Ekologisen kestävyyden arvioiminen yleistetyn kestävyysarvon avulla

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Tiivistelmä

Tässä artikkelissa ehdotetaan yksinkertaista mutta systemaattista tapaa aggregoida yrityskohtainen yleistetty kestävyysarvon (GSV – generalized sustainability value) mittari sektoritasolle. Yleistetyn kestävyysarvon laskenta voidaan laajentaa mihin erityiseen sektoriin, alueeseen tai ryhmään tahansa, kunhan voidaan olettaa, että yritykset toimivat yhteisen tuotantoteknologian puitteissa. Toinen keskeinen oletus on, että yritykset kohtaavat samat tuote- ja panoshinnat. Vaikka jälkimmäinen oletus vaikuttaa rajoittavalta, käytännössä tämä oletus on usein tehtävä, koska tilakohtaisia hintatietoja ei yleensä ole käytettävissä. Siten tuottoja ja kustannuksia joudutaan käyttämään tuotosten ja panosten määriä kuvaavina muuttujina.

GSV voidaan määrittää useilla eri menetelmillä, joista tässä sovelletaan ei-parametrista DEA –menetelmää panos-tuotossuhteiden kuvaamiseen. Ehdotetussa mallissa kestävyysarvon aggregointi voidaan tehdä teoreettisesti yhtäpitävällä tavalla edustavan/keskiarvoyrityksen avulla. Tämä yksinkertaistaa arvon laskentaa huomattavasti. Lisäksi jos otosaineiston edustavuus tiedetään, otoksen perusteella laskettu GSV voidaan yleistää koko perusjoukon tasolle.

Empiirisessä esimerkissä GSV-aggregointia sovelletaan sektoritasolla kahteen FADN-aineistoon pohjautuvaan esimerkkiaineistoon. Nämä koostuvat 332 suomalaisesta maitotilasta ja 141 viljatilasta. Tulosten mukaan tehokkaasti toimiviin tiloihin suhteutettuna aggregoitu menetys voi olla merkittävä.

On huomattava, että kestävyysarvo on tehokkaisiin tiloihin perustuva suhteellinen mitta. Se ei kykene kuvaamaan absoluuttista kestävyyden tasoa.

Avainsanat: tehokkuus, aggregointi, DEA

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 (SV) method (Figge and Hahn 2004) is one of the attempts to quantify the sustainability performance of firms. A firm is said to create SV 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 estimated in one way or another. The benchmark can be seen as a reference group/firm 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.

The recent study by Kuosmanen and Kuosmanen (2009a) (hereafter KK) criticizes the original SV estimator for making strong assumptions about a linear benchmark technology that is identified by just a single data point. Moreover, KK showed that both SV and sustainable efficiency can be viewed as special cases of the standard efficiency indices known in the literature of productive efficiency analysis for decades. Building an explicit link between SV 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.

In KK 2009b, the proposed generalized sustainable value (GSV) approach has been applied using alternative parametric and nonparametric methods in estimating benchmark technology and sustainable values of firms. Figge and Hahn (2009) claim that this approach is restricted to the firm level. This is not true. The aggregation of efficiency indices has been a subject of debate in the literature of productive efficiency analysis for some time (see, e.g., Blackorby and Russel 1999, Färe and Zelenyuk 2003, Kuosmanen *et al*. 2006).

The purpose of this paper is to develop a theoretical framework for estimating an aggregate GSV measure of any group of firms in a specific sector, specialization, region, or any other group, such that resulting GSV's were consistent with the firm-level estimates. We first briefly recapture the concept of GSV at firm-level, and next establish a theoretical framework for aggregate GSV at sector and region levels. Then we review econometric approaches currently available that can be usefully applied in the context of GSV for estimating the benchmark technology. Empirical section illustrates the proposed aggregate GSV estimation by two applications on data of Finnish dairy and cereal farms. The last section concludes.

Aggregation of SV indices

In this section, we first briefly recapture the notion of *generalized sustainable value* (GSV) and its estimation at firm level. Then we develop a theoretical framework for the aggregate GSV at the sector and region levels.

