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Autor: Jan, Pierrick / Lips, Markus / Dumondel, Michel

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Technical efficiency of Swiss dairy farms located in the mountain area considering both economic and environmental resources

Pierrick Jan[1),2)], Markus Lips[1)] & Michel Dumondel[2)]
[1)]Agroscope Reckenholz-Tänikon Research Station ART,
[2)]ETH Zürich, Institute for Environmental Decisions

Abstract

Increasing the efficiency of the use of economic and environmental resources of Swiss farms is a priority of Swiss agricultural policy as part of the objective of improving the sustainable performance of the Swiss agricultural sector. In this paper we assess the long-run technical efficiency of the use of economic and environmental resources of a sample of 480 Swiss dairy farms located in the mountain area using the non-parametric Data Envelopment Analysis approach. In a second step, using a linear regression, we investigate the determinants of this technical efficiency. The results of the regression performed show that farm size and the strategic orientation of farm activity have a much greater effect on efficiency than the characteristics of the dairy production system or dairy herd management. An increase in farm size and an increased orientation towards para-agricultural activities are shown to exert a strong positive effect on technical efficiency. Conversely, part-time farming turns out to have a substantial negative impact on the efficiency of resource use.

Key words: efficiency analysis, economic resources, environmental resources, dairy farms, Switzerland

JEL Classifikation: Q12, Q56, Q57

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1. Introduction

28% of the farms in Switzerland are located in the mountain area (FOAG 2007), which includes mountain zones 2, 3 and 4 (FOAG 2002) and which can be roughly defined as the agricultural production area located between 800 and 1500 meters above sea level. The mountain area accounts for 28% of the total agricultural production area of Switzerland (Stöcklin et al. 2007), whereas it amounts to approximately 60% of the total Swiss land area (unproductive areas like rocks, glaciers, lakes and rivers included). The farms located in the mountain area are principally grazing livestock farms and more particularly dairy farms. These dairy farms are not only important for the Swiss dairy sector, as they generate one third of Swiss milk production (FOAG 2006), but also play a major role in the conservation of national resources, the upkeep of rural scenery and the decentralised inhabitation of the country (Rieder et al. 2004). These objectives are assigned by the Swiss legislator to Swiss agriculture (Swiss Federal Constitution, Article 104).

In international comparisons Swiss dairy farms exhibit small size and low relative competitiveness. In 2008 the full cost of milk production on a typical Swiss dairy farm located in the mountain area amounted to around 1.7 Swiss francs per kg, around 75% in excess of the full production cost of similar dairy farms located in Germany and Austria (IFCN 2008). Whereas some of this lower relative competitiveness is explained by the high general price level in Switzerland, part of the lower competitiveness of Swiss dairy farms is due to the lower productivity of these farms in international comparisons.

The Swiss agricultural sector has traditionally benefited from high market protection and government support in international comparisons. For the period 2006-2008 the Organisation for Economic Cooperation and Development (OECD) reported for Switzerland a producer support estimate (PSE) of 60% (OECD 2009), the third highest PSE of the OECD countries (after Norway and Korea). Since the beginning of the nineties, and especially since 1999, the Swiss agricultural sector has been subject to the progressive liberalisation of its dairy market. Since 2007 the trade in cheese between the European Union and Switzerland has been fully liberalised. The Swiss Confederation is currently negotiating a free trade agreement with the EU in the agricultural and food sector. This probable further market liberalisation will put the Swiss dairy farms that want to remain involved in the dairy sector under pressure to increase their competitiveness and productivity.

The efficiency of the Swiss agricultural sector is a subject that has already been investigated at farm level. Ferjani (2006) analysed the total factor productivity change and the technical efficiency of Swiss farms using the non-parametric Data Envelopment Analysis approach. Only economic resources were considered for the analysis. Ferjani and Flury (2009) investigated the technical efficiency of Swiss dairy farms located in the mountain region using Stochastic Frontier Analysis, the main focus of this investigation being a comparison of the technical efficiency of organic and conventional farms. In that case also, only economic resources were taken into account for the assessment of efficiency.

In Switzerland, as in many other countries, the legislator has made the sustainability principle a keynote for the assessment of the performance of the agricultural sector (SR 919.118). This implies that, if possible, farm performance assessment should be carried out considering economic, environmental and social resources simultaneously.

The present paper aims to assess the long-run technical efficiency of Swiss dairy farms located in the mountain area taking into consideration both economic and environmental resources, and investigates the factors affecting this technical efficiency. The methods and data used to perform this study are described in chapter 2, 3 and 4. In chapter 5 we present the results of this investigation. In the subsequent part (chapter 6), the results are discussed and general conclusions are drawn.

2. Assessing farm technical efficiency

2.1 Definition of efficiency

Before going into details of the method used to assess the efficiency of the farms investigated, it might be appropriate to define exactly the term efficiency. Indeed, as outlined by Jollands (2006), the concept of efficiency has a wide range of potential interpretations in the resource use context. In the present paper we adopt a production economics perspective and measure the technical efficiency of the farms investigated. The concept of technical efficiency has been defined by Farrell (1957) as the success of a firm in producing maximal output from a given set of inputs and can be calculated as the actual productivity of a company compared to the maximum attainable productivity.

2.2 Introducing environmental issues in the measurement of productive technical efficiency

There are two major possibilities when considering environmental issues in a technical efficiency analysis performed from a production economics perspective. The environmental issues can either be considered as undesirable outputs [refer for example to Färe et al. (1989), Ball et al. (1994) and Tyteca (1997)], or as inputs [refer for example to Pittman (1981) or Cropper and Oates (1992)]. In the present paper the environmental issues are included as inputs in the efficiency analysis. Our motivation for proceeding in this way is pragmatic, as it is based on data availability considerations. Indeed, the only environmental data available for the present investigation are the amount of environmental resources used (inputs). The amount of environmental impacts generated (undesirable outputs) is not available. By proceeding in this way we integrate the environmental issues in a way similar to that adopted by Figge and Hahn (2004a, 2004b, 2005) in their Sustainable Value approach (for an application to the agricultural sector refer to Van Passel et al. (2007)) or by Kuosmanen and Kuosmanen (2009a, 2009b), who improved the Sustainable Value approach by introducing parametric and non-parametric approaches for estimating benchmark technology. This was also the procedure adopted by Van Passel et al. (2009) in their paper aimed at performing an integrated assessment of the environmental and economic performance of Flemish dairy farms.

2.3 Assessment of technical efficiency

2.3.1 Parametric *versus* non-parametric approach

To estimate Technical Efficiency (TE) we need to estimate the efficient production frontier. Based on the distance of a firm to this frontier, it is possible to calculate the degree of technical inefficiency of this firm. Two fundamental paradigms can be distinguished for the estimation of frontier in economics: the parametric and non-parametric approaches (Seiford and Thrall 1990). The two most widely used approaches to estimating the efficient production frontier are Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA).

