Estimating corporate contributions towards sustainability at the aggregate level of a sector, region or an industry

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Abstract

This study presents a systematic method for assessing aggregate sustainability of firms at sector, region or industry level. The proposed method is based on the generalized sustainable value; it allows to aggregate data of individual firms to any group of firms in a specific sector, specialization, region, or any other group. The method is illustrated by two empirical applications of the Finnish crop and dairy sectors, where the benchmark technology is estimated by data envelopment analysis. Our efficiency assessment shows that the representative crop farm achieves only about a half of its potential output. Efficiency of the representative dairy farm is somewhat higher.

Keywords: *sustainability assessment; sustainable value; productive efficiency analysis*

1. Introduction

Sustainability is a multidimensional concept embracing economic, environmental and social aspects. Operationalizing the qualitative concept of sustainability to practical quantitative measures has proved challenging due to the sheer number of meanings attached to sustainability (e.g., Tyteca, 1996; Callens and Tyteca, 1999). Sustainable value method proposed by Figge and Hahn (2004) is one of the attempts to quantify the sustainability performance of firms. A firm is said to create sustainable value whenever it uses its bundle of resources more efficiently than another firm would have used it. In other words, it compares performance of a firm to a benchmark. The benchmark can be seen as a reference group that sets the performance target for the evaluated firm. The production technology available for the benchmark firm is the benchmark technology. It can be characterized by the production function, which indicates the maximum amount of output that the benchmark technology can produce using the given amounts of input resources.

In the paper by Kuosmanen and Kuosmanen (hereafter KK) (2009a), the authors showed that the sustainable value estimator (Figge and Hahn, 2004) rests on a number of strong assumptions. Building an explicit link between the sustainable value method and frontier approach to environmental performance assessment, KK proposed to use a more general benchmark technology, which can be estimated from empirical data using established econometric methods. As has been shown in KK (2009a), sustainable value and sustainable efficiency of Figge and Hahn (2004) are the special cases of the standard efficiency indices known in the field of productive efficiency analysis for more than five decades; and the aggregation of efficiency indices has been a subject of debate in the literature for some time (see, e.g., Blackorby and Russel, 1999; Färe and Zelenyuk, 2003; Kuosmanen *et al*., 2006). Further, in KK (2009b), the proposed generalized formulation of the sustainable value has been examined and applied to the firm-level sustainability assessment. The authors estimated benchmark technologies and sustainable value scores using alternative parametric and nonparametric methods.

In this study we show that generalized approach to measuring sustainable values proposed in KK (2009a) is not restricted to the firm level, but it also can be usefully applied to the aggregate level of a sector, region or an industry. The main objective of this paper is to develop a consolidated theoretical framework for estimating an aggregate sustainability measure of firm’s performance for any group of firms in a specific sector, specialization, region, or any other group, such that resulting measures are consistent with the firm-level estimates.

The remainder of this paper is organized as follows. Section 2 briefly reviews the generalized approach of estimating corporate contributions towards sustainability at the firm level. Section 3 establishes a theoretical framework for estimating contributions towards sustainability at the aggregate level, such as a sector, region or an industry. In section 4 the proposed methodology is illustrated by two applications of the Finnish crop and dairy sectors. Finally, section 5 concludes.

2. Measuring contributions towards sustainability at firm level

Following definition of sustainable value presented in KK (2009a), assume firm *i* transforms a vector of *R* resources, including natural, physical, human, and intellectual capital, $\mathbf{x}_i = (x_{i1} \dots x_{iR})'$, into the economic output denoted by y_i, for every $i = 1,\dots,n$. Define *sustainable value* (SV) measure of the firm's sustainability performance as the difference between firm *i*'s economic output, y_i, produced by using a bundle of resources $\mathbf{x}_i = (x_{i1} \dots x_{iR})'$ and the opportunity cost of these amounts of resources, denoted by $OC(\mathbf{x}_i)$:

(1) $$SV_i \equiv y_i - OC(\mathbf{x}_i).$$

The rationale behind equation (1) is analogous to the conceptual definition of the sustainable value method proposed by Figge and Hahn (2004). However, definition (1) is more general and differs from the operational measure of the original sustainable value. In particular, the opportunity cost can be a nonlinear function of resources, and the functional form does not need to be assumed a priori.

