09 | 2.13E−09 | 5.00E−11 | −2.26E−10 | −1.33E−09 | 3.24E−08 | 3.95E−09 | −4.22E−11 | −6.56E−10 | −1.18E−08 |
| $\alpha_{22}$ | 2.70E−14 | −4.62E−15 | −3.21E−16 | 1.51E−15 | −4.65E−15 | −1.99E−13 | −7.32E−16 | −2.60E−15 | 3.73E−16 | 3.78E−14 |
| $\beta_{11}$ | 1.24E−12 | 1.68E−15 | −3.02E−15 | −3.46E−15 | −2.85E−14 | −4.65E−14 | 2.61E−14 | −7.24E−15 | −7.58E−15 | −2.89E−13 |
| $\gamma_{11}$ | 1.24E−06 | 1.68E−09 | −3.02E−09 | −3.46E−09 | −2.85E−08 | −4.65E−08 | 2.61E−08 | −7.24E−09 | −7.58E−09 | −2.89E−07 |
| $\varepsilon_{11}$ | −4.50E−08 | −1.27E−09 | −5.61E−10 | 1.79E−10 | −2.42E−09 | 1.60E−09 | 1.40E−08 | −1.76E−11 | 1.24E−09 | 4.06E−08 |
| $\varepsilon_{21}$ | −2.00E−13 | 2.93E−15 | 7.37E−16 | −6.71E−16 | 3.35E−14 | 3.18E−15 | −4.67E−14 | 1.95E−15 | 1.36E−15 | 1.82E−14 |
| $\eta_{11}$ | −4.50E−05 | −1.27E−06 | −5.61E−07 | 1.79E−07 | −2.42E−06 | 1.60E−06 | 1.40E−05 | −1.76E−08 | 1.24E−06 | 4.06E−05 |
| $\eta_{21}$ | −2.00E−10 | 2.93E−12 | 7.37E−13 | −6.71E−13 | 3.35E−11 | 3.18E−12 | −4.67E−11 | 1.95E−12 | 1.36E−12 | 1.82E−11 |
| $\rho_{11}$ | 1.24E−09 | 1.68E−12 | −3.02E−12 | −3.46E−12 | −2.85E−11 | −4.65E−11 | 2.61E−11 | −7.24E−12 | −7.58E−12 | −2.89E−10 |
| obs | 14 | 38 | 251 | 199 | 83 | 40 | 26 | 142 | 58 | 15 |
| (5) Scope 1 | | | | | | | | | | |
| | (5.1) | (5.2) | (5.3) | (5.4) | (5.5) | (5.6) | (5.7) | (5.8) | (5.9) | (5.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 9.09E+08 | 7.20E+08 | 2.54E+08 | 4.29E+07 | 1.25E+08 | 6.71E+07 | 1.19E+07 | 9.74E+07 | 4.36E+07 | 1.02E+08 |
| Constant ($\alpha$) | −4.87E+04 | −3.80E+04 | 1.01E+03 | 3.82E+02 | 3.49E+02 | −1.14E+02 | 4.30E+04 | −3.27E+02 | −1.70E+04 | 6.27E+05 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\alpha_1$ | 1.14E+01 | 1.87E+02 | 2.33E+00 | 2.64E−01 | 8.42E−01 | 9.00E−01 | 1.50E+01 | 7.18E−02 | 7.58E−01 | −2.38E+01 |
| $\alpha_2$ | −1.44E−06 | 1.44E−04 | 5.14E−06 | 1.51E−06 | 6.89E−06 | 4.69E−06 | −1.23E−05 | 1.06E−06 | 3.50E−05 | −2.04E−05 |
| $\beta_1$ | −5.85E−05 | −7.45E−04 | −1.84E−05 | −2.64E−06 | −7.93E−06 | −5.10E−06 | 2.44E−06 | −3.41E−07 | −3.45E−05 | −3.75E−04 |
| $\gamma_1$ | 9.42E−01 | 2.55E−01 | 9.82E−01 | 9.97E−01 | 9.92E−01 | 9.95E−01 | 1.00E+00 | 1.00E+00 | 9.66E−01 | 6.25E−01 |