SFA is a parametric stochastic approach which was developed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). It requires some assumptions with regard to the functional form of the production function and the distribution of the inefficiency scores. Its main advantage is that it is able to decompose the distance of a firm to the frontier into an inefficiency and a noise term.

The DEA approach is a non-parametric deterministic approach which is based on linear programming techniques. It was originally developed by Charnes et al. (1978) on the basis of the initial propositions of Farrell (1957). It does not require any assumption with regard to the functional form of the production function but only assumes that the production function is monotonically increasing and globally convex. One major disadvantage of this approach is that it cannot separate the inefficiency term from the stochastic noise and that it is thus very sensitive to measurement errors or outliers (Wilson 1995; Coelli et al. 2005).

In the present work we shall make use of non-parametric Data Envelopment Analysis to estimate the efficient frontier for the four following reasons:

- it does not require any a priori specification of the functional form of the production function (Seiford and Thrall 1990; Kalaitzandonakes et al. 1992)
- it does not impose any restriction on the distribution of the inefficiency scores as is the case for the parametric SFA approach (Kalaitzandonakes et al. 1992)
- it enables the estimation of production frontiers in the presence of multiple outputs and inputs without imposing any additional restrictive aggregation assumption (Kalaitzandonakes et al. 1992).
- different input and output measurement units can be used and knowledge of their relative prices is not necessary (Callens and Tyteca 1999)

2.3.2 The different technical efficiency measures and their associated DEA model

The original technical efficiency measure proposed by Charnes et al. (1978) is obtained as the "maximum of a ratio of weighted outputs to weighted inputs subject to the condition that the similar ratios for every Decision Making Unit (DMU)[1] be less than or equal to unity". This efficiency measure is an ordinary fractional programming problem. Using the Charnes-Cooper (1962) transformation it can be transformed into its linear programming equivalent, the multiplier form with associated dual problem, the envelopment form, this last form being the source of the name Data Envelopment Analysis. The envelopment form has a nice intuitive interpretation. Making use of mathematical programming methods and based on the DMUs of the sample investigated, a piecewise production frontier is built. Once the efficiency frontier is defined, it is possible to determine the relative efficiency of each DMU by calculating its distance to the production frontier.

The original model developed by Charnes et al. (1978), called the CCR model, implicitly assumes Constant Returns to Scale (CRS). Bankers et al. (1984) proposed an extension of the CCR model, called the BCC (Bankers, Charnes, Cooper) model, for Variable Returns to Scale (VRS) technologies. The CCR and BCC models differ only in that the latter, but not the former, includes a convexity constraint so that each DMU investigated can only be benchmarked against firms of a similar size. The efficiency score obtained from the CCR model (θ_{CCR}) is called the technical efficiency (TE) and the one obtained from the BCC model (θ_{BCC}) is called the pure technical efficiency (PTE). As described in Equation 1, technical efficiency can be split into pure technical efficiency (PTE) and scale efficiency (SE). The scale efficiency ascertains "how far the scale size of a unit is away from optimal" (Fried et al. 2008), the optimal scale size being defined as the "most productive scale size with reference to a constant mix of inputs and outputs" (Fried et al. 2008)

Equation 1

$$\frac{\text{Technical Efficiency (TE)}}{\text{Pure Technical Efficiency (PTE)}} = \text{Scale Efficiency (SE)}$$

[1] In Data Envelopment Analysis the term "Decision Making Units" refers to the entities analysed.

The CRS efficiency score provides a "measure of the overall or aggregate productivity improvement that is possible if the firm is able to alter its scale of operation" (Coelli et al. 2005). The VRS TE score in itself can be viewed "as a reflection of what can be achieved in the short-run, and the CRS TE score as something that relates more to the long-run" (Coelli et al. 2005).

As in the present investigation we are more interested in a long term perspective, we shall calculate CRS technical efficiency and decompose it into VRS technical efficiency and scale efficiency.

2.3.3 Model orientation

Two types of DEA models can be distinguished according to the orientation chosen: the output-oriented and the input-oriented models. Whereas the former indicates the potential proportional increase in output production, with input levels held fixed, the latter indicates the potential proportional reduction in input usage, with output levels held constant (Coelli et al. 2005). Under the assumption of Constant Returns to Scale, the two models yield very similar results (Coelli et al. 2005). Coelli et al. (2005) advises choosing the orientation according to which quantities (inputs or outputs) the managers have most control over.

For the present study we are going to use an input-oriented model. Indeed for the dairy sector, due to the presence of raw milk quotas[2], an increase in output production is impossible in most of the cases

2.3.4 The CCR Model (CRS Technical Efficiency)

Using the input-oriented CRS model, the efficiency of a DMU is determined by solving the linear program presented in Equation 2. The linear program presented below is the envelopment form.

[2] The data used for the present investigation refer to the year 2006. At that time the Swiss raw milk quota system, abolished in May 2009, was still in force.

Equation 2

$$
\begin{aligned}
&\min_{\theta,\lambda}\theta,\\
&\text{subject to}: -q_i + Q\lambda \geq 0,\\
&\qquad \theta x_i - X\lambda \geq 0,\\
&\qquad \lambda \geq 0
\end{aligned}
$$

where:

- q_i is a column vector representing the M outputs of firm i (i=1, ..., I)
- x_i is a column vector representing the N inputs of firm i
- X being the N x I input matrix
- Q being the M x I output matrix
- θ is a scalar being the efficiency score of the i^{th} firm[3]
- λ being a I x 1 vector of constants representing the weights associated with each firm. If the weight is different from zero, then it means that the firm associated with this weight is a peer (firm which defines the efficient production frontier for the firm i examined).

The efficiency scores obtained with DEA are per definition comprised between 0 and 1, a DMU located on the efficient frontier having an efficiency score equal to 1.

2.3.5 The BCC Model (VRS Technical Efficiency)

The input-oriented VRS model only differs from the input-oriented CRS model in the addition of a convexity constraint to account for Variable Returns to Scale (see Equation 3). This convexity constraint ensures that a firm is only "benchmarked" against firms of a similar size (Coelli et al. 2005). As outlined by Coelli et al. (2005), this "approach forms a convex hull of intersecting planes that envelope the data points more tightly than the CRS conical hull and thus provides technical efficiency scores that are greater than or equal to those obtained using the CRS model".

[3] ($1-\theta$) represents the proportional decrease in inputs usage that can be achieved by the i-th firm, with output quantities held constant.

