ASSESSMENT OF AGRICULTURE PUBLIC GOODS BY SHADOW PRICES

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Abstract - The paper focuses on assessment of agriculture public goods by shadow prices. It summarises the literature findings and compares literature sources dealing with shadow prices assessment. The original papers and case studies analysed in this paper come from Scopus and ISI Web of Knowledge databases. The key words used for search in the above mentioned databases included shadow price agriculture, trade-off, and shadow distance function agriculture. The results in the form of a literature survey may serve to other researchers dealing with similar topics.

Key words - Show Prices; Public Good; Agriculture; Trade Off.

I. INTRODUCTION

The agricultural production process can be characterised as transformation of many inputs (in the most general classification - land, work, capital) to many outputs, whether in the form of various main products or the main and side products, market or non-market production. The outputs of agricultural activities which do not pass through the market can be assessed by a shadow price, which Dréze and Stern (1990) define as an increase in affluence of society in consequence of availability of an additional unit of certain goods. A similar definition is provided for also by Squire and van der Tak (1995). A shadow price can, however, be perceived also as an equivalent to the price of certain goods in the case of their market realisation on a market with perfectly functioning competition, or in other words - shadow price is an implicit value of the non-market output of production (Lee et al., 2014).

II. MATERIALS AND METHODS

The aim of the presented paper is to perform summarisation and comparison of studies and specialised articles dealing with valuation of agriculture public goods with the help of shadow prices. An analysis of literature sources from the Scopus and ISI Web of Knowledge databases was carried out for the purpose of achievement of the objective set out. The key words used for search in the above mentioned databases included shadow price agriculture; trade-off, shadow distance function agriculture. The notion “shadow price agriculture” led to the finding of 81 results in the Scopus database, nevertheless not all of them use the distance function approach, but e.g. CGE instead. Altogether 65 results were found in the ISI Web of Knowledge database; and here again - not all of them use the distance function and not all of them assess public goods, but for example trade off between the profit and risk.

Under the key words shadow price distance function agriculture it was possible to find 6 results in the Scopus database and 9 results in the ISI Web of Knowledge database. The Results in the form of a literature survey may serve to other researchers dealing with similar topics.

III. RESULTS

The above mentioned facts lead to its quantification from income or cost functions, which were processed by Färe and Grosskopf (1998). The basis for the deriving of shadow prices in the cited publication is the procedure built upon Shephard (1970) output-oriented distance function (known as Output Distance Function, “ODF”) and upon the presumption of impossibility of disproportionate reduction of all outputs (known as the axiom of weak disposability of outputs), see (1) and (2).

\[ D_0(x,y) = \inf \{ \theta : (x',y') \in P(x) \} \]
\[ y \in P(x), 0 \leq \theta \leq 1 \rightarrow y \in P(x) \]

where \( x \) is a vector of inputs, \( y \) is a vector of outputs and \( P(x) \) represents the set of all available vectors of outputs produced by a given vector of inputs and \( \theta \) expresses maximum proportionate increase in vector \( y \) corresponding to the given vector \( x \).

In consequence of the above mentioned axiom of weak disposability of outputs (2), the following holds for ODF: \( D_0(x,y) \leq 1 \) (see Färe and Primont, 1995).

Färe and Grosskopf (1998) moreover use the relation of duality between the income function and ODF and the condition of maximisation of incomes:

\[ R(x,p) = \max_y p^y, s.t. D_0(x,y) \leq 1, \]

where \( p \) is the price vector of outputs. By solving the maximisation problem with the help of the Lagrangian method it is possible to subsequently obtain the shadow prices.
\[ p = h(x, p) \frac{\partial h(x, p)}{\partial y} \] \tag{4}

where \( \nabla \) is the ODF gradient.

Färe and Grosskopf (1998) complement the particular relation for the case of two outputs \((m \text{ and } n)\), when their relative price is obtained as a ratio of partial derivations of ODF:

\[ p_m = \frac{\partial y_m(x, p_m, 0, p_n)}{\partial y_m(x, p_m, 0, p_n)} \tag{5} \]

Provided that the shadow price of the market output (e.g. \( p_n \)) corresponds to its market price, it is possible to determine, from equation (5), the shadow price of the non-market output \((p_m)\):

\[ p_m = \frac{\partial y_m(x, p_m, 0, p_n)}{\partial y_m(x, p_m, 0, p_n)} \tag{6} \]

Shadow price of non-market goods is thus derived from the market price of the goods realised on the market and (as added by Hadley (1998)) it does not represent the costs of the society, but private costs of the producer.

