EFFICIENCY IN AGRICULTURAL PRODUCTION OF BIODIVERSITY: ORGANIC VS. CONVENTIONAL PRACTICES

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Abstract

Promotion of environmental sustainable farming practices is an important policy goal for the whole agricultural sector. However, when the efficiency of production is measured in practice, enhancement of environmental quality such as biodiversity and other environmental amenities does not seem to be recognized as a positive output produced by agriculture. Here, we include crop diversity index as an indicator of environmental output in a comparison of efficiency of conventional and organic crop farms. Non-parametric technical efficiency scores are estimated applying data envelopment analysis on a sample of Finnish crop farms for 1994 – 2002. The results show that in a pooled data set conventional crop farms are more technically efficient than organic farms when only crop output is considered. When taking crop diversity into account the difference between production techniques vanishes. In separate comparisons of conventional and organic farms, the average efficiencies of the two groups do not differ statistically significantly. Thus, the assumptions on the technology and reference sets are crucial with respect to the results of the comparison. This has important implications for policy evaluations when alternative farming technologies are compared.

JEL Classification:

Keywords: crop diversity, Shannon index, DEA, technical efficiency

1. Introduction

Agriculture is inherently multifunctional producing both food and fiber but also a wide range of other outputs and services. That is why the concept of multifunctionality has been adopted when reforming the European common agricultural policy to meet the demands of consumers with heterogeneous preferences. The challenge is how to translate the diverse objectives into effective policies. Increasing emphasis has been placed on the stewardship like payment schemes and social type objectives when support for farmers cannot be justified only as an effort to secure food supply (Dobbs and Pretty, 2004).

Biodiversity conservation on agricultural land is one of the objectives that has received a considerable attention from policy makers when policies have been developed to pursue environmental targets (see Wossink and van Wenum, 2003; van Wenum et al., 2004). As agriculture has shaped the landscapes for centuries, much of the apparently "natural" biodiversity in Europe is in fact a result of active farming practices. Evidently, agricultural production plays an important role in conserving biodiversity, and promotion of environmental sustainable farming practices is an overall goal for the whole sector independently of technology adopted. However, it seems that enhancement of environmental quality, such as biodiversity, is not explicitly recognized as a proper target, or a positive output when production efficiency is measured in practice. We hypothesize that this ignorance may create biases in traditional efficiency scores, and incomplete scores may discriminate environmentally benign technologies. This is an important issue to be taken into account in comparison of conventional and organic farming technologies in agriculture.

Several studies have investigated the differences in technical efficiency of organic and conventional farms. The results of Oude Lansink et al. (2002) indicate that the productivity of organic farms is considerably lower than that of conventional farms. In particular, productivity of capital, but also productivity of land and labor are low on organic farms. According to Ricci Maccarini and Zanoli (2004), this may be related to problems of converting from conventional to organic farming. Sipiläinen et al. (2005) show that technical efficiency decreases considerably when the conversion to organic farming starts but that significant learning effects can be observed over time even though the recovery of technical efficiency takes for a fairly long time. However, the previous studies only have taken into account inputs and outputs that are included in a standard bookkeeping. They do not take possible external effects - like nutrient leakages or landscape values - of different technologies into account. Including these effects may have a significant effect on efficiency and productivity measures. For example, crop rotation requirements suggest that organic farming may be characterized by more diverse cropping systems than conventional farming.

The existing studies on environmental performance of organic and conventional farms provide contradictory results on how well organic farming technology uses natural resources (Stoltze et al., 2000; Oude Lansink et al., 2002). Hole et al. (2005) have analyzed extensive literature on biodiversity and several biodiversity enhancing measures to investigate the superiority of organic farming in the biodiversity conservation. Even though further research is required to assess the performance of organic systems, they conclude that organic farming could play a significant role in increasing biodiversity. However, no economic impacts were considered in their analysis.

Our contribution is to analyze efficiency in production within the frame of economic theory by taking into account biodiversity as a good output produced on farms. The motivation is that if the environmental goals are truly part of agricultural policies, the performance of policies implemented should be possible to evaluate. In particular, it is necessary to have indicators for following up how the policies implemented have become manifested in technology choices and corresponding (environmental) benefits accrued. As the scarcity of resources is a point of departure for an economic analysis we make explicit the trade-offs in production of market and non-market outputs. It is these trade-offs that ultimately determine the costs of agri-environmental policies implemented.

The purpose of this paper is to estimate the performance of conventional and organic crop farms and to evaluate the effect of the inclusion of biodiversity on performance measures. Our measure of biodiversity, or more specifically, crop diversity is a farm level Shannon diversity index, which captures both richness and evenness of cultivated crops on the farms. Thus, we rely in our analysis on a landscape diversity indicator and do not consider for example genetic diversity. We evaluate how efficient alternative farming practices are in using scarce resources in production of both crop yield and crop diversity.

