RESOURCE USE EFFICIENCY OF DUTCH DAIRY FARMS; A PARAMETRIC DISTANCE FUNCTION APPROACH*

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Abstract

The objective of this paper is to define and to estimate a resource use efficiency measure using a panel of Dutch dairy farms. Resource use efficiency reflects observed to maximum revenue, including the non-positive revenue of bad outputs. It can be decomposed into technical and environmental efficiency. Our parametric output distance function allows the characteristics of non-point source pollution. Shadow prices of the undesirable output (nitrogen surplus per hectare) are found to be positive for all observations, due to the materials balance definition of nitrogen surplus. Intensive farms are found to be slightly more resource use efficient than extensive farms.

Introduction

Increasing agricultural productivity has been a long time policy objective in most Western European countries. Agricultural productivity has been increased by technological developments and by the substitution of fertilizer, concentrates and energy for labor and land. However this increased use of variable inputs is the source of the current environmental problems caused by agriculture. Now sustainable development of a competitive agriculture is the major objective of the Dutch agricultural policy.

To achieve a competitive agriculture, farms have to apply marketable inputs (conventional resources) as efficiently as possible, and to create an environment-friendly agriculture they have to deal efficiently with the environment (natural resources). This raises the question how efficient conventional resources and natural resources are used in Dutch dairy farming. To answer this question a resource use efficiency measure must be developed.

An environmental performance measure has been developed by Färe et al. (1989). They evaluate producer performance in terms of the ability to obtain an equiproportionate increase in desirable output and reduction in undesirable output. They use a nonparametric mathematical programming technique known as data envelopment analysis (DEA) to construct their best-practice frontier (see also Ball et al. and Tyteca). Mathematical programming techniques can also be used to calculate the parameters of an output distance function (see Färe et al. (1993) and Coggins and Swinton). In these two studies shadow prices of the undesirable outputs are calculated, but are imposed to be negative. This is a reasonable assumption for a point source pollution problem. For example in an industry the production of a good output, such as paper or electricity, typically is accompanied by the joint production of undesirable by-products such as suspended solids or SO_2. The fact that goods and bads are jointly produced means that reduction of bad output will be ‘costly’.

By definition, non-point source pollution does not enter the environment at a defined point. As a result it cannot be measured (easily) directly. We use nitrogen surplus (nitrogen in inputs minus nitrogen in desirable outputs) per hectare as a proxy for the emission of nitrogen to the environment. This undesirable output is the result of a materials balance definition, nitrogen in inputs has to be divided between good output and bad output. In this context the good output and the bad output are more likely to be substitutes. As a result the shadow price of bad output will be positive for technically efficient farms.

This paper makes a contribution to the applied literature on three fronts. First, we investigate the relation between good and bad outputs using econometric techniques to estimate an output distance function with a panel of Dutch dairy farms. This distinguishes our approach from all of those mentioned above. Second, our approach allows for the characteristics of non-point source pollution. We do not impose restrictions on the curvature of the output distance function. The shadow price of the undesirable output turns out to be positive. Third, we define an environmental efficiency measure and a resource use efficiency measure using the definitions of allocative efficiency and overall efficiency of the output mix, respectively.

Resource Use Efficiency In Good And Bad Output Space

Figure 1 represents the production possibilities set in the case of point source pollution, without using a materials balance definition (see e.g. Coggins and Swinton). The outer boundary 0BC depicts the best practice output frontier. According to Färe et al. (1989) the relation between good output and bad output is represented by a technology which is weakly disposable in bad output. A reduction in bad outputs is feasible only if desirable outputs are simultaneously reduced, conditional on the inputs.