The above described procedure has become a basis for quantification of shadow prices in a number of other publications (Singbo et al., 2015; Serra and Poli, 2015; Hou et al., 2015; Bokusheva and Kumbhakar, 2014; Lee et al., 2014; Zhang et al., 2014; Bostian and Herlily, 2014; Rosano-Peña et al., 2014; Cuesta et al., 2009; Van Ha et al., 2008; Bond and Farzin, 2007; Murty et al., 2006; Lee, 2005; Shaik et al., 2002; Reig-Martínez et al., 2001; Hadley, 1998), an overwhelming majority of which were focused on assessment of negative non-market outputs from production, e.g. emissions of CO2, NOx, water contamination. The outputs from the production process are differed in the above mentioned publications as desirable (demanded by consumers, \( y_d \)) and undesirable (causing loss of use, \( y_u \)), which enter into the models of shadow prices in the form of an index (e.g. index of ground water endangerment applied in Hadley (1998) or as quantity of a contaminating substance (e.g. nitrogen in Bokusheva and Kumbhakar (2014)).

At the same time it is supposed that an undesirable output is a side product during production of a desirable output. In consequence of the above mentioned side production there is not, according to Bokusheva and Kumbhakar (2014), any substitution between desirable and undesirable goods, and that is why at a given vector of inputs \( x \) and at a presumption of an effective production technology, it is not possible to reduce production of undesirable goods without simultaneous reduction of desirable goods (axiom of weak disposability of outputs). In other words, any reduction of undesirable output means certain costs (Molinos-Senante et al., 2015) and calls out economic-environmental displacement (Van Meensel et al., 2010). Joint production of the two given outputs leads also to the presumption that at a zero production of undesirable output the volume of desirable output is zero as well (the so-called null-jointness). Formally:

\[ (y_m, y_n) \in P(x) \text{ and } if \quad -l_i y_m = 0, \quad \eta_n = 0. \] \tag{6}

Desirable outputs are at the same time freely disposable (the so-called free disposability axiom), or in other words it is possible to produce lesser quantity of a desirable output at the given vector \( x \) (Rosano-Peña et al., 2014). The above mentioned statements mean, according to Molinos-Senante et al. (2015), a possibility of reduction of desirable outputs without reduction of undesirable outputs:

\[ (y_m, y_n) \in P(x), \text{then for } y'_m \leq y_m, (y_m, y'_n) \in P(x). \] \tag{7}

The shadow price of an undesirable output can then be defined as an opportunity cost of reduction of undesirable output by one unit (Zhang et al., 2014). The particular methodological apparatus of quantification of shadow prices on the basis of distance function differs in individual publications, according to Lee et al. (2014) in three main points: (i) in distance function orientation, (ii) in the distance function type, (iii) in the estimation method. The distance function orientation can be of two types: output-oriented function which is dual to the income function; and input-oriented function with duality to the cost function. Färe and Grosskopf (1998) founded determination of shadow prices on the output-oriented distance function (ODF) and maximisation of incomes. The input-oriented distance function (Input Distance Function, IDF) connected with minimisation of costs was applied to determine the shadow price e.g. by Singbo et al. (2015), Serra and Poli (2015), Sheng et al. (2015), Bokusheva and Kumbhakar (2014), Lee (2005), Shaik et al. (2002), both for quantification of the shadow price of input (Lee, 2005) and for the one of output (Bokusheva and Kumbhakar, 2014).

Lee et al. (2014) further outline the most frequently used types of the distance function, namely Shephard and directional (Directional Distance Function, DDF) types. Properties of these functions and examples of their use are provided for in table no. 1, in which DDF is stated in an output-oriented form. An example of the input-oriented form is provided by Serra and Poli (2015). Concerning less frequently used types of distance functions used at determination of shadow prices, it is possible to mention a hyperbolic distance function (Cuesta et al., 2009), or non-radial DDF (Choi et al., 2012).