| $\alpha_{11}$ | −3.78E−04 | −4.87E−03 | −9.78E−06 | −3.42E−06 | 3.06E−08 | −9.39E−05 | −5.97E−04 | −1.08E−06 | −1.23E−03 | −1.42E−03 |
| $\alpha_{12}$ | 2.12E−09 | −2.11E−10 | 6.03E−10 | −9.05E−12 | 1.31E−10 | 2.53E−10 | 1.76E−09 | 2.28E−11 | 1.22E−09 | 5.27E−09 |
| $\alpha_{21}$ | 2.12E−09 | −2.11E−10 | 6.03E−10 | −9.05E−12 | 1.31E−10 | 2.53E−10 | 1.76E−09 | 2.28E−11 | 1.22E−09 | 5.27E−09 |
| $\alpha_{22}$ | −2.96E−15 | 1.64E−15 | −2.47E−15 | −3.69E−17 | −2.92E−15 | −3.22E−15 | 1.84E−15 | −2.28E−16 | −5.45E−16 | 9.57E−16 |
| $\beta_{11}$ | −5.22E−15 | −1.17E−14 | −6.10E−15 | −6.06E−16 | −3.51E−15 | −3.33E−15 | −6.48E−14 | −7.33E−17 | −1.33E−14 | −1.60E−14 |
| $\gamma_{11}$ | −5.22E−09 | −1.17E−08 | −6.10E−09 | −6.06E−10 | −3.51E−09 | −3.33E−09 | −6.48E−08 | −7.33E−11 | −1.33E−08 | −1.60E−08 |
| $\varepsilon_{11}$ | −4.99E−09 | 6.69E−09 | 6.71E−11 | 3.91E−11 | −2.22E−11 | 1.65E−10 | −1.45E−09 | −1.04E−11 | 3.00E−09 | 3.86E−09 |
| $\varepsilon_{21}$ | 2.86E−15 | −2.47E−15 | −5.85E−15 | 3.66E−17 | 9.36E−16 | 1.94E−15 | −1.06E−14 | 3.34E−17 | −2.65E−15 | −6.39E−15 |
| $\eta_{11}$ | −4.99E−06 | 6.69E−06 | 6.71E−08 | 3.91E−08 | −2.22E−08 | 1.65E−07 | −1.45E−06 | −1.04E−08 | 3.00E−06 | 3.86E−06 |
| $\eta_{21}$ | 2.86E−12 | −2.47E−12 | −5.85E−12 | 3.66E−14 | 9.36E−13 | 1.94E−12 | −1.06E−11 | 3.34E−14 | −2.65E−12 | −6.39E−12 |
| $\rho_{11}$ | −5.22E−12 | −1.17E−11 | −6.10E−12 | −6.06E−13 | −3.51E−12 | −3.33E−12 | −6.48E−11 | −7.33E−14 | −1.33E−11 | −1.60E−11 |
| obs | 187 | 351 | 408 | 349 | 283 | 145 | 92 | 311 | 70 | 71 |
| | | | | | (6) Scope 1+2 | | | | | |
| | (6.1) | (6.2) | (6.3) | (6.4) | (6.5) | (6.6) | (6.7) | (6.8) | (6.9) | (6.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 8.66E+08 | 7.69E+08 | 2.56E+08 | 7.88E+07 | 1.62E+08 | 7.82E+07 | 1.24E+07 | 1.22E+08 | 4.60E+07 | 1.06E+08 |
| Constant ($\alpha$) | −3.49E+04 | −9.96E+04 | 9.68E+03 | 5.51E+02 | 4.89E+03 | 8.16E+02 | 2.18E+04 | 1.53E+04 | −1.60E+04 | 6.58E+05 |
| $\alpha_1$ | 7.27E+00 | 2.00E+02 | 6.18E−01 | 8.88E−01 | 2.03E+00 | 1.93E+00 | 6.96E+00 | 4.87E−01 | 7.06E+00 | −1.83E+00 |
| $\alpha_2$ | 1.96E−04 | 9.13E−05 | 2.40E−06 | 4.14E−07 | 2.58E−06 | 8.88E−05 | −8.92E−06 | 9.30E−06 | 1.01E−05 | −1.31E−04 |
| $\beta_1$ | −3.49E−04 | −7.31E−04 | −1.46E−05 | −1.32E−05 | −1.93E−05 | −4.54E−05 | 2.16E−06 | −1.45E−05 | −3.38E−05 | −3.04E−04 |