Equation 3

$$
\begin{aligned}
&\min_{\theta,\lambda} \theta, \\
&\text{subject to}: -q_i + Q\lambda \geq 0, \\
&\qquad \theta x_i - X\lambda \geq 0, \\
&\qquad I1'\lambda = 1 \\
&\qquad \lambda \geq 0
\end{aligned}
$$

where:

I1 is an I x1 vector of ones

3. Data

Before performing the efficiency assessment it is necessary to address the two following issues: (1) the description of the Decision Making Units to be analysed (2) the choice of the resources to be taken into account. These two issues are dealt with in the following sections.

3.1 Entities analysed and data source

In this article we focus on the Swiss dairy farms located in the mountain area. A dairy farm is defined here according to the farm typology of the Swiss Farm Accountancy Data Network (ART 2007).

The data used for the current assessment are retrieved from the Swiss Farm Accountancy Data Network (FADN), which is managed by the Farm Economics Research Group of Agroscope Reckenholz-Tänikon Research Station. This study is based on a sample of 480 dairy farms located in mountain zones 2, 3 and 4. The cross sectional data used for the present investigation refer to the year 2006.

One basic principle of an efficiency analysis based on Data Envelopment Analysis is "to compare DMUs that are comparable" (Hoffmann 2006). For that reason the DMUs investigated have to fulfill a series of homogeneity hypotheses (Dyson et al. 2001; Haas and Murphy 2003; Hoffmann 2006). First, the DMUs are assumed to undertake similar activities and to produce comparable products and services so that a common outputs set can be defined (Dyson et al. 2001; Haas and Murphy 2003; Hoffmann 2006). A second assumption is that "a similar range of resources is available to all the units" (Dyson et al. 2001). Furthermore, all DMUs should operate under the same conditions (Dyson et al. 2001; Haas and Murphy 2003; Hoffmann 2006). Especially in agriculture particular attention should be paid to the homogeneity of the natural environment (Hoffmann 2006). In the present case the group of farms investigated show a relatively high homogeneity, especially with regard to their natural environment. However, these farms might show some heterogeneity with regard to the quality of their land resource. Indeed the farm land area includes both usable agricultural area and forest area, and it has to be expected that the productivity of these two types of land will differ significantly. To correct for this homogeneity problem, a variable "proportion of forest area in the land area" will be included as a regressor in the second step regression when we analyse the determinants of the farm's technical efficiency.

Some selected descriptive statistics of the cross section investigated are presented in table 1 (continuous variables) and table 2 (categorical variables).

3.2 Resources considered and method of assessing the amount of each resource used

For the efficiency assessment we consider the following resources: (1) intermediate consumptions (2) land (3) capital (4) labour (5) nitrogen use and (6) energy use.

Intermediate consumptions, land, capital, labour are the typical economic resources accounted for in traditional assessments of economic performance. Labour can be considered as both an economic and social resource and can thus be referred to as a socio-economic input.

Nitrogen and energy are two environmental resources of high relevance for dairy farming. The choice of these two environmental resources has been principally motivated by data availability considerations.

Table 1: Descriptive statistics of continuous variables

Variable	Mean	SD	Min.	Max.
Milk produced [kg]	89'471	43'495	12'800	359'893
Total farm revenues[4] [1000 CHF]	177.64	73.51	54.19	539.12
Farm land area [ha]	26.9	16.9	5.6	187.6
Usable agricultural area [ha]	21.2	10.3	5.6	64.6
Labour [normal working days]	479	156	163	1034
Capital [1000 CHF]	46.8	23.1	6.6	206.7
Intermediate consumptions [1000 CHF]	81.0	40.0	27.2	356.7
Proportion of forest in the farm land area [%] (*forest*)	14.0	14.6	0	68.7
The names in brackets are the names given to the variables in the regression model.				

Source: Data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

Table 2: Descriptive statistics of categorical variables

Variable	%
Area (*area*) • mountain zone 2 • mountain zones 3 and 4	 68.1 31.9
Production form *(prodform)* • proof of ecological performance[5] • organic farming	 72.5 27.5
Proportion of part-time farms *(parttime)*	21.3
Stall type: proportion of farms with *(stall)* • tie house • loose house	 83.1 16.9
Proportion of farms with *(silagefree)* • silage milk • silage free milk: cheese milk[6]	 69.4 30.6
Proportion of farms whose manager has an agricultural education *(agreduc)*	66.9
The names in brackets are the names given to the variables in the model.	

[4] All direct payments included

[5] In Switzerland all direct payments require a certain "proof of ecological performance". These requirements are actually equivalent to those of the former Swiss integrated production label, which was in force until 1998. Conventional farming does not exist anymore in Switzerland.

[6] In Switzerland farms producing milk for the production of cheese are not allowed to feed silage to their cows. This is the reason for differentiating between two different production systems: (i) "silage milk" (the milk is used for the elaboration of dairy products other than cheese) and (ii) "silage-free milk" (the milk is used for cheese production).

Source: Data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

The amount of intermediate consumptions employed is measured in Swiss francs. The amount of land used is measured in hectares of farm land area[7]. Capital is defined as the sum of amortizations, interest on debts, calculated interest on equity capital and rents, all measured in Swiss francs. Labour input is measured as the total number of normal working days on the farm. We opted for the number of normal working days rather than for the number of annual work units as this should more accurately reflect the real amount of work on the farm and thus be more appropriate from a sustainability perspective in which labour is considered as both a social and an economic resource. The aforementioned quantities are all collected in the Swiss Farm Accountancy Data Network (FADN). The descriptive statistics related to economic resource use are presented in table 1.

The two environmental resources considered (energy and nitrogen use) are not stored as such in the FADN databank and have thus to be computed using the variables available in this databank.

For the amount of energy consumed we consider both direct and indirect energy inputs into the agricultural production system. For both direct and indirect energy inputs we use primary energy demand as defined by Gaillard et al. (1997). It includes preparation energy, process energy and intrinsic energy.

The computation of the total primary energy demand for each of the farm inputs listed in table 3 consists in deriving the physical amount of farm input from the monetary variable available in the FADN data (cost position) and then in multiplying this physical amount by the primary energy demand per physical unit of this input. The values used for the primary energy demand for each farm input are shown in table 3.
The descriptive statistics of the energy use of the sample of farms considered are presented in table 4.

[7] The farm land area includes the usable agricultural area and the farm land area located outside the usable agricultural area, which is composed mainly of forest area.