Zhou et al. (2014) compares frequency of application of individual types of the distance function and comes to an opinion that Shepard functions were most frequently used in the past in models of shadow prices, nevertheless at present the number of studies applying DDF is growing.
Table 1– Properties of distance functions and their use

<table>
<thead>
<tr>
<th>Type</th>
<th>Approach</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-parametric</td>
<td>DEA</td>
<td>Simar and Wilson (2000); Färe et al. (2010); Zhang et al. (2015); Färe et al. (2013)</td>
</tr>
<tr>
<td>Parametric</td>
<td>Non-parametric programming (linear)</td>
<td>Molinos-Senante et al. (2015); Zhang et al. (2014); Reig-Martínez et al. (2001); Hadley (1998)</td>
</tr>
</tbody>
</table>

Source: Author’s own source prepared according to Zhou et al., 2014

The main difference in the above listed functions consists in the proportionality of the change in outputs/inputs. Shephard functions are, according to Lee et al. (2014), founded on a presumption of a simultaneous increase in desirable as well as undesirable outputs, while DDF functions suppose an asymmetric change in these outputs. Shephard functions therefore show, according to Wu et al. (2013), an absurd situation when a growth of the undesirable output is associated with growing effectiveness, and in a final consequence they are distorting shadow prices. Bokusheva and Kumbhakar (2014) as well as Molinos-Senante et al. (2015) add that DDF enables an increase in the desirable output at a simultaneous reduction of the undesirable output. It is possible to express the above mentioned facts also with the help of a hyperbolic distance function, however in a multiplicative form only (Lee et al., 2014).

Zhang et al. (2014), when comparing Shephard functions and DDF, comes to the conclusion that shadow prices determined on the basis of DDF are significantly higher than the prices determined according to Shephard ODF. The values of shadow prices quantified according to DDF are, however, sensitive to the choice of the direction vector (g), as proven by Vardayan and Noh (2006). In spite of the above, in a number of publications a unit vector with a negative sign at undesirable output is used (e.g. Rodseth, 2013; Färe et al., 2006).

The models of shadow prices can be estimated by parametric (linear programming, SFA-Stochastic Frontier Analysis) or non-parametric techniques (DEA-Data Envelopment Analysis), see table no. 2.

Table 2 – Types of estimations of models of shadow prices

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Non-parametric</td>
<td>DEA</td>
<td>Serra and Poli (2013); Simbo et al. (2015)</td>
</tr>
<tr>
<td>Parametric</td>
<td>Deterministic programming (linear)</td>
<td>Molinos-Senante et al. (2015); Zhang et al. (2014); Rosano- Pinto et al. (2014)</td>
</tr>
<tr>
<td>Stochastic</td>
<td></td>
<td>Bokusheva and Kumbhakar (2014); Ucsor et al. (2009); Hadley (1998)</td>
</tr>
</tbody>
</table>

Source: Author’s own source prepared according to Zhou et al., 2014

Leleu (2013) deals with a non-parametric approach at a detailed level. An advantage of that approach is absence of the necessity to outline a particular functional form (see Molinos-Senante et al., 2015; Zhang et al., 2014). On the other hand, a disadvantage is that the results are not valued statistically (Singbo et al., 2015). This inconvenience is solved by Singbo et al. (2015) by completing the DEA with a bootstrap algorithm published in Simar and Wilson (2000).

Application of the parametric approach in comparison with the above stated method requires the outlining of a particular analytical form of the distance function, which subsequently represents the actual production technology. Inclusion of a time vector into the distance function furthermore makes it possible to model the effect of a technical change. Zhang et al. (2014) consider the above mentioned characteristics to be advantages of the parametric approach if compared to the non-parametric one.

From parametric approaches as well as from estimation methods in general it is linear programming that is, according to Van Ha et al. (2008), the most frequently used method of estimation of the model of shadow prices, and this holds for several reasons: no specific probability distribution is required, with a relatively small number of observations it is possible to calculate a large number of parameters, and it is relatively simple in terms of computations. The disadvantages of the above mentioned approach, however, include its actual deterministic nature and absence of statistical criteria for assessment of consistency of the parameters obtained. The disregarding of random shocks which can influence the outputs of production can distort economic results. The above mentioned disadvantages remove stochastic parametrical approaches.