| $\gamma_1$ | 6.51E−01 | 2.69E−01 | 9.85E−01 | 9.87E−01 | 9.81E−01 | 9.55E−01 | 1.00E+00 | 9.85E−01 | 9.66E−01 | 6.96E−01 |
| $\alpha_{11}$ | 6.40E−04 | −5.95E−03 | −5.30E−06 | −1.35E−05 | −2.49E−05 | −4.99E−04 | −2.20E−04 | −7.32E−06 | −1.24E−03 | −4.08E−04 |
| $\alpha_{12}$ | −4.46E−09 | 2.74E−10 | 7.21E−10 | 1.24E−11 | 1.81E−10 | −1.31E−09 | 2.23E−10 | 2.55E−10 | 1.05E−09 | 1.09E−08 |
| $\alpha_{21}$ | −4.46E−09 | 2.74E−10 | 7.21E−10 | 1.24E−11 | 1.81E−10 | −1.31E−09 | 2.23E−10 | 2.55E−10 | 1.05E−09 | 1.09E−08 |
| $\alpha_{22}$ | −3.06E−15 | −4.77E−16 | −2.57E−15 | −1.02E−16 | −2.61E−15 | 2.18E−14 | 1.63E−15 | −2.37E−15 | 9.03E−17 | 2.10E−15 |
| $\beta_{11}$ | −1.20E−14 | −9.42E−15 | −9.14E−15 | −8.26E−16 | −4.96E−15 | −3.65E−15 | −5.89E−14 | −6.72E−16 | −1.31E−14 | −1.72E−14 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\gamma_{11}$ | −1.20E−08 | −9.42E−09 | −9.14E−09 | −8.26E−10 | −4.96E−09 | −3.65E−09 | −5.89E−08 | −6.72E−10 | −1.31E−08 | −1.72E−08 |
| $\varepsilon_{11}$ | 2.91E−09 | 6.13E−09 | 7.84E−11 | 5.89E−11 | −1.47E−11 | 2.30E−09 | −1.23E−09 | −9.53E−11 | 3.10E−09 | −8.05E−10 |
| $\varepsilon_{21}$ | 5.72E−15 | −5.36E−16 | −6.59E−15 | 1.49E−16 | 9.80E−16 | −9.85E−15 | −9.09E−15 | 6.11E−16 | −2.84E−15 | −5.76E−15 |
| $\eta_{11}$ | 2.91E−06 | 6.13E−06 | 7.84E−08 | 5.89E−08 | −1.47E−08 | 2.30E−06 | −1.23E−06 | −9.53E−08 | 3.10E−06 | −8.05E−07 |
| $\eta_{21}$ | 5.72E−12 | −5.36E−13 | −6.59E−12 | 1.49E−13 | 9.80E−13 | −9.85E−12 | −9.09E−12 | 6.11E−13 | −2.84E−12 | −5.76E−12 |
| $\rho_{11}$ | −1.20E−11 | −9.42E−12 | −9.14E−12 | −8.26E−13 | −4.96E−12 | −3.65E−12 | −5.89E−11 | −6.72E−13 | −1.31E−11 | −1.72E−11 |
| obs | 162 | 333 | 398 | 329 | 277 | 144 | 92 | 309 | 71 | 66 |
| (7) Scope 1+2+3 | | | | | | | | | | |
| | (7.1) | (7.2) | (7.3) | (7.4) | (7.5) | (7.6) | (7.7) | (7.8) | (7.9) | (7.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 1.78E+08 | 1.90E+08 | 1.18E+08 | 1.65E+08 | 1.41E+08 | 5.69E+07 | 2.16E+06 | 1.92E+08 | 2.42E+07 | 4.01E+07 |
| Constant ($\alpha$) | 2.28E+05 | 2.11E+05 | 5.17E+04 | −3.89E+03 | −1.12E+04 | −6.90E+04 | 2.87E+04 | −8.36E+03 | 4.98E+02 | −3.84E+05 |
| $\alpha_1$ | −7.26E+01 | 2.05E+02 | 2.67E−01 | 1.02E+01 | 4.61E+00 | 2.27E+01 | 2.69E+00 | 8.66E−01 | 6.84E+00 | 4.67E+02 |