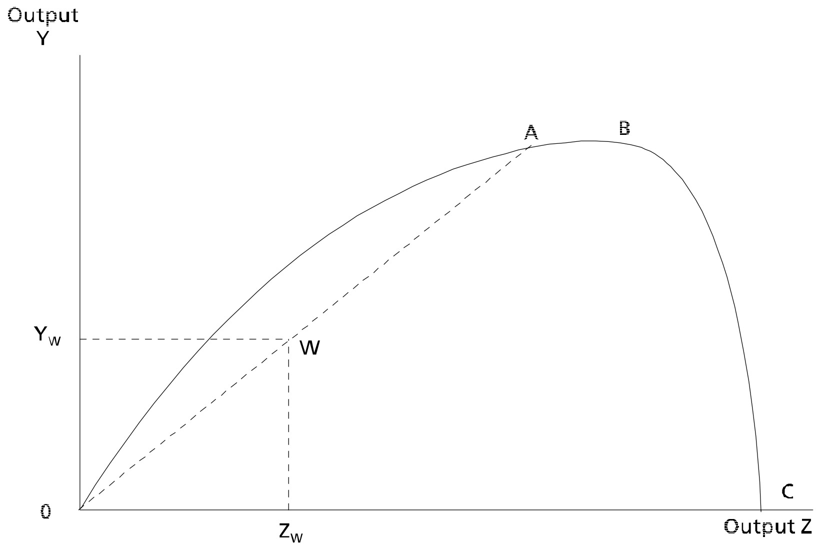

Figure 1. Production possibility set in good output, Y, bad output, Z, space.

The technology is represented by the output set $P(X)=\{(Y,Z)$: X can produce $(Y,Z)\}$, where X is the input vector, Y is the good output vector and Z is the bad output vector. The technology satisfies weak disposability if $(Y,Z) \in P(X)$ implies that $(\theta Y, \theta Z) \in P(X)$, for every $\theta \in [0,1]$. Further it is assumed that the desirable outputs are strongly disposable $(Y,Z) \in P(X)$ and $Y' < Y$ imply $(Y',Z) \in P(X)$. For a treatment of the properties that $P(X)$ customarily satisfies, see Färe and Primont.

An alternative representation of the technology, conveying the same information, is the output distance function. The output distance function is defined as

$$D_O(Y,Z,X) = \min\{\theta : (Y/\theta, Z/\theta) \in P(X)\} \quad (1)$$

The distance function will take a value which is less than or equal to one if the output vector (Y,Z) is an element of the feasible output set $P(X)$. The distance function will take a value of unity if (Y,Z) is located on the outer boundary of the output set. The distance function measure is the inverse of the Farrell-type output-oriented measure of technical efficiency. In Figure 1 the distance value associated with output bundle W is $D_O(Y_W, Z_W, X)$= 0W/0A.

The distance function can be used to compute shadow prices of the bad output. The ratio of the good output shadow price and the bad output shadow price is reflected by the slope of the distance function frontier at the observed output mix (F≅re and Primont)

$$\frac{r_Y}{r_Z} = \frac{\partial D_o(X,Y,Z)/\partial Y}{\partial D_o(X,Y,Z)/\partial Z} \qquad (2)$$

Where r_Z is the shadow price of the undesirable output and r_Y is the shadow price of the desirable output. In empirical studies in which the negative shadow prices of the bad output is imposed (e.g. Färe et al.,1993; Coggins and Swinton), the focus is only on the trajectory 0B.

In the case of non-point source pollution, the undesirable output is the result of a materials balance definition. Nutrients in inputs have to be divided between good output and bad output. In this context the relation between good output and bad output is more likely to be in line with the standard relation between desirable outputs, similar to the trajectory BC in Figure 2. This relation between good and bad output is characterized by positive shadow prices for the bad output. In this figure it is assumed that there are no points in the production possibility set left to the line 0B, due to technical (biological) restrictions. Point B in Figure 2 can be defined as $(Y_B, Z_B) \in P(X)$ where $R(X,p) = \max\{p_yY + p_zZ: (Y_B, Z_B) \in P(X), p_z \leq 0\}$

where p_y and p_z denote vectors of output prices (good output and bad output respectively) and $R(X,p)$ is the revenue function described by Färe and Primont. The price of bad output is equal to zero, or negative if a tax is imposed on the undesirable output.

