Impacts of environmental regulations on the efficiency of arable farms in France and Germany

ISABELLE PIOT-LEPETIT, BERNHARD BRÜMMER and WERNER KLEINHANSS

Auswirkungen von Umweltregelungen auf die Effizienz von Ackerbaubetrieben in Frankreich und Deutschland

In diesem Beitrag werden Methoden verwendet, die eine asymmetrische Behandlung erwünschter und unerwünschter Outputs ermöglichen. Mit dem hyperbolischen Effizienzmaß werden kurzfristige Anpassungen der Produktion an Umweltregelungen berücksichtigt, während das radiale Effizienzmaß die längerfristigen Anpassungen beschreibt. Mittels nicht-parametrischer (DEA) und stochastischer Frontieranlyse (SFA) werden die Auswirkungen von Umweltregelungen auf die technische Effizienz und Umwelteffizienz von Ackerbaubetrieben in Frankreich und Deutschland ermittelt. Nach den Ergebnissen sind nur geringe Potenziale zur Verbesserung der Umwelteffizienz insbesondere in solchen Betrieben vorhanden, die an Agrarumweltprogrammen teilnehmen.

Schlüsselwörter: Frontier Analyse; technische Effizienz; Umwelteffizienz; Umweltregelungen

Summary

This paper develops a methodology for asymmetric treatment of desirable and undesirable outputs. First, a hyperbolic output efficiency measurement is used to describe a middle term transformation of production processes where producers try to improve their competitiveness together with a reduction of the negative impact on the environment. Second, a radial efficiency measurement, called directional output distance function, is used to depict a long-term transformation of the production process. A non-parametric Data Envelopment Analysis (DEA) and a Stochastic Frontier Analysis (SFA) are used to evaluate the impact of agricultural policy changes, both in France and Germany, on the technical and environmental efficiency of arable farms, taking into account participation or not in agri-environmental programs. The results from both methods indicate only limited possibilities for environmental improvements, mainly for farms participating in agri-environmental programs.

Keywords: Frontier analysis; technical and environmental efficiency; environmental regulations

1 Introduction

The negative externalities of intensive farming activities receive growing attentiveness in the EU. Numerous studies have already dealt with various policy instruments of internalization (VAN HUYLENBROECK et al., 1999), but most of them assume that farms are technically efficient and only focus on price adjustments. However, inefficient input-use still remains a fundamental cause of pollution. This inefficiency may appear in forms such as input-waste and polluting residues. The aim of this paper is to develop technical and environmental efficiency indexes that allow the evaluation of both, production improvement and pollution reduction. Indices are constructed by comparing production processes under alternate assumptions of disposability for pollutants (strong or weak). They are obtained by two approaches; the first one is non-radial and provides a hyperbolic output efficiency measurement while the second one is radial and uses a directional output distance function. A non-parametric Data Envelopment Analysis (DEA) and a Stochastic Frontier Analysis (SFA) are used to evaluate the impact of agricultural policy changes, both in France and Germany, on the technical and environmental efficiency of arable farms, taking into account participation or not in agri-environmental programs.

2 Hyperbolic and Directional Efficiency Measurements

Environmental efficiency indices rely on comparisons of production processes under alternate assumptions on the disposability of pollutants, as in FÄRE et al. (1989, 1996). An efficiency measurement is an index that characterizes how closely a firm operates to the frontier of the technology set. To handle undesirable and bad output differently, we used a non-radial and a radial measurement which simultaneously increases the level of desirable output and decreases the level of bad output (BALL et al., 1994; REINHARD et al., 1996; TYTECA, 1997).

