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HELIS LUIK, RAUL OMEL, ANTS-HANNES VIIRA
Estonian University of Life Sciences

Paper prepared for presentation at the EAAE 2011 Congress
Change and Uncertainty
Challenges for Agriculture,
Food and Natural Resources

August 30 to September 2, 2011
ETH Zurich, Zurich, Switzerland

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Helis Luik, Raul Omel and Ants-Hannes Viira

Estonian University of Life Sciences

Abstract

The purpose of this paper is to analyse productivity change of Estonian dairy farms during the period 2001-2009. Data envelopment analysis (DEA) was used to estimate the technical efficiency of producers and Malmquist productivity index for analysis of productivity change. Estonian FADN data was used in analysis. Performed analysis indicated that Estonian EU accession in 2004 increased considerably total factor productivity. Farm gate milk prices have considerable effect on total factor productivity change. Number of cows and milk yield has positive and dependence on subsidies, stocking density and capital to working hours ratio have negative effects on total factor productivity change.

Keywords: Malmquist productivity index, technical efficiency, technical change, data envelopment analysis, dairy production.

Introduction

Milk production has historically been the main production line in Estonian agriculture comprising for 25-30% of the value of agricultural output. Like many other Eastern European countries, Estonian agriculture has been a subject for many reforms and the process of transition is still ongoing after 20 years since its start (Viira et al., 2009). Accession to the EU remarkably changed economic and policy environment for Estonian farmers. The liberal economic and agricultural policy was replaced by more regulated CAP with policy measures of wider scope, and with significantly higher average payment levels.

From 2001 until today one of the priorities of Estonian agricultural policy has been fostering farm investments. This policy orientation has been motivated by lack of new investments in 1990s and the need to modernise Estonian farms that used the Soviet equipment and technologies. Naturally, the aim of any investment programme is always to improve the productivity and efficiency of farms. As a result of investment support programmes approximately half of the dairy cattle are kept in new cowsheds with up to date feeding and milking technologies.

Another shift in policy focus that can be associated with the EU accession lies in the domain of agri-environmental issues. The Rural Development Plan provides farmers with an opportunity to join the agri-environmental programme which implies more restrictive environmental obligations accompanied with compensation for associated income loss. Also, farms that are located in less favoured areas (LFA) are receiving payments that should equalise the level of their income compared to farms in more productive regions.

Also, organic farming programme can be associated with wider agri-environmental issues. All three programmes – agri-environmental programme, less favoured areas and organic farming – are characterised by less competitive production conditions compared to highly productive farms and additional compensatory payments to keep such farms in business and provide the society with cleaner and more diverse nature and healthier food.

The structure of Estonian dairy sector is of dual nature. There are large dairy farms, many of which are privatised ex-collective farms. And there are small dairy farms which were established in 1990s in the process of agricultural restructuration (Viira et al. 2009). Like in many other countries Estonian dairy sector follows the similar structural change pattern, the pace of the changes may be quicker, though. The number of small dairy farms is decreasing and the share of larger units is increasing. Another characteristic of large dairy farms is that they have more diverse production structure, i.e. they also produce cereals and oilseeds, in some cases pigs etc.

Estonian agriculture has undergone major changes - in particular the structure of households. The number of dairy households has been reduced from 17527 households in 2001 to 6121 in 2007. The number of dairy cows declined over this period from 127969 cows to 107884 cows. The number of cows has declined mainly because of the disappearance of small households. The largest decline occurred among farmers with 1-9 cows, which have reduced the number of households from 16254 to 5067, however, the number of large herds (>300 cows) has risen from 76 to 91. The average number of dairy cows has risen from 7.3 cows to 17.6 cows. Also, livestock farmers have increased the average size of agricultural land from 28.8 to 49.2 ha, while the average land area of all farm households has risen from 15.6 to 38.9 ha, which means that the, livestock producers have larger than average farms. Milk production has increased from 2000-2008 from 4660 to 6781 kg per cow, which makes an average 236 kg per cow per year.