| $\alpha_2$ | 7.16E−04 | 1.93E−04 | 7.19E−06 | −1.30E−05 | −6.35E−06 | −9.56E−05 | −4.88E−06 | 2.28E−04 | 2.77E−06 | 4.96E−05 |
| $\beta_1$ | −1.08E−03 | −9.42E−04 | −5.27E−05 | −2.20E−05 | 1.70E−06 | −6.42E−06 | −6.69E−05 | 7.69E−07 | −2.57E−05 | −9.22E−04 |
| $\gamma_1$ | −7.61E−02 | 5.82E−02 | 9.47E−01 | 9.78E−01 | 1.00E+00 | 9.94E−01 | 9.33E−01 | 1.00E+00 | 9.74E−01 | 7.81E−02 |
| $\alpha_{11}$ | 1.04E−02 | 1.52E−03 | −4.17E−06 | −1.08E−04 | −1.63E−04 | −1.10E−03 | 8.33E−05 | −3.55E−05 | −1.33E−03 | −5.48E−03 |
| $\alpha_{12}$ | −2.76E−08 | −1.13E−08 | 5.34E−10 | −2.87E−10 | 1.15E−09 | 1.97E−10 | 7.13E−09 | −9.73E−12 | 2.18E−09 | −6.19E−09 |
| $\alpha_{21}$ | −2.76E−08 | −1.13E−08 | 5.34E−10 | −2.87E−10 | 1.15E−09 | 1.97E−10 | 7.13E−09 | −9.73E−12 | 2.18E−09 | −6.19E−09 |
| $\alpha_{22}$ | −3.36E−15 | 1.91E−14 | −5.71E−15 | 5.89E−16 | −1.14E−14 | −1.93E−14 | 3.02E−15 | −5.28E−15 | −3.84E−15 | −6.15E−15 |
| $\beta_{11}$ | −1.32E−15 | 5.22E−16 | −1.03E−14 | −2.37E−14 | −2.34E−14 | −2.02E−14 | 6.13E−15 | −9.84E−15 | −1.56E−14 | −4.80E−15 |
| $\gamma_{11}$ | −1.32E−09 | 5.22E−10 | −1.03E−08 | −2.37E−08 | −2.34E−08 | −2.02E−08 | 6.13E−09 | −9.84E−09 | −1.56E−08 | −4.80E−09 |
| $\varepsilon_{11}$ | 5.48E−09 | 8.53E−10 | 1.35E−10 | 1.17E−09 | 8.24E−10 | 2.30E−09 | −5.19E−09 | −7.92E−12 | 1.17E−09 | 8.94E−10 |
| $\varepsilon_{21}$ | 3.44E−15 | −2.81E−15 | −1.83E−15 | 1.29E−15 | −1.17E−15 | 1.66E−14 | −4.74E−14 | 1.82E−15 | 1.38E−15 | 7.54E−15 |
| $\eta_{11}$ | 5.48E−06 | 8.53E−07 | 1.35E−07 | 1.17E−06 | 8.24E−07 | 2.30E−06 | −5.19E−06 | −7.92E−09 | 1.17E−06 | 8.94E−07 |
| $\eta_{21}$ | 3.44E−12 | −2.81E−12 | −1.83E−12 | 1.29E−12 | −1.17E−12 | 1.66E−11 | −4.74E−11 | 1.82E−12 | 1.38E−12 | 7.54E−12 |
| $\rho_{11}$ | −1.32E−12 | 5.22E−13 | −1.03E−11 | −2.37E−11 | −2.34E−11 | −2.02E−11 | 6.13E−12 | −9.84E−12 | −1.56E−11 | −4.80E−12 |
| obs | 48 | 104 | 213 | 191 | 118 | 72 | 37 | 173 | 50 | 43 |
| (8) SOx | | | | | | | | | | |
| | (8.1) | (8.2) | (8.3) | (8.4) | (8.5) | (8.6) | (8.7) | (8.8) | (8.9) | (8.10) |

| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
|---|---|---|---|---|---|---|---|---|---|---|
| Objective value | 7.80E+07 | 4.31E+07 | 2.67E+07 | 3.80E+07 | 6.63E+07 | 4.00E+07 | 0.00E+00 | 3.46E+07 | | 2.30E+06 |
