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and Bernhard Brümmer**

Farm Efficiency and Productivity Growth in Ukrainian Agriculture

July 2003

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1 Introduction

Transition from a planned to a market-oriented economy has proved to be a painstaking process for almost all Central and Eastern European countries. Nevertheless, it is perceived that market orientation brings about improved efficiency and favors efficient resource allocation through more developed and flexible price mechanisms. The first ten years of transition in Ukrainian agriculture were marked by a persistent decline in output. Agricultural output in 2000 accounted only for 53% of 1990 level and it is only since 2000 that it has begun to recover. A natural question arises: why did market mechanisms fail to produce the expected improvements and to which factors can the observed patterns of development in Ukrainian agriculture be attributed?

Generally, a decline in output can be explained by a reduction in input usage, a fall in pure technical efficiency (i.e. by less efficient utilization of resources), a decline in scale efficiency (i.e. a deviation from scale efficient output level) and a technology regress. All these factors contribute to changes in production levels and their effects may be quite opposite; that is, production increases due to technological progress and may be dwarfed by a simultaneous deterioration of technical efficiency. To which factors an increase (or decrease) in output can be attributed is an empirical question. It is the goal of this paper to analyze the effect of each of the factors on the productivity change in Ukrainian agriculture over the 1996-2000 period.

Efficiency analysis is important for several reasons. First, at the aggregate level the decomposition of productivity changes may be valuable for policy-makers, since it reveals potential sources of productivity growth and, possibly, output expansion. Furthermore, efficiency analysis at the farm level may be helpful in determining optimal farm size, the optimal resource mix and the minimum amounts of inputs required to produce a given output.

This paper attempts to estimate technical and allocative efficiencies at the level of individual agricultural enterprises and to analyze the linkages between an enterprise's efficiency and its ownership pattern. An effort is also made to determine optimal inputs ratios and optimal amounts of each input required to produce a unit of output. At the aggregate level, we review the trends in Ukrainian agriculture over a five-year period and provide a comprehensive analysis of the changes in productivity, technical efficiency and technological change.

The paper is organized as follows. Section 2 describes the methodology employed. Section 3 contains a discussion of the data used. The rest of the study actually consists of two parts that can be considered as two separate analyses. The first part covers the performance of agricultural enterprises at the regional level from 1996 through 2000 and, thus, aims at explaining changes in Ukrainian agriculture as a whole. This analysis is presented in Section 4. The second part of the study focuses on the analysis of particular agricultural enterprises in 5 central regions of Ukraine, which is presented in Section 5. The concluding section discusses implications and policy recommendations.

2 Methodology

This research employs Data Envelopment Analysis (DEA). The advantage of this (non-parametric) approach over parametric approaches applied to Ukrainian and Russian agriculture (Peter Voigt (2002), Kurkalova & Jensen (2002)) is that it assumes no specific form of production function.

First, we introduce the conceptual framework of productivity and efficiency analysis based on DEA. When one talks about the efficiency of a firm one usually refers to the ability of that firm to extract a maximum output from a given set of inputs (output-oriented technical efficiency). Or, alternatively, one could say that efficiency means the ability of a firm to produce a given amount of output using a minimum amount of inputs (input-oriented technical efficiency). Both statements are interchangeable under the assumption of constant returns to scale and which is used depends on the optimization behavior of the producing unit. If the enterprise aims at maximizing revenue then the former formulation is appropriate, however, if the enterprise follows a cost minimization principle, then the latter formulation is the one to use. In our specific setting we assume that agricultural enterprises act as cost minimizing decision-making units. This is a reasonable assumption, since under the planned economy agricultural enterprises were given output targets and were supposed to achieve these targets at any cost, even at the cost of highly inefficient resource use. At the outset of transition, input supplies by the state to agricultural enterprises started gradually declining and enterprises were forced to economize on inputs in order to maintain output levels. Thus, we can assume that the goal of the enterprises is to return to pre-transition output levels using as few resources as possible. Hence, in our analysis we focus on input oriented measures of efficiency, which will be explained and discussed below.