Table 3: Reference values used for the calculation of the primary energy demand of the farm inputs considered

Farm input	Unit	Primary energy demand in MJ per unit of farm input	Source
Diesel and heating oil	kg	50.5	[1]
Electricity	kWh	15.8	[1]
Mineral fertilizer N	kg N	56.3	[1]
Mineral fertilizer P	kg P_2O_5	19.7	[1]
Mineral fertilizer K	kg K_2O	11.6	[1]
Mineral fertilizer Mg	kg Mg	5	[1]
Energy concentrates for dairy production	kg product	5.2	[2]
Protein concentrates for dairy production	kg product	13.2	[2]
Milk production concentrates	kg product	7.5	[2]
Minerals	kg product	5.0	[3]
Cattle salts	kg product	4.9	[2]
Grass silage	kg D.M.[8]	1.5	[2]
Hay	kg D.M.	2.4	[2]
Straw or litter	kg D.M.	1.0	[3]
Herbicide	kg product	129.5	[1]
Seeds	kg product	14.8	[1]
Own machinery	l diesel consumed	12	[4]
[1]: Gaillard et al. (1997) [2]: Zimmermann (2006) [3]: Wells (2001) [4]: Dalgaard et al. (2001)			

Source: own representation

[8] Dry Matter

For the second environmental resource (nitrogen use), the amount of input used is defined as the total nitrogen supply (in kg N) coming from the excrement of the farm animals and from the use of mineral fertilisers. The nitrogen supply due to animal excrement is calculated on the basis of the inventory of animals held on the farm and on the basis of the reference values of the nitrogen supply of each animal category (according to the species, sex and age). The reference values applied to the present work are those commonly used by the Swiss farm extension services as given in Agridea and FOAG (2006) and Walther et al. (2001). The nitrogen supply from mineral fertilisers is calculated on the basis of the FADN cost position for mineral fertilizers, making some assumptions as to the type of mineral fertiliser used and considering the average market price of one unit of fertiliser. These average market prices are made available in the annual "gross margin" catalogue published by the Swiss farm extension services (Agridea 2006). The statistics for the nitrogen use of the sample of farms considered are shown in table 4.

Table 4: Descriptive statistics related to environmental resources

Variable	Mean	SD	Min.	Max.
Nitrogen Use (in kg N)	2„172	1'094	467	8'131
Energy Use (in 1000 MJ)	571.8	293.0	70.8	2'146

Source: own calculations based on the data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

3.3 Output

Output is made up of one variable, given by the sum of gross revenue from agricultural activities, gross revenue from para-agricultural activities and ecological and ethological direct payments. We decided not to include general direct payments in the output variable as we wanted to consider only the direct payments remunerating a real concrete ecological service provided by the farm to society. The output statistics are presented in table 5.

Table 5: Output statistics of the farms investigated

Variable	Mean	SD	Min.	Max.
Revenue from agricultural activities [1000 CHF]	89.8	47.7	22.2	427.5
Revenue from para-agricultural activities [1000 CHF]	27.5	28.8	0.1	298.5
Ecological and ethological direct payments [1000 CHF]	8.9	5.6	0.1	37.4

Source: data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

4. Investigation of the determinants of CRS Technical Efficiency

The main objective of the present study is to investigate the factors affecting the long-run technical efficiency, i.e. the CRS technical efficiency[9], of the use of economic and environmental resources by dairy farms located in the mountain region. For that purpose we performed a multiple linear regression analysis with the cross-sectional data of the 480 dairy farms using the technical efficiency score as the dependent variable and the six following types of variables as independent variables:

- characteristics of the natural environment of the farm
- structural characteristics of the farm
- sociological characteristics of the farm manager
- production orientation and output composition
- input composition and financial situation of the farm
- characteristics of the dairy production system/technology and dairy herd management indicators.

These groups of determinants were derived from an analysis of the literature on farm efficiency analysis.

[9] This variable has been given the name "*eff*" in the model.

The general specification of the model is the following:

Equation 4

$$y_i = \beta_0 + \beta_k x_{ik} + \varepsilon_i$$

with:

- i the subscript for the individual i
- y_i the dependent variable
- x_{ik} the k^{th} independent variable
- ε_i the stochastic error

Due to the fact that the dependent variable is defined on a [0;1] scale and arguing that the efficiency scores are generated by a censoring data generating process, many studies investigating the determinants of technical efficiency calculated with DEA have made use of a two-limit tobit (2LT) approach with limits at zero and unity as the regression procedure. McDonald (2009) has shown that the DEA efficiency scores are not generated by a censoring process but are fractional data. In that case a Tobit estimation is thus inappropriate. By contrast, ordinary least squares is shown to be a consistent estimator (McDonald 2009). We shall therefore estimate this model with the Ordinary Least Squares procedure which minimises the sum of squared residuals to estimate the $ß_k$ parameters of interest.

The independent variables presented in table 6 have been included in the model.

Table 6: Specification of the regression model (the names in brackets are the names given to the variables in the model)

Category	Variable
Natural environment of the farm	Agricultural production area (*area*) 0: mountain zone 2 1: mountain zones 3 and 4
	Proportion of forest land in the farm area (in %) (*forest*)
Structural characteristics of the farm	Size: farm output defined as the sum of the revenue from agricultural activities, from para-agricultural activities and ecological and ethological direct payments (*size*)
	Part-time farming (*parttime*) 0: no 1: yes
	Proportion of the farm land area rent (in %) (*landrent*)
Sociological characteristics of the farmer	Age of the farmer in years (*age*)
	Agricultural education (*agreduc*) 0: no 1: yes
Production orientation and output composition	Production form (*prodform*) 0: proof of ecological performance 1: organic farming
	Importance of para-agricultural activities in the farm output Ratio: farm revenue coming from para-agricultural and miscellaneous activities / total farm revenue (in %) (*paraagr*)
	Ecological orientation of the farm (*ecolor*) Amount of ecological and ethological direct payments received by the farm in CHF / usable agricultural area in ha
Input composition and financial situation	Capital intensity: Ratio: capital used in CHF / Normal Working Days (*caplab*)
	Proportion of salaried labour in the total labour force of the farm (*salar*)
	Borrowing ratio: borrowed capital/total capital (in %) (*borrow*)
Characteristics of the dairy production system or of the technology used and dairy herd management indicators	Housing type for cows (*stall*) 0: tie-stall 1: free-stall
	Silage-free milk (*silagefree*) 0: no 1: yes
	Milk production intensity (*mperha*) Amount of milk produced in kg per ha main fodder area
	Intensity of the concentrates use (*conccosts*) Costs of concentrates for dairy cattle (in rappen[10]) per kg milk produced
	Milk yield in kg per cow and year (*myield*)
	Culling rate (in %) (*cullrate*)
	Presence of own aestivation activity (*aestiv*) 0: no 1: yes

[10] 1 rappen = 0.01 CHF

5. Results

The statistics relating to technical efficiency are presented in table 7.