The non-radial measurement is based on a "hyperbolic technical efficiency measurement" (FÄRE et al., 1989) which seeks the maximum simultaneous expansion for desirable output and the contraction of undesirable output:

$$(1)\quad HTE_o(x,y,b) = \max\{\theta : (\theta y, \theta^{-1} b) \in P(x)\}$$

The hyperbolic output technical efficiency characterizes a technology in measuring a non-radial expansion of good output and a reduction of bad output along a hyperbolic path. This measurement is not the shortest distance to the production frontier but a hyperbolic distance. As illustrated in figure 1, point A is technically inefficient. Along the hyperbolic path, its performance can be improved by increasing its desirable output and decreasing its undesirable output as point B.

Directional and hyperbolic efficiency measurement

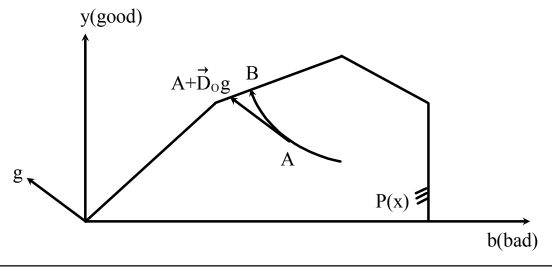

Figure 1

The radial measurement is based on a "**directional output distance function**" (CHUNG, 1996) which is a generalization of the usual output distance function in the presence of undesirable outputs with g as a reference vector (SHEPHARD, 1970). For $g = (y, -b)$, the directional output distance function measures the maximum expansion of goods and the reduction of bads by the same proportion β as (2):

$$\vec{D}_o(x,y,b;y,-b) = \max_{\theta}\{\beta : (x,(1+\beta)y,(1-\beta)b) \in P(x)\}$$

The directional output distance function characterizes the technology by measuring a radial expansion of output in the direction of the g vector which defines a radial path to the production frontier. To obtain this measure, we add $\beta\ g$ to *(y,b)* until we find the largest β such that $(y,b)+\beta\ g$ belong to *P(x)*. In figure 1, the performance of point A can be improved by increasing its desirable output and decreasing its undesirable output along the radial path in the direction of the g vector, until point $A+\vec{D}_o g$. When $g=(y,-b)$, both measurements can be compared. As noticed in Chung (1996, p. 37), the directional distance function is a linear approximation of the hyperbolic efficiency measurement.

3 Model Specification

For constructing a reference technology from the observed data, two methods are available: the parametric and non-parametric approaches.

3.1 Non-parametric model for technical and environmental efficiency measurements

Under strong disposability of bad output, the **hyperbolic technical efficiency measure** can be computed for the firm k as the solution to the following non-linear programming problem[1]):

$$HTE_0^S(x_k, y_{k,} b_k) = \max_{\theta_k \lambda_k} \theta_k$$

subject to:

$$(3)\quad \begin{aligned} &\sum_{j=1}^{J} y_{mj}\lambda_{jk} \geq \theta\ y_{mk} && m=1,\dots,M \\ &\sum_{j=1}^{J} b_{sj}\lambda_{jk} \geq \theta^{-1} b_{sk} && s=1,\dots,S \\ &\sum_{j=1}^{J} x_{nj}\lambda_{jk} \leq x_{ik} && n=1,\dots,N \\ &\sum_{j=1}^{J} \lambda_{jk} = 1 \\ &\lambda_{jk} \geq 0 && j=1,\dots,J \end{aligned}$$

The hyperbolic environmental efficiency measurement can be obtained for each observation from the ratio of technical efficiency scores under alternative assumptions on the disposability of the pollutant[2]):

$$(4)\qquad HEE_o(x_k, y_k, b_k) = \frac{HTE_0^S(x_k, y_k, b_k)}{HTE_0^W(x_k, y_k, b_k)}$$

This measure takes a value of 1 only for those farms which have the same efficiency score under both assumptions on the disposability of undesirable output. In this respect, no opportunity cost of transforming the production process exists. When technical efficiency scores are different, the hyperbolic environmental efficiency index is larger than unity.