DEA is based on the construction of a best-practice frontier. This is achieved by solving the following linear optimization problem for each observation in the sample:

$$F_k^t = \min \lambda \qquad (1a)$$

subject to $y_{k,m}^t \leq \sum_{k=1}^{K} z_k^t y_{k,m}^t$, m=1…M

$$\lambda\ x_{k,n}^{t} \geq \sum_{k=1}^{K} z_{k}^{t} x_{k,n}^{t} \quad \text{, n=1…N}$$

$$z_{k}^{t} \geq 0\text{,}\quad \sum_{k=1}^{K} z_{k}^{t} = 1 \quad \text{(VRS)}$$

where F_k=min λ stands for technical efficiency of firm k, z_k are variables which show the intensity with which each farm is used in order to construct the best practice frontier, $y_{k,m}$ is an m-th output of k-th firm, $x_{k,n}$ is the n-th input employed by firm k, t – time index and k = 1…K – the number of enterprises. The solutions to this optimization problem are obtained using the computer program DEAP developed by Coelli.

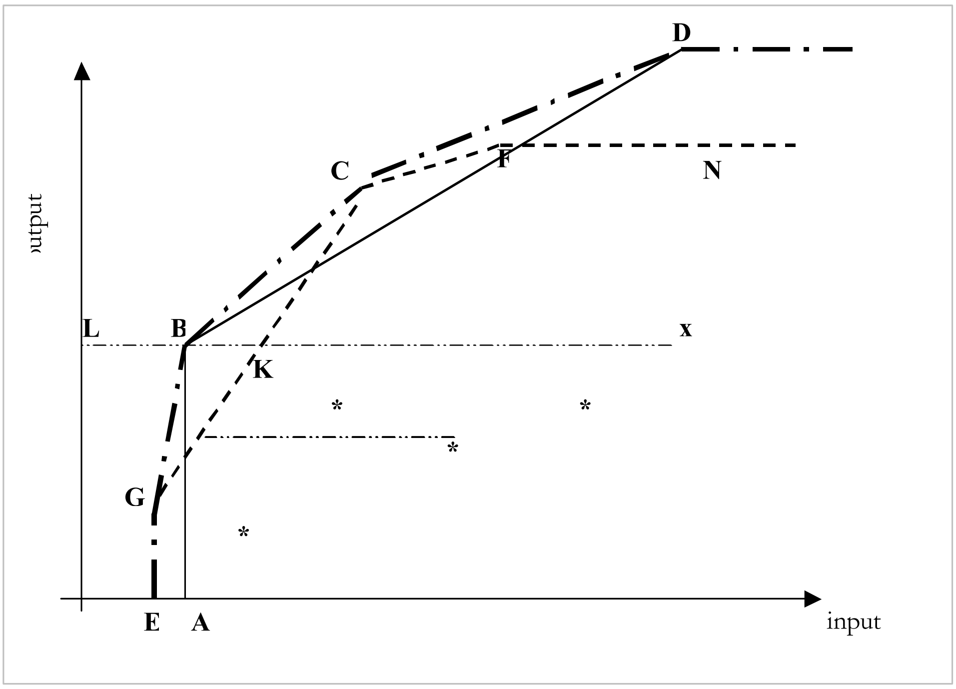
Before proceeding, a few qualifications to be made when interpreting technical efficiency should be mentioned. First, technical efficiency is a relative measure, that is, we consider an enterprise's technical efficiency relative to other enterprises. If the sample is small enough and the enterprises are more or less homogeneous then it might appear that the majority of enterprises is efficient, even though from an economic point of view they do not utilize resources efficiently. Introducing new enterprises into the analysis will significantly lower efficiency scores if these enterprises are found to be much more efficient *relative* to the others. Since technical efficiency (F_k) measures relative performance, it is very sensitive to outliers, and, hence, before starting the analysis a careful look at the data is required with outliers being excluded from the sample.

A second qualification arises with respect to inputs. In the real world, it rarely happens that inputs used in the production are actually the same inputs for all enterprises. This point is especially relevant for agricultural inputs such as land. To provide a complete and accurate picture of the real world, one should somehow allow for this input heterogeneity. But heterogeneity, for example, in land reflects differences in climate, natural land fertility and other factors that cannot be easily modeled. Thus, for the sake of simplicity a strong assumption of input homogeneity is made.