Table 7: Technical Efficiency statistics

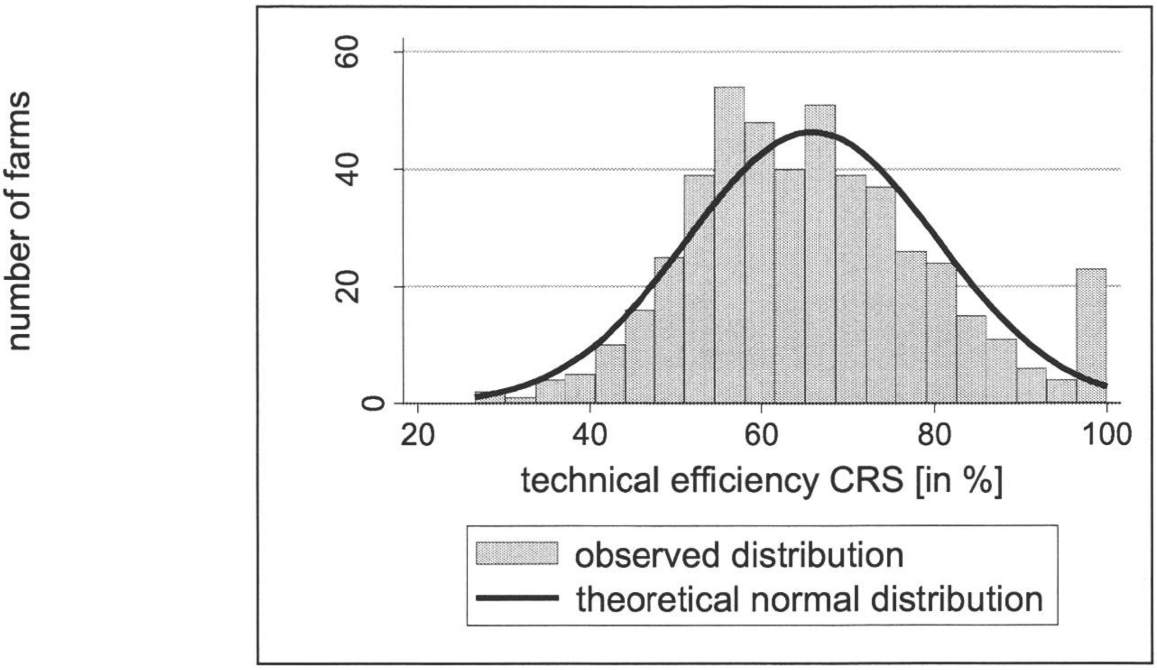
	Mean	SD	Min.	Max.
CRS Technical Efficiency (DEA, CCR model) [%]	65.9	14.4	26.7	100
VRS Technical Efficiency (DEA, BCC model) [%]	74.9	12.9	46.7	100
Scale Efficiency [%]	88.3	12.8	39.5	100

Source: own calculations based on the data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

The Constant Returns to Scale Technical Efficiency of the sample of farms investigated amounts on average to 65.9%. 4% of the farms are located on the production frontier and thus show a CRS efficiency score equal to one. The 34.1% technical inefficiency results from 26.1% pure technical inefficiency and 11.7% scale inefficiency.

Before performing the linear regression analysing the determinants of long-run technical efficiency, we investigate the degree of collinearity between the regressors using the Variance Inflation Factor (VIF). The VIF shows the increase in the standard error of the regression coefficient of the independent variable j due to its correlation with the other independent variables (Backhaus et al. 2003). Values above 20 are suggested as indicative of a multicollinearity problem (Greene 2003). In the present case the VIF scores do not exceed 2.30, which shows that multicollinearity is not a problem.

The assumption of normal distribution of the residuals is checked below. The distribution of the residuals is shown in figure 1. At first glance the distribution of the residuals seems very close to a normal distribution. However, the application of the Skewness/Kurtosis test led us to reject the H_0 hypothesis of normality of the residuals distribution ($p<0.001$).



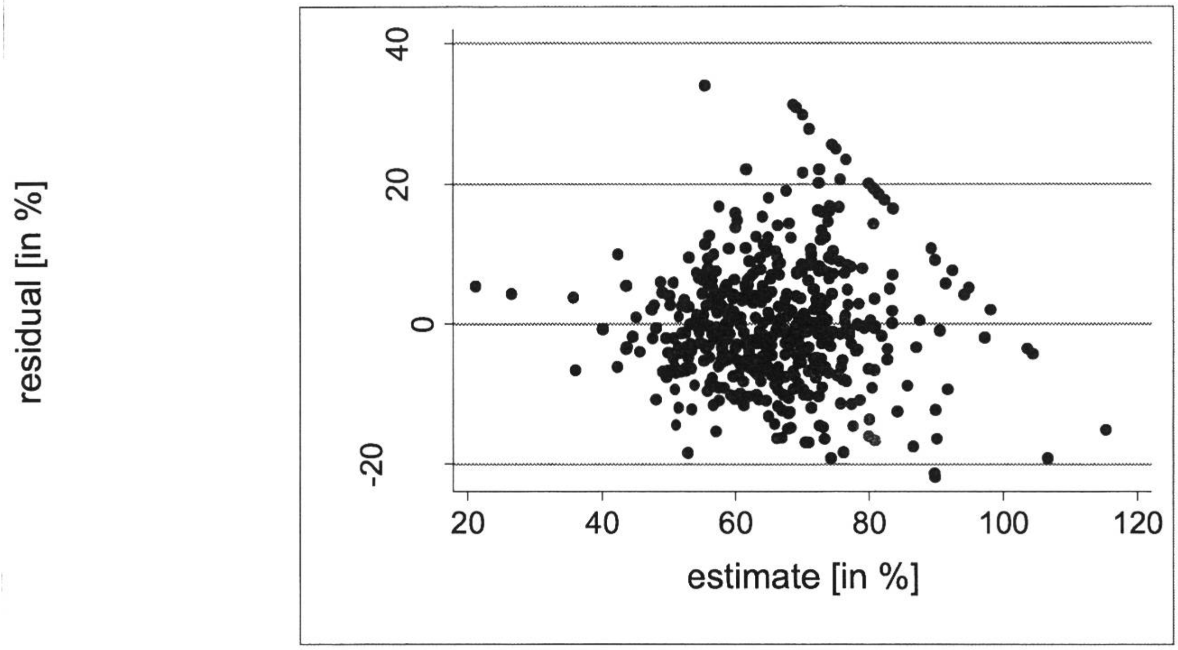
Source: own calculations based on the data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

Figure 1: Distribution of the residuals of the regression

To remove this problem we eliminated the outliers in the distribution of residuals and performed a second regression. After the elimination of 10 outliers we obtained a normal distribution of residuals[11]. We then compared the results of this second regression with the results of the first one (i.e. the regression without elimination of outliers). Since the results of these two regressions were not significantly different, and in view of the fact that the observations eliminated could not be considered *strictu senso* as outliers, the regression was performed without ignoring any data.

Figure 2 shows that the homoscedasticity assumption is not satisfied. This finding is also supported by the Breusch-Pagan test ($p<0.001$). To correct for this problem we used the heteroscedasticity-consistent covariance matrix estimator (also called "White (robust) standard errors estimator") proposed by White (1980) to estimate this model.