Under strong disposability of bad output, the **directional distance function** with the g vector *(y,-b)* is computed for a farm k, *(k=1,…,J)* as the solution to the following linear program:

$$\vec{D}_0^S(x_k, y_{k,} b_k; y_k, -b_k) = \max_{\beta_k \lambda_k} \beta_k$$

subject to:

$$(5)\quad \begin{aligned} &\sum_{j=1}^{J} y_{mj}\lambda_{jk} \geq (1+\beta) y_{mk} && m=1,\dots,M \\ &\sum_{j=1}^{J} b_{sj}\lambda_{jk} \geq (1-\beta) b_{sk} && s=1,\dots,S \\ &\sum_{j=1}^{J} x_{nj}\lambda_{jk} \leq x_{ik} && n=1,\dots,N \\ &\sum_{j=1}^{J} \lambda_{jk} = 1 \\ &\lambda_{jk} \geq 0 && j=1,\dots,J \end{aligned}$$

The directional environmental efficiency measurement can be obtained for each observation from the ratio of technical efficiency scores under alternate assumptions on the disposability of the pollutant:

$$(6)\quad DEE_o(x_k, y_k, b_k) = \frac{1+\vec{D}_0^S(x_k, y_k, b_k; y_k, -b_k)}{1+\vec{D}_0^W(x_k, y_k, b_k; y_k, -b_k)}$$

3.2 Parametric model for technical and environmental efficiency measurements

To estimate a parametric hyperbolic distance function we first had to select an appropriate functional form. COELLI and PERELMAN (1999) enumerated the desirable properties of the functional form for the distance function. The following flexible translog form for the hyperbolic output distance function defined in (7) is used for the estimation:

(7)

$$\begin{aligned} \ln D_H(y,b,x) = {} & \alpha_0 + \sum_{i=1}^{2}\alpha_i \ln y_i + \gamma_1 \ln b + \sum_{i=1}^{4}\beta_i \ln x_i + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2}\alpha_{ij}\ln y_i \ln y_j \\ & + \frac{1}{2}\gamma_{11}(\ln b)^2 + \frac{1}{2}\sum_{i=1}^{4}\sum_{j=1}^{4}\beta_{ij}\ln x_i \ln x_j + \sum_{i=1}^{2}\eta_{yi}\ln y_i \ln b \\ & + \sum_{i=1}^{2}\sum_{j=1}^{4}\delta_{ij}\ln y_i \ln x_j + \sum_{i=1}^{4}\eta_{xi}\ln x_i \ln b \end{aligned}$$

CHUNG (1996) noticed that the following 'almost homogeneity' condition holds for a hyperbolic distance function: $HTE_o(x,ky,k^{-1}b) = k^{-1}HTE_o(x,y,b)$ for any *k>0*. This may be exploited to estimate the model by Maximum

1) For computing reasons the model is transformed into a linear programming model (see FÄRE et al., 1985).

2) The technical efficiency score $HTE_0^W(x_k, y_k, b_k)$ is computed for a technology that assumes weak disposability for undesirable outputs and strong disposability for desirable outputs, i.e., where the formula $\sum_{j=1}^{J} b_{sj}\lambda_{jk} \geq \theta^{-1} b_{sk}$ of model (3) has been transformed into $\sum_{j=1}^{J} b_{sj}\lambda_{jk} = \theta^{-1} b_{sk}$.

Likelihood (ML) techniques. Let $k = 1/y_1$, then

$$D_H\left(\frac{y_2}{y_1}, by_1, x\right) = y_1 D_H(y,b,x), \text{ or equivalently,}$$

$$\ln D_H(\frac{y_2}{y_1}, by_1, x) = \ln D_H(y,b,x) + \ln y_1 .$$

Noting that hyperbolic distance measure will always be larger or equal than one, we can substitute the unobservable value of $\ln D_H(y,b,x)$ with a non-negative random variable u, and, after rearranging, we get the following equation (8):