The third qualification arises with regard to input and output aggregation. Initially, the corresponding technical efficiency measure (F_k) was developed for physical amounts of inputs and outputs. However, data on physical amounts of all inputs employed and all outputs produced are difficult if not impossible to collect. Rather, what one usually observes is aggregated output (e.g. revenue) and aggregated input (e.g. labor and material cost). The benefit of aggregation does not come for free (Färe, Grosskopf & Zelenyuk, 2002). Even though DEA can be employed using aggregated outputs and inputs, aggregation may result in a downward bias of efficiency scores.

One of the objectives of the paper outlined in the introduction is to compare the performance of enterprises depending on their ownership pattern. To detect the impact of ownership form on efficiency we estimate the frontier under the assumption of common technology (Grand Frontier). The idea of this approach is represented in Graph 1 for the one input-one output case and two kinds of ownership structures.

Graph 1
Grand Frontier



Let EGCFN be a technology boundary (constructed on the basis of the most efficient enterprises) for, say, private enterprises. Efficient observations lie on the boundary and the less efficient the observation is the further it lies below. Points, denoted by stars (*) represent such inefficient observations. A similar technology boundary is constructed for, say, state enterprises. Let this technology set be the set ABD. For each private enterprise and for each state enterprise we can find projected (optimal) values of inputs by simply multiplying each input by it corresponding efficiency score λ^k. When we solve the optimization problem (1) for a pooled data set using the projected values (instead of the actual ones) we get a technology boundary represented by EGBCD, which is the Grand Frontier. Inefficiency within this Grand Frontier is inefficiency attributed to ownership pattern. For example, consider the observation x in Graph 1. The technical efficiency of this observation within a homogeneous environment, which in this case is private ownership, is calculated as the ratio LK/Lx = TE_i (inefficiency is presented by Kx). The inefficiency due to the type of ownership is represented by BK and for further reference will be referred to as "structural" technical inefficiency.

Another important concept of the DEA, which is to be estimated in the study, is *allocative* efficiency. It is calculated as a ratio of the minimum production costs to the cost of the observed input mix at the frontier and measures an enterprise's ability to choose an optimal mix of inputs. Allocatively efficient enterprises choose such a combination of inputs for which the isocost line is tangent to the isoquant represented by SS' (see Graph 2). For example, consider the observation Q, This observation is both technically and allocatively inefficient. The allocative inefficiency of the observation Q is given by the distance RB and is calculated as the ratio A_k

= OR/OB. The observation E in the figure is allocatively efficient. The product of allocative and technical efficiency scores yields the measure of *overall* (or economic) efficiency. Thus, economic efficiency measures the ability of an enterprise both to use resources efficiently and to choose an optimum input mix and is represented by the ratio OR/OQ = E_k in Graph 2. Thus, economic efficiency can be calculated as the ratio of the minimum costs represented by the curve AA' to the observed costs in point Q, that is, $E_k = C(y,w)/c^j$. The minimum costs can be found by solving the following linear optimization problem:

$$C(y, w) = \min wx \tag{1b}$$

subject to constraints

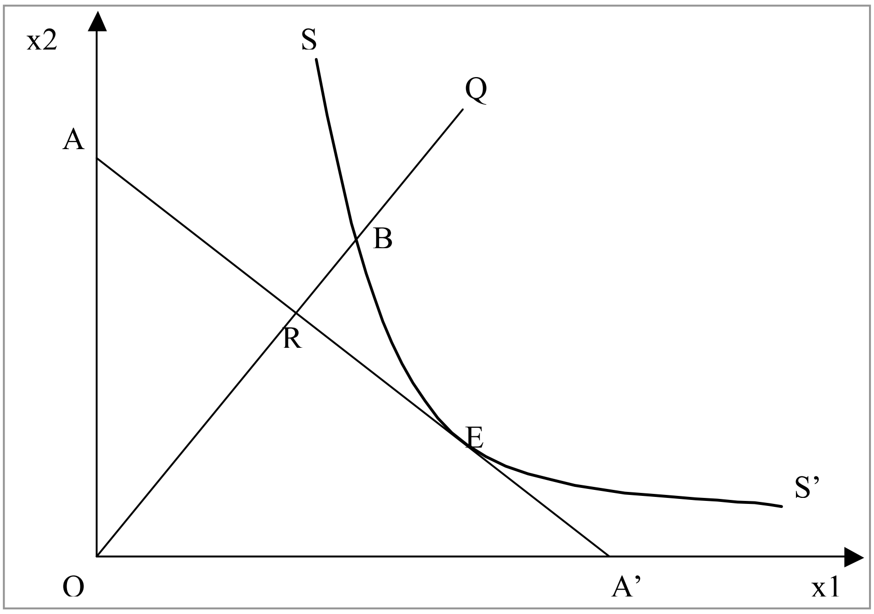
$$y_{k,m}^{t} \leq \sum_{k=1}^{K} z_k^t y_{k,m}^{t}, \quad m=1\ldots M$$