Since opportunity cost of resources is not directly observable, it must be estimated in one way or another. In economics, the opportunity cost of using a resource for a specific activity refers to the income foregone by not using the resource in the best alternative activity. However, the best alternative use is not always self-evident. It generally depends on the technology and the other resources available for the alternative activity. In mathematical terms, the technology available to a firm is described by a neoclassical production function $f : \mathbb{R}_+^R \to \mathbb{R}_+$, which is the maximum amount of output that can be obtained from the given amounts of input resources. We assume that function *f* is an increasing and concave function. Hence, without loss of generality, we may interpret the numerical value of the production function $f(\mathbf{x})$ as the total opportunity cost of resource bundle **x**.

Applying the previous insights, the general definition of sustainable value (1) can be rewritten as:

(2) $$SV_i = y_i - f(\mathbf{x}_i).$$

Equation (2) is not restricted to any particular functional form of the production function *f*. It not only allows resources to be interdependent and allows non-substitutability between resources, but it also allows preserving some critical level of resources, which is in line with strong sustainability concept. Further, the production technology *f* can be estimated from empirical data using well established econometric techniques or mathematical programming. In fact, KK (2009b) present a review of econometric approaches to estimating production functions and environmental performance in the context of the sustainable value estimation.

3. Measuring contributions towards sustainability at the aggregate level

We next consider an aggregation of the firm level sustainable value measures to a sector, region and an industry level, which is not as straightforward as it might seem. Firstly, consider the following example.

Suppose there are two firms:

A: $(x_A, y_A) = (1,1)$ and

B: $(x_B, y_B) = (9,3)$,

where x and y are input resource unit and output unit, respectively. The production function is given by the equation: $f(x) = x^{0.5}$.

Thus, total resource use is simply sum of the firms' resource units: $x_A + x_B = 1+9 = 10$, and total output is $y_A + y_B = 1+3 = 4$. Note that both firms are technically efficient, which means that it is impossible to increase output at the given allocation of resources. However, it is possible to increase output by reallocating resources. For instance, if firm B is split into nine separate firms, each endowed with one unit of resource to produce 1 unit of output, the total output would increase from 4 to 10.

In theory, the optimal allocation in this example would involve creating an infinite number of infinitesimally small firms that use a positive but infinitesimally small quantity of resource, i.e., x approaches to 0 for all firms. This example demonstrates that even if firms are technically efficient at the firm level, there may be a lack of coordination, which shows as inefficiency at the aggregate level. Although the average inefficiency of the two firms is zero, the average vector: $\left[(x_A, y_A)+(x_B, y_B)\right]/2=(5,2)$ is inefficient, because $f(5)\approx 2.236$, and thus $(y_A+y_B)/2-f([x_A+x_b]/2)=2-2.236=-0.236$.

Hence, the average of the firm level SV is different from the SV of the average vector. Whether we use the firm level or the aggregate level data, it is important to ensure that the firm level SV measures match with their counterparts at the aggregate level.

To develop a simple but systematic aggregation scheme, we propose the following aggregate SV measure. Consider a group of firms $I=\{1,\ldots,n\}$. Group I can represent firms in a specific sector, specialization, region, country, or any other group. Assume that firms in group I have access to the same production technology described by the production function $f:\mathbb{R}_+^R\rightarrow\mathbb{R}_+$. The production function f is increasing and concave function and indicates the maximum amount of output that can be obtained from the given amounts of input resources.

To pave the way for the aggregate SV formulation, we introduce a *representative firm* of group I that is characterized by the average output and average resource vector. The average resource vector is calculated as:

$$(3)\qquad \bar{\mathbf{x}}=\sum_{i\in I}\mathbf{x}_i/n,$$

where vector $\mathbf{x}_i=(x_{i1}\ldots x_{iR})'$ characterizes the resource use by firm i. The average output of group I is simply calculated as:

$$(4)\qquad \bar{y}=\sum_{i\in I}y_i/n,$$

where y_i is output of firm *i*.