$$\ln y_1 = \alpha_0 + \alpha_1 \ln\frac{y_2}{y_1} + \sum_{i=1}^{4}\beta_i \ln x_i + \gamma_1 \ln(by_1) + \frac{1}{2}\alpha_{11}\ln\left(\frac{y_2}{y_1}\right)^2 + \frac{1}{2}\gamma_{11}\ln(by_1)^2$$
(8)
$$+\eta_{y1}\ln\frac{y_2}{y_1}\ln(by_1) + \frac{1}{2}\sum_{i=1}^{4}\sum_{j=1}^{4}\beta_{ij}\ln x_i \ln x_j + \sum_{i=1}^{4}\delta_{1i}\ln\frac{y_2}{y_1}\ln x_i + \sum_{i=1}^{4}\eta_{xi}\ln(by_1)\ln x_i - u + v$$

where

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

u is a non-negative random error term, intended to capture technical inefficiency in output, which is assumed to be independently distributed as truncations from below at zero of the $N(m_i,\sigma_u^2)$ distribution (BATTESE and COELLI 1995), where $m_i = Z\rho$ gives the firm-specific mean of the distribution. The ρ coefficients measure the impact of the exogenous Z variables on inefficiency; a positive coefficient implies that the corresponding variable has a negative impact on the efficiency measurement.

This function may be estimated directly by ML. The hyperbolic distance function measure can then be obtained by using the conditional expectation[3]) of $exp(u)$ given $(v\text{-}u)$. The above formulation imposes neither restrictive scale assumptions nor strong disposability. The imposition of strong disposability in the SFA context can be achieved by using restrictions on the logarithmic derivatives of the hyperbolic efficiency measurement. Strong disposability requires that the hyperbolic efficiency measure is decreasing in the strongly disposable output. Lack of strong and prevalence of weak disposability, on the other hand, requires that the shadow prices of the output under consideration are non-negative. The HTE_o measure is declining in the strongly disposable output and increasing in the weakly disposable output. In terms of monotonicity conditions, strong disposability of output implies negative elasticities, while weak disposability require the opposite sign.

4 Empirical application to French and German arable farms

Data used in this paper were drawn from farm accountancy data networks both in France and Germany for the year 1997/98. Arable farms were selected referring to criteria of homogeneity and consistency. The French sample includes 175 farms and the German ones 132 farms. All these farms have a nitrogen surplus and consequently, a potential detrimental impact on environment. We assume that all these farms apply the same production process, characterized by two desirable outputs: cereals (*y1*) and other products (*y2*), jointly with one detrimental output, nitrogen surplus[4]) (*y3*). They use five inputs: land (*x1*), labour (*x2*), capital and equipment (*x3*), specific variable inputs for crop production as fertilizers and pesticides (*x4*) and other variable inputs (*x5*).

4.1 Non-parametric output oriented hyperbolic and directional efficiency measurements

Efficiency indices were obtained by solving program (3) for hyperbolic efficiency measurement and program (5) for the directional distance function under alternate assumptions on the disposability of detrimental output. Further, these measurements were used to calculate environmental efficiency indices (4) and (6). Means of efficiency are reported in table 1.

Table 1: **Technical and environmental efficiency of arable farms**

	France				Germany			
	mean	(Std)[2]	AE program[1] part.	AE program[1] non-part.	mean	(Std)[2]	AE program[1] part.	AE program[1] non-part.
#	175		4	171	132		44	88
Middle term transformation: Hyperbolic output efficiency								
HTE_o^S	1.055	(0.059)	1.073	1.054	1.044	(0.064)	1.068	1.034
HTE_o^W	1.044	(0.055)	1.072	1.043	1.037	(0.060)	1.061	1.025
HTE_o	1.011	(0.028)	1.000	1.011	1.007	(0.020)	1.004	1.008
Long term transformation: Directional output efficiency								
$1+D_o^{\to S}$	1.135	(0.151)	1.157	1.135	1.121	(0.188)	1.174	1.095
$1+D_o^{\to W}$	1.106	(0.140)	1.148	1.105	1.098	(0.161)	1.149	1.073
$1+D_o$	1.027	(0.063)	1.006	1.027	1.019	(0.047)	1.018	1.020

[1] Participation or not in agri-environmental programs – [2] Standard deviation.

