Performance of Swiss dairy farms under provision of public goods

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Abstract: Farmers provide not only agricultural products but also public goods and services. When analyzing farm performance, these different outputs should be modelled separately. In this study, we investigated Swiss dairy farms located in the plain, hill and mountainous regions for the period between 2003 and 2009. For the representation of production technology, we employed a parametric output distance function and modeled particular public goods and services as a separate output. The resulted elasticities of agricultural output coincided with the corresponding shares of this output. However, the elasticities of particular public goods and services were higher than the corresponding shares. This might be related to the fact that this output contains different kinds of direct payments, "production" of which does not require additional inputs or trade-off with other outputs. Our results showed that the level of pro ductivity in the plain region did not depend on the scale of production, but more on the improvement in the technical efficiency. However, in the hill and mountainous regions, there was potential for scale adjustments. Sample farms in these regions showed significant decreasing returns to scale, which suggests that the average farm in these subsamples could improve its productivity by scaling down its production. Our results might also be confirmation of decelerated structural change, since decreasing returns to scale might reflect an obstacle to growth. We found the wide range of the efficiency scores for Swiss farms, which indicates potentials for improvements. Among others, off-farm income as well as high level of ecological services showed significantly positive influence on the technical efficiency of Swiss farms in all three regions.

Key words: efficiency, direct payments, output distance function, Swiss agriculture

Direct payments compensate farmers for public goods and services provided in addition to agricultural products. They influence the on- and off-farm distribution of labour, investment decisions, the farm growth, the farm exit etc. (Kumbhakar and Lien 2010). Therefore, a particular attention should be paid to the modelling of these payments when analyzing the farmers' efficiency. Empirical studies have reported varying results regarding the effect of direct payments on the performance of farms, and the results widely depended on the modelling frameworks used. Previous studies have modelled direct payments either as an input variable or as an exogenous variable that explains technical efficiency. Furthermore, McCloud and Kumbhakar (2008) treated subsidies as "facilitating" inputs. They modelled these inputs endogenously and allowed them to affect the farm output and technical efficiency[1].

Swiss farms also operate in a highly regulated environment. In addition to agricultural goods, Swiss agricultural policy encourages farmers to provide public goods and services remunerated through direct payments. The current system of direct payments in Switzerland distinguishes between the general and ecological direct payments. General direct payments compensate farmers for ensuring food supplies, maintaining the landscape and contributing to the preservation of social structure in rural areas. These payments are linked to the area of the farms and to the number of grazing animals. Ecological direct payments remunerate farmers for particular environmental services, such as managing extensive meadows, managing permanently flowering meadows, organic farming etc. (FOAG 2004).

The recently proposed reforms to Swiss agricultural policy (FOAG 2012a) emphasize the protection of natural resources and the promotion of biodiversity. However, in view of the potential free trade agreement with the European Union, Swiss farms should use their resources optimally and be competitive, although the provision of public services (particularly environmental services) often forces Swiss farmers to the suboptimal use of their inputs. This possible

[1]For further discussion on existing approaches for analyzing the effect of subsidies on farm productivity and efficiency, see Kumbhakar and Lien (2010).

trade-off between the optimal use of resources and provision of public services is a widely debated issue in Swiss agriculture. In this context, an analysis of the performance of Swiss farms, paying particular attention to the modelling of public goods and services, would provide additional insights.

Most studies that have assessed the performance of Swiss farms (Ferjani 2008; Jan et al. 2010; Todesco et al. 2011; Jan et al. 2012) have used the Data Envelopment Analysis (DEA), which is a deterministic and non-parametric approach. In addition, Ferjani and Flury (2009) applied the Stochastic Frontier Analysis (SFA), which is parametric and capable of considering the stochastic noise of the data.

In this study, we modelled the production technology of Swiss dairy farms by using the parametric output distance function, which allows for the consideration of multiple outputs and multiple inputs. Since Swiss farmers produce rather heterogeneous outputs, separate modelling of direct payments as well as other (non-agricultural) outputs might be more appropriate for this analysis. Modelling of the multiple output technology allowed us to assess the relative importance of these outputs. Therefore, we distinguished between the following outputs: (i) agricultural output, (ii) other output and (iii) particular public goods and services provided by farms (remunerated through particular direct payments[2]).

The production technology used by farms in the three different regions of Switzerland (plain, hill and mountainous) differ considerably, due to climate, topography etc. Therefore, we modelled the production technology of farms with a separate frontier in each region.

This study thus contributes to the empirical literature on the performance analysis of farms in the following ways: First, we modelled the production technology of Swiss farms with the parametric output distance function, and considered public goods and services as an additional output. Second, we used separate frontiers for farms in each region, since they might have used a differing production technology. Third, we analyzed the production scale and the optimality of the resource use for Swiss dairy farms in the plain, hill and mountainous regions.

Before proceeding further, a brief explanation of the Swiss dairy sector is in order. Half of Swiss farmers are engaged in milk production. Milk output constitutes over 20% of Swiss agricultural output (FOAG 2012b), and Switzerland produces 93% of the consumed milk and milk products domestically (FSO 2011). The Swiss dairy sector has undergone several structural changes in the last two decades; the number of Swiss milk producers has almost halved and the average herd size has increased. Milk production per farm has also increased (SFU 2012). Today, Swiss dairy farms own 20 cows and 21 hectares of agricultural land, in average (Mouron and Schmid 2010).

METHODOLOGY

In this section, we first provide a definition of production technology as a basis for the measurement of efficiency. Next, we summarize the methods used for the estimation of production technology and expand on the stochastic estimation that we used.