Table 1. The number of dairy cows and households in herd size groups from 2001 to 2007

	2001		2003		2005		2007	
Herd size, cows	House-holds	Dairy cows	House-holds	Dairy cows	House-holds	Dairy cows	House-holds	Dairy cows
1-9	16254	31042	11220	20646	8082	14876	5067	9686
10-19	622	8186	511	6788	444	5685	386	4864
20-29	176	4199	179	4276	177	3988	167	3795
30-49	122	4449	144	5245	150	5549	133	4735
50-99	104	7352	97	6766	112	7280	132	8650
100-199	113	16151	102	14737	99	13931	80	11058
200-299	60	14610	64	15850	60	14671	64	15031
≥300	76	41980	81	45497	86	49249	91	50065
Total	17527	127969	12397	119805	9210	115230	6121	107884

Source: Statistics Estonia

Considering the characteristics of Estonian dairy sector and changes in agricultural policy associated with the EU accession the aim of this paper is to investigate whether there have been changes in efficiency and productivity of dairy farms in the period of 2001 to 2009.

Methodology and data

DEA analysis can identify the efficient farm units and results for an inefficient unit will show by how much each input can be reduced or output increased to produce an optimal output. Farrell defined the technical efficiency in two ways: the ability of a farm to produce the maximum feasible output with a given bundle of inputs or the ability of a farm to use minimum inputs to produce a given level of output. (Cooper et al., 2004)

Beginning with the work of Farrell in 1957, a simple measure of efficiency accounting for a single output and multiple inputs was defined. Efficiency consists of technical efficiency, which reflects the economic unit's ability to obtain maximum output from a given set of inputs. Efficiency measures assume that the production function, which shows the maximum output attainable from a given set of inputs, of the fully efficient economic unit is known. DEA analysis identifies the efficient units; the results for inefficient units will show by how much each input can be reduced or output increased to produce an optimal output. Farrell suggested that the function, if not known, should be estimated from sample data using a nonparametric piece-wise linear technology, resulting in the development of DEA. (Cooper et al., 2004)

In this study, we employed an input-oriented model. We determine how much companies should reduce their inputs to achieve efficiency, provided that the volume of production remains the same. The method was used to measure technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) for Estonian dairy farms. We used constant returns to the scale model (CRS model) to estimate technical efficiency and variable returns to the scale model (VRS model) to estimate pure technical efficiency.

In the second stage fixed effects models are used to estimate the effects of various factors on the PTE change and total factor productivity change.

Efficiency is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs. To express mathematically the constant returns to scale model, we considered a theoretical data set of N inputs and M outputs for each of I farms. For i-th farm input and output, data are represented by the column vectors x_i and q_i, respectively. The NxI input matrix, X, and the MxI output matrix, Q, represent the data for all I farms in the sample. The technical efficiency measure under the assumption of constant return to scale (CRS) can be formulated as:

$$\min_{\theta,\lambda} \theta,$$

$$\text{st} \quad -q_i + Q\lambda \geq 0,$$

$$\theta x_i - X\lambda \geq 0,$$

$$\lambda \geq 0,$$

where θ is a scalar and λ is a Ix1 vector of constant. Using the variables λ and θ, the model is solved once for each farm, looking for the largest radial contraction of the input vector x_i within the technology set. The value of θ obtained is the efficiency score for the i-th farm. It satisfies: $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient farm. (Coelli 2005)

The assumption of CRS is correct only as long as firms are operating at an optimal scale. Various constraints on inputs such as imperfect competition, government regulations, constraints on finance etc., may cause a firm not to be operating at optimal scale (Coelli 2005). The CRS linear programming problem can be easily modified to account for VRS by adding the convexity constraint: I1´λ=1 to equation 2 to provide:

$$\min_{\theta,\lambda} \theta,$$

$$\begin{aligned} \text{st} \quad & -q_i+Q\lambda\geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & I1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned}$$

where I1 is an Ix1 vector of ones. A value less than one indicates the unit, which has been given the existing set of observations, can improve the productivity of its inputs by forming benchmarking partnerships and emulating the best practices of its reference or peer group. (Coelli et al. 2005)

Scale efficiency (SE) measures can be obtained for each farm by conducting both CRS and VRS DEA. A difference between the TE and PTE scores for a particular farm indicates that the farm has scale inefficiency (Coelli et al., 2005). In the CRS specification, it is assumed that farms are operating at their optimal scale (Fraser and Cordina, 1999), whereas under VRS, the scale explains part of the inefficiency. A comparison of the scores from both specifications expresses the scale efficiency at which a farm operates.