For **France,** the average hyperbolic efficiency (describing a middle-term transformation of the production process) equals to 1.055 for the entire sample under the strong disposal assumption, with 64 farms behaving efficiently (36.6 %). This suggests that farms could increase production by 5.5 % and simultaneously decrease nitrogen surplus by 5.5 %, holding inputs fixed and if a reduction of wastes generates no costs in terms of desirable output. The introduction of a regulation on the polluting output, pronounced by weak disposability, induces cost in terms of foregone desirable production. The average efficiency index is 1.044, with 75 efficient farms (42.8 %). In this respect, farms could increase desirable output by 4.4 % and reduce nitrogen surplus by the same amount. The comparison of potential changes in both, desirable and undesirable output under two assumptions of disposability, shows a loss in foregone desirable output of 1.1 %. Thus, the hyperbolic environmental efficiency is on average 1.011 with 98 efficient farms (56 %).

Indices provided by the directional output efficiency measurement are higher and describe a longer-term transformation of the production process. Under strong disposability of the nitrogen surplus, the average efficiency is 1.135 with 61 efficient farms (34.8 %), while under weak disposability of the nitrogen surplus, it is 1.106 with 70 efficient farms (40 %). Farms could increase desirable output

3) For reasons of convenience, the measure is calculated as $1/E[exp(-u)|(u-v)]$. The denominator is calculated as the standard predictor for technical efficiency in the cross-sectional case (JONDROW *et al.*, 1982).

4) Nitrogen surplus is evaluated based on standard practices.

and decrease nitrogen surplus by more than 13 % and almost 10 %, respectively. Thus, in long-term, higher impacts both on the competitiveness and environment can be expected. The average environmental efficiency is 1.027 with 85 efficient farms (48.6 %). The loss in foregone desirable output resulting from an environmental regulation is 2.7 % on average.

Results for **German** arable farms don't differ much from the French ones regarding the level of efficiency. Under the assumption of weak disposability the average technical efficiency HTE_o^W is 1.037 and the hyperbolic environmental efficiency HEE_o is 1.007. The directional technical efficiency is 1.098, with 74 efficient farms, that is 56 % of the sample. The environmental efficiency is 1.019, with 86 environmentally efficient farms (65 %). Considering this outcome German arable farms show a slightly better technical and environmental efficiency than the French ones in the medium and long term.

Results obtained by farms involved or not in **agri-environmental programs** (AE) are also included in table 1. In France, only 2.3 % of the farms are participating in AE programs, while in Germany the share is higher (33.3 %). For **France**, average technical efficiency indices for participating farms are higher than for farms without any AE program, indicating a lower efficiency in middle and long terms. As for the French sample, **German** farms applying for AE measures are less technical efficient and show a better environmental efficiency. This is true for both, the hyperbolic and directional measurements.

Opportunity costs for environmental regulations

To investigate the opportunity cost of transforming the production process from one with all output freely disposable to one with pollution emissions costly to dispose, the desirable output loss is calculated as $(HEE_0 - 1) * y$ for the hyperbolic measurement or as $(DEE_0 - 1) * y$ for the directional measurement. The results are provided in Table 2 on average for the two samples and by farms taking part or not in agri-environmental programs.

If weak disposability for the nitrogen surplus were strictly imposed as the result of an environmental regulation, the average value of production loss for the entire sample of **French** farms would be 1.1 thousand € with the hyperbolic measurement and 2.7 thousand € with the directional measurement. This corresponds to 0.8 and 2 % of total production, respectively. For farms participating in an AE program environmental efficiency is higher and the loss of desirable output is very small since they have already taken into account the cost involved by this environmental regulation.

