Technical and scale efficiency in Austrian dairy farming

Dipl.-Ing. Josef HAMBRUSCH,
Researcher in the department: Market and food economics, (Vienna, Austria)

Dipl.-Ing. Dr. Leopold KIRNER,
Researcher in the department: Farm management, (Vienna, Austria)

Dipl.-Ing. Karl Michael ORTNER,
Deputy director Federal Institute of Agricultural Economics, (Vienna, Austria)

Abstract:
The number of dairy farms in Austria has decreased during the last decade. Comparisons with other European countries reveal that dairy farms in Austria are quite small. Thus there is a serious concern about the competitiveness and efficiency of the dairy sector in the future. The objective of this study is to measure efficiency scores of Austrian dairy farms and to examine the relationship between efficiency and farm size. Data envelopment analysis (DEA) was applied to a sample of 222 highly specialised dairy farms. The results show an average technical efficiency of 79 % and a scale efficiency of 94 %. This suggests that natural conditions and management practices had a stronger impact on technical efficiency than farm size. An analysis of returns to scale revealed that 18 % of the sample farms were operating at constant returns to scale, 9 % above and 73 % below efficient scale. 

Key words: Dairy farming, Efficiency, Austria, Returns to scale, Data Envelopment Analysis (DEA).

Introduction
Dairy farming traditionally plays a crucial role in Austrian agriculture. With about 900 Mio. € of revenues in 2004, the dairy sector was the largest farm sector and contributed about 15 % to the total agricultural production value (BMLFUW, 2005). As a result of the specific agro-climatic conditions grassland management and dairy farming prevail in the mountainous parts of Austria. About two third of total milk production originate from those regions. Due to increasing competition on markets and the small structured character of Austrian dairy farms many farmers phased-out milk production. From 1995 to 2003 the total dairy cow population decreased by 17 % to 558,000 whereas the average number of dairy cows per farm increased from 7.8 to 8.8. However, the development showed significant differences between herd sizes. Whilst the number of dairy cows and farmers of small farms with less than 10 cows per farm decreased by 48 % and 38 % respectively, large farms experienced a considerable increase. The number of farms and dairy cows in the class with more than 30 cows grew by 1,000 and 43,000, meaning an increase by more than 180 % in both figures (AWI, 2005). Similar results obtain from an analysis of the milk quota distribution. In 1998 more than 31,800 (42 %) milk suppliers had a quota of less than 20 t. Six years later their number declined by 13,500 (43 %) and their contribution to total milk supply by about 190,000 kg (almost 50 %). During the same period the number of farms with a quota of more than 100 t almost doubled, and their supply trebled. These developments indicate a disproportionate loss of small farms. According to a study by KIRNER (2005) a milk quota of some 70 t per farm was found to be a growth barrier. Whilst farms below this quota experienced a decrease in number and amount of supply, those with more than 70 t showed an opposite development. However, a further rise of the growth barrier level can be expected in the future.

Major outcomes of the recent CAP-reform for the dairy sector (single farm payment scheme, price reductions for butter and skimmed milk powder) may be going to support these structural changes in Austria. Despite compensations for natural disadvantages and environmentally friendly production techniques competitiveness and efficiency are increasingly becoming key determinants in dairy farming. That raises the ques-
tion about the determinants of efficiency differences between farms. Therefore, the present paper has two objectives. The first is to analyse and assess technical efficiency (TE) of a sample of Austrian dairy farms, and the second to examine interrelations between farm size and efficiency. The paper is structured as follows. After a short introduction to Data Envelopment Analysis (DEA), the following chapter describes the data used. In chapter 3 the results of the analysis are presented. The final chapter provides a discussion of the results along with a summary of the findings.