GSV at firm level

Assume firm *i* ($i = 1,\dots,n$) 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 GSV as the firm's sustainability performance, which can be measured as the difference between firm's economic output produced by using a bundle of resources and the opportunity cost of these amounts of resources

(1) $$GSV_i = y_i - OC(\mathbf{x}_i).$$

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

Opportunity cost of resources is not directly observable, and therefore 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 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. Hence, without loss of generality, we may interpret the numerical value of production function $f(\mathrm{x})$ as the total opportunity cost of resource bundle **x** (KK 2009a).

Applying the previous insights, the general definition of SV can be rewritten as

(2) $$GSV_i = y_i - f(\mathrm{x}_i)$$

Formulation (2) is not restricted to any particular functional form of the production function *f*, it allows resources to be interdependent, allows non-substitutability between resources and it also allows preserving some critical level of resources to be consistent with strong sustainability.

Note that identity (2) defines SV as the residual between the observed output and the production function. If we simply reorganize the terms of equation (2), obtain the following

(3) $$y_i = f(\mathrm{x}_i) + GSV_i .$$

This can be interpreted as the standard regression equation, where generalized sustainable value GSV_i can be seen as the disturbance term. To be more specific, introduce a composite disturbance term ε_i that consists of differences in sustainability performance (i.e., sustainable value SV_i) and the effects of measurement errors, differences in unobserved or omitted variables, and other deviations from the production function *f*, captured by the random noise term v_i. Hence,

(4) $$\begin{aligned} y_i &= f(\mathrm{x}_i) + GSV_i \\ &= f(\mathrm{x}_i) + \varepsilon_i \\ &= f(\mathrm{x}_i) + SV_i + v_i . \end{aligned}$$

From this perspective, the generalized SV formulation (4) conforms with the classic approach to measuring performance differences across firms based on regression residuals (e.g., Timmer 1971, Richmond 1974). In fact, recent paper by KK (2009b) has provided a detailed examination and classification of alternative methods available for estimating production functions such as (4). In addition to reviewing the theoretical properties of alternative methods, this paper has presented a critical examination of advantages and disadvantages of the methods. It has illustrated a practical implementation of the reviewed methods to the empirical data of 332 Finnish dairy farms, where the SV measures have been estimated at farm-level. In the next section we consider an aggregation of firm-level GSV measures to any group of firms in a specific sector, specialization, region, or any other group.

GSV of sector

Aggregation of firm-level GSV measures to sector, region or country levels is not as straightforward as it might seem. Even if firms are technically efficient at the firm level, there may be lack of coordination, which shows as inefficiency at the aggregate level Thus, average of firm level GSV is different from GSV of the average vector. Whether we use firm-level or aggregate level data, it is important to ensure that the firm-level GSV measures match with their counterparts at aggregate level.

To develop a simple but systematic aggregation scheme, we propose the following aggregate GSV 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. Let the average output of group *I* be $\bar{y} = \sum_{i\in I} y_i / n$, and the average resource vector $\bar{\mathrm{x}} = \sum_{i\in I} \mathrm{x}_i / n$. These values characterize the representative firm of this group. Given the production function *f*, the aggregate GSV measure can be calculated simply as the GSV of the representative firm multiplied by number of the firms in the group

(5) $$AGSV_I = n\cdot\left(\bar{y} - f(\bar{\mathrm{x}})\right).$$

Figure 1 illustrates an example of estimating aggregate GSV of group of firms.

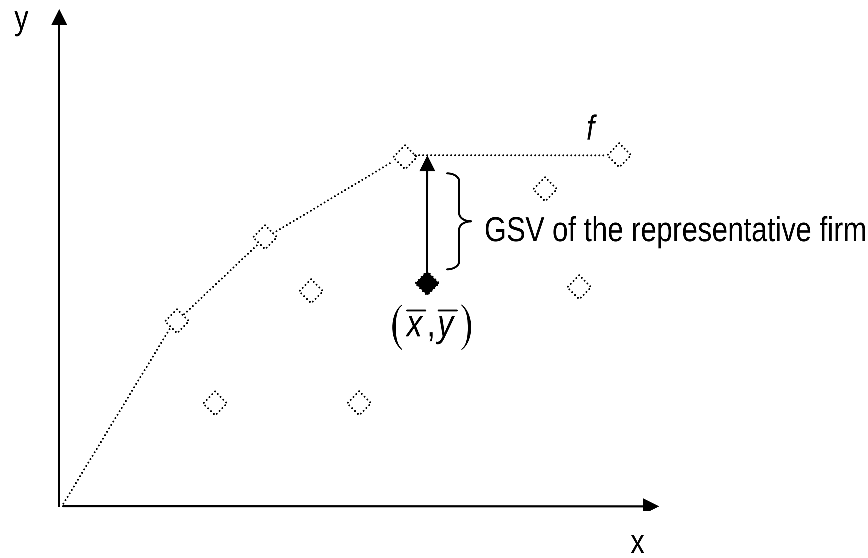

Figure 1. Production frontier estimated by DEA; representative firm and aggregate GSV.