Production technology and efficiency measure

A farm i uses $N X 1$ input vector to produce $M X 1$ output vector (elements of these vectors are non-negative real numbers). Input vector is denoted by x and output vector is denoted by y. The set of the feasible input-output combinations available to farm i represent technology, T:

$$T = \{(x, y) \in R_+^n \times R_+^m \mid x \; can \; produce \; y\} \tag{1}$$

The technology can be described in two different ways: by production function (production frontier) or by distance functions. When a farm uses several inputs to produce a single output, the technological possibility set of such a farm can be summarized using the production function:

$$y = (f)\mathrm{x} \tag{2}$$

Production function (also called production frontier) represents the maximum output attainable from each input level, and reflects the current state of the technology (Coelli et al. 2005, p. 12).

Distance functions are an alternative way of defining the production technology of farms with multiple outputs and multiple inputs. In this case, the production technology is described by input or output sets, as follows (Coelli et al. 2005, p. 42–44). The input set $L(\boldsymbol{y})$ describes all input vectors, $\boldsymbol{x}$, that can produce a given output vector, $\boldsymbol{y}$:

[2]For a discussion of particular direct payments, which are rather not joint products of agricultural production and remunerate farmers for the provision of environmental goods and services, see Todesco et al. (2011). Following this study, we also separately modelled those particular direct payments which remunerate farmers for additional environmental services. All other types of direct payments are added to other output.

$$L(\boldsymbol{y}) = \{\boldsymbol{x}: \boldsymbol{x}\ can\ produce\ \boldsymbol{y}\} = \{\boldsymbol{x}: (\boldsymbol{x}, \boldsymbol{y}) \in T\} \quad (3)$$

The output set $P(\boldsymbol{x})$ represents the set of all output vectors, $\boldsymbol{y}$, that can be produced using the given input vector, $\boldsymbol{x}$:

$$P(\boldsymbol{x}) = \{\boldsymbol{y}: \boldsymbol{x}\ can\ produce\ y\} = \{\boldsymbol{y}: (\boldsymbol{x}, \boldsymbol{y}) \in T\} \quad (4)$$

On the basis of the sets described above, distance functions are represented as follows (Coelli et al. 2005, pp. 44–49). An input distance function is defined on input set, $L(\boldsymbol{y})$:

$$D_i(\boldsymbol{x}, \boldsymbol{y}) = \max\{\rho: (\boldsymbol{x}/\rho) \in L(\boldsymbol{y})\} \quad (5)$$

It measures the maximum amount by which the input usage can be radially reduced, but remains feasible to produce the given vector of outputs.

An output distance function is defined on an output set, $P(\boldsymbol{x})$, as:

$$D_o(\boldsymbol{x}, \boldsymbol{y}) = \min\{\delta: (\boldsymbol{y}/\delta) \in P(\boldsymbol{x})\} \quad (6)$$

Therefore, the output distance function defines the minimum amount by which an output vector can be deflated and remain producible with the given input vector.

Input and output distance functions allow for the measurement of the technical efficiency of farms. The literature distinguishes between the output-oriented and input-oriented measures; Farrell (1957) input-oriented technical efficiency measure the amount by which the input quantities can be proportionally reduced when the outputs are given, while Farrell (1957) output-oriented technical efficiency measures the maximum radial expansion in all outputs, without changing the input quantities. Technical efficiency is expressed in terms of the output-distance function $D_o(x, y)$ as:

$$TE = 1/D_o(x, y) \quad (7)$$

As the primary goal of this study, there was to analyze the performance of farms under provision of different outputs, including public goods and services, we used an output-oriented distance function for the representation of the production technology of Swiss farms.

Estimation of the production technology

Efficiency measures presume that all compared farms have a common underlying production technology. The production technology is unknown and must be estimated on the basis of the observed data. The literature distinguishes between the non-parametric and parametric estimation approaches. Non-parametric models are less restrictive, since they only presume a broad class of increasing convex functions. In contrast, parametric models assume a given functional form for the representation of the production technology. Therefore, these models are defined *a priori,* with the exception of unknown parameters (e.g. parameters referring to the distribution of random noise or inefficiency). Conversely, the literature distinguishes between the deterministic and stochastic models for the production technology. Deterministic models do not consider the possibility of noise in data; therefore, they regard deviations from the frontier as inefficiencies. However, stochastic models account for the fact that the random noise may affect the individual observations (Bogetoft and Otto 2011, p. 17).

Two main approaches have been established in the modern efficiency analysis, the DEA[3] and the SFA[4], which fit into the classification described above, as follows: the DEA is a non-parametric and mostly deterministic approach, whereas the SFA is parametric and stochastic. For further details regarding taxonomy of frontier models, see Bogetoft and Otto (2011, pp. 17–18).

Since random shocks may play an important role in agricultural production, we considered the SFA approach as being more appropriate for this analysis. Although we used the stochastic output distance function, for the sake of convenience, we describe the basic SFA model based on single output production function. After some adaptions, this SFA model could be used for the estimation of the distance functions.

The stochastic production frontier can be written as follows (Kumbhakar and Lovell 2000, p. 65):

$$y_i = f(x_i; \beta) \times \exp\{v_i\} \times TE_i \quad (8)$$

Where $f(x_i;\beta)$ is the production frontier (which is common to all farms), $\exp\{v_i\}$ captures farm-specific random shocks and stands for the technical efficiency. Therefore, the technical efficiency (TE) is defined as the ratio of the observed output to the maximum feasible output in an environment characterized by random shocks:

$$TE_i = \frac{y_i}{f(x_i;\ \beta)} \times \exp\{v_i\} \quad (9)$$

In the case of the log linear Cobb-Douglas form for production function, equation (8) can be written as (Kumbhakar and Lovell 2000, p. 72):

[3]DEA was introduced by Charnes et al. (1978).

[4]SFA was introduced by Aigner et al. (1977) and Meeusen and van den Broeck (1977).

$$\ln y_i = \beta_0 + \sum_n \beta_n \ln x_{ni} + v_i - u_i \qquad (10)$$

Where v_i is a "noise" component and u_i stands for the technical inefficiency (note that $TE_i = \exp\{-u_i\}$.