[11] We eliminated the observations with residuals higher than 22% (10 observations). We then carried out a regression without the 10 outliers and obtained residuals which were normally distributed (Kolmogorov Smirnov, p=0.27).



Source: own calculations based on the data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

Figure 2: Plot of residuals against predicted values

As far as the mean independence assumption is concerned, the results of a regression performed between the residuals of the model and the independent variables (probability associated with the F-Test of overall significance is equal to 1.0) clearly show that this assumption is satisfied.

The results of the regression performed with the independent variables described in table 6 using robust standard errors are presented in table 8. The coefficient of determination of the model is equal to 0.62, which means that 62% of the total variance of the dependent variable is explained by the model.

Prior to executing the regression we calculated the partial correlation coefficients between the dependent variable, i.e. the technical efficiency, and each regressor, keeping all other regressors constant. The results of this analysis were of particular interest as they would help us to interpret the results of the regression. The "*size*" variable, which is an indicator of farm size, is the variable which shows the highest partial correlation with the dependent variable ($r=+0.46$, $p<0.001$).

Table 8: Ordinary Least Squares estimation of the model with robust standard errors

Variable	**Coefficient**	**t**	**P>|t|**	**[95% Conf. Intervall]**	
area	-2.86	-2.74	0.006	-4.91	-0.81
forest	-0.02	-0.42	0.673	-0.09	-0.06
size	1.10e-04	11.03	0.000	0.90e-04	1.29e-04
parttime	-7.65	-6.84	0.000	-9.85	-5.45
landrent	4.13e-03	0.22	0.825	-3.25e-02	4.08e-02
age	-0.09	-1.91	0.057	-0.19	2.78e-03
agreduc	0.40	0.43	0.669	-1.45	2.26
prodform	3.31	2.41	0.016	0.61	6.01
paraagr	0.27	7.31	0.000	0.20	0.34
ecolor	6.83e-03	1.76	0.078	-0.78e-03	14.44e-03
caplab	2.42e-02	2.20	0.029	0.26e-02	4.59e-02
salar	-1.44e-02	-0.52	0.603	-6.89e-02	4.01e-02
borrow	-5.48e-02	-3.06	0.002	-9.00e-02	-1.96e-02
stall	-1.81	-1.47	0.142	-4.23	0.61
silagefree	0.78	0.85	0.395	-1.02	2.58
mperha	1.46e-03	4.24	0.000	0.78e-03	2.13e-03
conccosts	-0.28	-6.29	0.000	-0.36	-0.19
myield	-4.78e-04	-1.22	0.225	-12.5e04	2.95e-04
cullrate	-8.05e-03	-0.38	0.705	-4.99e-02	3.38e-02
aestiv	-0.91	-0.92	0.356	-2.84	1.02
Number of observations			= 480		
F(20, 459)			= 39.83		
Prob > F			= 0.0000		
R-Squared			= 0.62		
Root MSE			= 9.05		

Source: own calculations based on the data of the Swiss Farm Accountancy Data Network (Year 2006, n= 480 dairy farms)

The "*paraagr*" variable, which reflects the importance of para-agricultural activity in farm activity, is also of major importance as its correlation coefficient with "*eff*", all other regressors kept constant, is equal to +0.38 ($p<0.001$). The third most important regressor is the *parttime* variable, as its partial correlation coefficient with *eff* is equal to -0.29 (p<0.001). The fourth most important variable in terms of partial correlation with *eff* is the *conccosts* variable (r=-0.23, p<0.001), which reflects the intensity of feed concentrate use. The intensity of milk production per ha fodder area (*mperha* variable) is also strongly correlated with the technical efficiency score (r=+0.21, p<0.001). Other variables which are significantly correlated with technical efficiency, but to a lesser extent than the variables presented previously, are the following (in decreasing order of partial correlation intensity): *borrow (r=-0.14; p=0.002), area (r=-0.13; p=0.005), prodform (r=+0.11; p=0.016), caplab (r=+0.11; p=0.016), ecolor (r=+0.09; p=0.053), age (r=-0.09; p=0.054)*. The partial correlation coefficients between technical efficiency and each of the following variables are not significant: *stall, silagefree, landrent, salarlabour, agreduc, myield, cullrate.*

We shall now present in detail the results of the regression performed (see table 8).

Farm size has a significant positive effect on technical efficiency. An increase of 10'000 CHF in economic size leads *ceteris paribus* to an absolute increase of 1.1% in CRS technical efficiency. The proportion of para-agricultural activity in the output also has a significant positive impact on technical efficiency. An absolute increase of 10% in the "output coming from para-agriculture/total farm output" ratio leads *ceteris paribus* to an absolute increase of 2.7% in the technical efficiency of the farms investigated[12]. Part-time farms show *ceteris paribus* a 7.6% lower efficiency than non part-time farms. The intensity of the use of feed concentrates, as reflected by the cost of feed concentrates per kg milk produced, negatively affects efficiency. An increase of 10 rappen per kg milk in the costs of feed concentrates leads *ceteris paribus* to an absolute decrease of 2.8% in efficiency. The intensity of milk production per ha fodder area positively influences technical efficiency. An increase of 1'000 kg in the amount of milk produced per ha fodder area induces an absolute increase of 1.5% in technical efficiency. A *ceteribus paribus* absolute increase of the borrowing ratio by 10% is associated with a 0.5% absolute decrease in efficiency. The farms located in mountain

[12] For example, if the "output from para-agriculture/total farm output" ratio increases absolutely by 10% from 10% to 20%, technical efficiency increases absolutely by 2.7% from TE to TE+2.7%.

zones 3 and 4 show a 2.9% lower technical efficiency than similar farms located in mountain zone 2. Organic farms present *ceteris paribus* a 3.3% higher efficiency than non-organic farms. A *ceteris paribus* augmentation of 10 CHF in the capital used per annual working hour results in a 0.2% increase in the efficiency score. A rise of 100 CHF in the amount of ecological and ethological direct payments received per ha of usable agricultural area leads *ceteris paribus* to an absolute 0.6% increase in the efficiency score. Age has a negative impact on the efficiency score. However, the effect remains quite marginal (ten additional years of age result in a 0.9% absolute decrease in the efficiency score). As already mentioned previously in the analysis of partial correlation coefficients, the *stall, silagefree, landrent, salarlabour, agreduc, myield, cullrate, forest, aestiv* variables do not have any significant effect on technical efficiency.