The main assumption is that all firms have access to the same production technology. Hence, the production frontier can be estimated using one of the available methods, e.g., data envelopment analysis (DEA). DEA is the nonparametric, mathematical programming-based technique to be discussed in more details in the section 3. It constructs the frontier by enveloping the data as tight as possible. In practice, having empirical data of inputs and outputs, the average output and the average inputs are calculated, which symbolizes a representative firm of this group. Next, the representative firm is included in the data set and the production function *f* is estimated. Finally, the aggregate GSV is calculated according to formula (5) as the difference between the average output of the group (output of the representative firm), $\bar{y}$, and the numerical value of the production function $f(\bar{\mathrm{x}})$ in point $\bar{\mathrm{x}}$, multiplied by number of firms in the group.

Proposed AGSV measure has a compelling profit interpretation. More specifically, define the profit function as

$$\pi(\mathrm{w}) = \max_{\mathrm{x}} \{ y - \mathrm{w}'\mathrm{x} \mid y = f(\mathrm{x}) \} = \max_{\mathrm{x}} \{ f(\mathrm{x}) - \mathrm{w}'\mathrm{x} \}.$$

Without loss of generality, the output price can be normalized as 1, 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*. 2009).

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.

AGSV 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 GSV measure* $AGSV_I = \bar{y} - f(\bar{\mathrm{x}})$ *indicates the average profit efficiency of the firms in group I at the most favorable non-negative input prices. Specifically:*

$$AGSV_I = \max_{\mathrm{w} \geq 0} \left(\sum (y_i - \mathrm{w}'\mathrm{x}_i) - \pi(\mathrm{w}) \right) / n.$$

GSV of region or group

Formulation of aggregate GSV can be extended to any group of firms, for example, firms located in specific region, as long as the production technology *f* is the same. Let the average output and the average resource vector of group *g* be $\overline{y}_g$ and $\overline{\mathrm{x}}_g$. Then, the aggregate GSV of group *g* is

(6) $GSVG = n \cdot \left(\overline{y}_g - f\left(\overline{\mathrm{x}}_g\right)\right)$, where *n* is the number of firms in group *g*.

Consider two production lines, for example, dairy and crop. Can we compare performances of dairy and crop farms under the same production technology? Obviously not. For estimating production frontier and aggregate GSV measures, the evaluated groups of firms must be homogeneous and comparable, that is, the firms must be engaged in a similar set of operations and have access to the same production technology. To compute the aggregate GSV of several groups, one should estimate the aggregate GSV of each group and then add together the resulted measures. For example,

(7) $GSVG_{total} = k \cdot \left(\overline{y}_g^{crop} - f^{crop}\left(\overline{\mathrm{x}}_g^{crop}\right)\right) + m \cdot \left(\overline{y}_g^{dairy} - f^{dairy}\left(\overline{\mathrm{x}}_g^{dairy}\right)\right)$, where *k* and *m* are the number of farms in the groups of dairy and crop farms, respectively.

Data and method

Estimating production technology

In formulation (4), interpreted as the standard regression equation, GSV_i can be seen as the disturbance term capturing the effects of measurement errors, differences in unobserved or omitted variables, and other deviations from the production function *f*. GSV_i seems to be easy to calculate. However, the true production function is unknown, and therefore its empirical estimation is needed. Starting from equation (4), we classify the methods in six categories according to how the production function *f* and the composite disturbance ε_i are specified (for more detailed description of the methods available for estimating benchmark technology in the context of SV analysis see KK 2009b).

One of the alternative methods available for estimating the benchmark technology in the context of SV analysis is data envelopment analysis (DEA) (Charnes *et al*. 1978). Since we have applied this mathematical programming-based technique in both applications and, we review it in more details.