The model (10) is a so-called "composed error" ($\varepsilon_i = v_i - u_i$) model, where v_i is assumed to be *iid* and symmetric. Furthermore, it is assumed that is distributed independently of u_i. The goal is to obtain estimates of the production technology parameters β in $f(x_i;\beta)$ as well as estimates of farm-specific technical efficiencies u_i. These estimations are primarily calculated by using the maximum likelihood method, because the OLS method fails to provide consistent estimates for intercept and for u_i (Kumbhakar and Lovell 2000).

We can then define a stochastic output distance function model (Kumbhakar and Lovell 2000, p. 94):

$$1 = D_o(x, y; \beta) \times \exp\{u_i - v_i\} \qquad (11)$$

Expression (11) must be converted into an estimable regression model, the details of which are discussed in Kumbhakar and Lovell (2000, pp. 94–95).

EMPIRICAL ANALYSIS

In this chapter, we first describe the data used in this analysis. We then present the empirical model that we have employed.

Data

This analysis uses the farm level bookkeeping data from the Swiss Farm Accountancy Data Network (FADN)[5]. We analyzed dairy farms operating in the three regions of Switzerland (in plain, hill and mountainous region) from 2003 to 2009, and used three subsamples of the Swiss FADN sample to correspond to the three different regions. In order to ensure a similar production structure for the compared farms, we applied the following selection criteria[6]: (a) conventional farms (non-organic farms); (b) share of the off-farm income is less than 50%. This selection resulted in a total number of 1362, 2504 and 1958 observations for the subsamples in the plain, hill and mountainous regions, respectively. The descriptive statistics of the subsamples are shown in Appendix A (Table A1–A3).

Specification of the model

We used six input variables: (1) land of the farm area measured in hectares; (2) labour in man-years, including both farm and hired labour; (3) capital defined as the depreciation value of machinery and buildings (in Swiss francs); (4) livestock measured in the standardized animal units; (5) intermediate inputs, defined as the material costs (in Swiss francs); and (6) feed defined as costs of the purchased feed (in Swiss francs). We specified three different outputs: (i) gross revenue from agricultural activities (in Swiss francs); (ii) gross revenue from other activities (para-agriculture, forest and all other outputs; in Swiss francs); (iii) particular public goods and services remunerated through particular direct payments (in Swiss francs). We deflated the inputs and outputs with monetary values by their respective price indices[7].

We chose a translog specification of the output distance function. After imposing a homogeneity property[8], the stochastic output distance function, with three different outputs and six different inputs and considering time (t), is expressed as follows (for derivation see Brümmer et al. 2002; Newman and Matthews 2007):

$$\begin{aligned} -\ln y_{1it} = \; & \alpha_0 + \sum_{m=2}^{3} \alpha_m \ln \frac{y_{mit}}{y_{1it}} + \frac{1}{2}\sum_{m=2}^{3}\sum_{m'=2}^{3} \alpha_{mm'} \ln \frac{y_{mit}}{y_{1it}} \ln \frac{y_{mit}}{y_{1it}} + \sum_{n=1}^{6} \beta_n \ln x_{nit} \\ & + \frac{1}{2}\sum_{n=1}^{6}\sum_{n'=1}^{6} \beta_{nn'} \ln x_{nit} \ln x_{n'it} + \sum_{n=1}^{6}\sum_{m=2}^{3} \delta_{nm} \ln x_{nit} \ln \frac{y_{mit}}{y_{1it}} + \omega_t t + \frac{1}{2}\omega_{tt} t^2 \\ & + \sum_{n=1}^{6} \omega_{nt} \ln x_{nit}\, t + \sum_{m=2}^{3} \omega_{mt} \ln \frac{y_{mit}}{y_{1it}}\, t + v_{it} + u_{it} \end{aligned} \qquad (12)$$

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[5]This is an unbalanced panel dataset collected annually from about 3000 Swiss farms. The Swiss research station ART Agroscope manages this data.

[6]The selection is necessary to validate the assumption that the farms analyzed shared the same technology.

[7]Sources for prices indices are: the Swiss Federal Office of Agriculture (FOAG 2012b), the Swiss Farmers' Union (SFU 2012) and the Federal Statistical Office (FSO 2012).

[8]See the property D_O3 in Kumbhakar and Lovell (2000, p. 32).

Indices in (12) are as follows: m denotes three different outputs, n indicates six different inputs, i is the farm index and t stands for time period. The composed error term consists of v_{it} and u_{it}. The term v_{it}indicates the "noise" component, which is assumed to be identically and independently distributed $N_+(0, \sigma_v^2)$and the term u_{it} denotes the technical inefficiency. We used a half-normal model, which assumes that the u_i are half-normally $N_+(0, \sigma_u^2)$ distributed. Further, we assumed that both v_{it} and u_{it} are heteroscedastic (Kumbhakar and Lovell 2000), and that their variance function was dependent on the farms characteristics:

$$\sigma_{ui} = f(z_{ki};\, \alpha) \ \text{ and } \ \sigma_{vi} = f(z_{ki};\, \alpha) \tag{13}$$

where (z_{ki}) are the farm characteristics (such as age, education etc.) and α denotes unknown parameters.

We used the following farm characteristics to explain the variance of u and v: (z1) age, (z2) education, (z3) altitude, (z4) share of rented land, (z5) share of hired labour, (z6) off-farm work, (z7) ecological direct payments per animal.

The farm level technical efficiency is estimated as the conditional distribution of u_{it} by the given ε (error term) (Battese and Coelli 1995):

$$TE_{it} = \exp(-\hat{u}_{it}) = \mathrm{E}[\exp\,(-u_{it}\,)|\varepsilon_{it}\,] \tag{14}$$

The parameters for the distance function and the inefficiency model[9] are estimated simultaneously ("one stage procedure") using the maximum likelihood method.