Environmental constraints, imposed by the weak disposability restrictions, would induce a lower reduction of desirable output in **German** farms than in France; this is true for both measurements. As for France, opportunity costs for the reduction of nitrogen surplus, pronounced in output loss per kg of the nitrogen surplus, are higher in the long term than in the middle term, with respectively, 1.19 and 1.49 €/kg for the total of farms. Opportunity costs for the reduction of the nitrogen surplus are considerably lower in farms taking part in agri-environmental programs.

Table 2: **Desirable output loss from imposing weak disposability**

	France			Germany		
	Total	AE program[1]		Total	AE program[1]	
		part.	non-part.		part.	non-part.
#	175	4	171	132	44	88
Middle term transformation: Hyperbolic output efficiency						
Desirable output loss (€)	1 149	32	1 175	814	391	1 026
Share in tot. des. output (%)[a]	0.82	0.01	0.86	0.56	0.34	0.65
Outp. loss €/kg nitrogen surplus[b]	0.40	0.004	0.42	1.19	0.57	1.50
Long term transformation: Directional output efficiency						
Desirable output loss (€)	2 765	816	2 811	2 291	1 814	2 530
Share in tot. des. output (%)[a]	1.99	0.35	2.06	1.59	1.58	1.59
Outp. loss €/kg nitrogen surplus[b]	0,97	0.11	1.02	1.49	0.74	2.23

[1] Participation or not in agri-environmental programs – [a] Weighted by total output. – [b] Weighted by N-surplus.

4.2 Parametric hyperbolic efficiency measurement

Point estimates for technical efficiency were obtained by estimating equation (8) using Maximum Likelihood[5]). One advantage of the SFA approach is the possibility of checking for various determinants of technical efficiency (*Z*-variables), which in our analysis are (a) the level of AE-payments, (b) a participation dummy which indicates whether a farm takes part in agri-environmental programs or not.

As outlined above, the models' estimations were done under varying restrictions regarding the elasticities of the output. As a first step an unrestricted model run was done to get an idea of the overall fit of the model. Table 3 gives some indicators for the overall characteristics of the model[6]). The results for the two countries are quite different. In France, the econometric approach gives an estimate with a high value for the log-likelihood function and an acceptable percentage of significant parameters. However, the results clearly show that any observable deviation from the frontier is attributed to unsystematic influences. The variance decomposition between systematic and unsystematic error terms attaches only 0.001 % of the total variation to inefficiency. This is reflected by the test statistic as well. The average level of efficiency is virtually equal to one. This pattern proved to be very stable across slightly different model formulations. Considering these results, the further analysis must neglect the French sample because no statistical evidence for non-random deviations from the frontier could be found.

The picture looks different for the **German** sample. The overall fit of the model is worse, as shown by the figures in rows one and two. The inefficiency term plays an important role, because about 60 % of the total variation originates from systematic influences. The inefficiency model is preferred over the average model since the test statistic is larger than the critical value from the corresponding mixed χ^2–distribution of 9.35. The average level of efficiency is 8 %. This degree of inefficiency is not influenced by the age and education of the farmer. The impact of agri-envionmental payments proved to be significant: although

5) Compared to DEA we aggregated x_4 and x_5 to avoid multicollinearity and degrees of freedom problems which could otherwise arise.

6) Due to size constraints of the paper, detailed parameter estimates are not included; they are available from the authors.

participation in the program alone did not have an impact, higher payments lead to lower efficiency.

Table 3: **Summary results SFA (unrestricted models)**

	France (175 farms)	Germany (132 farms)
Log likelihood function	166.58	63.11
Percentage of sig. par's[1]	43.3 %	36.4 %
VAR (u) / VAR (total)	0.001 %	60.4 %
Test of inefficiency	1.6967	10.56
Average efficiency	0.99	0.86

[1] At the 5 % level.