These average values $\overline{\mathbf{x}}$ and $\overline{y}$ characterize the representative firm of group *I*. The representative firm's data are next included in the data set as an additional entity; and the production technology *f* is estimated by applying an alternative econometric methods. Given the production function *f*, the aggregate SV measure is calculated as the SV of the representative firm of group *I* , denoted as SV_{repr}, multiplied by the number of firms in group *I*:

$$(5) \qquad aggrSV_I = n \cdot SV_{repr} ,$$

where the SV measure of the representative firm SV_{repr} is the difference between the average output of group *I*, $\overline{y}$ (or output of the representative firm), and the numerical value of the production function $f\left(\overline{\mathbf{x}}\right)$ in point $\overline{\mathbf{x}}$:

$$(6) \qquad SV_{repr} = \overline{y} - f\left(\overline{\mathbf{x}}\right).$$

Alternatively, the aggregate SV can be presented as:

$$(7) \qquad aggrSV_I = n \cdot \left(\overline{y} - f\left(\overline{\mathbf{x}}\right)\right).$$

Note that the proposed aggregate SV measure has a compelling profit interpretation. More specifically, define the profit function as:

$$(8) \qquad \pi\left(\mathbf{w}\right) = \max_{\mathbf{x}} \left\{ y - \mathbf{w}'\mathbf{x} \middle| y = f\left(\mathbf{x}\right) \right\} = \max_{\mathbf{x}} \left\{ f\left(\mathbf{x}\right) - \mathbf{w}'\mathbf{x} \right\}.$$

Without loss of generality, the output price can be normalized as one, so that *y* represents both the output quantity and the revenue. The profit function indicates the maximum profit obtainable at given input prices **w** (Kuosmanen *et al*., 2010).

The notion of profit efficiency was first introduced by Nerlove (1965). He suggested two alternative measures of profit efficiency: the ratio measure (ratio of observed profit to maximum profit) and the difference measure (difference between observed and maximum profit). The ratio measure is generally ill-defined if the maximum profit equals zero. It is also difficult to interpret when maximum and/or actual profit levels are negative. In contrast, the difference measure has a natural interpretation in terms of chosen currency units, and it is able to handle negative or zero profits.

The aggregate SV can be interpreted as the profit efficiency of the group *I* at the most favorable prices from the perspective of group *I*.

Theorem: *The aggregate SV measure* $aggrSV_I = n\cdot\left(\overline{y} - f\left(\overline{\mathbf{x}}\right)\right)$ *indicates the sum of profit efficiencies of the firms in group I at the most favorable non-negative input prices. Specifically:*

$$aggrSV_I = \max_{\mathbf{w}\geq\mathbf{0}} \sum_{i=1}^{n}\left((y_i - \mathbf{w}'\mathbf{x}_i) - \pi(\mathbf{w})\right)$$

The proof to the theorem is given in the appendix.

Formulation of the aggregate SV can be extended to any group of firms, for example, firms located in a specific region. For estimating production frontier and aggregate SV measures, the evaluated groups of firms must be comparable, that is, the firms must be engaged in a similar set of operations and have access to the same production technology *f*. For example, let the average output and the average resource vector of group g be $\overline{y}_g$ and $\overline{\mathbf{x}}_g$. Then, the aggregate SV of group *g* is

$$(9)\qquad aggrSV_g = n\cdot\left(\overline{y}_g - f\left(\overline{\mathbf{x}}_g\right)\right),$$

where *n* is the number of firms in group *g*. However, if the firms located in a specific region do not engage in a similar set of operations and have different production technology, e.g., dairy and crop farms, one cannot compare performances of these farms under the same production technology.

To compute the aggregate SV of several groups, one should estimate the aggregate SV of each group first and then add together the resulted measures. For example, the aggregate SV of dairy and crop farms as two separate groups located in the same region is calculated as the sum of the aggregate SV measures of each group:

(10) $$SV_{total} = k \cdot aggrSV_g^{crop} + m \cdot aggrSV_g^{dairy} \text{ or}$$

$$SV_{total} = k \cdot \left(\overline{y}_g^{crop} - f^{crop} \left(\overline{\mathbf{x}}_g^{crop} \right) \right) + m \cdot \left(\overline{y}_g^{dairy} - f^{dairy} \left(\overline{\mathbf{x}}_g^{dairy} \right) \right),$$

where *k* and *m* are the number of farms in the groups of dairy and crop farms, respectively. In formula (10), the expressions within the brackets are the SVs of the representative crop and dairy farms, respectively.

5. Empirical application

This section includes two applications of estimating the aggregate SV measures at sector level conducted on data sets of 332 Finnish dairy farms and 142 crop farms. The data were extracted from the Farm Accountancy Data Network (FADN) database. The economic output of crop farms is the total revenue from crops and crop products and the economic output of dairy farms is the total revenue from milk and other products in euro. Economic resources include labor in hours, total utilized agricultural area (UAA) measured in hectares and farm capital in Euros. Environmental resources include the total energy cost and fertilizers. An overview of the key characteristics of the data is presented in Table 1 and 2 in the form of mean, standard deviation, minimum and maximum values.