RESULTS AND DISCUSSION

The first part of this section reports the results of testing for a common technology for the sample farms in the three regions. In the second part, we illustrate and discuss the estimated technological parameters. The third part of this section deals with the marginal products of inputs. In the fourth and fifth part, we present and discuss the estimated technical efficiency scores and factors explaining the variations in inefficiency across farms.

Testing

We performed the likelihood ratio test in order to justify the use of a separate frontier for the farms in each region. We tested the null-hypothesis (H_0) that farms in all three regions share the same technology against the alternative-hypothesis (H_A) that technology differs across regions.

The likelihood ratio test is: $\lambda = -2$ [LL (H_0) – LL (H_A)], where LL(H_0) is the value of the log-likelihood function for the frontier estimated with the pooled data and LL(H_A) is the sum of the values of the log-likelihood functions of the three regional frontiers (see Battese et al. 2004 and Newmann and Matthews 2007 for similar tests). The calculated value of the test statistic was 496. The critical value of the Chi-square distribution at the 1% significance level and with 146 degrees of freedom (number of parameters under H_A minus number of parameters under H_0) is 189. Therefore, the data rejected the hypothesis that all regions share the same technology (poolability of the data) at the 1% significance level.

Technological parameters

Here, we present and discuss the primary results of the estimated production technology[10]. Coefficient estimates for outputs show the relative contribution of the outputs to the distance function value. This allows for the investigation of the output composition of farms. Other outputs (y2) show the following estimated elasticities: 0.192***[11], 0.134*** and 0.185*** in plain, hill and mountainous regions, respectively. The estimated elasticities for direct payments, which remunerate particular public goods and services (y3) are 0.177***, 0.254*** and 0.303*** in the plain, hill and mountainous regions, respectively. Subsequently, elasticities of agricultural output (y1) are 0.631, 0.612 and 0.512 in plain, hill and mountainous regions, respectively. The presented elasticities can be interpreted as follows: a 1% increase of public goods and services (y3) (*ceteris paribus*) would shift the distance function upwards by 0.18% in the plain region, by 0.25% in the hill region and by 0.30% in the mountainous region. This indicates that this output is of a great importance for Swiss farms in all three regions, and it is the highest for mountainous farms.

Output distance elasticities under the revenue maximization should be equal to the revenue share of each output (Brümmer et al. 2002). The share of other output is approximately 32% in the plain region, 37% in the hill region and 39% in the mountainous region. Therefore, the estimated output elasticities for this output appear to be somewhat low. Conversely,

[9]For details see Battese and Coelli (1995).

[10]Complete parameter estimates of the output distance function are shown in Appendix B (Table B).

[11]***significant at 1%, **significant at 5%, *significant at 10% , n.s. not significant.

Table 1. Elasticities of inputs and returns to scale

Variable	Plain		Hill		Mountainous	
	mean	S.D.	mean	S.D.	mean	S.D.
Land	0.196***	(0.03)	0.118***	(0.02)	0.041**	(0.02)
Labour	0.056*	(0.03)	0.049**	(0.02)	0.063***	(0.02)
Capital	0.149***	(0.02)	0.088***	(0.01)	0.082***	(0.02)
Livestock	0.319***	(0.04)	0.373***	(0.03)	0.437***	(0.04)
Materials	0.144***	(0.03)	0.195***	(0.02)	0.230***	(0.02)
Feed	0.093***	(0.01)	0.078***	(0.01)	0.034**	(0.01)
Returns to scale	0.957n.s.		0.901***		0.887***	

S.D. = standard deviation

significant at 1% = ***, significant at 5% = **, significant at 10% = *, not significant = n. s.

the estimated output elasticities for particular public goods and services (y3) are much higher than the corresponding shares of this output (5%, 10% and 17% in plain, hill and mountainous regions, respectively). This might be connected to the fact that production of some of this output ("production" of some direct payments) does not require any inputs or trade-offs with other outputs.

For agricultural output, the estimated elasticities and corresponding output shares (66%, 57% and 49% in the plain, hill and mountainous regions, respectively) are quite similar.

Table 1 reports the input elasticities (the first order parameter estimates) in each region. All first order estimates are significant at the 10% level.

The estimated elasticities indicate that the inputs land and livestock provide the greatest contribution to production. The elasticity of land is the highest in the plain region and the lowest in the mountainous region. This is reflective of the more difficult production conditions on farms situated in higher altitudes.

Elasticities of inputs sum up to the returns to scale. We also tested whether the obtained returns to scale are significantly different from one (null-hypothesis: return to scale is equal to one – constant returns to scale). Data on farms in the plain region did not reject the hypothesis of constant return to scale[12]. However, for the hill and mountainous regions, the test was significant, suggesting variable returns to scale for these subsamples. According to our results, the production of sample dairy farms in the hill and mountainous regions exhibits decreasing returns to scale, meaning that a proportional increase in all inputs causes a less than proportional increase in the produced outputs.

Marginal products

We calculated the marginal products[13] of inputs in order to investigate the optimality of resource use of Swiss farms[14]. Table 2 presents the marginal products of inputs for dairy farms in the plain, hill and mountainous regions.

The marginal product of land is the highest in the plain region and the lowest in the mountain region. In the period under investigation, the median rent price in the plain, hill and mountain regions of Switzerland varied (according to the year) between 685–750 CHF per ha[15], 505–530 CHF/ha and 350–374 CHF/ha, respectively. Therefore, sample farms in plain and hill regions clearly underused land, whereas the use of this input in the mountainous region was quite close to the optimal level.