Productivity change of Estonian Dairy farms is measured with the Malmquist index. We used the approach suggested by Färe et al (1994) for decomposition of the Malmquist productivity index to technical efficiency change and technical change.

$$M = \frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)} \times \left[\frac{D_t(x_{t+1}, y_{t+1})}{D_{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_t(x_t, y_t)}{D_{t+1}(x_t, y_t)} \right]^{1/2} \quad (1)$$

First term of the equation (1) is technical efficiency change and second term (in parenthesis) indicates technical change in periods $t+1$ and t. Technical change is estimated as geometric mean of two productivity indices. Term in parenthesis represents productivity of two production points. Values above one indicate positive growth of total factor productivity from period t to period $t+1$.

The technical efficiency scores and Malmquist productivity index are estimated for dairy farms using data envelopment analysis and the input orientation approach based on Estonian FADN database. The sample includes farms where the value of milk produced exceeds 60% of the total production value (excluding subsidies). Panel data from 2001-2009 comprised of 58 Estonian dairy farms. The panel includes 522 observations over 9 years. The monetary values have been deflated, using input price indices according to national statistics based on year 2001.

The analysis applies two outputs and five inputs. The revenue of milk is measured in monetary value (Y1). Other output cover outputs other than milk and is measured in monetary value (Y2). Direct payments and other subsidies are excluded. The inputs include labour, land, materials, capital, cows. Labour is in the form of annual working hours and it includes all labour, both paid and unpaid, which has contributed to the work on the farm during the accounting year (x1). Land is measured as the total area of farmland in hectares (x2). Materials include purchased feed, energy and other costs and are measured in monetary value (x3). The capital cost includes depreciation, rent, interest and the specific cost for machinery and buildings and is measured in monetary value (x4). The number of cows is taken account as an average of the year (x5).

Descriptive statistics of outputs and inputs are summarized in table 2.

Table 2. Descriptive statistics of outputs and inputs by years

	Milk €		Other outputs €		Land Hectares		Cows Number		Labour Hours		Capital €		Materials €	
	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
2001	31344	33903	5944	8219	139	140	37	42	8928	9069	8319	7476	18716	20835
2002	31283	31968	5752	7548	149	128	39	43	9296	10306	11708	11071	18007	17634
2003	37384	37567	6617	6397	163	132	43	44	9009	8671	12476	11719	20441	19095
2004	53391	52197	8969	9811	172	133	46	44	9044	8677	17163	16493	27322	26267
2005	62008	59489	10744	13152	172	133	48	46	9134	9273	19185	17988	32113	32912
2006	65852	66523	12170	15170	172	133	49	46	9243	9293	21605	19449	33118	33280
2007	76819	74950	15690	18498	175	135	52	47	9282	9102	26769	24500	36056	37905
2008	87102	87534	19942	25886	177	139	52	47	9030	8975	31866	30958	35772	37736
2009	62320	58774	17418	22743	171	135	53	45	8336	8503	29517	28150	31111	30654

Results and discussion

At first we calculated the technical efficiency using constant returns to scale and variable returns to scale approaches based on the Envelopment Model (see table 3). Obtained results show no significant change in technical efficiency in Estonian dairy farms over the period of 2001-2009.