We compare how efficient production is when only conventional output (crop yield) and when also environmental by-product (biodiversity) is taken into account. Moreover, we consider efficiency scores when one of the outputs is held as a minimum constraint. Non-parametric technical efficiency scores are estimated applying data envelopment analysis (DEA). The empirical analysis is based on annual cross sections of Finnish crop farms participating in the bookkeeping system for 1994 – 2002. Since the number of organic farms is small we first rely on the assumption that both conventional and organic farms face the same production frontier, although organic production can be seen as a more restricted production technology[1]. In addition, we estimate efficiency scores for organic and conventional technologies separately. In this separate estimation we apply so called window analysis (Charnes et al., 1985) for organic farms. In that case we assume progressive technical change in four year periods.

The results show that when only crop output is considered assuming that all farms face the same production frontier, conventional crop farms are more technically efficient than organic farms. When taking into account the effect of crop diversity on economic performance the difference between the farming technologies vanishes. On average, efficiency scores are even higher on organic than conventional farms. In separate comparisons of conventional and organic farms, assuming different production frontiers the average efficiencies of the groups do not differ significantly. This shows that the assumptions made about the technology and reference sets are crucial with respect to the results of the comparison.

The paper is organized as follows. In Section 2 we introduce the crop diversity index applied in the study and in section 3 we elaborate the production economic grounds of the study. Section 4 presents the empirical method and the next section the Finnish data. Section 6 includes empirical results and the last section concludes.

2. Biodiversity - Crop diversity

Biodiversity (biological diversity) is defined as the variety of all forms of life and can be subdivided into genetic diversity, species diversity, and ecological or ecosystem diversity (Biodiversity, 2005). The concept is widely used, and a distinction can be made between functional – emphasizing the perspective of ecosystem and evolutionary processes - and compositional – emphasizing in turn the perspective of populations, species and other categories (Callicott et al., 1999). Biodiversity is also often connected to the conservation of biological variation, the extent and future value of which are largely unknown.

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[1] Organic farming as a method of production puts high emphasis on environmental protection. It avoids, or largely reduces, the use of synthetic chemical inputs like fertilizers, pesticides or additives. In the field of crop production fertilization with manure, growing legumes to bind nitrogen from the air, compost of vegetables of low soluble fertilizers, and preventive measures to control pests and diseases, are used. Also crop rotations, mechanical weed control and protection of beneficial organisms are important (Organic Farming in the EU: Facts and Figures, 2004). These restrictions most likely affect the performance of organic farms.

Two different schools of considering diversity have evolved in the literature, where different species are given different weights. The ecological school weighs different species according their relative abundance, whereas the economical school emphasizes that different species should be given different weights in the diversity measure due to the attributes they possess (Baumgärtner, 2005). The attributes are what the society actually values and consumes. Here we choose to incorporate an ecological measure of diversity into an economical production theory framework. This approach is based on the idea that the ecological diversity is a good that the society values.

In agricultural systems, biodiversity may be produced as a positive by-product in addition to marketable output such as cereals. Management practices may have various impacts on biodiversity due to crop rotation, application of chemical inputs etc. The problem is that biodiversity is a complex concept with several dimensions. Therefore, it is a challenge to choose proper measures or indicators for biodiversity. The availability of data is a major limitation for the empirical analysis. Here, we rely on a relatively simple measure of biodiversity, so called crop diversity index which can be described as a landscape diversity measure. According to a classification of Callicott et al. (1999) crop diversity index belongs to compositional measures of species diversity.

The species level of biodiversity is quantified in the number of species in a given area (richness) and how evenly balanced the abundances of each species are (evenness) (Armsworth et al., 2004). Note that the species level biodiversity is only one of the levels that can be used in analyzing the biodiversity issue. For example, community level biodiversity describes the species interactions in their natural habitats. The spatial scale is also important since richness increases with area. Usually the choice is either an economically or an ecologically meaningful scale. We choose to study the diversity of agricultural land use at the farm level, within an economical production theory framework. At the farm level, we know the number of crops cultivated and the area under these specific crops.

In this study, richness is measured by the number of cultivated crops like barley, grass silage, potato, or fallow. Evenness refers to how uniformly the arable land area of the farm is distributed to these different crops. Evenness and richness, describing diversity, can be quantified by Shannon diversity index (SHDI) (Armsworth et al., 2004). It has its origin in the information theory (Shannon 1948) and it has been applied in a number of environmental economic studies (e.g., Pacini et al., 2003; Hietala-Koivu et al., 2004; Latacz-Lohman, 2004; Miettinen et al., 2004; Di Falco and Perrings, 2005).

SHDI is calculated applying the following formula:

$$SHDI = -\sum_{i=1}^{J} (P_i \times \ln P_i) \qquad (1)$$

where J is the number of cultivated crops, P_i denotes the proportion of the area covered by a specific crop and ℓn the natural logarithm[2]. The diversity index in equation (1) equals zero when there is only one crop, indicating no diversity. The value increases with the number of cultivated crops and when the cultivated areas under various crops become more even. The index reaches its maximum when the crops are cultivated in equal shares, i.e., when $P_i = 1/J$ (McGarical and Marks 1995).