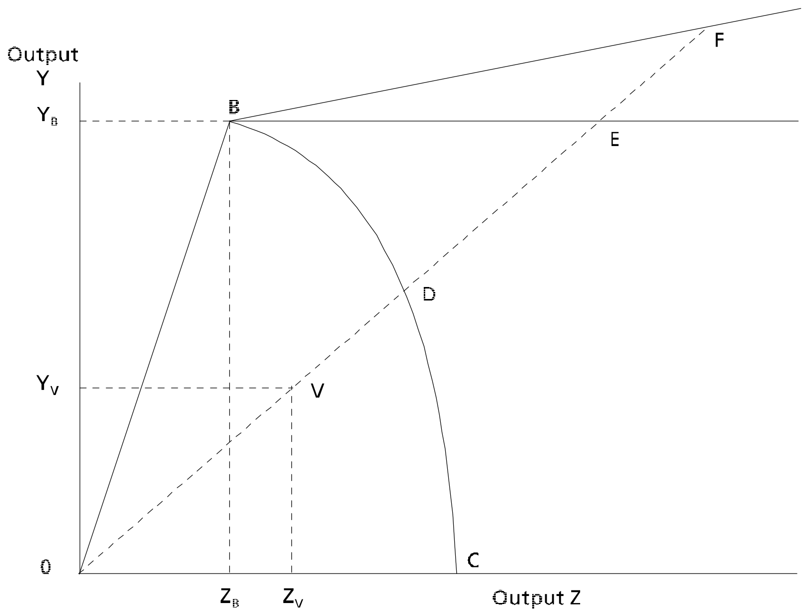

Figure 2. Production possibility set in good output, Y, bad output, Z, space.

In point B in Figure 2 the resources are optimally used, because (i) point B is on the frontier, so the conventional resources are used in a technically efficient manner, (ii) in point B the natural resources are optimally used, because it is the technically efficient point with the lowest production of undesirable outputs per unit of desirable output.

To obtain a measure of technical efficiency the output distance function can be used. In Figure 2 the technical output-oriented efficiency measure (*TE*) associated with output bundle V is

$$TE_V\,(Y_V\,,Z_V\,,X\,) = \frac{1}{D_O\,(Y_V\,,Z_V\,,X\,)} \tag{3}$$

and is equal to 0D/0V in Figure 2. In Figure 2 point D is equal to V/ $D_O(Y_V, Z_V, X)$.

The measure for environmental efficiency (*EE*) has to relate the ratio of good and bad output at point D (equal to the ratio at V) to the maximum ratio, at point B. A convenient measure is to use the definition of allocative output efficiency (Färe and Primont), which for the output bundle V is equal to

$$EE_V(Y_V, Z_V, X, p_Y, p_Z) = \frac{R(X, p)}{(p_Y Y_V + p_Z Z_V) / D_O(Y_V, Z_V, X)} \quad (4)$$

If p_Z is equal to 0 then EE_V is given by 0E/0D. If p_Z is negative then EE_V is given by 0F/0D.

We call point B in Figure 2 'resource use efficient', since the conventional resources and the natural resources are used efficiently. For our measure of resource use efficiency we want to compare the observed point *V* with resource use efficient point B. A convenient measure for resource use efficiency (*RE*) is the definition of overall output efficiency. *RE* compares the observed revenue with the maximum revenue of the desirable and undesirable outputs given the amount of inputs and the output prices. *RE* for output bundle V is equal to

$$RE_V(Y_V, Z_V, X, p_Y, p_Z) = \frac{R(X, p)}{(p_Y Y_V + p_Z Z_V)} \quad (5)$$

Maximum revenue is represented in Figure 2 by the line BE in case of a price of the bad output equal to zero, *RE* is given by 0E/0V. Maximum revenue is represented by the line BF if p_Z is negative, *RE* = 0F/0V. The more negative the price of the bad output, the higher the resource use inefficiency score will be.

It follows from the above definitions that resource use efficiency can be decomposed into a technical inefficiency and an environmental inefficiency component

$$RE_V(Y_V, Z_V, X, p_Y, p_Z) = TE_V(Y_V, Z_V, X) * EE_V(Y_V, Z_V, X, p_Y, p_Z) \quad (6)$$

If the relation between good and bad output can be represented by figure 1, identical definitions of the efficiency scores can be used. Then the optimal point will be to the left of point B if a negative price of bad output is assumed. In the optimal point the slope of the distance function is equal to the price ratio of good and bad output.