DEA is the most widely used nonparametric frontier approach. It is a deterministic linear programming method. It does not require any prior assumptions about the functional form of *f*, but only assumes that *f* belongs to the family of monotonic increasing and globally concave functions, similar to CNLS. An important advantage of DEA is that it does not require any statistical assumptions about the composite disturbance term ε_i. However, the main disadvantage is that DEA does not take into account any stochastic noise (i.e., $v_i = 0 \ \forall i = 1,...,n$). Indeed, DEA efficiency scores are sensitive to extreme observation and outliers.

DEA estimator of production function *f* can be expressed as

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

This yields a continuous, piece-wise linear frontier that envelopes the observed data from above. If $y_i = f_{DEA}(\mathrm{x}_i)$, then $SV_i = 0$, and the firm is diagnosed as efficient. If $y_i < f_{DEA}(\mathrm{x}_i)$, then $SV_i < 0$, and the firm is said to be inefficient. In standard DEA, outcome $y_i > f_{DEA}(\mathrm{x}_i)$ is not possible. Given a resource vector **x**, the values of this production function are easy to compute by linear programming.

In summary, for calculating SV, the benchmark technology (or the production function) must be estimated in one way or another (partners may use any of the available methods from table 1). SV can be estimated separately for each sector or region, if data permits and the sample size is large enough. Next, we consider two applications of the aggregate GSV.

Data

The data sets are extracted from the Farm Accountancy Data Network (FADN) database. The economic output of cereal farms is the total revenue from crops and crop products (SE131), and is expressed in €. The economic output of dairy farms is the total revenue from milk and other products (SE131), expressed in €. Economic resources include labor (SE011) expressed in hours (hr), total utilized agricultural area (SE025) in hectares (ha) and farm capital (SE510) in €. Environmental resources include the total energy cost (SE345) in € and fertilizers (SE295) in €. 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.

Table1: Descriptive statistics for the sample of dairy farms; year 2004, sample size n=332

Variable	Mean	St. Deviation	Min	Max
Total output,€	91676	52336	16671	393392
Labor, hr	5123	1719	399	13458
Farm capital,€	261150	191099	18779	1481375
Energy, €	5843	3561	713	25541
UAA, ha	49.1	25.4	13.1	146.8
Fertiliser, €	4746	3558	0	22922

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

Variable	Mean	St. Deviation	Min	Max
Total output,€	54838	54349	2493	342863
Labor, hr	2139	1286	160	6807
Farm capital,€	228020	162428	32599	997866
Energy, €	7074	4770	692	34973
UAA, ha	80.5	44.5	22.1	324.3
Fertiliser, €	7018	5209	0	28535

Results and discussion

First of all, we defined the average outputs of the farms for each production line simply as:

$$\overline{y}^{dairy} = \sum_{i \in I} y_i^{dairy} / n ,$$

$$\overline{y}^{cereal} = \sum_{i \in I} y_i^{cereal} / n ;$$

and defined the average resource vector as:

$$\overline{\mathrm{x}} = \sum_{i \in I} \mathrm{x}_i / n .$$

These averages stand for the representative dairy and cereal farms. Next we included the representative farms' data in the data samples and estimated the benchmark technologies for both production lines by output oriented DEA model with variable returns to scale. In the DEA-model, each farm is benchmarked against the efficient frontier constructed by efficient farms. For brevity, we do not report the efficiency scores of all farms, but only for the representative dairy and cereal farms. Thus, the resulting efficiency score of the *representative cereal farm* is equal to 0.513 (that is, the representative farm achieves only about half of its potential output), and the efficiency score of the *representative dairy farm* is equal to 0.649. Next we calculated the GSV values for both representative farms. It resulted in about -52,102€ for the representative cereal 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.

Finally, to obtain aggregate GSV measures for each production line, the estimated GSV's of representative farms are multiplied by number of farms in the sample. Thus, the aggregate GSV of the Finnish cereal production line resulted in about -7.4 million euros in year 2004 (-7,398,545€) and the aggregate GSV of the Finnish dairy production line resulted in about -16.5 million euros in the same year (-16,521,842€).

Conclusions

In conclusion, we estimated a monetary value of potential sustainability improvements by technical efficiency of the representative cereal and dairy farm. Potential efficiency improvements have been estimated by DEA with an output orientation. We have to highlight that that possibilities for improving relative sustainability through efficiency exist, but we cannot say, what is the exact sustainability level of improved production.

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