**Method**

DEA is a data oriented, non-parametric, deterministic approach for evaluating the performance of a set of peer entities called Decision Making Units (DMUs) which convert multiple inputs into multiple outputs (COOPER et. al., 2004). Unlike other methods (e.g. traditional regression methods) DEA constructs a frontier by comparing the data of each DMU with data of benchmark DMUs that perform better. Observations lying on the production frontier are defined as technically efficient (TE) those lying below the frontier are considered inefficient. The frontier is composed by solving linear programming models for each DMU. At first the efficiency score of a DMU is calculated (1) and used to detect input slacks or output surpluses in a second step (2).

\[
\begin{align*}
\theta^* &= \min \theta \\
\text{subject to} & \\
\sum_{j=1}^{n} x_{ij} \lambda_j &\leq \theta x_{i0} & i = 1,2,...,m; \\
\sum_{j=1}^{n} y_{rj} \lambda_j &\geq y_{r0} & r = 1,2,...,s; \\
\lambda_j &\geq 0 & j = 1,2,...,n.
\end{align*}
\]

\[
\begin{align*}
\max & \sum_{i=1}^{m} s^-_i + \sum_{j=1}^{n} s^+_j \\
\text{subject to} & \\
\sum_{j=1}^{n} x_{ij} \lambda_j + s^-_i & = \theta^* x_{i0} & i = 1,2,...,m; \\
\sum_{j=1}^{n} y_{rj} \lambda_j - s^+_r & = y_{r0} & r = 1,2,...,s; \\
\lambda_j, s^-_i, s^+_r &\geq 0 \forall i, j, r & j = 1,2,...,n.
\end{align*}
\]

Figure 1 graphically illustrates the relationship between CRS and VRS. Under CRS the best-practice frontier is a single ray emanating from the origin. To be on the technical efficiency frontier a farm would have to be operating at its efficient scale. Under VRS, a convex, piece-wise linear frontier determines best practice and reflects the differing rates of input to output combination efficiencies by size of operation (see BARNES and OGLETHORPE, 2004). From three different farms (A, B, C) only farm B is operating at efficient size as it touches the CRS-ray. Farm A lies on the VRS-frontier but not on the CRS-frontier and represents therefore only pure technical efficiency but not scale efficiency. Experiencing decreasing returns to scale a reduction in size would improve scale efficiency of farm A. Farm C is neither technical nor scale efficient. Overall inefficiency of Dairy farms usually have more control over their input variables rather than their output variables. Therefore, the dual input-oriented linear programming model, as originally presented in CHARNES et al. (1978), was chosen for our study: where $\theta$ is a scalar representing the efficiency score, $\lambda$ is a vector describing the contribution of benchmark DMUs to the virtual DMU, $x$ and $y$ are input and output values respectively, $s^-$ and $s^+$ are slacks (input reduction) and surpluses (output increase) used to convert inequalities to equivalent equations. The value of $\theta^*$ represents the efficiency score of the j-th farm. Given the observed sample and model specification, a value of less than one indicates an inefficient farm, which could improve its efficiency by reducing inputs proportionally.

The specified model above assumes constant returns to scale (CRS, CCR-model). However, if agricultural farms operate in an environment with variable returns to scale (VRS, e.g. law of diminishing returns), doubling of all inputs would lead to a less than or greater than a doubling of all outputs. A DMU to be considered as CCR efficient must be both scale and technical efficient. A BCC efficient DMU only needs to be technically efficient (BOWLIN, 1998). BANKER et. al. (1984) addressed this problem at first by imposing an additional convexity constraint to the model (BCC-model):

\[
\sum_{j=1}^{n} \lambda_j = 1
\]
farm C can be decomposed in technical inefficiency and scale inefficiency. Hence, farm C could increase its scale efficiency by moving up on the VRS-frontier and its technical efficiency by reducing its inputs.

For the determination of increasing (IRS), constant (CRS) or decreasing returns to scale (DRS) different procedures have been developed (see Färe et. al. 1985 and Banker et. al. 1984). For the present study the approach proposed by Seiford and Zhu (1999) was chosen; it requires the solution of a CCR and BCC model. First, all farms are selected that show the same optimal values in both models. These farms exhibit CRS. For all other farms the sums of weights ($\Sigma \lambda_j^*$) are calculated and used for the determination of IRS or DRS. If $\Sigma \lambda_j^*$ of a farm is less than 1 IRS prevails on DMUj, otherwise DRS.