The previously depicted positive impact of farm size on technical efficiency results from two effects: the positive effect of farm size on scale efficiency and its positive effect on pure technical efficiency. As far as the first effect is concerned, it arises from the fact that the farms investigated mostly operate below the most productive scale size. Indeed, among the farms investigated, 82.5% operate under increasing returns to scale (IRS), 6.7% are scale efficient and 10.8% operate under decreasing returns to scale (DRS). The average farm size of the farms operating under IRS amounts to 109'804 CHF, whereas farms operating at an optimal scale and under DRS account for 188'330 and 212'972 CHF respectively. The strong positive influence of farm size on pure technical efficiency was revealed by an additional regression performed between the VRS technical efficiency scores and the independent variables listed in table 6 (this regression is not presented in the present paper).

6. Discussion and conclusions

6.1 Discussion of the results

The results of the regression reveal that the technical efficiency of the use of economic and environmental resources of Swiss dairy farms located in the mountain region is influenced foremost by farm size, the orientation of farm activity towards more para-agriculture, the presence of off-farm work and, to a lesser extent, by the characteristics of the operative management of the dairy activity or of the dairy production system.

The positive effect of farm size on technical efficiency highlights the considerable existing resource-saving potential which results from scale effects.

As far as the orientation of farm activity is concerned, an increased orientation towards para-agriculture to the detriment of agricultural activity is associated with an increase in technical efficiency. This might be accounted for by the fact that para-agricultural activities, which are more "service activities" than "production activities", might require not only a lower amount of economic resources per unit of output produced but also a lower amount of ecological resources per unit of output produced in comparison with agricultural activities. These results are in good accordance with the observation made by Flury et al. (2009) in their study examining the evolution of the economic situation of Swiss farms located in the mountain region. These authors observed that over the period 1998-2007 para-agriculture gained in importance in the output of Swiss farms located in the mountain region. This evolution might most likely result from a competitive advantage of para-agricultural activity over agricultural activity.

The *part-time* variable was found to have a major strong negative effect on CRS technical efficiency. An explanation for this observation might lie in the fact that participation in the off-farm labour market reduces the time available for farm-management, especially for the management of the dairy herd. The negative effect of part-time farming on technical efficiency observed in the present investigation goes hand in hand with the findings of Goodwin and Mishra (2004). These authors investigated the relationship between economic efficiency and off-farm labour supply on American farms. Their results show an important and significant inverse relationship between these two variables. Their findings confirmed the hypothesis formulated by Smith (2002) that off-farm work may hinder "smart farming", this latter being understood as the practice of collecting and analysing data on the various aspects of the farm's production system for the sake of optimising the production process and inputs use.

Even if the characteristics of the dairy herd management and of the dairy production system are not the major determining factors affecting the technical efficiency of the farms investigated, however, two characteristics of the milk production system – the intensity of concentrate use and milk production intensity per hectare – play a non-negligible role.
In terms of technical efficiency the negative effect of high intensity concentrate use clearly shows that milk production heavily based on rough forage is technically more efficient than milk production heavily based on concentrate use.
The positive effect of the milk production intensity per hectare on the technical efficiency of the use of economic and environmental resources reflects the importance of the efficient use of the most restricting production factor of farms in Switzerland, *viz.* the land production factor.

The positive effect of an increase in the capital/labour ratio is clear evidence that the substitution of labour by capital enhances the efficiency of the farms examined.

An increased orientation of farm activity towards the provision of ecological services remunerated by ecological direct payments *(ecolor)* proves to be positive in terms of technical efficiency. The same reasons as those invoked for the explanation of the positive effect of *paraagr* on technical efficiency might account for this result.

The negative effect of the variable *area* provides clear evidence of the influence of the natural environment on technical efficiency. With increasing altitude the natural production conditions become more unfavourable and thus technical efficiency decreases. This factor is beyond the farm manager's control and thus the farms located in mountain zones 3 and 4 have, in comparison with the farms located in mountain zone 2, a competitive disadvantage of 3% in terms of technical efficiency. These results go hand in hand with the findings of Brümmer (2001) for Slovenian private farms or Ortner (2008) for Austrian dairy farms.

The positive impact of organic farming in terms of technical efficiency may result from two factors: Firstly, it may result from an intrinsically more efficient use of inputs. Secondly, the higher market remuneration of the milk sold may also account for this higher technical efficiency. Indeed, the average price of the milk sold amounts to 79.1 rappen for organic farms and to 71.4 rappen for non-organic farms.

As far as the sociological characteristics of the farm manager are concerned, they only have a minor influence on technical efficiency.
The agricultural education level does not affect the efficiency of resource use, which is quite counterintuitive and contrary to the conclusions of the majority of studies investigating the relationship between farm economic efficiency and agricultural education (see for example Andreakos et al. 1997; Wilson et al. 2001; O'Neill et al. 1999; Mathijs and Vranken 2001; Igliori 2005). The absence of positive effect of the education level on the technical efficiency of economic resource use has, however, also been reported in some studies like those conducted by Goodwin and Mishra (2004) and Barnes (2006).
The negative effect of the age of the farm manager on the technical efficiency of economic and environmental resource use is also in line with the results found in the literature on the effect of the farmer's age on the efficiency of economic resources use (refer for example to Van Passel et al. (2007) or Godwin and Mishra (2004)). As demonstrated by Godwin and Schroer (1994) for a sample of farms in the United States, this effect might result from the fact that older farmers may be less likely to adopt new technologies and thus may fail to realize certain efficiency advantages that come with technological advances.

To conclude the analysis of the factors affecting the technical efficiency of the use of economic and ecological resources on Swiss dairy farms located in the mountain region, we shall classify these factors in three groups (see table 9):

- Group 1 is made up of the factors which are under the control of the farm manager in the short-run
- Group 2 is made up of the factors which the farm manager can influence only in the long-run
- Group 3 is made up of the factors over which the farm manager has no control

As is obvious from table 9, the factors which are under the control of the farm manager in the short-run are quite limited. To increase the technical efficiency of his farm in the short-run the farmer can only reduce the intensity of the use of concentrates and the ecological orientation of his farm.

Table 9: Factors affecting technical efficiency classified according to the ability of the farm manager to control them

Group	Variable
1) Factors which are under the control of the farm manager in the short-run	*conccosts* *ecolor*
2) Factors which the manager can influence only in the long-run	*size* *parttime* *paraagr* *prodform* *mperha* *borrow* *caplab*
3) Factors over which the farm manager has no control	*area* *age*

Source: own representation

In the long-run he can increase the efficiency of his farm by augmenting the size of his farm, moving towards full-time farming instead of part-time farming, increasing para-agricultural activity, switching to organic farming, increasing milk production intensity per ha, decreasing the debt ratio and substituting capital for labour.

We might question if the strategy of moving towards full-time farming instead of part-time farming is realistic as there exists a strong path dependence in this regard. Part-time farming is more an "exit door" from full-time farming than an "entrance door" to it. "*parttime*" is more a variable that can be influenced by policy makers than by the farmers themselves. Through policy measures created for that purpose, policy-makers could indeed promote full-time farming and thus enhance the technical efficiency of the Swiss dairy farms located in the mountain region.