Table 3. The average value of CRS, VRS and SE scores by years

Year	CRS	VRS	SE
2001	0.861	0.918	0.938
2002	0.829	0.893	0.931
2003	0.822	0.911	0.906
2004	0.844	0.916	0.922
2005	0.819	0.910	0.901
2006	0.862	0.922	0.935
2007	0.815	0.889	0.918
2008	0.817	0.896	0.910
2009	0.835	0.908	0.919

Table 4 describes the distribution of technical efficiency over the years. There have been only minor changes in efficiency distribution during the investigated period. The share of firms with at least 95 percent level of technical efficiency from maximum level has been between 43.1% and 63.8%. Notable changes in efficiency distribution have been in 2004 and 2007.

Table 4. Distribution of technical efficiencies by year

Year TE VRS (%)	2001	2002	2003	2004	2005	2006	2007	2008	2009
-70	6.90	12.07	12.07	6.90	6.90	5.17	8.62	12.07	3.45
70-80	13.79	15.52	3.45	3.45	8.62	8.62	17.24	6.90	18.97
80-85	8.62	6.90	6.90	12.07	13.79	8.62	8.62	12.07	5.17
85-90	1.72	5.17	8.62	10.34	12.07	12.07	10.34	5.17	6.90
90-95	5.17	5.17	13.79	17.24	5.17	6.90	12.07	12.07	6.90
95-	63.79	55.17	55.17	50.00	53.45	58.62	43.10	51.72	58.62

Table 5 presents Malmquist index averages as geometric means. Values in 2002, 2006 and 2009 are below one indicating negative growth of total factor productivity. Highest growth in total factor productivity has been in 2004 when Estonia joined the EU. Technical efficiency change, that should explain increases in production while the use of inputs is unchanged, has been lower than technological change in most of the years. Only in 2002 and 2009 technical efficiency has been higher than technological change.

Table 5. Malmquist index summary of annual means

Year	Technical efficiency change	Technological change	Pure technical efficiency change	Scale efficiency change	Malmquist index change
2002	0.964	0.959	0.969	0.994	0.925
2003	0.992	1.101	1.022	0.971	1.092
2004	1.029	1.171	1.010	1.019	1.206
2005	0.966	1.120	0.991	0.975	1.082
2006	1.055	0.920	1.014	1.040	0.971
2007	0.941	1.170	0.962	0.978	1.102
2008	0.997	1.101	1.004	0.993	1.097
2009	1.030	0.798	1.016	1.014	0.822

Average productivity change is summarised in table 6. Technical efficiency change has had less influence on productivity change. Technological change, indicating the shift in frontier technology, has had greater effect both in decline and increase of productivity. Process and product modernisation has been in focus and can explain the technological change in dairy production.

Table 6. Average productivity change and its components

Period	Technical efficiency change (%)	Technological change (%)	Pure technical efficiency change (%)	Scale efficiency change (%)	MPI change (%)
2001/2002	-3.73	-4.28	-3.20	-0.60	-8.11
2002/2003	2.82	12.90	5.19	-2.37	15.29
2003/2004	3.60	5.98	-1.19	4.71	9.45
2004/2005	-6.52	-4.55	-1.92	-4.51	-11.46
2005/2006	8.44	-21.74	2.27	6.25	-11.43
2006/2007	-12.11	21.37	-5.41	-6.34	11.89
2007/2008	5.62	-6.27	4.18	1.51	-0.46
2008/2009	3.20	-37.97	1.18	2.07	-33.45

In the second stage of analysis fixed effects models were used in order to estimate the effects various factors on technical efficiency (DEA PTE scores) and TFP index. The fixed effects model was preferred to first difference model because of lower serial correlation of the error term. The estimated fixed effects models were following:

(2) $TE = \beta_1 y2002 + \beta_2 y2003 + \beta_3 y2004 + \beta_4 y2005 + \beta_5 y2006 + \beta_6 y2007 + \beta_7 y2008 + \beta_8 y2009 + \beta_9 \log(cows) + \beta_{10} \log(yield) + \beta_{11} subsdep + \beta_{12} \log(stockdens) + \beta_{13} \log(captowkhrs) + \beta_{14} \log(large*captowrkhrs) + u$