By considering all in- and outputs simultaneously data envelopment analysis (DEA) offers two main advantages in estimating efficiency scores. First, it does not require the assumption of a functional form to specify the relationship between inputs and outputs, and second, it does not require an assumption about the distribution of the inefficiency term. However, DEA results need to be interpreted with care as they do not take into account the differences between farms in respect of operating environment, farm management and trade-off between the different inputs and outputs. Limitations of DEA concern the implicit assumption that all differences in performances of different DMUs are caused by inefficiencies (e.g. errors in measurement could be interpreted as inefficiencies). But in reality, some of the differences between the actual and predicted best performance may be due to data and measurement errors, while stochastic frontier analysis (SFA) recognizes the possibility of stochastic errors in measurement of inefficiencies.

Data

Data for the present study were obtained from the voluntary farm accounting data network which collects recordings of some 2,400 Austrian farms. This sample offers a representative profile of Austrian agriculture covering 54 % of farms and 95 % of dairy cows (BMLFUW, 2004). By definition 550 of the 2,400 farms belong to specialised dairy farms, i.e. more than 75 % of their standard gross margin originates from forage cropping and their standard gross margin from milk production exceeds that from cattle fattening.

Although the majority of these dairy farms primarily focus on the production of milk, some of them sell also crops, fatten bulls or keep other animals. To secure a high level of homogeneity within the sample for the study in hand, additional conditions must be met:

- revenues from diversification (e.g. direct marketing, farm holidays) must be less than 10 %
- revenues from cash crops must be less than 10 % and

![](image)

Fig. 1 Relationship between inefficiencies and returns to scale

Technical Efficiency $(TE) = \frac{0C'}{0C}$

Pure Technical Efficiency $(PTE) = \frac{0C''}{0C}$

Scale Efficiency $= \frac{TE}{PTE} = \frac{0C'}{0C''}$
at least 95% of livestock units must be cattle.

222 dairy enterprises fulfilled the conditions above and provided data for the years 2001, 2002 and 2003. In order to mitigate the influence of extraordinary events during individual years, the averages of three years was taken as a basis for the DEA analysis.

DYSON et al. (2001) suggest that to achieve a reasonable level of discrimination between efficiency scores the number of DMUs should be at least the double of the product of the number of inputs and outputs. By considering two outputs and six inputs this condition was fulfilled. Outputs are the total quantity of milk produced minus milk for feeding purposes per year (in kg) and other revenues (excluding revenues for milk and direct payments). Inputs involve activities that have impact on revenue, such as expenses for animal husbandry (e.g. feed, vet), expenses for machinery and energy (e.g. fuel, repair) and other expenses (taxes, insurances); these three inputs are measured in € per farm. The other three are utilized agricultural area (UAA) in ha, labour (in unpaid family work units FWU) and heavy livestock units. Cloutier and Rowley (1993) compared the distribution of efficiency scores across Canadian dairy farms between 1988 and 1989 using three outputs (total quantity of milk, revenue milk sale, other revenue) and five inputs (herd size, labour, cultivated land, animal feed, other inputs) of 187 farms. Table 1 summarises the characteristics of the in- and outputs of the selected sample farms.

Results

Table 2 presents a summary of results on technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) scores. The sample farms have an average TE of 79%; thus if all farms were able to move to the efficient production frontier, this would result in a production of the same level of output with a proportional reduction by 21% of all inputs. Barnes and Oglethorpe (2004) split their sample into two farm types depending on the number of dairy cows per farm (more or less than 90); regarding three years TE ranged between 60% and 73%. A study of New Zealand dairy farms presented an average TE of 83% (Jaforullah and Whiteman, 1998). Other dairy studies conducted in Australia, the Netherlands and Great Britain calculated an average TE of 52%, 78% and 87%, respectively (Fraser and Graham 2005, Reinhard et. al. 2000, Gerber and Franks 2001).