In this paper, the index is used to approximate the diversity produced by farms, and is therefore modeled as a good output within the frames of production theory. Crop diversity has usually been applied as a landscape indicator at the regional level. However, the use of crop diversity as a proxy for biodiversity at the farm level can be motivated by the fact that the number of different habitats is likely to increase with crop diversity. In conventional farming, a monoculture may be successful whereas organic production technology sets higher requirements for crop rotation ruling out the possibility of monoculture. Thus, organic farming technology is likely to produce higher crop diversity. Numerous studies have also shown that crop rotations conserve soil fertility (Riedell et al., 1998; Watson et al., 2002), improve nutrient and water use efficiency (Karlen et al., 1994) and increase yield sustainability (Struik and Bonciarelli, 1997; see also Herzog et al., 2006).

3. Production Theory

3.1 Technology

To describe production technology formally, let $y = (y_1,..., y_m) \in \Re_+^M$ and $x = (x_1,..., x_n) \in \Re_+^N$ be vectors of outputs and inputs, respectively. Production technology can then be represented by the output possibilities set

$$P(x) = \{y \mid (x, y) \in T\} \qquad (2)$$

[2] Shannon diversity index appears in the literature by names Shannon-Wiener (-Weiner or –Weaver) index. According to Keylock (2005) it belongs to the Hill family of indices (like Simpson diversity index) and is based on Bolzmann-Gibbs-Shannon entropic form. Sometimes the index is presented in the form of exp(SHDI). At the maximum the latter form provides the number of species for the uniform distribution (maximum entropy).

which describes all feasible output and input combinations of the producer. The technology is denoted by T, and the condition $(x, y) \in T$ is interpreted as x can produce y. We assume that $P(x)$ is convex, closed, and bounded, i.e., compact, and that $P(0) = \{0\}$. The latter equality ensures that inactivity is possible but there is no free lunch. Finally, outputs and inputs are assumed to be freely disposable.

Input and output distance functions can be used to describe the technology when only input and output quantities are known (Shephard, 1953; 1970). In contrast to the traditional scalar-valued production function, distance functions allow multiple outputs (and multiple inputs). For any (x,y) $\in R_+^{M+N}$ the output distance function $D_o(x,y)$ is such that

$$D_o(x,y) = \min \{\lambda > 0: y/\lambda \in P(x)\}. \tag{3}$$

The output distance function calculates the largest expansion of y along the ray through y as far from 0 as possible while staying in P(x), which means that y belongs to the producible output set if and only if $D_o(x,y) \leq 1$. It is also obvious that the distance function takes the value one only if the output vector belongs to the frontier of the corresponding input vector. Therefore, the output distance function completely characterizes the technology, because it inherits its properties from P(x).

The Farrell (1957) measure of output oriented technical efficiency is the reciprocal of the output distance function, i.e. $F_o(x,y) = (D_o(x,y))^{-1}$. Thus

$$F_o(x,y) = \max \{\mu: \mu y \in P(x)\}. \tag{4}$$

Probably the most often used models of technical efficiency are variants of the Farrell type model[3]. By duality output and input orientations have a convenient interpretation as an increase in revenue and a reduction in costs, respectively. One desirable property of the Farrell type measure is that it is invariant with respect to the units of measurement in inputs and outputs.

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[3] Chambers et al. (1998) have shown that the proportional distance function (the reciprocal of Farrell technical efficiency) is a special case of directional distance functions.

3.2 Modeling Biodiversity as a Good Output

To illustrate the measurement of technical efficiency, we assume first that a farm is producing only one good output, crop (Figure 1a). At the output level *b* (on the vertical axis) and input level *a* (on the horizontal axis), the technical output efficiency of the farm depends on the choice of reference set. If the reference set is technology 1 the efficiency is 0b/0c, but if it is technology 2 the efficiency is lower, 0b/0d. In this context, technology 2 is more productive than technology 1, which may be constrained by restrictions on the use of inputs or crop rotation requirements (as is the case for organic farming technology).