| Constant ($\alpha$) | 2.11E+04 | 9.43E+02 | −1.50E+02 | −6.66E+02 | −1.15E+02 | −2.12E+03 | −3.96E+03 | −7.83E+01 | | 3.70E+05 |
| $\alpha_1$ | −1.44E+00 | 5.01E−02 | 1.88E−01 | −3.46E−02 | 3.18E−01 | 5.50E+00 | 0 | 6.88E−02 | | −9.18E+01 |
| $\alpha_2$ | 1.89E−06 | 7.92E−07 | 1.77E−06 | 5.21E−06 | −1.96E−10 | −4.99E−07 | 0 | 9.20E−07 | | −4.33E−05 |
| $\beta_1$ | −2.64E−06 | −3.12E−06 | −3.22E−06 | −7.31E−07 | 5.35E−09 | −1.16E−05 | 0 | −1.10E−06 | | −1.37E−04 |
| $\gamma_1$ | 9.97E−01 | 9.97E−01 | 9.97E−01 | 9.99E−01 | 1.00E+00 | 9.88E−01 | 1 | 9.99E−01 | | 8.63E−01 |
| $\alpha_{11}$ | −2.93E−04 | −3.12E−05 | 4.76E−06 | −9.28E−06 | 6.36E−07 | −4.69E−04 | 0 | −1.29E−06 | | −1.10E−02 |
| $\alpha_{12}$ | 2.32E−10 | 2.07E−10 | −1.43E−12 | 7.40E−11 | 3.39E−11 | 1.79E−09 | 0 | 4.16E−12 | | 9.12E−09 |
| $\alpha_{21}$ | 2.32E−10 | 2.07E−10 | −1.43E−12 | 7.40E−11 | 3.39E−11 | 1.79E−09 | 0 | 4.16E−12 | | 9.12E−09 |
| $\alpha_{22}$ | −6.57E−18 | −2.80E−16 | −2.85E−17 | −4.67E−17 | −5.37E−16 | −6.78E−15 | 0 | −7.83E−17 | | −2.18E−15 |
| $\beta_{11}$ | −4.06E−15 | −5.35E−15 | −5.50E−15 | −2.51E−15 | −5.08E−16 | −1.12E−15 | 0 | −1.25E−16 | | −2.51E−14 |
| $\gamma_{11}$ | −4.06E−09 | −5.35E−09 | −5.50E−09 | −2.51E−09 | −5.08E−10 | −1.12E−09 | 0 | −1.25E−10 | | −2.51E−08 |
| $\varepsilon_{11}$ | 6.83E−10 | 5.67E−11 | 1.22E−10 | 1.04E−10 | 8.21E−12 | 5.63E−10 | 0 | 9.01E−12 | | 1.72E−08 |
| $\varepsilon_{21}$ | 1.34E−17 | 4.21E−17 | 1.97E−16 | −7.81E−16 | 1.06E−16 | −2.23E−15 | 0 | 1.18E−17 | | −4.94E−15 |
| $\eta_{11}$ | 6.83E−07 | 5.67E−08 | 1.22E−07 | 1.04E−07 | 8.21E−09 | 5.63E−07 | 0 | 9.01E−09 | | 1.72E−05 |
| $\eta_{21}$ | 1.34E−14 | 4.21E−14 | 1.97E−13 | −7.81E−13 | 1.06E−13 | −2.23E−12 | 0 | 1.18E−14 | | −4.94E−12 |
| $\rho_{11}$ | −4.06E−12 | −5.35E−12 | −5.50E−12 | −2.51E−12 | −5.08E−13 | −1.12E−12 | 0 | −1.25E−13 | | −2.51E−11 |
| obs | 126 | 541 | 312 | 184 | 184 | 144 | 1 | 189 | 0 | 21 |

(9) NOx

| | (9.1) | (9.2) | (9.3) | (9.4) | (9.5) | (9.6) | (9.7) | (9.8) | (9.9) | (9.10) |
|---|---|---|---|---|---|---|---|---|---|---|
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 8.76E+07 | 7.75E+07 | 3.77E+07 | 6.60E+07 | 5.06E+07 | 4.80E+07 | 6.40E+05 | 3.86E+07 | 0.00E+00 | 1.66E+07 |