Translog Output Distance Function

The true curvature of the distance function is not clear beforehand (either Figure 1 or Figure 2). If we select a flexible functional form for the output distance function we may capture the true relationship between good and bad outputs. The translog output distance function for one desirable output and one undesirable output can be described as:

$$\ln D_{Oit} = \alpha_0 + \alpha_Y \ln Y_{it} + \alpha_Z \ln Z_{it} + \frac{1}{2}\alpha_{YY}(\ln Y_{it})^2 + \frac{1}{2}\alpha_{ZZ}(\ln Z_{it})^2 + \frac{1}{2}\alpha_{YZ} \ln Y_{it} \ln Z_{it}$$

$$+ \frac{1}{2}\alpha_{ZY} \ln Y_{it} \ln Z_{it} + \sum_{k=1}^{3} \beta_k \ln X_{itk} + \frac{1}{2}\sum_{k=1}^{3}\sum_{l=1}^{3} \beta_{kl} \ln X_{itk} \ln X_{itl} + \sum_{k=1}^{3} \beta_{kY} \ln X_{itk} \ln Y_{it}$$

$$+ \sum_{k=1}^{3} \beta_{kZ} \ln X_{itk} \ln Z_{it} + \sum_{t=2}^{4} \beta_t TD_t \qquad (7)$$

where for all farms indexed with a subscript i=1,…,I, and for all years indexed with a subscript t=1,…T,

D_{Oit} denotes the output distance function measure;

Y_{it} is the desirable output per hectare;

Z_{it} is the undesirable output per hectare (nitrogen surplus per hectare);

X_{it} is a vector of conventional inputs per hectare (X_{it1} = labor, X_{it2} = capital, X_{it3} = variable input);

TD_t is a time dummy variable;

α, β parameters to be estimated;

Using the linear homogeneity restrictions, choosing the desirable output as the normalizing output, adding a random error term and rewriting the distance measure lnD_{Oit} as -U_{it}, the output distance function can be rewritten as:

$$-\ln Y_{it} = \alpha_0 + \alpha_Z \ln(Z_{it} / Y_{it}) + \frac{1}{2}\alpha_{ZZ} \{\ln(Z_{it} / Y_{it})\}^2 + \sum_{k=1}^{3} \beta_k \ln X_{itk}$$

$$+ \frac{1}{2}\sum_{k=1}^{3}\sum_{l=1}^{3} \beta_{kl} \ln X_{itk} \ln X_{itl} + \sum_{k=1}^{3} \gamma_{kZ} \ln X_{itk} \ln(Z_{it} / Y_{it}) + \sum_{t=2}^{4} TD_t + U_{it} + V_{it} \quad (8)$$

where

V_{it} is a random error term, independently and identically distributed as $N(0,\sigma_v^2)$, intended to capture events beyond the control of farmers;

U_{it} is a non-negative random error term, independently and identically distributed as $N^+(\mu,\sigma_u^2)$, intended to capture time-invariant technical inefficiency in outputs;

μ parameter to be estimated.

The stochastic translog distance function can be estimated by maximum likelihood using the FRONTIER package developed by Coelli.

Data

In this study we utilize data describing the production activities of 613 strongly specialized dairy farms that were in the Dutch Farm Accountancy Data Network (FADN) for part or all of the 1991-1994 period. The FADN is representative of specialized dairy farms. We have a total of 1,545 observations in this unbalanced panel. The period 1991-1994 has been chosen because detailed information describing the nitrogen flows at each farm is available from 1991 onwards. In the specification we have chosen, the conventional inputs are aggregated into three categories: labor, capital (buildings, equipment, livestock) and variable inputs (hired labor, concentrates, roughage, fertilizer and other variable inputs). The desirable outputs (milk, meat, livestock and roughage sold) are aggregated into a single index of dairy farm output. Implicit quantity indexes are obtained as the ratio of value to the price index and therefore output is in prices of a specific year, 1991 being the base year. The price index used in this study is the average of a multilateral Törnqvist price index across farms for each year (Caves et al.). Nitrogen surplus, the difference between nitrogen input and nitrogen contained in desirable outputs, is measured in kilograms N. Because we defined the bad output as nitrogen surplus per hectare, we transformed all variables into a per hectare measure.

Empirical Results

Less than one third of the parameter estimates appeared to be insignificant (at the 95% significance level). We tested whether some parameters could be deleted. The full translog distance function was tested to be the most appropriate specification. The hypothesis of time invariant inefficiency could not be rejected.

One of the central elements of the paper is the investigation of the relation between the good and the bad output. The first derivatives of the output distance function with respect to output (either good or bad) are positive for all observations. Therefore, the ratio of the first derivatives with respect to the outputs is positive. Desirable output and nitrogen surplus behave like substitutes, as depicted in Figure 2. To compute the shadow price of bad output using equation (2), the market price of desirable output is assumed to reflect the shadow price. The shadow price of nitrogen surplus turns out to be positive for all observations, see Table 1.