Table 1: Descriptive statistics for the sample of dairy farms; year 2004, sample size n=332.

Variable	Mean	St. Dev.	Min	Max
Total output, €	91,676	52,336	16,671	393,392
Labor, hr	5,123	1,719	399	13,458
Farm capital, €	261,150	191,099	18,779	1,481,375
Energy, €	5,843	3,561	713	25,541
UAA, ha	49.1	25.4	13.1	146.8
Fertiliser, €	4,746	3,558	0	22,922

Table 2: Descriptive statistics for the sample of crop farms; year 2004, sample size n=141.

Variable	Mean	St. Dev.	Min	Max
Total output, €	54,838	54,349	2,493	342,863
Labor, hr	2,139	1,286	160	6,807
Farm capital, €	228,020	162,428	32,599	997,866
Energy, €	7,074	4,770	692	34,973
UAA, ha	80.5	44.5	22.1	324.3
Fertiliser, €	7,018	5,209	0	28,535

Firstly, the average values for the *representative dairy* and *crop farms* $\left(\overline{y}^{dairy}, \overline{\mathbf{x}}^{dairy}\right)$ and $\left(\overline{y}^{crop}, \overline{\mathbf{x}}^{crop}\right)$ for the dairy and crop sectors were calculated. Next, the representative farms' data were included in the data samples and the benchmark technologies for both sectors were estimated using output oriented DEA model with variable returns to scale:

$$(11) \qquad f_{DEA}(\mathbf{x}) = \max_{\lambda \geq 0} \left\{ \sum_{i=1}^{n} \lambda_i y_i \middle| \mathbf{x} \geq \sum_{i=1}^{n} \lambda_i \mathbf{x}_i ; \sum_{i=1}^{n} \lambda_i = 1 \right\}.$$

The resulting efficiency score of the representative crop farm equals to 0.513, which means that the representative crop farm achieves only about half of its potential output. The efficiency score of the representative dairy farm equals to 0.649, that is, somewhat higher than for the representative crop farm. Next, the SV values for both representative farms were calculated and resulted in about -52,102€ for the representative crop farm and -49,615€ for the representative dairy farm. The results are negative by construction, since in the DEA model, the frontier envelopes the observed data from above and only farms with SV = 0 are diagnosed as efficient.

Table 3 reports the weights of inputs for the representative crop and dairy farms. For the representative crop farm, two inputs, such as UAA and fertilizer are used so excessively that their marginal product is estimated to be zero. Farm capital has the largest weight. In case of the representative dairy farm, the labor input has the smallest weight, it is equal to 0.01. However, the energy input has a weight of 0.88.

Table 3: Weights of inputs for the representative crop and dairy farms.

Inputs	Repr. crop farm	Repr. dairy farm
Labor	0.55	0.01
Farm capital	1.43	0.15
Energy	0.08	0.88
UAA	0	0.05
Fertiliser	0	0.19

Finally, to obtain the aggregate SV measures for dairy and crop sectors, the estimated SV values of the representative farms were multiplied by the number of farms in the samples. Thus, the aggregate SV of the Finnish crop sector resulted in about -7.4 million Euros in year 2004 and the aggregate SV of the Finnish dairy sector resulted in about -16.5 million Euros for the same year.

7. Conclusions

This paper extends the scope of the previous studies of the sustainable value method from the farm level to the aggregate level. The proposed aggregate sustainable value method can be applied to any group of firms in a specific sector, specialization, region, or any other group. It allows corporate contributions towards sustainability at aggregate level. The proposed aggregation method is illustrated by two applications of Finnish crop and dairy sectors. Resulting efficiency score of the representative crop farm is equal to 0.5, which means that the representative crop farm achieves only about half of its potential output. The efficiency score of the representative dairy is somewhat higher (0.6). Aggregate sustainable value of the Finnish crop and dairy sectors for year 2004 resulted in about -7.4 and -16.5 million Euros.