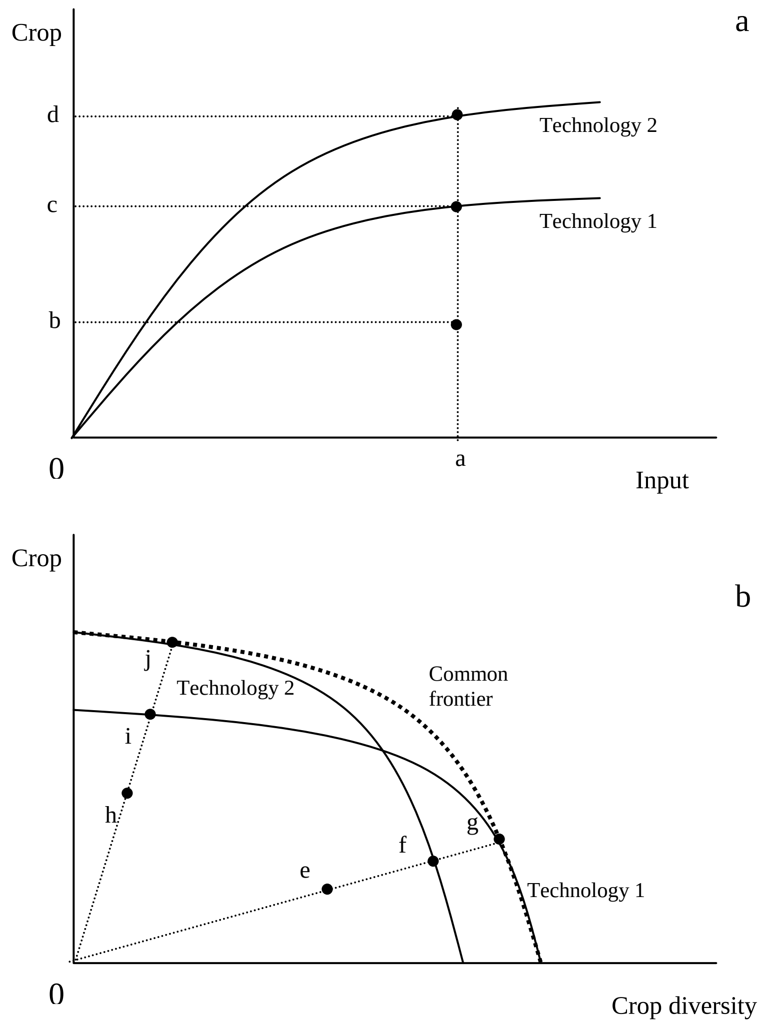

Figure 1a and b. An illustration of technical output efficiency in one (crop) and two output (crop and crop diversity) cases.

In Figure 1a we only consider production of crops that can be sold on the market. However, agricultural production provides also other, non-market outputs. This is illustrated in Figure 1b where we have two outputs: crop output and non-market crop diversity. The transformation curves show how much of the crop output has to be sacrificed to increase crop diversity, given inputs. Technologies 1 and 2 (organic vs. conventional) which allow for different production possibilities at a given input level are illustrated by two separate transformation curves (or outer boundaries of producible output sets). Technical efficiencies are derived from the radial distances from the frontier. For example, a technical efficiency score for point e with respect to technology 1 (0e/0g) is different compared to technical efficiency with respect to technology 2 (0f/0g). In our illustration in Figure 1b, producible output sets of the two technologies cross[4]. Therefore, if we use a common, joint reference frontier without separating two underlying technologies, it is defined by the units representing different technologies. In the high crop output – low crop diversity dimension the frontier is defined by the units applying technology 2 but in the opposite case it is defined by the units using technology 1. Figure 1b shows that the assumption of whether all farms having access to the same technology, or of whether organic and conventional farms not having access to the same technology, may be crucial in the measurement of efficiency.

4. Empirical Method

4.1 Data Envelopment Models

The firm is said to be technically efficient if it lies on the boundary of the output possibility set, $P(x)$. There are several possibilities to define the boundary, often referred as the frontier. Data envelopment analysis (DEA) is a non-parametric method that provides a piecewise linear, either convex or non-convex envelopment for the observations. It has been developed for evaluating the performance of multi-input multi-output production (see Debreu, 1951; Farrell, 1957 and Koopmans, 1951; Charnes et al., 1978).

The DEA models applied in this study are output oriented assuming that $P(x)$ satisfies convexity. If technical efficiency obtains its maximal value (one), the production is efficient, and it is not possible to increase output (given inputs) in comparison to the reference units. If production is technically output inefficient, output can be increased using given inputs.

DEA models are fairly simple linear programming (LP) models which have to be solved for each decision making unit (farm) separately. In the case of variable returns to scale, we define the model with outputs, y_m, and inputs, x_n, when k decision making units form the reference set and each of them, k', is in turn compared to the reference set. In our notation below, $F_o(VRS, S)$ or ϕ denotes

[4] It is of course possible that one of the technologies dominates at all output combinations.

technical output efficiency under variable returns to scale (V) and strong disposability (S) assumptions. The efficiency measure is the reciprocal of output distance function, $(D_o(x, y))^{-1}$ (Färe et al., 1994). The superscript *t* in Equation (5) refers to the annual solution of the LP problem.

$$
\begin{aligned}
& F_o(VRS, S) = (D_o^t(x, y))^{-1} = \max \phi \\
& s.t. \;\; \phi y_{k'm}^t \le \sum_{k=1}^{K} z_k y_{km}^t, m = 1, \ldots, M, \\
& \sum_{k=1}^{K} z_k x_{kn}^t \le x_{k'n}^t, n = 1, \ldots N, \\
& \sum_{k=1}^{K} z_k = 1, \\
& z_k \ge 0, k = 1, \ldots, K.
\end{aligned} \tag{5}
$$

The DEA model of variable returns to scale is obtained by a constraint for intensity variables $\sum z_k = 1$, which restricts the scaling of units in the search for an optimal solution such that the sum of weights of the observations has to equal to one. When the intensity variables z are not constrained, the scaling of reference units up and down is unlimited, which coincide with constant returns to scale (CRS). The CRS assumption implies that the efficiency ranking of units is independent of the choice of orientation, be it input or output. In agriculture, larger farms tend to be more technically efficient than smaller ones when assessed by the CRS DEA model (e.g., Sipiläinen, 2003). The possible heterogeneity in size, or indication on the economies of scale is partially removed when VRS models are applied. This also supports the VRS type model for our application as the average sizes of farms in alternative production technologies differ.