| Constant ($\alpha$) | 3.34E+03 | −2.55E+02 | 7.12E+02 | −2.72E+02 | −6.72E+02 | 2.82E+02 | −3.85E+05 | −1.70E−01 | −3.29E+03 | 1.27E+04 |
| $\alpha_1$ | 9.29E−02 | 4.00E−02 | −2.02E−01 | 4.38E−01 | −6.74E−01 | 1.33E−01 | 4.14E+01 | 3.59E−04 | 0 | −5.75E+00 |
| $\alpha_2$ | 1.17E−06 | 1.71E−06 | 1.73E−06 | −7.01E−07 | 2.69E−05 | 1.09E−05 | 1.20E−03 | 6.14E−09 | 0 | 1.05E−06 |
| $\beta_1$ | −3.18E−06 | 7.33E−09 | −6.72E−07 | −1.30E−06 | −7.15E−06 | −5.30E−06 | −2.15E−03 | −7.44E−09 | 0 | −9.29E−06 |
| $\gamma_1$ | 9.97E−01 | 1.00E+00 | 9.99E−01 | 9.99E−01 | 9.93E−01 | 9.95E−01 | −1.15E+00 | 1.00E+00 | 1 | 9.91E−01 |
| $\alpha_{11}$ | −1.41E−05 | 3.17E−06 | 4.71E−06 | −7.18E−06 | 4.71E−05 | −4.11E−05 | 7.41E−02 | −5.91E−09 | 0 | 1.50E−03 |
| $\alpha_{12}$ | 5.21E−11 | 2.30E−12 | 1.06E−10 | 3.27E−11 | −2.24E−10 | −2.82E−11 | −1.95E−07 | 3.84E−14 | 0 | 5.75E−10 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\alpha_{21}$ | 5.21E−11 | 2.30E−12 | 1.06E−10 | 3.27E−11 | −2.24E−10 | −2.82E−11 | −1.95E−07 | 3.84E−14 | 0 | 5.75E−10 |
| $\alpha_{22}$ | −4.67E−17 | −5.03E−17 | −4.70E−16 | 2.82E−17 | −2.46E−15 | 8.00E−16 | −1.14E−12 | −8.20E−19 | 0 | −3.54E−16 |
| $\beta_{11}$ | −7.25E−16 | −7.40E−16 | −6.01E−15 | −8.98E−17 | 6.07E−16 | −8.18E−16 | 1.07E−12 | −8.33E−19 | 0 | −1.11E−14 |
| $\gamma_{11}$ | −7.25E−10 | −7.40E−10 | −6.01E−09 | −8.98E−11 | 6.07E−10 | −8.18E−10 | 1.07E−06 | −8.33E−13 | 0 | −1.11E−08 |
| $\varepsilon_{11}$ | 2.77E−11 | 1.20E−11 | 7.82E−11 | 2.51E−11 | −9.74E−11 | 2.44E−10 | −2.40E−07 | 4.83E−15 | 0 | −3.03E−09 |
| $\varepsilon_{21}$ | 9.45E−17 | −1.54E−16 | 1.55E−16 | −3.83E−16 | 2.75E−16 | −6.21E−16 | 2.02E−12 | 3.14E−19 | 0 | 1.66E−15 |
| $\eta_{11}$ | 2.77E−08 | 1.20E−08 | 7.82E−08 | 2.51E−08 | −9.74E−08 | 2.44E−07 | −2.40E−04 | 4.83E−12 | 0 | −3.03E−06 |
| $\eta_{21}$ | 9.45E−14 | −1.54E−13 | 1.55E−13 | −3.83E−13 | 2.75E−13 | −6.21E−13 | 2.02E−09 | 3.14E−16 | 0 | 1.66E−12 |
| $\rho_{11}$ | −7.25E−13 | −7.40E−13 | −6.01E−12 | −8.98E−14 | 6.07E−13 | −8.18E−13 | 1.07E−09 | −8.33E−16 | 0 | −1.11E−11 |
| obs | 197 | 747 | 442 | 254 | 248 | 205 | 11 | 254 | 1 | 100 |
| | | | | | (10) VOC | | | | | |
| | (10.1) | (10.2) | (10.3) | (10.4) | (10.5) | (10.6) | (10.7) | (10.8) | (10.9) | (10.10) |