(3) $TFP = \delta_1 y2002 + \delta_2 y2003 + \delta_3 y2004 + \delta_4 y2005 + \delta_5 y2006 + \delta_6 y2007 + \delta_7 y2008 + \delta_8 y2009 + \delta_9 \log(cows) + \delta_{10} \log(yield) + \delta_{11} subsdep + \delta_{12} \log(stockdens) + \delta_{13} \log(captowkhrs) + \delta_{14} \log(large*captowrkhrs) + v$

In this stage our aim was to estimate the effects of number of cows (*cows*), milk yield per cow (*yield*), share of subsidies in total farm income (*subsdep*), stocking density of dairy cows (*stockdens*), capital to working hours ratio (*captowkhrs*) and capital to working hours ratio in farms that were larger than 40 ESUs (*large*captowrkhrs*). Independent variables *y2002-y2009* represent time dummies for years 2002-2009.

The regression results for model (2) are given in Table 7 and for model (3) in Table 8.

Table 7. Fixed Effects estimation of technical efficiency

Independent variables	Coefficient	Standard Error	t-value	Pr(>|t|)
y2002	0.0012	0.0157	0.0753	0.9400
y2003	0.0006	0.0161	0.0357	0.9715
y2004	0.0676	0.0219	3.0899	0.0021**
y2005	0.0590	0.0233	2.5347	0.0116*
y2006	0.0815	0.0260	3.1315	0.0019**
y2007	0.0437	0.0270	1.6195	0.1060
y2008	0.0579	0.0286	2.0248	0.0435*
y2009	0.0809	0.0299	2.7054	0.0071**
log(cows)	0.0379	0.0257	1.4714	0.1419
log(yield)	0.1096	0.0365	3.0039	0.0028**
subsdep	-0.5377	0.0792	-6.7925	0.0000***
log(stockdens)	0.0003	0.0210	0.0155	0.9876
log(captowkhrs)	-0.0198	0.0106	-1.8698	0.0622.
*log(large*captowrkhrs)*	0.0001	0.0002	0.4479	0.6544

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Total Sum of Squares: 3.3978

Residual Sum of Squares: 2.7846

F-statistic: 7.07821 on 14 and 450 DF, p-value: 0.0000

The results of the first model (2) indicate that (as expected) yield improvements have positive and statistically significant effect on farm technical efficiency. Increase of subsidy dependence, i.e. the share of subsidies in total income has significant negative effect on farm technical efficiency. The value of this variable is related to milk sales revenue and sales revenue of other produce that were used as outputs in DEA model. If the farm has higher sales revenue compared to similar farms and receives the same amount of subsidies, it is natural that its subsidy dependence (as calculated here) is smaller and at the same time it is technically more efficient. The effect of capital to working hours ratio is weakly significant indicating that increase in capital does not bring along immediate improvement in technical efficiency. One could assume that there is a positive relationship between these factors but there is a longer than one year lag between the investment and its full effects on production. After the EU accession the technical efficiency of Estonian dairy farms has been 4 to 8 percentage points higher than in the base year 2001. The results show no significant relationship between the number of cows (scale of farm) and technical efficiency, and stocking density and technical efficiency. Also, we cannot assure that in larger dairy farms (>40 ESU) the effect of capital to labour hours ratio has positive effect on technical efficiency.

Table 8. Fixed Effects estimation of total factor productivity

Independent variables	Coefficient	Standard Error	t-value	Pr(>ltl)
y2002	0.0586	0.0426	1.3762	0.1695
y2003	0.0504	0.0437	1.1536	0.2493
y2004	0.5233	0.0593	8.8314	0.0000***
y2005	0.6370	0.0631	10.0923	0.0000***
y2006	0.6350	0.0706	8.9996	0.0000***
y2007	0.7567	0.0731	10.3507	0.0000***
y2008	0.9286	0.0775	11.9846	0.0000***
y2009	0.6837	0.0810	8.4420	0.0000***
log(cows)	0.3543	0.0697	5.0814	0.0000***
log(yield)	0.3385	0.0988	3.4253	0.0007 ***
subsdep	-2.3298	0.2145	-10.8604	0.0000***
log(stockdens)	-0.1353	0.0569	-2.3789	0.0178*
log(captowkhrs)	-0.1074	0.0287	-3.7413	0.0002***
*log(large*captowrkhrs)*	0.0024	0.0005	4.8395	0.0000***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Total Sum of Squares: 56.473