If we are only interested in technical efficiency of crop production, disregarding crop diversity, we may apply the model with only one traditional crop output. We may, however, easily extend the analysis taking into account other outputs. If we assume that crop diversity is a desirable output that farms also produce we may solve the LP problem with two outputs. The very nature of the DEA models is that after adding other outputs the number of efficient decision making units increases.[5] This property coincides with the problem of omitted outputs since in that case we may underestimate the true technical efficiency of a decision making unit.

[5] Coelli et al., (1998) writes: ”The addition of an extra input or output in a DEA model cannot result in a reduction in the technical efficiency scores” (p. 181).

The traditional two output DEA model assumes that the efficiency score is calculated as a possibility for an equi-proportional increase in outputs, given inputs and reference units. Thus, we in principle assume that socially optimal proportions of these outputs are already produced but our target is to produce more both of them. This is a critical assumption when we take into account non-market outputs which do not have a market price. We may also think that the target of the society would be to increase either crop diversity given inputs and traditional output or to increase traditional output given inputs and crop diversity. This would be interpreted as if a socially optimal level of one of the outputs was already produced but the purpose was to evaluate the possibilities to increase the other output. To assess these options, we introduce in the LP model a slightly different set of constraints. In particular, we assume that only the traditional output is adjusted but the crop diversity is treated as an ordinary constraint indicating that crop diversity of the feasible solution should be at least as large as in our decision making unit. Technical efficiency is thus only measured in relation to traditional output. This is similar to technical sub-vector efficiency introduced by Färe et al. (1994), and applied to variable inputs by Oude Lansink et al. (2002).

Traditional technical efficiency and sub-vector efficiencies are illustrated in Figure 2. The output set includes both crop output and crop diversity. Traditional Farrell type technical output efficiency is measured as a proportional expansion of outputs along the solid line from point A to the frontier. The crop sub-vector efficiency specified in Equation (6) below is described as an increase of crop output along the vertical broken line from point A to the frontier, and crop diversity sub-vector efficiency is defined as an expansion of crop diversity output along the horizontal dotted line from point A to the frontier.

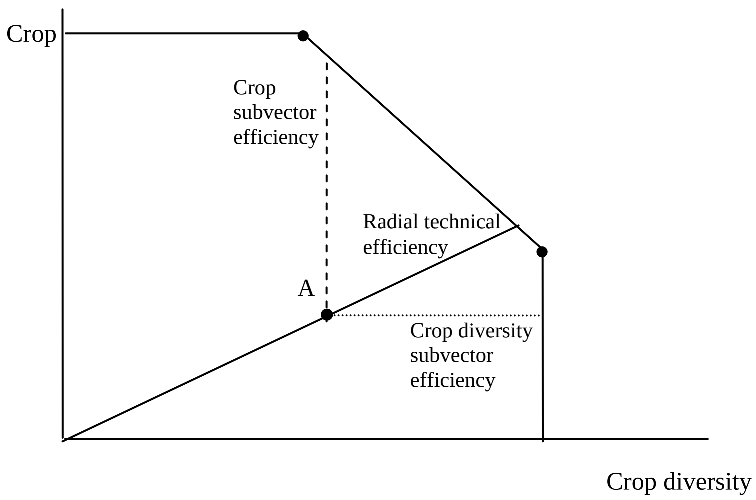

Figure 2. An illustration of traditional and sub-vector technical efficiencies.

A formal presentation of the crop sub-vector efficiency when m=1 denotes crop output and m=2 crop diversity is the following[6]:

$$
\begin{aligned}
& F_o(VRS, S, sub) = (D_o^t(x, y))^{-1} = \max \phi \\
& s.t.\ \ \phi y_{1k'}^t \leq \sum_{k=1}^{K} z_k y_{1k}^t \\
& y_{2k'}^t \leq \sum_{k=1}^{K} z_k y_{2k}^t \\
& \sum_{k=1}^{K} z_k x_{kn}^t \leq x_{k'n}^t, n = 1, \ldots N, \\
& \sum_{k=1}^{K} z_k = 1, \\
& z_k \geq 0, k = 1, \ldots, K.
\end{aligned}
\tag{6}
$$

We still have to choose the reference sets for the efficiency analysis. When solving an optimization problem applying an annually pooled data set we actually assume that the farms have access to each others' technology independently of their actual farming technology (conventional or organic). In other words, efficient units and their linear combinations may consist of organic and/or conventional farms. This is somewhat problematic since the production possibilities sets of organic and conventional farms may differ because of the restrictions for organic farming in the application of inputs like fertilizers and pesticides. In spite of this, the data are in the basic case annually pooled because of the small number of organic farms. The results of this analysis serve as a benchmark for further analysis. The models are solved separately for each farm in each year. Thus, there is no technical change over time in the model.