The marginal products of livestock are quite similar in the plain and hill regions. In the mountainous region, we observe a higher value for the marginal product of this input. The base price of a cow in

[12]Ferjani (2008) found constant returns to scale for Swiss farms in all three regions of Switzerland. This study uses another period (from 1900 to 2001), and considers all types of farms together.

[13]The marginal product of input is the output that results from additional unit of the respective input, holding all other inputs constant. We can calculate the marginal product of input n as follows: $MP_n = \frac{\partial y}{\partial x_n} = \frac{\partial lny}{\partial lnx_n} \times \frac{y}{x_n}$. The first component of the marginal product are output elasticities for each input (e_n). Therefore, using these elasticities of the marginal product of each input is $MP_n = e_n \times \frac{y}{x_n}$.

[14]To analyze the optimality of input use, we compared the marginal product of inputs with the respective input prices.

[15]1 CHF = 0.83 EURO.

Table 2. Marginal products of inputs

Variable	Plain		Hill		Mountainous	
	mean	S.D.	mean	S.D.	mean	S.D.
Land	2 254.24	(705.55)	1 161.11	(520.32)	323.21	(154.13)
Labour	8 772.98	(3 504.06)	6 766.32	(2482.96)	7 493.20	(3 165.08)
Capital	1.25	(1.43)	0.70	(0.43)	0.61	(0.36)
Livestock	2 566.20	(719.64)	2 967.72	(827.47)	3 643.62	(1 252.78)
Materials	0.57	(0.16)	0.79	(0.22)	0.97	(0.34)
Feed	1.69	(3.39)	1.18	(1.12)	0.56	(1.73)

Switzerland is approximately 2000 CHF. Therefore, considering the annual rotation of animals[16], sample farms underused this input in all three regions of Switzerland. This result is in line with the goal of the Swiss agricultural policy, since more livestock units are associated with a higher negative pressure on the environment.

Our findings are largely similar to those of another study, which assessed the performance of Swiss farms during the period 2001–2006. Bokusheva et al. (2012) found that milk and crop farms in the plain region underused land and livestock, while they overused labour and capital.

Technical efficiency estimates

Table 3 reports the results of the estimated output-oriented technical efficiency of Swiss dairy farms in the plain, hill and mountainous regions.

The farms in the samples showed a high technical efficiency in average. The mean efficiency was 0.93, 0.94 and 0.95 for farms in the plain, hill and mountainous regions, respectively. The results imply the following average technical inefficiency levels; for the subsample in the plain region, inefficiency averages 7.53%[17], for the hill region, it averages 6.38% and for the mountainous region, it averages 5.26%.

The technical efficiency scores estimated in our study are much higher than those reported in other studies on Swiss farms. For example, Ferjani (2008) analysed the efficiency of Swiss farms between 1990 and 2001 using the DEA approach and estimating two models, one with direct payments and one without direct payments. The reported mean technical efficiency was between 0.78 and 0.80 (according to region) under the model with direct payments and between 0.58 and 0.77 under the model without direct payments. A study conducted by Jan et al. (2010) on dairy farms in the mountainous region of Switzerland reported the mean technical efficiency of 0.75, while the analysis of Swiss dairy farms conducted by Ferjani and Flury (2009) estimated the mean technical efficiency as being 0.88 for non-organic farms.

There may be several reasons for the differences between the results of the previous studies and those of our study. First, the DEA approach usually results in a lower efficiency scores because it counts all deviations from the frontier as inefficiencies. Using the SFA approach, Ferjani and Flury (2009) obtained technical efficiency scores that were closer to our results. Second, the previous studies used a different timeframe, and third, the sample composition was very different in the previous studies. Ferjani (2008) did not differentiate between farm types and thereby employed a very heterogeneous sample, while Ferjani and Flury (2009) analysed dairy farms from different regions together. We have applied far more restrictive selection criteria in order to ensure that the analyzed farms faced the same technology.

Table 4 presents the results on the determinants of the technical efficiency variation across farms. The reported coefficient estimates show the influence of farm characteristics on technical inefficiency (u). Therefore, a negative sign of the coefficient indicates a positive influence of the variable on technical efficiency.

Age showed a slightly significant negative impact on technical efficiency for the sample farms in the hill region. This might be associated with the fact that older farmers are less motivated to adopt new technologies. Empirical studies have reported varying

[16]Here we used an annual rotation rate of 0.25. However, it is very difficult to determine the rotation rate, due to the diversity of composition of the livestock units on farms and the existing heterogeneity across farms in this regard.

[17]Technical inefficiency level: $\frac{1-TE}{TE} \times 100$

Table 3. Technical efficiency scores

	Plain	Hill	Mountainous
Mean	0.93	0.94	0.95
Range	0.58–1.00	0.48–1.00	0.61–1.00
Standard deviation (S.D.)	0.06	0.05	0.04
Share of farms with efficiency less than 0.85 (in %)	11	6	3

results regarding the impact of age on the the technical efficiency of farms. Thirtle and Holding (2003), Brümmer and Loy (2000), Hadley (2006), Karagianias et al. (2006) and Jan et al. (2010) reported a negative effect, whereas Mathijs and Vranken (2001), O'Neill and Matthews (2001), Wilson et al. (2001) and Barnes (2006) found a positive impact.

Education was positively associated with the technical efficiency of the sample farms in the plain and mountainous regions of Switzerland, but it was not significant in the hill region. Generally, farmers with a higher educational level are expected to perform better, since they might make a better use of inputs, they may more rapidly adopt new technology etc. Our study confirms this hypothesis for farms in the plain and mountainous regions. However, variable findings regarding the influence of education on technical efficiency of farms exist in the literature. While several studies (Liu and Zhuang 2000; Mathijs and Vranken 2001; O'Neil and Matthews 2001; Wilson et al. 2001; Igliori 2005) reported a positive impact of education on the technical efficiency, in others (e.g. Goodwin and Mishra 2004; Barnes 2006; Lakner 2009; Jan et al. 2010), no significant impact of this variable was observed.