In- and Outputs of the 222 sample farms

<table>
<thead>
<tr>
<th>Variables</th>
<th>Unit</th>
<th>Input/Output</th>
<th>Mean</th>
<th>Min.</th>
<th>Max.</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of milk</td>
<td>kg</td>
<td>O</td>
<td>104,317</td>
<td>9,833</td>
<td>329,691</td>
<td>61,054</td>
</tr>
<tr>
<td>Other revenue</td>
<td>€</td>
<td>O</td>
<td>26,669</td>
<td>3,665</td>
<td>62,709</td>
<td>12,138</td>
</tr>
<tr>
<td>Animal husbandry</td>
<td>€</td>
<td>I</td>
<td>13,005</td>
<td>1,515</td>
<td>440,455</td>
<td>8,579</td>
</tr>
<tr>
<td>Machinery &amp; Energy</td>
<td>€</td>
<td>I</td>
<td>13,364</td>
<td>2,377</td>
<td>34,415</td>
<td>5,951</td>
</tr>
<tr>
<td>Other expenses</td>
<td>€</td>
<td>I</td>
<td>17,801</td>
<td>3,767</td>
<td>63,592</td>
<td>9,849</td>
</tr>
<tr>
<td>Cultivated land</td>
<td>ha</td>
<td>I</td>
<td>22.04</td>
<td>4.13</td>
<td>66.36</td>
<td>10.12</td>
</tr>
<tr>
<td>Livestock units</td>
<td>LU</td>
<td>I</td>
<td>30.68</td>
<td>5.98</td>
<td>75.96</td>
<td>13.84</td>
</tr>
<tr>
<td>Labour</td>
<td>FWU</td>
<td>I</td>
<td>1.85</td>
<td>0.61</td>
<td>3.82</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>TE, PTE and SE of 222 sample farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Efficient farms</td>
</tr>
<tr>
<td>Mean efficiency</td>
</tr>
<tr>
<td>Minimum efficiency</td>
</tr>
</tbody>
</table>

Implementing variable returns to scale (VRS) in the model, about a fourth of the sample farms exhibit pure technical efficiency. The average PTE score is 84 %.

Accordingly, scale efficiency (SE) is quite high (94 %); only 6 % of total inefficiency could be removed by an adoption of the efficient farm size (see Table 2). About 75 % of all farms have a SE of more than 90 %. The lower score of PTE in comparison to SE indicates that TE is predominately influenced by PTE rather than by SE. Hence, management practises and natural conditions had a stronger influence on technical efficiency than farm size. Several reasons may explain this outcome. Despite our restrictive data selecting process there are still differences between the dairy farms for instance in terms of agro climatic conditions and soil quality. Other impacts may originate from different socio-economic backgrounds and farmers’ objectives. Several papers analysed the relationship between education level of farmers and technical efficiency and found a positive relationship (e.g. see Stefanou and Saxena, 1988). However, unlike in that study our results show no significant correlation between education level and efficiency scores.

Distributions of TE and PTE follow similar patterns (see Figure 2). Most farms show an efficiency level between 0.7 and 0.9. Almost one fourth of all farms operates at the pure technical efficiency frontier. But the distribution of SE is quite different. About 58 % of all farms belong into the scale efficiency class between 90 and less than 100 %.

Basically three different constitutions of returns to scale (RTS) are possible. In case of CRS a doubling of all inputs would also double all outputs. Otherwise VRS is exhibited. In this case farms do not operate on efficient scale and show either increasing IRS or decreasing returns to scale (DRS). Table 3 summarises characteristics of different farm types according to their distribution of RTS. The bulk of farms (162 farms or 73 %) were operating on IRS. Hence, increasing all inputs by one percent would result in an increase of output of more than one percent. On the other hand 19 farms show DRS. Generally, scale inefficiencies for IRS farms are greater than for DRS farms and indicate that a scaling up in size would have greater effects on efficiency for small farms than a size reduction of large farms.