In previous studies, it has been observed that organic farms are less technically efficient than conventional farms when observations on both organic and conventional farms are pooled, but that the technical efficiency of organic farms in relation to their 'own' technology reference frontier is higher than the efficiency of their conventional counterparts (Oude Lansink et al., 2002; Ricci Maccarini and Zanoli, 2004). Finding evidence for this hypothesis may not be easy by using DEA when the number of organic farms is small compared to conventional ones. The small number of observations poses a challenge for analyzing organic farms separately. Therefore, we apply window analysis suggested by Charnes et al. (1985): observations from several years (in our case four years) are assumed as different units. In traditional window analysis the earliest period is dropped out when a new period is introduced. We apply a four years' window, or a rotating unbalanced panel. In principle, we take a technical change into account as the reference set for the last period in the window includes observations of this specific year and three earlier years. However, we cannot totally avoid the problem of a small number of observations in these comparisons as the averages of technical efficiencies tend to diminish when the number of observations increases. When the number of observations in the sample increases, the convergence to the minimum is relatively slow.

5. Data

We use a Finnish bookkeeping farm data set which covers the period from 1994 to 2002. The original farm data formed a complete panel, but because of a small number of organic farms the panel was complemented with organic farms which participated in the bookkeeping system at least for two years. This increased the number of observations towards the end of the study period, in addition to the switches from other production lines (e.g., milk production) to crop production. The farms were classified as crop farms if their animal density was less than 0.1 animal units per hectare and the share of grains in total sales return at least 20 %. The first criterion was the same as in a previous study of Oude Lansink et al. (2002). The second one drops specialized sugar beet and potato farms out of the sample. The total number of observations was 78 in 1994 and it increased up to 103 by 2002. The data set consists of 831 observations in total.

Table 1. Descriptive statistics of conventional and organic farms.

	Conventional		Organic	
N	689		142	
	Mean	St.dev.	Mean	St.dev.
Output (FIM)	195725	148859	88901	122026
SHDI	1.30	0.18	1.41	0.33
Labor (h)	1831	1010	1533	1104
Land (ha)	64.39	35.98	48.67	42.73
Energy (FIM)	32377	20427	26481	32303
Other variable (FIM)	119262	82880	72815	106696
Capital (FIM)	376637	262078	303522	341838

[6] Also in this case the VRS model is obtained by adding a constraint for weights z that should sum up to one.

The number of organic crop farms was 11 in 1994, and in 2002 it was 20. We use crop returns as a proxy of the quantity of aggregate marketable output. Crop output is measured at constant prices of the year 2000. Both for organic and conventional farms output at constant prices is obtained by dividing crop returns by the respective price indices of conventional outputs published by Statistics Finland[7]. The main reason for using only price indices for conventionally produced goods is that we do not have a reliable price index for organic products. In addition, we do not know the exact magnitude of a price premium for organic production. This means that we have to assume equal prices and price changes for organic and conventional products, and a possible price premium for organic products will increase our proxy of the output quantity. In spite of this, the average traditional crop output is considerably lower on organic than on conventional farms (see Table 1). All subsidies (direct payments) paid on the basis of the arable land areas of the farms are excluded. As a measure of another positive output, or desirable environmental by-product, we use an indicator of crop diversity, or a Shannon crop diversity index (SHDI). The average crop diversity index is on average larger on organic farms.[8]

The outputs are produced by using five inputs. Labor is measured in hours as a sum of family and hired labor input. Land is measured in hectares covering total arable land area of the farm. Input variables accounted for at constant prices of 2000 are 1) energy including both fuel and electricity, 2) other variable input consisting of purchased fertilizers, seed, feed etc., and 3) capital including the value of buildings and machinery. The respective input price indices are obtained from Statistics Finland. The average arable land area of conventional farms is more than 16 hectares larger than that of organic farms, and the difference is statistically significant (t-test statistics 4.58). Conventional farms consume on average more of all inputs than organic farms.

When comparing crop farms we observed very low crop output values in some cases. Low output relative to inputs yields also a low technical efficiency score for the farm. However, it is difficult to determine whether these observations should be regarded as outliers and on which grounds. Therefore, no observation has been dropped.

[7] The division of monetary input or crop output values by respective indices is not necessary if we only analyze the farms in cross-sections of specific years. However, when we employ for example a window analysis over time for organic farms the use of constant monetary values is necessary.

[8] The t-test statistics for differences in output and crop diversity index were 8.01 and 5.60, respectively.

6. Results

6.1 Joined data set for conventional and organic farms

Pooling all the data we implicitly assume that organic and conventional farms have access to the same technology.[9] Thus, all the observations of the same year, for each year separately, are in the reference set against which each farm in the respective year is evaluated. First we estimate the Farrell type technical output efficiencies for the pooled data set applying a model of one output (crop output) and five inputs and variable returns to scale (Equation 5). The overall mean technical efficiency is 0.708[10]. This indicates that on average only approximately 71 percent of the obtainable output is produced, given inputs. Table 2 shows arithmetic average technical efficiencies for all farms as well as both for conventional and organic farms for each year in 1994 – 2002. The annual average is higher in the group of conventional than organic farms except in 1998 and 1999, when the harvests were on average poor. However, according to Wilcoxon rank sum -test, annual technical efficiencies between organic and conventional farms differ significantly at five percent risk level from each other only in 2000. When we compare the efficiencies in these two groups over the whole research period, we observe that technical efficiencies are significantly higher on conventional than organic farms (p-value = 0.0285), although the difference is only six percentage units. Annual averages of efficiency scores vary but there is no statistically significant trend of change in the technical efficiency over time.