$$x_{k,n}^{t} \geq \sum_{k=1}^{K} z_k^t x_{k,n}^{t}, \quad n=1\ldots N$$

$$z_k^t \geq 0, \quad \sum_{k=1}^{K} z_k^t = 1 \text{ (VRS)},$$

where w – stands for a vector of input prices and all other variables as defined above.

Graph 2
Input requirement set and the best practice isoquant



When calculating efficiency scores, an assumption about returns to scale is important. In our analysis we assume variable returns to scale (VRS) technology (which is reflected by the last constraint in optimization problem (1)), since VRS is less restrictive than the assumption of constant returns to scale (CRS).

The technical efficiency measures discussed above lend themselves readily to productivity measurement. In fact they are the natural building blocks for measuring Total Factor Productivity (TFP) which lies at the heart of our discussion of regional patterns of agricultural development. TFP is the ratio of average products in certain time periods, that is

$$TFP = \frac{y^{t+1}/x^{t+1}}{y^t/x^t} \tag{2}$$

In a multi-input case, distance functions are employed in calculating TFP. Distance functions are reciprocals of the technical efficiency measures. Thus, an input-oriented distance function (D_i) can be found as: $D_i = \frac{1}{F_i}$.

The input-oriented Malmquist Productivity Index (M_i) is calculated as follows:

$$M_i(x^{t+1}, y^{t+1}, x^t, y^t) = \left(\frac{D_i^t(x^{t+1}, y^{t+1})}{D_i^t(x^t, y^t)} \cdot \frac{D_i^{t+1}(x^{t+1}, y^{t+1})}{D_i^{t+1}(x^t, y^t)} \right)^{1/2} \tag{3}$$

or, alternatively,

$$M_i(x^{t+1}, y^{t+1}, x^t, y^t) = E(x^{t+1}, y^{t+1}, x^t, y^t) \cdot T(x^{t+1}, y^{t+1}, x^t, y^t) \tag{4}$$

E(.) is a relative efficiency change index under the constant returns to scale which measures the degree of catching up to the best-practice frontier for each observation between time period t and t+1, while T(.) represents the technological change index which measures the shift in the frontier (or innovation) between two time periods (Mao and Koo, 1996).

3 Definition of variables and data description

3.1 Data resources for measuring TFP

This study uses the data on agricultural inputs and outputs for 25 regions Ukraine-wide over the 1996-2000 period. In total there is a panel of 125 observations. A remark should be added that the data are aggregated across agricultural enterprises only (households and family farms are excluded).

The outputs and inputs used to measure TFP as well as efficiency and technological changes at the aggregate level are:

- *Labor* – the number of workers employed in agricultural enterprises. The data were taken from the Statistical Yearbook of Ukraine in 2001.

- *Land* – area of agricultural land under usage by agricultural enterprises. The data were calculated from the information provided by the Ministry of Agrarian Policy on net profits of agricultural enterprises and profits per 100 hectares of agricultural land.
- *Machinery power* – a proxy for capital input and measured in horse power. The data were taken from the publication by the Ministry of Agrarian Policy. The limitation of using this variable as a capital input is that it does not take into account the age of the capital stock and whether machinery is modern or not. However, no other variables for capital stock are available.
- *Mineral Fertilizers* – the sum of effective weight of fertilizers employed measured in thousands of tons. The data were taken from the publication by the Ministry of Agrarian Policy.
- *Gross value of production by agricultural enterprises* – output measured in mln. UAH (in constant 1996 prices).