![Fig. 2 Distribution of farms according to TE, PTE and SE](image-url)
Differences between farms with CRS, IRS and DRS are evident from Table 3. Farms operating at an efficient scale keep on average 22.6 dairy cows and manage about 22 ha utilised agricultural area. Concerning the proportion of grassland DRS farms show the lowest share which means that on these kinds of farms arable farming is more important. Differences in farm sizes are also reflected in economic indicators (e.g. agricultural income). The high level of direct payments of DRS farms (31,851 €) originates on the one hand from market supports (e.g. area based) and on the other hand from payments based on less favoured area status. On average, DRS farms have almost 139 mountain farm cadastre points which is additionally confirmed by a high average altitude (725 m above sea level).

Figure 3 contrasts the distribution of RTS with respect to utilised agricultural area and number of livestock units. As pointed out in table 3 the majority of farms (73 %) operates at IRS. Both figures show similar distributions. In the case of utilised agricultural area only 17 % of the farms with less than 10 ha exhibit CRS. There are increasing percentages of farms with DRS as areas increase. In the class with more than 40 ha UAA,

Table 3

<table>
<thead>
<tr>
<th>Variables</th>
<th>CRS</th>
<th>DRS</th>
<th>IRS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of farms</td>
<td>41</td>
<td>19</td>
<td>162</td>
<td>222</td>
</tr>
<tr>
<td>TE score</td>
<td>0.97</td>
<td>0.83</td>
<td>0.74</td>
<td>0.79</td>
</tr>
<tr>
<td>PTE score</td>
<td>0.97</td>
<td>0.85</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>SE score</td>
<td>1.00</td>
<td>0.97</td>
<td>0.92</td>
<td>0.94</td>
</tr>
<tr>
<td>UAA*</td>
<td>21.88</td>
<td>35.43</td>
<td>20.51</td>
<td>22.04</td>
</tr>
<tr>
<td>Grassland in % of UAA</td>
<td>74.62</td>
<td>70.22</td>
<td>76.11</td>
<td>75.33</td>
</tr>
<tr>
<td>Heavy Livestock unit no.</td>
<td>32.95</td>
<td>46.73</td>
<td>28.22</td>
<td>30.68</td>
</tr>
<tr>
<td>Dairy cows head</td>
<td>22.64</td>
<td>27.27</td>
<td>16.77</td>
<td>18.76</td>
</tr>
<tr>
<td>Milk quota kg</td>
<td>135,556</td>
<td>162,464</td>
<td>84,207</td>
<td>100,388</td>
</tr>
<tr>
<td>Milk production (brutto) kg</td>
<td>153,128</td>
<td>184,609</td>
<td>99,661</td>
<td>116,806</td>
</tr>
<tr>
<td>Agricultural income €</td>
<td>34,086</td>
<td>48,749</td>
<td>22,019</td>
<td>26,535</td>
</tr>
<tr>
<td>Direct payments €</td>
<td>15,494</td>
<td>31,851</td>
<td>15,726</td>
<td>17,063</td>
</tr>
<tr>
<td>Standard gross margin €/farm</td>
<td>29,241</td>
<td>38,248</td>
<td>23,308</td>
<td>25,683</td>
</tr>
<tr>
<td>Mountain farm cadaster points score</td>
<td>95</td>
<td>139</td>
<td>111</td>
<td>111</td>
</tr>
<tr>
<td>Sea level m</td>
<td>636</td>
<td>725</td>
<td>622</td>
<td>634</td>
</tr>
<tr>
<td>Agricultural education**</td>
<td>2.66</td>
<td>2.58</td>
<td>2.35</td>
<td>2.42</td>
</tr>
</tbody>
</table>

* alpine pastures included.
** 1 = none, 2 = vocational or apprentice school, 3 = master craftsman, 4 = high school or university.