Table 2. Technical efficiencies of one output – five input VRS models.

	All farms		Conventional		Organic	
	Mean	St.dev	Mean	St.dev	Mean	St.dev
1994	0.680	0.180	0.693	0.178	0.598	0.181
1995	0.730	0.228	0.745	0.223	0.654	0.245
1996	0.746	0.222	0.762	0.203	0.658	0.305
1997	0.751	0.222	0.768	0.213	0.664	0.251
1998	0.659	0.249	0.652	0.237	0.697	0.322

[9] This is a simplistic assumption as chemical inputs (fertilizers, pesticides) cannot be used in organic farming. However, to certain extent this is compensated, e.g., by increased use of labor per output unit. As long as all inputs are measured this should not be a problem but reflect the alternative strategies in the use of inputs to maximize outputs.

[10] We report technical efficiency as a value between 0 and 1, which is a reciprocal to the value defined in Equation 4.

1999	0.630	0.281	0.626	0.275	0.646	0.612
2000	0.782	0.214	0.810	0.181	0.651	0.301
2001	0.693	0.249	0.733	0.243	0.690	0.312
2002	0.697	0.248	0.750	0.216	0.631	0.337
Mean	0.708	0.239	0.719	0.226	0.655	0.287

The outcome changes when we take into account biodiversity effects of the production. This is described in Table 3. The overall mean technical efficiency is 0.874 when we have two outputs; the traditional crop output and crop diversity. The former one is sold on the market and the latter is assigned to the landscape effects. From Table 3 we can see that in the two output case the efficiency scores are on average higher and the difference is quite large compared to the results in Table 2. The ranking of technologies also changes; the average efficiency is higher in the group of organic farms except in 1995. The efficiencies differ at five percent risk level in 1996, 1998, 1999, 2001 and 2002. Over the whole period, the average technical efficiency on organic farms is approximately six percentage units higher than on conventional farms. According to the Wilcoxon test, the difference is statistically significant (p-value < 0.0001).

Table 3. Technical efficiencies of two output – five input VRS models.

	All farms		Conventional		Organic	
	Mean	St.dev	Mean	St.dev	Mean	St.dev
1994	0.845	0.132	0.837	0.133	0.892	0.120
1995	0.914	0.113	0.916	0.109	0.903	0.136
1996	0.918	0.124	0.906	0.130	0.986	0.036
1997	0.895	0.126	0.888	0.127	0.932	0.118
1998	0.844	0.158	0.827	0.157	0.952	0.123
1999	0.834	0.169	0.806	0.173	0.947	0.082
2000	0.890	0.145	0.888	0.144	0.900	0.158
2001	0.856	0.151	0.844	0.150	0.908	0.153
2002	0.870	0.137	0.860	0.138	0.916	0.125
Mean	0.874	0.143	0.863	0.145	0.925	0.124

On conventional farms, the mean technical efficiency is 0.863. Thus, it should be possible to increase crop output and crop diversity by about 16 percent. This can be compared to an increase in the Shannon diversity index (SHDI) e.g., given evenness. SHDI increases approximately by 26 percent when we increase the number of crops from 3 to 4 and 16 percent when the number of crops increases from 4 to 5. Similarly, when the evenness of two crops changes from 30:70 to 50:50 the index value increases by 13 percent.

Table 4 shows the technical efficiencies of the pooled data when the sub-vector efficiency model suggested by Färe et al. (1994) is applied (Equation 6). We could measure either crop output or crop diversity sub-vector efficiency. Here we present only the sub-vector efficiency of crop output which means that we introduce the crop diversity as an ordinary output constraint in the DEA model. The average efficiencies lie between the values of Tables 2 and 3. The overall difference between the efficiencies of the two groups is also smaller than in the two earlier models but it is still in favor of the organic farms. The Wilcoxon test shows that the overall averages differ significantly from each other (p-value = 0.0072). If we compare the annual values the only significant difference is in 1998 (in favor of organic farms). Only in 1995 and 2000 the average is larger in the group of conventional farms.

Table 4. Technical efficiencies of two output – five input crop sub-vector VRS models.