For the measurement of environmental efficiency, it is important that the disposability assumptions are specified correctly with appropriate signs of the logarithmic derivatives. To get results compatible to the theoretical model, we decided to restrict the signs of the distance elasticities: the measure HTE_o^S is estimated by imposing negative signs on the elasticities of both desirable output and the nitrogen surplus, while HTE_o^W is based on a model run with unchanged restrictions for the desirable output but with positive signs of the elasticities of the nitrogen output imposed. Restrictions on the elasticities leads to lower likelihood values; however, the drop in the likelihood function is modest: the logarithmic function value drops from 63.1 to 60.8 (HTE_o^S) and 60.9 (HTE_o^W), respectively.

Table 4: **Efficiency results for the German sample (SFA)**

	#	HTE_o^S	HTE_o^W	HEE_o
All Farms	132	1.133	1.123	1.009
Rank coorelation with DEA		0.56	0.51	0.50
Grouped by AE payments				
Without AE payments	88	1.123	1.111	1.011
With AE payments	44	1.152	1.146	1.006

The use of two methods for efficiency measurement allows a comparison between DEA and SFA results (restricted to the German sample). Table 4 shows in the average estimates from SFA and the rank correlation coefficient between SFA and DEA results. The average hyperbolic efficiency level is slightly higher for SFA (1.13 and 1.12) than for DEA (1.05 and 1.04), regardless of the maintained disposability assumptions. This is somewhat surprising since SFA attributes part of the observed deviation to white noise, therefore mainly estimating lower inefficiencies compared to the deterministic approaches. This results is probably influenced by the more restrictive, parametric functional form in SFA, and by the 'curse of dimensionality', i.e. the DEA results are based on one additional input category, leading to an higher average efficiency estimate[7]). The environmental efficiency measure HEE_o , however, is estimated almost equal in both methods (DEA:1.007, SFA: 1.009). In both cases, we can conclude that the opportunity cost of imposing environmental regulations is not very high. For a comparison of the methods, the relative results are more appropriate since they separate any level effects. The rank correlation coefficients indicate that the two models yield similarly but not identical rankings for the efficiency measures. This suggests that the differences between the two approaches (modelling of white noise, parametric functional form) have indeed some influence on the efficiency estimates; the main characteristics, however, remain remarkably unchanged.

This line of reasoning is further supported by the results in Table 4 where the average efficiency estimates according to agri-environmental payments, are given. Although slightly different regarding the efficiency level, the results follow a common pattern. The German farmers with AE payments are technically more inefficient than their counterparts without these payments. For the environmental efficiency, it is just vice versa.

The overall picture is characterized by small differences in the efficiency estimates. This brings up the question how many of these differences can be regarded as statistically significant? The SFA approach offers the possibility of easily deriving confidence intervals for the efficiency estimators (HORRACE and SCHMIDT, 1996). Figure 2 shows the corresponding 95 % intervals for the hyperbolic efficiency measures.

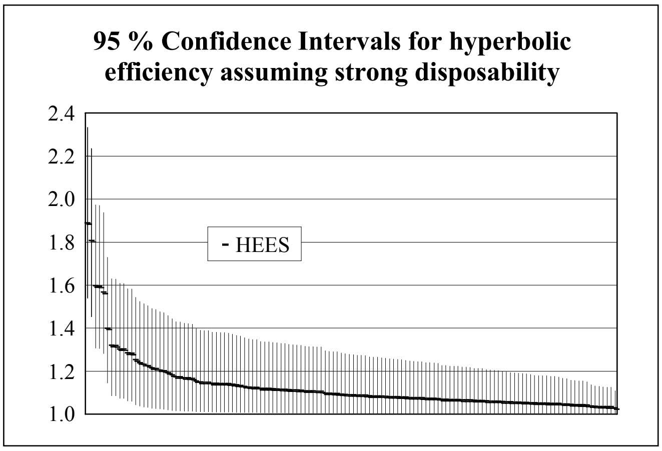

Figure 2

It is obvious that the efficiency levels have been estimated with only low precision since the intervals are quite wide. For example, the null hypothesis of full efficiency could not be rejected for most observations. Regarding the environmental efficiency measure, we must conclude that SFA finds no significant environmental inefficiency. The efficiency confidence intervals for the weakly and the strongly disposable technology overlap to a large extent, suggesting that the environmental efficiency estimate is not significantly different from one.