Altitude showed a significant positive impact on the technical efficiency of farms in all three regions, which does not confirm our hypothesis that farms in higher altitudes are less technically efficient, since they face more unfavourable production conditions (difficulty of cultivation). However, several other studies do support this hypothesis. For example, Brümmer and Loy (2000) and Jan et al. (2010) reported a negative impact of altitude on technical efficiency. The contrasting results we found might be associated with the fact that Swiss farmers receive higher direct payments with the increased altitude. Therefore, farmers are sufficiently compensated for production under the unfavourable conditions.

The share of rented land was positively associated with the technical efficiency of the sample dairy farms in the hill region, which does not confirm the hypothesis that farmers tend to manage their own land more efficiently. However, several studies have confirmed this hypothesis (e.g. Mathijs and Vranken 2000; Thirtle and Holding 2003; Hadley 2006).

Hired labour was significantly associated with higher technical efficiency scores of the farms in all three regions, which is not in line with our hypothesis that hired labour might result in lower efficiency scores, since it is related to higher transaction costs (e.g. for controlling). However, while Mathijs and Vranken (2000), Karagiannis et al. (2006) and Cabrera et al. (2010) found results that confirmed this hypothesis, a study by Latruffe et al. (2004) reported higher efficiency of farms with higher share of hired labor. Bojnec and Latruffe (2009) found that this variable had no influence on the technical efficiency.

Off-farm income positively influenced the sample dairy farms in the plain and mountainous regions.

Table 4. Determinates of technical efficiency (TE) variation across farms

	Plain		Hill		Mountainous	
	coeff.	on TE	coeff.	on TE	coeff.	on TE
Age	0.011$^{n.s.}$	–	0.014*	negative	0.007$^{n.s.}$	–
Education	–0.398***	positive	0.013$^{n.s.}$	–	–0.190*	positive
Altitude	–0.002**	positive	–0.001**	positive	–0.003**	positive
Share rented land	0.001$^{n.s.}$	–	–0.012***	positive	–0.005$^{n.s}$.	–
Share hired labour	–0.027***	positive	–0.031***	positive	–0.038***	positive
Off-farm work	–0.753***	positive	–0.142$^{n.s.}$	–	–1.230***	positive
Ecological direct payments per animal	–0.010***	positive	–0.009***	positive	–0.005***	positive

significant at 1% = ***, significant at 5% = **, significant at 10% = *, not significant = n. s.

This might be related to the fact that farmers involved in the off-farm activities have higher labour opportunity costs, which might increase their motivation to manage their farm efficiently. There are contrasts in the literature with regard to the influence of this variable on the technical efficiency. Several studies found that off-farm work had a negative influence (Brümmer et al. 2001; O'Neill and Matthews 2001; Goodwin and Mishra 2004; Jan et al. 2010), while others, such as Huffman and Evenson (2001), Mathijs and Vranken (2001) and Tonsor and Featherstone (2009), reported a positive influence.

Ecological direct payments had a positive impact on the technical efficiency of sample farms in all three regions, which is not in line with our hypothesis that farmers with higher ecological direct payments use extensive farming activities, leading to a lower efficiency. Empirical analyses have reported contrasting results with regard to the impact of subsidies on the farm technical efficiency. The majority of studies have reported that subsidies have a negative influence (Giannakas et al. 2001; Emvalomatis et al. 2008; Ferjani 2008; Bojnec and Latruffe 2009; Lakner 2009; Bakucs et al. 2010; Zhu and Lansink 2010; Bokusheva et al. 2012), although some have reported a positive influence (Hadley 2006; Jan et al. 2010). Serra et al. (2008) pointed out that the impact of subsidies on farm performance very much depends on the risk aversion of farmers.

In general, caution must be exercised when making a comparison between different empirical studies. Results very much depend on the definition of variables (categorical variable; ratios, share etc.), as well as on the composition of the sample used.

CONCLUSIONS

This study analyzed the performance of Swiss dairy farms under the consideration of public goods and services they provide. We investigated dairy farms located in the plain, hill and mountainous regions of Switzerland for the period between 2003 and 2009. Particular direct payments, which compensate farmers for public goods and services, were considered as a separate output.

Output elasticities for three different outputs (agricultural output, other output and particular public services) allows for some insights into their relative importance for Swiss farmers. Output elasticities for agricultural output are very similar to the corresponding shares of this output. However, this is not true for particular public goods and services. The observed differences between elasticities and the corresponding shares of this output might be related to the fact that this output contains different kinds of direct payments, "production" of which does not require additional inputs or trade-off with other outputs.

We observed high elasticities of the inputs land and animals in all three regions. Among other reasons, this might be related to the fact that a large part of direct payments is linked to these two inputs.

Furthermore, we investigated the production scale of Swiss farms. Sample data on farms in the plain region failed to provide evidence for variable returns to scale (null-hypothesis of constant returns to scale was not rejected). We can conclude that the level of productivity in the plain region does not depend on the scale of production, but more on an improvement in the efficiency. However, in the hill and mountainous region, there is potential for scale adjustments. Sample farms in these regions showed significant decreasing returns to scale, which suggests that the average farm in these subsamples can improve its productivity by scaling down its production. Our results might also be the confirmation of the decelerated structural change: decreasing returns to scale might reflect an obstacle to growth (cf. Brümmer et al. 2006).

Beyond high values of the average technical efficiency on Swiss farms, the range of efficiency scores was between 0.48 and 1.00 (according to region), which indicates the potential for improvement. Most determinants of the technical efficiency of the sample farms showed similar patterns in all three regions. The following factors consistently showed a statistically significant effect on variation of efficiency across farms: off-farm income (positive), share of rented land (positive), altitude (positive)[18], share of hired labour (positive), ecological direct payments (positive). Our results regarding the influence of farmers' socio-demographic characteristics (age and education) on technical efficiency were rather ambiguous.