	All farms		Conventional		Organic	
	Mean	St.dev	Mean	St.dev	Mean	St.dev
1994	0.769	0.193	0.762	0.190	0.808	0.216
1995	0.800	0.213	0.810	0.209	0.750	0.232
1996	0.827	0.209	0.816	0.211	0.894	0.194
1997	0.817	0.223	0.814	0.215	0.837	0.268
1998	0.727	0.260	0.704	0.251	0.868	0.280
1999	0.677	0.285	0.656	0.280	0.762	0.297
2000	0.846	0.197	0.854	0.179	0.813	0.270
2001	0.739	0.253	0.694	0.234	0.766	0.299
2002	0.752	0.233	0.713	0.222	0.757	0.300
Mean	0.772	0.237	0.767	0.230	0.800	0.267

6.2 Separate data sets for conventional and organic farms

In the previous analysis the observations were annually pooled in the same data set. This is mainly due to practical reasons since the number of organic farm observations is fairly small. However, we applied DEA on separate data sets of conventional and organic farms. For organic farms, we used so called window analysis assuming progressive technical change. This means that, for example, the efficiency scores for 1997 are calculated using the observations from 1994 to 1997 as the reference set but the mean is calculated on the basis technical efficiencies of the farms observed in 1997[11]. Using several years' observations as the reference set of organic farms increases the dimensions in the DEA almost to the same level as in the annual analysis of conventional farms (without a window).

The results for separate data sets for conventional and organic farms (window analysis for organic) are presented in Tables 5 and 6. The means of these two groups are very close to each other but the pattern of changes varies; in the group of conventional farms the average technical efficiencies are at their lowest level in 1998 and 1999, and at their highest in 2000. In the group of organic farms, efficiency decreases constantly since 1999. It seems that the variation in these two technologies is somewhat different but this may be explained by the different ways of constructing the reference sets.

Table 5. Technical efficiencies for conventional farms (annual reference sets).

	1O5I		2O5I		2O5Isub	
	Mean	St. dev	Mean	St. dev	Mean	St. dev
1997	0.771	0.177	0.911	0.095	0.832	0.177
1998	0.671	0.203	0.834	0.132	0.717	0.215
1999	0.663	0.241	0.872	0.129	0.735	0.246
2000	0.835	0.154	0.903	0.113	0.867	0.150
2001	0.728	0.189	0.878	0.115	0.789	0.190
2002	0.723	0.196	0.897	0.099	0.793	0.183
Mean	0.734		0.883		0.791	

1O5I – one output, five input Farrell type model; 2O5I – two output, five input Farrell type model; 2O5ICsub - two output, five input crop sub-vector efficiency model.

Table 6. Technical efficiencies for organic farms (reference sets of four year windows).

	1O5I		2O5I		2O5Isub	
	Mean	St. dev	Mean	St. dev	Mean	St. dev
1997	0.787	0.209	0.905	0.115	0.804	0.209
1998	0.749	0.282	0.933	0.086	0.812	0.269
1999	0.756	0.236	0.950	0.061	0.818	0.211

[11] When we apply a four year window and assume technical progress we cannot calculate mean efficiencies in 1994-1996.

2000	0.710	0.236	0.898	0.114	0.805	0.222
2001	0.734	0.240	0.882	0.133	0.780	0.230
2002	0.719	0.253	0.886	0.123	0.746	0.258
Mean	0.740		0.906		0.791	

1O5I – one output, five input Farrell type model; 2O5I – two output, five input Farrell type model; 2O5ICsub - two output, five input crop sub-vector efficiency model.

We should notice that the number of observations on which the annual average technical efficiencies of organic farms are calculated, is only 14-20[12]. However, the results suggest that the average efficiencies in the two technologies do not differ considerably when the reference group applies the same technology, i.e., organic reference technology for organic farms and conventional for conventional farms. The result is independent of the model the analysis is based upon. This partially contradicts the result obtained when all farms were assumed to face the same technology, i.e. the frontier of pooled reference set as presented in Tables 3 and 4, indicating the importance of technology assumptions

7. Summary and Conclusions

We have estimated technical efficiencies for conventional and organic farms using data envelopment analysis. When only traditional crop output is taken into account, conventional farms prove to be technically more efficient than organic farms. A similar result has been obtained in several studies (e.g., Oude Lansink et al., 2002) suggesting that conventional farms are more productive than organic ones. Traditional technical efficiency analysis only accounts for market inputs and outputs although the grounds for promotion of organic farming actually builds on the demand of the society for non-market, environmental attributes.

The inclusion of crop diversity as another desirable output in the analysis leads to a relative increase in technical efficiency of organic farms compared to conventional ones. Presuming the society to prefer more diversity to less, for given crop output, conventional farms are no longer more efficient than organic farms from the social point of view.

[12] The number of annual observation in the last year of the window.

The Shannon crop diversity index used in comparison of conventional and organic practices in this study has been an attempt to introduce another desirable output into the production process and extend the analysis of different production technologies to a more comprehensive level. Further research is needed in specifying possible inputs and outputs which should be taken into account in the efficiency comparisons. In our analysis, we concentrated on the annual diversity variation at the farm level. Regarding the evaluation of landscape values, the scale of analysis should, however, exceed the borders of farm units. Therefore, the aggregation over farms and time become important issues for policy assessments.

Even though our approach is only a first step towards analyzing simultaneously economic and environmental impacts of alternative farming technologies, the overall message of our analysis is clear. Normally, there is a trade-off between several outputs. Multiple outputs, including environmental impacts, should be accounted for as the efficiency ranking of alternative technologies is dependent on what is actually considered as outputs.

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