Residual Sum of Squares: 20.447

F-statistic: 56.6332 on 14 and 450 DF, p-value: 0.0000

The regression results for model (3) are given in Table 8. It appears that in 2004 there was a significant jump in total factor productivity compared to 2001. This could be partly explained by Estonian EU accession in 2004, and accompanying increase in farm gate milk prices by about 33.2% in 2004 compared to 2003. Also, it appears that in 2009 the total factor productivity declined compared to 2008. In 2009 milk prices were 29.1% lower than in 2008. Therefore the regression coefficients of year-dummies roughly represent the effect of farm gate milk prices on total factor productivity change.

The results indicate that increasing the number of cows while keeping other factors fixed improves total factor productivity. This is an expected result as increase in number of cows increases farms output and if we assume that inputs are fixed the productivity must increase. There is also a positive and significant relationship between milk yield and TFP. As in case of the results of model (2) the higher dependence on subsidies has negative effect on total factor productivity. Also increase in stocking density and capital to working hours ratio have negative effects on TFP change. If the farm has higher stocking density it probably has less land for production of other goods (e.g. cereals or oilseeds) and therefore the farms output of other goods is lower which affects its total factor productivity negatively. It appears that increase in capital relative to working hours has significant negative impact on TFP. This implies that in year-to-year comparison the farms tend to overinvest. However, the full positive effect of investments may appear only after several years. We assumed that larger farms may benefit more from capital intensive technology and our results indicate that there is a significant positive relationship between capital to working hours ratio and TFP in larger farms.

Conclusion

This analysis has argued that data envelopment analysis is a good instrument to analyze efficiency and productivity of agricultural production for an economy in transition. The present study was designed to determine the following questions:

For this purpose analysis of the efficiency of Estonian dairy sector was conducted. Measurement of technical efficiency gives a good estimation of the technical efficiency of the firm's production compared to some ideal production.

Evaluation of DEA efficiency scores showed that in dairy sector there has been no significant change in technical efficiency in yearly average scores from 2001 to 2009. In efficiency distribution there have been only minor changes. The share of producers with highest efficiency, with more than 95% of maximum, is declined in 2004 and 2007. Values of Malmquist productivity index indicate highest growth in total factor productivity in 2004 when Estonia joined European Union. Most years have witnessed higher technological change compared to technical efficiency change. Therefore technical efficiency change has had less influence on productivity change.

In order to estimate the effects of various factors on technical efficiency and total factor productivity the fixed effects models were used.

Estimation of different characteristics of farming on farm efficiency scores indicate that yield improvements have positive effect on technical efficiency and the share of subsidies in total income has negative effect on technical efficiency. Capital to working hours ratio indicates that increase in capital has modest effect to technical efficiency. And there is no significant relationship between the scale of the farm and stocking density and technical efficiency.

Estimation of different characteristics of farming on total factor productivity show that Estonian EU accession in 2004 increased considerably total factor productivity which can be explained by an increase of milk price. Analysis revealed that farm gate milk prices have considerable effect on total factor productivity change. Number of cows and milk yield has also positive relationship to total factor productivity. Dependence on subsidies, stocking density and capital to working hours ratio have negative effects on total factor productivity change.

A number of caveats need to be noted regarding the present study. The most important limitation lies in the fact that farm accountancy data used in this study is not always reliable. Especially data gathered from small farms has its limitations as for instance the use of labour is declared questionably. Another limitation of the study was the estimation of the impact of investments. Thou the decision behind investments should be of increasing efficiency, but the real effect in achieving higher efficiency has time lag. The time lag of the impact of investments was not under investigation in this study. As the result of the analysis is to a great extent determined by the choice and composition of input variables, the proper methods for selection of input data have to be investigated more thoroughly.

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