Since farms with off-farm income appear to be more efficient, the policy should encourage those activities. A positive influence of ecological direct payments on technical efficiency hints that ecological services provided by farmers should be further supported and encouraged.

[18]For further discussion on existing approaches for analyzing the effect of subsidies on farm productivity and efficiency, see Kumbhakar and Lien (2010).

Finally, we address the caveats of this study. The Swiss FADN considers only farms that use specific accounting software, which are at the maximum 20% of the entire farming population. Lips et al. (2011) and Roesch (2011) discussed the drawbacks of the current sampling system in Switzerland. The current Swiss FADN sample is not a random sample, which hinders the generalization of results to the entire farming sector of Switzerland. Another caveat is related to the efficiency measurement. Efficiency analysis requires that farms used for estimation of production technology possibly have a similar production structure. Therefore, the selection we undertook might have failed to realistically illustrate the heterogeneity of Swiss farms.

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APPENDIX

A Descriptive statistics

Table A1. Descriptive statistics of the variables: subsample in the plain region (N = 1362 observations)

	Mean	S.D.	Min	Max
Inputs				
Land (farm area in hectares)	22.92	8.77	6.68	68.22
Labour (in man year)	1.68	0.53	0.20	4.26
Capital (in Swiss francs)	37 096.64	19 869.14	0.00	127 891.30
Livestock (in standardized animal units)	32.86	14.09	8.74	105.91
Intermediates (in Swiss francs)	69 580.77	37 033.68	15 120.22	267 741.50
Feed (in Swiss francs)	26 749.17	25 400.75	313.95	224 452.40
Outputs				
Agricultural output (in Swiss francs)	160 111.60	76 790.57	10 614.74	53 4513.70
Other output: paraagriculture+forest+other (in Swiss francs)	83 053.66	51 574.81	13 491.99	53 5773.00
Public services remunerated by direct payments (in Swiss francs)	13 751.39	8 705.20	0.00	8 0141.00
Shares of different farm outputs				
Share agricultural output of total output (in %)	65.70	11.80	18.62	92.34
Share other output of total output (in %)	32.18	11.05	12.14	78.28
Share public services of total output (in %)	5.53	2.97	0.00	19.67
Farm characteristics				
Age of farmer	45	9	23	72
Education of farmer	3.34	0.69	1.00	5.00
Altitude (in meters above sea level)	545.97	95.16	350.00	1 050.00
Share rented land (in %)	40.69	29.19	0.00	100.00
Share hired labour (in %)	17.78	18.82	0.00	74.07
Share off-farm income of total income (in %)	2.42	399.67	–14 639.34	49.77
Ecological direct payments per animal (in Swiss francs)	295.48	121.77	0.00	1 093.46

Table A2. Descriptive statistics of the variables: subsample in the hill region (N = 2504 observations)

	Mean	S.D.	Min	Max
Inputs				
Land (farm area in hectares)	25.28	12.99	1.48	146.01
Labour (in man year)	1.67	0.50	0.36	5.13
Capital (in Swiss francs)	32 640.78	15 992.40	0.00	133 989.00
Livestock (in standardized animal units)	29.20	12.08	4.18	109.80

Continuation Table A2

	Mean	S.D.	Min	Max
Intermediates (in Swiss francs)	59 556.90	31 161.77	14 991.40	285 493.20
Feed (in Swiss francs)	22 260.51	18 179.57	638.62	210 569.70
Outputs				
Agricultural output (in Swiss francs)	119 693.00	56 889.11	13 872.40	501 106.60
Other output: paraagriculture+forest+other (in Swiss francs)	83 590.90	46 826.47	7018.12	441 463.30
Public services remunerated by direct payments (in Swiss francs)	21 731.99	9 817.74	0.00	99 087.30
Shares of different farm outputs				
Share agricultural output of total output (in %)	56.83	11.52	16.56	91.55
Share other output of total output (in %)	36.77	11.33	9.27	79.53
Share public services of total output (in %)	10.12	3.62	0.00	29.71
Farm characteristics				
Age of farmer	46	10	21	75
Education of farmer	3.16	0.73	1.00	5.00
Altitude (in meters above sea level)	695.94	136.52	325.00	1 030.00
Share rented land (in %)	39.12	29.23	0.00	100.00
Share hired labour (in %)	15.58	19.01	0.00	94.92
Share off-farm income of total income (in %)	14.96	16.70	–323.50	49.86
Ecological direct payments per animal (in Swiss francs)	267.06	126.11	0.00	1 110.64

Table A3. Descriptive statistics of the variables: subsample in the mountainous region (N = 1958 observations)

	Mean	S.D.	Min	Max
Inputs				
Land (farm area in hectares)	28.26	16.50	4.49	188.44
Labour (in man year)	1.73	0.55	0.18	4.22
Capital (in Swiss francs)	31 915.67	28 472.94	0.00	1 037 066.00
Livestock (in standardized animal units)	24.47	10.16	6.07	87.73
Intermediates (in Swiss francs)	51 129.51	31 385.16	9 467.93	434 404.10
Feed (in Swiss francs)	19 001.76	13 806.10	113.23	128 266.20
Outputs				
Agricultural output (in Swiss francs)	86 565.49	44 736.17	–8 862.15	386 293.80
Other output: paraagriculture+forest+other (in Swiss francs)	78 931.14	53 725.34	11 378.53	1 182 821.00
Public services remunerated by direct payments (in Swiss francs)	31 495.38	12 963.16	0.00	98 480.89
Shares of different farm outputs				
Share agricultural output of total output (in %)	47.88	11.77	4.17	83.16
Share other output of total output (in %)	39.10	11.09	14.79	94.09
Share public services of total output (in %)	16.91	5.55	0.00	40.63
Farm characteristics				
Age of farmer	46	9	20	73
Education of farmer	2.88	0.85	1.00	5.00
Altitude (in meters above sea level)	970.31	218.58	420.00	1 740.00
Share rented land (in %)	38.75	30.50	0.00	100.00
Share hired labour (in %)	13.81	18.03	0.00	83.33
Share off-farm income of total income (in %)	13.77	80.20	–2 461.22	49.99
Ecological direct payments per animal (in Swiss francs)	242.99	124.74	0.00	1 292.02