Table 1. Elasticities and shadow prices of the estimated output distance function model

	mean	min	max

mean derivative Z	0.229	0.04	1.21
mean derivative Y	0.686	0.22	1.23
mean shadow price Z	0.304	0.03	1.47

The estimates of output-oriented technical inefficiency (reciprocal to the distance function measure) seem reasonable, ranging from 1.01 to 2.31 and a mean of 1.22. In the research period nitrogen surplus was not restricted for dairy farms, therefore we select p_z equal to zero. This is an upper bound for the real price of the undesirable output. Environmental inefficiency is higher on average (1.27), and exhibits less variability, than output-oriented technical inefficiency. The resource use inefficiency is by definition larger than the technical and environmental measures, ranging from 1.12 to 2.86 and a mean of 1.55. The rank correlation between the technical inefficiency and the environmental inefficiency scores is zero. Technical inefficiency and environmental inefficiency are positively correlated to the resource use inefficiency measure, due to the definition of resource use efficiency.

There has been an ongoing debate in the Netherlands whether the use of the number of cows per hectare is an appropriate proxy for the nitrogen emission. We find that the environmental inefficiency and the intensity (measured as dairy cows per hectare) are slightly positively correlated. Thus the more cows (and more manure) per hectare the higher the environmentally inefficiency score of the farm will be. This relation is not as strong as expected because intensive farms are characterized by buying a large share of the necessary feed (in contrast to producing the feed itself). These farms have less nitrogen losses from nitrogen fertilizer. These lower chemical nitrogen fertilizer losses partly compensate the large manure production per hectare of intensive farms. The relation between technical inefficiency and intensity is opposite, intensive farms are more technically efficient. The resource use efficiency score is the result of these opposite relations, see Table 2. The rank correlation between resource use inefficiency and intensity is therefore small but negative.

Table 2. Distribution of Dairy Farms by Environmental Efficiency and Intensity measured as cows per hectare

	Resource Use Efficiency					
Cows/ha	1.12-1.40	1.40-1.51	1.51-1.66	1.66-2.86	Total	# Farms
0 - 1.81	20%	18%	29%	33%	100%	383
1.81-2.14	23%	28%	27%	22%	100%	389
2.14-2.47	32%	27%	21%	20%	100%	388
2.47-5.20	28%	24%	24%	24%	100%	385
% Farms	26%	24%	25%	25%	100%	1545

Conclusions

In this paper a resource use efficiency measure is defined and estimated using a panel of Dutch dairy farms. Resource use efficiency reflects observed to maximum revenue, including the non-positive revenue of bad outputs. This resource use efficiency measure enables the identification of farms that are characterized by efficient use of conventional resources (technical efficiency) and efficient use of natural resources (environmental efficiency; defined as the ratio of observed to maximum production of desirable output per unit of undesirable output).

The undesirable output of dairy farms investigated in this paper is nitrogen surplus per hectare. Nitrogen emission from dairy farming is a typical non-point source pollution, it is measured using a materials balance. Using the Stochastic Frontier Approach a translog output distance function model is estimated without assumptions on the shadow price of the bad output. Due to the materials balance definition of nitrogen surplus good output and bad output turn out to be substitutes, in contrast to assumptions on point source pollution in previous research (F≅re et al. 1993; Coggins and Swinton). The shadow price for nitrogen surplus is positive for all observations.

The mean ‘lower bound’ resource use efficiency for Dutch dairy farms is 1.55, which is the product of the technical inefficiency (with a mean of 1.22) and the ‘lower bound’ environmental inefficiency (with a mean of 1.27). These inefficiency measures are lower bounds because a negative revenue of the bad output is not taken into account. The nitrogen surplus is not taxed in the research period. Large differences in the ranking according to the technical and resource use efficiency measures exist.

It is important for policy purposes to be able to characterize farms which are resource use efficient and those which are not. Intensive farms (measured in cows per hectare) are found to be more technically efficient than extensive farms. The latter are slightly more environmentally efficient. These opposite relations are combined in the resource use inefficiency measure. The resulting rank correlation of intensity and resource use inefficiency is negative.

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