References

BALL V. E.; LOVELL C.A.K.; NEHRING R.F.; SOMWARU A. (1994): Incorporating undesirable output into models of production: an application to the US agriculture, *Cahiers d'Economie et Sociologie Rurales*, 31, 60-74.

BATTESE G.E.; COELLI T.J. (1995): A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data, *Empirical Economics*, 20, 325-332.

CHUNG Y. (1996): *Directional distance functions and undesirable outputs*, PhDissertaion, Carbondale, Southern Illinois University.

7) Further calculations indicated that the use of this additional input category led to a substantial move towards full efficiency.

COELLI T.J. (1995): Recent developments in frontier modelling and efficiency measurement, *Australian Journal of Agricultural Economics*, 39, 219-245.

COELLI T.J.; PERELMAN S. (1999): A Comparison of Parametric and Non-parametric Distance Functions: With Application to European Railways", *European Journal of Operations Research*, 117, 326-339.

FÄRE R. (1988): *Fundamentals of production theory*, Berlin: Springer

FÄRE R.; GROSSKOPF S.; LOVELL C.A.K. (1985): *The measurement of efficiency of production*, Boston: Kluwer-Nijhoff.

FÄRE R.; GROSSKOPF S.; LOVELL C.A.K. (1994): *Production Frontiers*, Cambridge University Press

FÄRE R.; GROSSKOPF S.; LOVELL C.A.K.; PASURKA C. (1989): Multilateral productivity comparisons when some outputs are undesirable, *The Review of Economics and Statistics*, 71, 90-98.

FÄRE R.; GROSSKOPF S.; TYTECA D. (1996): An activity analysis model of the environmental performance of firms – application to fossil-fuel-fired electric utilities, *Ecological Economics*, 18, 161-175.

HORRACE , W.C.; SCHMIDT P. (1996): Confidence Statements for Efficiency Estimates from Stochastic Frontier Models, *Journal of Productivity Analysis*, 7, 257-282.

REINHARD S.; LOVELL C.A.K.; THIJSSEN G.J. (1996): Econometric estimation of technical and environmental efficiency: an application to Dutch Dairy Farms, American Journal of Agricultural Economics, 81, 44-60.

SHEPHARD R.W. (1970): Theory of cost and production functions, Princeton: Princeton University Press.

TYTECA D. (1997): Linear programming models for the measurement of environmental performance of firms – concepts and empirical results, *Journal of Productivity Analysis*, 8, 183-198.

VAN HUYLENBROECK G.; WHITBY M. (1999): *Countryside Stewardship: Farmers, Policies and Markets*, Elsevier Science Ltd.

Authors:

Dr. ISABELLE PIOT-LEPETIT, Institut National de la Recherche Agronomique (INRA), Unité d'Economie et Sociologie Rurale (ESR), rue Adolphe Bobierre, CS 61103, 35011 Rennes cedex, France; email: Isabelle.Piot@roazhon.inra.fr

Dr. BERNHARD BRÜMMER, Christian-Albrecht-Universität zu Kiel, Institut für Agrarökonomie, Lehrstuhl Marktlehre, Olshausenstr. 40, 24098 Kiel, Germany; email: bbruemmer@email.uni-kiel.de

Dr. WERNER KLEINHANSS, Bundesforschungsanstalt für Landwirtschaft (FAL), Institut für Betriebswirtschaft, Agrarstruktur und ländliche Räume, Bundesallee 50, 38116 Braunschweig, Germany; email: werner.kleinhanss@fal.de