3.2 Data resources for estimating technical, allocative and economic efficiencies

This part of the analysis employs data at the enterprise level for agricultural enterprises in 5 central regions in Ukraine: Vinnytsa, Kirovograd, Cherkasy, Kyiv and Poltava regions. The main reason we concentrate only on central regions is that here climatic and soil conditions are very similar, and this enables us to assume that land input is homogeneous among these regions.

The analysis of technical, allocative and economic efficiencies covers four types of agricultural enterprises discriminated on the basis of ownership structure. The data at the enterprise level were provided by Derzhkomstat and were contained in form #50 for agriculture. The research covers 84% of all agricultural enterprises that functioned in 2001 in the named 5 regions. The data were "cleaned" for missing data, outliers and nonsensical data. The sample produced a *cross-section* of 2482 agricultural enterprises: agricultural companies (or, alternatively, economic partnerships, 1480 enterprises), cooperatives (386), state enterprises (67) and private enterprises (549). In calculating allocative efficiency and overall (economic) efficiencies the state enterprises were excluded from the analysis and the overall sample was reduced to 2415 enterprises.

We followed a conventional capital/land and labor division of inputs. As an output sales revenue (thd. UAH) was taken. One might argue that sales revenue is not an appropriate measure of output, and gross value of output might serve much better as an output variable. However, the choice of outputs was stipulated by the availability of information and no other data that might serve as an output was available we had no other choice. The potential problem with using sales revenue as an output variable is that agricultural enterprises of different forms of ownership are likely to face different prices for their outputs. It might be the case, for example, that state enterprises get deliveries of inputs from the state but at the same time they are forced to sell their produce to procurement organizations at lower prices than, say, private enterprises do. Thus, given the same production of output in physical units state enterprises may be less efficient because they face lower price for output. For the sake of simplicity, we assume that output prices are equal for enterprises of all forms of ownership.

The inputs used are the following:

- *Energy* – the cost of electrical energy used in production (thd. UAH). Even though this input is given in monetary units it is perfectly comparable among enterprises, for all enterprises face the same price for energy and, thus, we can easily transform monetary units into physical ones.
- *Land* – the total area of agricultural land (owned or leased) in hectares. In the analysis we calculate technical efficiency scores for two cases. In the first case, we include land as a non-discretionary factor. The fact that land can be viewed as a fixed input is supported by the peculiarities of land market in Ukraine. Since most of the enterprises rent their land plots and rent contracts are usually drawn up for 3-5 years, agricultural enterprises cannot immediately dispose of (reduce) land plots. On the other hand, however, when enterprises make their decisions on how much land to rent they do take into consideration the availability of other inputs (e.g, workers) as well as the rent payments to be made in the future (i.e. land price). Thus, one might also argue that enterprises do not take land as given but rather can choose how much of it to rent or lease out and in this case land can be considered as a discretionary input. As will be shown later in the paper, technical efficiency scores remain almost unaffected by this assumption, and efficiency scores obtained treating land as a fixed (or discretionary) input can be considered as short-run (or long run) technical efficiency.
- *Labor* – the average annual number of workers employed in the production process over the year.
- *Value of fixed and floating capital.* We assume proportionality between the service flows from the capital stock and its stock. Accordingly, the value of total assets refers to capital input and is measured in thd. UAH.

The calculation of allocative and economic efficiency requires knowledge of input prices, which were calculated as follows:

- *price of land*. The price of land was found by dividing rent payments by the area of rented land. For most of the enterprises, data on land rented and rent payments were available. State enterprises were removed from the analysis, since only few of them rented some land plots and it does not appear reasonable to substitute the missing prices by regional averages.
- *price of labor* was calculated by dividing the wage bill by the average annual number of workers.
- *Price of energy* was the same for all enterprises – 0.188 UAH per kW-hour.
- *Price of capital.* We made a strong assumption about the price of capital. Based on economic theory we assumed that the price of a unit of capital (1000 UAH) was equal to the real interest rate, which

was 24.9% in 2001. This price can be interpreted as an opportunity cost – what enterprises might have earned by putting assets to the bank rather than using them in production.