In the publications using parametric approaches it is also possible to find various function forms, in particular transcendental logarithmic (“translog”, Bokusheva and Kumbhakar, 2014; Zhang et al., 2014; Van Ha et al., 2008; Lee, 2005; Reig-Martínez et al., 2001; Hadley, 1998) and quadric (Molinos-Senante et al., 2015; Färe et al., 2006). From the above mentioned list it is obvious that a translog function form meeting (according to Zhou et al. (2014)) the linear homogeneity condition and satisfactory axiom of weak disposability of outputs prevails. With regard to the fact that the quadratic function fulfils the transformation characteristic, it is possible to further add that it is more suitable in case of DDF, while a transcendental logarithmic function is more suitable for Shephard distance function with a homogeneity requirement of level one and more. A detailed comparison of the above mentioned functions is provided by Färe et al., 2010, coming to the conclusion (on the basis of a Monte Carlo simulation) that the DDF approach is more advantageous in terms of the model estimation’s efficiency and computational simplicity.
experiment) that a quadratic function is more flexible than a transcendental logarithmic function.

An alternative approach to the above mentioned variants can be found in the publication by Bokusheva and Kumbhakar (2014), where the technology of desirable and undesirable outputs is modelled separately, with the help of a hedonic function that represents the aggregated output of the producer and explicitly describes the relation between the two given outputs. For the purpose of determination of shadow prices this function is subsequently included into IDF.

From the publications that assess agricultural public goods on the basis of the Färe and Grosskopf (1998) approach it is possible to mention especially Bostian and Herlihy (2014), applying DDF in a quadratic form to assess the so-called trade-off between the agricultural production and improvement of functionality of wetlands, namely on the basis of linear programming with the use of a wetland quality index as one of the production process outputs. A quantified shadow price thus reflects opportunity costs of giving up a part of agricultural production, which however leads, according to the above mentioned authors, to underestimation of its value for the society. A similar conclusion is derived also by Berre et al. (2013), who compare the shadow price of emissions from dairy cattle breeding from the position of a producer and from the viewpoint of the society.

The discordance between the opportunity costs and willingness of the society to pay for certain public goods is highlighted also by the research of Ruijs et al. (2013) assessing agricultural public goods with the help of opportunity costs corresponding to the loss of incomes from the agricultural production in consequence of a marginal increase of the ensured public goods, of both social (measured by the tourist attractiveness index) and environmental (biodiversity, carbon sequestration) nature. The trade-off between the agricultural production and public goods implying from a change in the use of the production factor (soil), is quantified on the basis of two-level semi-parametrical estimation (for more details see Florens and Simar, 2005) of Shephard ODF.

The income, cost or profit functions are directly used by a minority part of publications to derive shadow prices. For example, Ziołkowska (2015) used the net income function derived from the evaluated production function to quantify the shadow price of water. In a similar way, Pitman (1981) used the production function to derive the profit function and to subsequent quantification of shadow prices. Myrria and Pietola (2002) were estimating, in a direct manner, the profit function from which they quantified the shadow price of soil. Unlike the distance function, however, the above mentioned approaches require information about prices of inputs and outputs, that are not always available, and observance of the presumption of cost minimisation or profit maximisation. The release of the above mentioned requirements is considered by Van Ha et al. (2008) to be the main advantage of the distance function.

At the end it is necessary to stress that the above described approaches are based on the existence of opportunity costs of increasing the production of public goods (alternatively reducing in case of undesirable goods) by a unit. The study by Barraquand and Martinet (2011), investigating the influence of agro-environmental measures on biodiversity in an agricultural countryside, however, refers to limited displacement of agricultural production by ensuring the above mentioned public goods. Sauer and Wossink (2013) add that there may be a complementary relation between the agricultural production and public goods, when a marginal increase in public goods will contribute to an increase in the agricultural goods. In the given case, opportunity costs are zero and this means that the shadow price of the public goods is zero as well.

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