| #Industry | #10 | #15 | #20 | #25 | #30 | #35 | #40 | #45 | #50 | #55 |
| Objective value | 7.53E+07 | 2.45E+07 | 3.66E+07 | 4.01E+07 | 7.25E+06 | 6.35E+07 | 1.21E−08 | 2.48E+07 | | −1.28E−09 |
| Constant ($\alpha$) | 4.00E+04 | −5.29E+02 | −3.76E+02 | −3.02E+03 | 1.34E+06 | 5.31E+03 | 1.38E+06 | 3.02E+03 | | 3.44E+05 |
| $\alpha_1$ | 1.51E+00 | 1.35E+00 | 2.74E−01 | 7.57E−01 | 3.67E+01 | −6.73E−01 | 0.00E+00 | 1.36E+00 | | −9.15E+01 |
| $\alpha_2$ | 9.99E−07 | 1.56E−06 | −1.99E−07 | 1.51E−05 | −1.12E−03 | 6.58E−06 | 0.00E+00 | −5.01E−06 | | 0.00E+00 |
| $\beta_1$ | −1.02E−05 | 3.35E−09 | −9.96E−08 | −4.21E−05 | −1.80E−04 | −2.74E−06 | −3.50E−03 | 3.06E−07 | | −3.39E−04 |
| $\gamma_1$ | 9.90E−01 | 1.00E+00 | 1.00E+00 | 9.58E−01 | 8.20E−01 | 9.97E−01 | −2.50E+00 | 1.00E+00 | | 6.61E−01 |
| $\alpha_{11}$ | −9.16E−05 | −3.37E−05 | −6.03E−06 | −1.66E−05 | 5.96E−03 | −5.32E−05 | −3.57E−03 | −4.12E−07 | | 8.24E−03 |
| $\alpha_{12}$ | 6.00E−11 | 3.64E−11 | 6.65E−11 | 3.66E−11 | −4.30E−08 | 4.27E−10 | 0.00E+00 | −4.03E−11 | | 1.76E−08 |
| $\alpha_{21}$ | 6.00E−11 | 3.64E−11 | 6.65E−11 | 3.66E−11 | −4.30E−08 | 4.27E−10 | 0.00E+00 | −4.03E−11 | | 1.76E−08 |
| $\alpha_{22}$ | −7.79E−17 | −9.55E−17 | −3.27E−16 | −4.37E−16 | 7.29E−13 | −3.66E−15 | −3.44E−14 | 3.31E−16 | | −9.82E−15 |
| $\beta_{11}$ | −1.47E−15 | −3.02E−15 | −2.27E−15 | −7.36E−16 | 3.67E−14 | −1.14E−15 | −2.28E−13 | −1.69E−15 | | 2.48E−13 |
| $\gamma_{11}$ | −1.47E−09 | −3.02E−09 | −2.27E−09 | −7.36E−10 | 3.67E−08 | −1.14E−09 | −2.28E−07 | −1.69E−09 | | 2.48E−07 |
| $\varepsilon_{11}$ | 1.42E−10 | 4.10E−11 | 7.96E−11 | 2.10E−10 | −1.06E−08 | 6.69E−11 | 3.32E−08 | −1.42E−10 | | −4.96E−08 |
| $\varepsilon_{21}$ | 2.45E−16 | −7.87E−17 | −1.90E−16 | −3.60E−16 | 2.81E−14 | 8.36E−16 | 3.36E−13 | 4.37E−16 | | 0.00E+00 |
| $\eta_{11}$ | 1.42E−07 | 4.10E−08 | 7.96E−08 | 2.10E−07 | −1.06E−05 | 6.69E−08 | 3.32E−05 | −1.42E−07 | | −4.96E−05 |
| $\eta_{21}$ | 2.45E−13 | −7.87E−14 | −1.90E−13 | −3.60E−13 | 2.81E−11 | 8.36E−13 | 3.36E−10 | 4.37E−13 | | 0.00E+00 |
| $\rho_{11}$ | −1.47E−12 | −3.02E−12 | −2.27E−12 | −7.36E−13 | 3.67E−11 | −1.14E−12 | −2.28E−10 | −1.69E−12 | | 2.48E−10 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| obs | 127 | 248 | 186 | 119 | 21 | 114 | 4 | 65 | 0 | 6 |