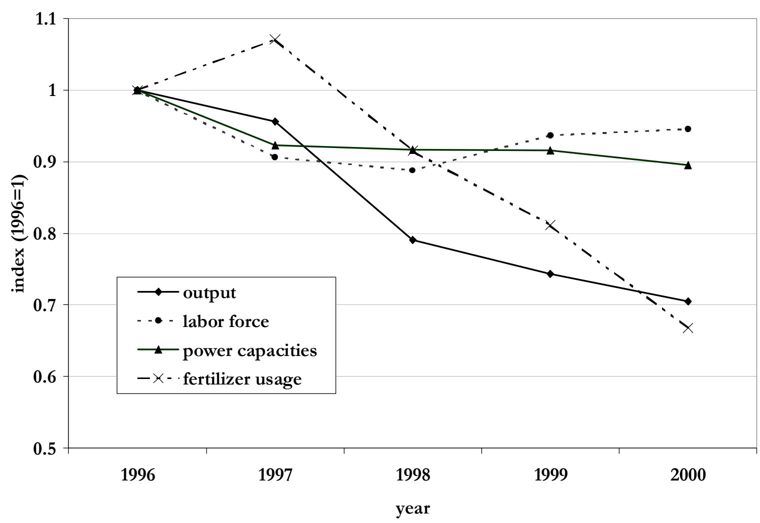
Clearly, based on these data and assumptions analysis will provide only rough estimates of allocative and economic efficiencies, since input markets are not well developed and input prices are probably somewhat distorted in Ukraine.

4 Total factor productivity change in Ukrainian agriculture: *empirical results*

We first present the results of the aggregated analysis using data on agricultural inputs and outputs for all of the 25 regions in Ukraine between 1996 and 2000.

Over 1996-2000 Ukrainian agriculture experienced a decline in output of about 30%. This decline might have been attributed to a reduction in inputs use as the enterprises adjusted input requirements to ever-increasing input prices. As can be seen from Graph 3 labor employed by agricultural enterprises declined in the course of the first two years but then it increased; capital input decreased only in the first year and remained roughly constant afterwards. At the same time fertilizer use plummeted, which may have negatively effect land productivity and, as a result, lead to reduced output. Agricultural production changes cannot, however, be explained without also considering efficiency and technological changes over the period.

Graph 3
Output and input trends (agricultural enterprises all of Ukraine)



Source: Derzhkomstat; the Ministry of Agricultural Policy of Ukraine

A priori we formulate the following hypotheses: (i) as the number of private enterprises increased each year technical efficiency is expected to have increased, since private ownership creates incentives for the efficient use of resources; (ii) technological changes were only of minor importance, for no major innovations occurred over this period. Testing whether this is true is left for empirical analysis.

Malmquist indices (TFP indexes) were calculated for each period. Average annual changes in TFP are reported in Table 1. The results reveal that productivity grew by only 0.7% per year on averagewith technological change contributing 2.1% to this growth and efficiency change contributing -1.3%. The decomposition of technical efficiency change shows that no improvements occurred in both pure technical efficiency and scale efficiency. Hence, the modest annual increase in TFP in Ukrainian agriculture arose from the technological innovations rather than improvements in technical efficiency.

Of 25 regions studied the performance of Lviv, Rivne and Ternopil regions was the poorest with TFP declining annually on average by 8.6%. The decomposition of TFP into technological change and technical efficiency reveals the sources of decline in productivity. As the results show, in total, thirteen regions experienced a fall in technical efficiency. The highest increase in technical efficiency occurred in Zaporizzya region, meanwhile Kirovograd enjoyed the highest growth in technology.

Table 2 reports mean annual changes in TFP and its components. In 1997 growth in TFP was composed of efficiency change of 7.7% combined with the deterioration in technology of (-7.4%). Looking at Graph 3, one can see that the decline in output was the greatest in 1998 over the five-year period. From Table 2 we see that in this year efficiency decreased dramatically by about 20% and technological improvement of 2% only partially offset this decrease. Graph 3 shows that in this year fertilizer use fell dramatically. Thus, the fall in efficiency is likely to have occurred due to decreased productivity. The year 2000 is characterized by high technological progress (20.5%); technical efficiency, however, declined by about 2%. One explanation for high technological progress in 2000 might be the increase in output prices at the beginning of 2000, which enabled enterprises to earn more profits and invest in new technology.