Fig. 3 Distribution of RTS according to different farm sizes (UAA and livestock units)
half of the farms show DRS although 40% of the farms still exhibit IRS. The distributions of CRS-farms follow more or less a constant pattern. In terms of milk quota there are no farms operating at CRS or DRS with less than 20 t.

Taking into account that DEA only measures the relative efficiency within the sample, the study provides evidence that technical and scale inefficiencies exist in Austrian dairy farms. Similar results were obtained by Barnes and Oglethorpe (2004). Their findings indicate that large farms would benefit from reductions in scale, whereas small to medium farms are recommended to increase farm size, and the latter group would obtain greater efficiency scores from such changes. Jaforullah and Whiteman (1998) found that more than half of the sample dairy farms were operating at below their efficient scale and consequently could increase their technical efficiency by increasing farm size. Gerber and Franks (2001) examined scale efficiencies for farms in England and Wales and found that dairy farms with herds between 70 and 160 cows operated at constant returns to scale, whereas farms with less or more cows showed diseconomies of scale.

Even though the farms in the present study are quite small, a comparison between sample farms and all dairy farms in Austria reveals that the enterprises chosen for this study are above average in terms of farm size (see Figure 4). In particular, the number of dairy cows and the amount of milk quota per sample farm is more than twice the Austrian average. A considerable difference exists also in the proportion of organic farms which is higher in the sample. Consequently, it can be concluded that the majority of Austrian dairy farms show even higher scale inefficiencies than the sample farms.

Summary and conclusions

This paper focuses on the measurement of technical, pure technical and scale efficiency for a sample of 222 highly specialised dairy farms in Austria. Data envelopment analysis (DEA) was used to obtain different kinds of efficiencies which were used to determine returns to scale for each farm. The analysis revealed an average level of technical, pure technical and scale efficiency of 79%, 84% and 94%, respectively and was thus in line with the findings of other studies on dairy farming. Primary attention was paid to the determination of returns to scale. The analysis exhibited considerable variability among farms operating at increasing, constant or decreasing returns to scale. In general, scale efficiency was quite high (94% on average). Farms operating at increasing returns to scale have a higher potential (8% scale inefficiency) to increase their scale efficiency than farms operating at decreasing returns to scale (3% scale inefficiency).

Technical efficient farms were found in different size categories, indicating that beside of farm size also management skills and other factors play an important role. Compared to other EU-countries dairy farms in Austria are still very small. For many farms there should be a potential to increase efficiency and agricultural income at the same time. But the move to an efficient scale is subject to investment decisions which may take a long time to materialise. F.i. to buy one kg of milk quota affords today the investment of 8 Cent per year over 8 years (derived from a quota price of 80 Cent per kg), in addition to direct costs of 20 Cent per kg milk produced (in 2004). Farms in mountainous regions which are highly dependent on special topography and agro-climatic conditions have almost

![Fig. 4 Comparison between the sample data set and all Austrian dairy farms](image-url)
no alternatives to dairy farming for the provision of income. The paper produced evidences that the average efficient size of dairy farms in Austria may be smaller than in other countries.

According to the results further analysis focussing on farm management practises in detail would be of interest. In this context the Austrian Agri-Environmental Programme plays a crucial role for Austrian farmers. Depending on what measurements were chosen farmers subject to different production standards (e.g. reduction of fertilizers and pesticides) and may influence their relative efficiency. Different cost structures for land tenancy and milk quota may have other important impacts on competitiveness and efficiency. Considering future challenges (liberalisation of agricultural markets, increasing demands on animal welfare, food safety and environment protection) an increase of farm size might not be the only alternative to secure farm existence. According to the diverse character of dairy farms in Austria several other strategies are feasible (e.g. milk processing on farm and/or direct marketing). Disregarding scale efficiency the results of the study may prove this statement as efficient farms (pure technical efficiency) were found in all return to scale classes.

References