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Appendix

Theorem: *The aggregate SV measure* $aggrSV_I = n\cdot\left(\overline{y} - f\left(\overline{\mathbf{x}}\right)\right)$ *indicates the sum of profit efficiencies of the firms in group I at the most favorable non-negative input prices. Specifically:*

$$aggrSV_I = \max_{\mathbf{w}\geq\mathbf{0}} \sum_{i=1}^{n}\left((y_i - \mathbf{w}'\mathbf{x}_i) - \pi(\mathbf{w})\right)$$

Proof**:** Starting from the average profit inefficiency stated on the right-hand side of the equation posited in the Theorem, we can reorganize the expression as

$$\text{(A1)} \quad \max_{\mathbf{w}\geq\mathbf{0}} \sum_{i=1}^{n}\left((y_i - \mathbf{w}'\mathbf{x}_i) - \pi(\mathbf{w})\right)$$

$$\text{(A2)} \quad = n\cdot\max_{\mathbf{w}\geq\mathbf{0}}\left(\sum_{i=1}^{n} y_i / n - \sum_{i=1}^{n}\mathbf{w}'(\mathbf{x}_i / n) - \pi(\mathbf{w})\right)$$

$$\text{(A3)} \quad = n\cdot\max_{\mathbf{w}\geq\mathbf{0}}\left(\overline{y} - \mathbf{w}'\overline{\mathbf{x}} - \pi(\mathbf{w})\right)$$

$$\text{(A4)} \quad = n\cdot\left(\overline{y} - \min_{\mathbf{w}\geq\mathbf{0}}\left(\mathbf{w}'\overline{\mathbf{x}} + \pi(\mathbf{w})\right)\right).$$

Regarding the minimization problem, note that the cost of the average input vector (i.e., $\mathbf{w}'\overline{\mathbf{x}}$) increases as the input prices $\mathbf{w}$ increase, whereas the profit function $\pi(\mathbf{w})$ is a decreasing function of $\mathbf{w}$. Since f is concave, $\pi(\mathbf{w})$ is convex, and thus the minimization problem has a unique global optimum.

Differentiating $\left(\mathbf{w}'\overline{\mathbf{x}} + \pi(\mathbf{w})\right)$ with respect to input prices $\mathbf{w}$, we have the first-order conditions:

$$\text{(A5)} \quad \overline{\mathbf{x}} + \nabla\pi(\mathbf{w}) = 0,$$

where $\nabla\pi(\mathbf{w})$ is the subgradient of the profit function at $\mathbf{w}$. If f is differentiable, then the subgradient reduces to the gradient vector $\nabla\pi(\mathbf{w}) = \left(\frac{\partial\pi(\mathbf{w})}{\partial w_1}\cdots\frac{\partial\pi(\mathbf{w})}{\partial w_R}\right)'$.

By Hotelling's lemma (Hotelling 1932):

(A6) $$\nabla \pi(\mathbf{w}) = \begin{pmatrix} -x_1^*(\mathbf{w}) \\ \vdots \\ -x_R^*(\mathbf{w}) \end{pmatrix} = -\mathbf{x}^*(\mathbf{w}),$$

where $\mathbf{x}^*(\mathbf{w})$ is the optimal profit maximizing input vector at prices **w**.

Hotelling's lemma can also be established for non-differentiable functions by using the sub-gradients (see e.g., Blume 2008 for details). In that case, $\mathbf{x}^*(\mathbf{w})$ is not unique, but it does not influence the optimal solution to the minimization problem in (A4).

Inserting the right-hand side of (A6) to equality (A5), we have the first-order condition:

(A7) $$\overline{\mathbf{x}} - \mathbf{x}^*(\mathbf{w}) = 0.$$

Therefore, the optimal solution to the minimization problem of (A4) can be expressed as:

(A8) $$\min_{\mathbf{w} \geq \mathbf{0}} \left(\mathbf{w}'\overline{\mathbf{x}} + \pi(\mathbf{w}) \right) = \mathbf{w}'\overline{\mathbf{x}} + (f(\overline{\mathbf{x}}) - \mathbf{w}'\overline{\mathbf{x}}) = f(\overline{\mathbf{x}}).$$

Inserting the last expression of (A8) back to (A4), we have:

(A9) $$\max_{\mathbf{w} \geq \mathbf{0}} \left(\sum (y_i - \mathbf{w}'\mathbf{x}_i) - \pi(\mathbf{w}) \right) = n \cdot \left(\overline{y} - f(\overline{\mathbf{x}}) \right) = aggrSV_I.$$