B Parameter estimates from the output distance function

Table B. Parameter estimates from output distance function

	Plain		Hill		Mountain	
y2 (other output)	0.192	***	0.134	***	0.185	***
y3 (public services)	0.177	***	0.254	***	0.303	***
t	–0.012	***	0.007	n.s.	0.005	n.s.
tt	0.002	n.s.	–0.002	*	–0.001	n.s.
xl (land)	–0.196	***	–0.118	***	–0.041	**
xw (labour)	–0.056	*	–0.049	**	–0.063	***
xk (capital)	–0.149	***	–0.088	***	–0.082	***
xa (livestock)	–0.319	***	–0.373	***	–0.437	***
xm (intermediates)	–0.144	***	–0.195	***	–0.230	***
xf (feed)	–0.093	***	–0.077	***	–0.034	**
xlt	0.011	n.s.	0.004	n.s.	0.000	n.s.
xwt	0.006	n.s.	–0.006	n.s.	–0.005	n.s.
xkt	0.006	*	–0.001	n.s.	–0.005	n.s.
xat	–0.010	n.s.	–0.010	n.s.	–0.004	n.s.
xmt	–0.009	n.s.	0.003	n.s.	0.010	**
xft	0.002	n.s.	–0.001	n.s.	–0.006	**
y2t	0.000	n.s.	0.002	n.s.	0.000	n.s.
y3t	–0.009	***	–0.002	n.s.	–0.007	*
y2y2	–0.003	n.s.	–0.012	n.s.	0.015	n.s.
y3y3	0.013	***	0.022	***	0.035	***
y2y3	0.070	***	0.121	***	0.181	***
xll	0.165	**	–0.063	***	–0.032	n.s.
xww	–0.014	n.s.	–0.049	n.s.	–0.025	n.s.
xkk	–0.010	***	–0.007	***	–0.008	***
xaa	0.173	n.s.	–0.251	***	–0.416	***
xmm	–0.061	n.s.	–0.238	***	–0.174	***
xff	–0.051	***	–0.071	***	–0.013	n.s.
xlw	–0.037	n.s.	0.136	**	0.094	n.s.
xlk	0.219	***	0.045	*	0.017	n.s.
xla	–0.674	***	–0.061	n.s.	0.040	n.s.
xlm	–0.103	n.s.	0.057	n.s.	–0.002	n.s.
xlf	0.171	***	0.054	*	–0.006	n.s.
xwk	–0.151	**	0.001	n.s.	–0.005	n.s.
xwa	0.301	**	0.116	n.s.	0.030	n.s.
xwm	0.038	n.s.	–0.071	n.s.	–0.073	n.s.
xwf	0.000	n.s.	–0.020	n.s.	–0.020	n.s.
xka	–0.101	*	0.025	n.s.	0.051	n.s.
xkm	0.028	n.s.	0.036	**	–0.032	n.s.
xkf	0.009	n.s.	–0.035	***	–0.083	***
xam	0.289	**	0.444	***	0.494	***
xaf	–0.061	n.s.	0.062	n.s.	0.228	***
xfm	–0.090	**	0.013	n.s.	–0.048	n.s.
y2xl	0.000	n.s.	0.039	***	0.047	**
y2xw	0.084	***	0.009	n.s.	0.038	n.s.
y2xk	–0.036	**	–0.039	***	–0.018	n.s.

Continuation Table B

	Plain		Hill		Mountain	
y2xa	0.036	n.s.	–0.142	***	–0.007	n.s.
y2xm	–0.073	***	0.159	***	0.124	***
y2xf	–0.013	n.s.	–0.034	***	–0.004	n.s.
y3xl	0.017	n.s.	0.069	***	–0.079	***
y3xw	0.018	n.s.	–0.088	***	–0.088	***
y3xk	–0.013	n.s.	0.021	n.s.	–0.056	***
y3xa	–0.063	*	0.025	n.s.	0.025	n.s.
y3xm	0.033	**	–0.141	*	–0.078	***
y3xf	0.005	n.s.	0.034	***	0.093	***
_cons	–0.032	**	–0.052	***	–0.066	***
usigmas						
Off farm work	–0.754	**	–0.143	n.s.	–1.230	***
Share rented land	0.001	n.s.	–0.012	***	–0.005	n.s.
Share hired labour	–0.027	***	–0.031	***	–0.038	***
Altitude	–0.002	**	–0.001	**	–0.003	***
Age	0.011	n.s.	0.014	*	0.007	n.s.
Education	–0.398	***	0.013	n.s.	–0.190	*
Ecological direct payments per animal	–0.010	***	–0.009	***	–0.005	***
_cons	0.560	n.s.	–2.021	***	0.544	n.s.
vsigmas						
Off farm work	–0.306	n.s.	–0.344	***	–0.252	n.s.
Share rented land	–0.004	*	0.002	*	0.002	n.s.
Share hired labour	0.008	**	0.004	*	0.006	**
Altitude	–0.003	***	–0.001	***	0.001	***
Age	–0.015	**	–0.002	n.s.	0.007	n.s.
Education	–0.142	n.s.	–0.097	*	–0.107	**
Ecological direct payments per animal	0.003	***	0.001	**	0.001	***
_cons	–2.727	***	–3.774	***	–5.475	***

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