6.2 Limits of the results

It is first of all important to emphasize that the estimated technical inefficiency, which can be interpreted as input saving potential, is of a theoretical nature. Indeed, this long-term saving potential can be reached only if the decision-making units are operating under perfectly similar conditions, especially regarding their natural and regulatory environment. Even if we have focused on a relatively homogeneous group of farms, in reality the farms investigated operate under very different environmental conditions, for example with regard to the gradient of the land, the accessibility of the fields, atmospheric temperatures and soil fertility. As a consequence, as shown by Ortner (2008), the overall input saving potential assessed within the efficiency analysis will overestimate the real reachable input saving potential. Part of the inefficiency calculated cannot be attributed to the inefficiency of farm management or to farm characteristics but is due to unfavourable natural conditions which are beyond the manager's control (Ortner 2008). For example, in the present assessment we have shown that a location in mountain zones 3 or 4 is associated with an efficiency 2.7% lower than that of a location in mountain zone 2. To calculate the real input saving potential achievable by the group of farms investigated, it would be necessary to have very precise details on the characteristics of the natural environment of the farms analysed and to include this information in the regression. Unfortunately such variables are not available in the FADN database used.
For the reasons set out previously, the interest of the present paper lies not in quantifying the absolute level of the technical efficiency of these farms in itself, but in analyzing the factors affecting this technical efficiency and thus in exploring ways of promoting the efficiency of this sector.

In the present investigation off-farm employment has been proven to have a negative effect on the technical efficiency of dairy farms in the mountain region. We should, however, be very careful when advising policy makers to promote full-time farming. Although part-time farming is associated with lower technical efficiency, as outlined by Schultz (1990), off-farm employment is "an important means by which farm households can manage risk through diversification of income and sources". In the context of expected further liberalisation of the dairy market and considering the increasing volatility of the agricultural commodities markets, this aspect might be of major importance for long-term farm survival.

6.3 Discussion of the approach used and perspectives

After having presented and discussed the results and their implications, we shall now briefly discuss the approach used here to assess economic and environmental farm performance.

One major interest of this investigation is that it considers both economic and ecological resources. Economists have often been reproached for focusing only on the efficiency of the use of economic resources, thereby totally ignoring environmental resources. In the present study we have considered two important environmental resources for the type of farm investigated.

However, from a perspective of the measurement of farm sustainable performance, we feel that an analysis of the efficiency of resource use is not sufficient and should be complemented by additional analyses considering other major sustainability issues, and especially the carrying capacity issues. As emphasized by Jollands (2006), "efficiency is a necessary but not sufficient condition for improving sustainability". For that reason, efficiency should be embedded within broader considerations (Jollands 2006).

Daly (1992) suggested that beyond the objective of efficient allocation of resources, the goals of "equitable distribution" and "sustainable scale" should also be considered when making decisions related to sustainable development. Whereas the objective of "equitable distribution" is difficult to address at a micro-level, "sustainable scale" is not only addressable but also of major relevance for the present assessment. This goal refers to "the physical volume of the throughput, the flow of matter-energy from the environment as low-entropy raw materials, and back to the environment as high-entropy wastes" (Daly 1992). The significance of this goal is relative "to the natural capacities of the ecosystem to regenerate the inputs and absorb the waste outputs on a sustainable basis" (Daly 1992). A sustainable scale is then defined as "one that does not erode environmental capacity over time" (Daly 1992). Even if the sustainable scale goal developed by Daly (1992) refers to a macro-level it can also be extended at a micro-level, especially for activities having a close relationship with their surrounding local ecosystem (as opposed to the global ecosystem at macro-level). This is the case for farming activity based on the use of a very important component of the local ecosystem, the soil, which cannot be considered independently of the aquatic ecosystem. The concept of sustainable scale implemented at a micro-level (or local ecosystem level) would then mean that the environmental impacts generated per ha by a farm do not exceed the carrying capacity[13] of the local ecosystem. A farm would thus contribute to more sustainability if it used its economic and environmental resources very efficiently by complying at the same time with the environmental carrying capacity of the local ecosystem on which it is based.

A further limitation of the present assessment is that qualitative environmental issues (e.g. the preservation and the enhancement of biodiversity, soil protection) have not been considered principally for data availability reasons but also due to the fact that it would not have been possible to include them in an analysis of resource use efficiency.

Finally, it is important to mention here that the database of the FADN is not the best appropriate database for an assessment of environmental resource use. In fact, no data on the amount of ecological resources used are available in this database. These parameters therefore have to be estimated using accountancy variables and making several assumptions with regard to input composition. Whereas for dairy farms in the mountain area this estimation is possible, as these farms are highly specialized in milk production, in the case of a farm with several agricultural branches such an estimation would probably be very challenging. It would be necessary to use precise complementary data related to the environmental issues investigated in order to be able to perform a reliable assessment of ecological efficiency.

6.4 Conclusions

This paper assesses the determinants of the long-run technical efficiency of economic and environmental resource use by Swiss dairy farms located in the mountain region.

The results of the regression performed demonstrate that technical efficiency can be controlled by the farm manager. An increase in farm size, an increased orientation towards more para-agricultural activities to the detriment of agricultural activities and a decrease in the intensity of the use of concentrates are the three principal means of action the farm

[13] By carrying capacity we mean sustainability constraints in the form of the assimilative capacity of the environment (Atkinson et al. 1997).

manager has at his disposal for enhancing the technical efficiency of his farm. Promoting full-time farming should also represent quite a promising strategy for enhancing the efficiency of this sector.
This investigation thus provides interesting insights for farm managers and policy makers into the means of action available for increasing the efficiency of the Swiss dairy sector in the mountain region.
By considering both economic and environmental resources, this study addresses a central issue of farm sustainable performance, *viz.* the joint efficient use of economic and environmental resources. Sustainable performance cannot however be reduced only to a question of resource use efficiency. Additional aspects, and especially carrying capacity issues, should also be taken into account to perform a corporate sustainable assessment in line with the principles of the sustainable development concept.
Further research is thus needed to analyse the economic and environmental performance of these farmers in a broader context, i.e. not only considering the farm level but also taking into account the societal or macro-perspective. This further research will, however, only be possible if data related to environmental issues are available in quantity and quality. In the present context this is undoubtedly the greatest limiting factor in performing a reliable and exhaustive sustainable performance assessment going far beyond the single question of resource use efficiency.

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Kontaktautor:

Pierrick Jan
Agroscope Reckenholz-Taenikon Research Station ART
Farm Economics Research Group
Tänikon 1
CH-8356 Ettenhausen

E-Mail: pierrick.jan@art.admin.ch