Since the Malmquist index and its components are multiplicative we can calculate cumulated effects over the entire period (Table 3). The results are presented in Table 3. Over the whole period TFP increased by 6%. This increase was due to technological progress (9.2%) moderated by a reduction in technical efficiency due to a fall in both pure technical efficiency (-2.8%) and scale efficiency (-0.9%). Lviv region experienced the largest decline in productivity (-30.5%) and technology (-6.6%), while Kirovograd region showed the highest growth in productivity (61.6%) and technology (39.7%). To provide a plausible explanation of the observed pattern in Ukrainian agriculture the last column of Table 3 contains data on average farm size in each of the 25 regions. The distinctive feature is that the regions where agricultural enterprises are relatively small in size show the poorest performance. For example, the average size of an agricultural enterprise in the Western regions that rank the last with respect to TFP growth is about 565 hectares, while that of an enterprise in South-Eastern regions (Kirovograd, Kherson, Mykolaiv, Zaporizzya) that experienced the highest growth in TFP over the entire period is about four times as large (about 2000 hectares). This finding supports large-scale production and it appears that the benefits from large farm size such as easier access to credits and modern technologies, more efficient utilization of resources due to economies of scale outweigh the costs of monitoring that usually increase with farm size. This contradicts the claim made by many researchers that in developing countries small farms are more technically efficient and experience higher productivity growth than large farms and has important policy implications.

Summarizing, in general average annual growth in agricultural productivity was only modest and was primarily attributed to technological improvements. Technical efficiency as well as its components declined from year to year. These findings somewhat contradict our a priori expectations, but they are consistent with other studies (see Mao and Koo, 1996).

5 Farm efficiency: empirical considerations

This section of the paper is devoted to measuring technical, allocative and economic efficiencies at the farm level in 2001 using a cross-section of 2482 agricultural enterprises in 5 central regions of Ukraine. The main objectives are to detect the effect of ownership structure on the performance of the enterprise and on the basis of technical and allocative efficiency scores to determine an optimum amount of inputs used to produce one unit of output and optimal combination of resources.

The impact of firm ownership has long interested agricultural economists. In sectors such as agriculture where economies of scale are weak and technology is not overly complicated firms controlled by families may have an advantage over those where a clear separation between ownership and control exists (Gallacher M., 1999). It is well known that owner-managed firms, private firms, state firms and cooperatives are each associated with distinctive sets of incentives for efficiency. In private enterprises in most cases the manager is the owner and he has a strong incentive to keep a close eye on things. In enterprises where there are a few owners and management is separated from ownership managers may have an incentive to satisfy their own objectives rather than use resources in the most efficient way. Thus, a priori concerning the effect of ownership pattern on efficiency the following hypothesis could be formulated: *private enterprises are the most efficient form, followed by agricultural companies (economic partnerships) and cooperatives; and state enterprises are likely to be the most inefficient.*

For each form of ownership individually we calculated input-oriented efficiency scores under the assumption of variable returns to scale using the methodology outlined in Section 2. On the basis of efficiency estimates all enterprises were divided into 5 categories: enterprises with efficiency scores of 1.00, 0.75-0.99, 0.5-0.74, 0.25-0.49 and less than 0.25. The distribution of the enterprises is depicted in Graph 1 in the Appendix. For 85.7% of the private enterprises technical efficiency is less than 0.5, which means that these enterprises could reduce inputs by more than half and still maintain output. The share of private agricultural enterprises falling into the most efficient category (efficiency of 1.00) is very small and accounts for 4.6% or 26 out of 566 enterprises. With respect to the state enterprises, 50.7% have efficiency scores less than 0.5 and 22.4% find themselves on the isoquant (efficiency of 1.00). For cooperatives and agricultural companies the share of enterprises with efficiency below 0.5 is 61.6% and 90.5% respectively, while the shares with efficiency score of 1.00 is 8 and 2.6%, respectively. Average efficiency scores are pulled down considerably by the fairly large number of farms in Ukraine that are highly inefficient. The mean value of efficiency scores is the lowest for agricultural companies (0.29) and is closely followed by the mean value of efficiency scores for private enterprises of 0.33. Those of cooperatives and state enterprises are twice as large and equal to 0.51 and 0.56 respectively.

As can be seen from Graphs 2 and 3 the most efficient enterprises tend to use less land and labor to produce one unit of output. Furthermore, cooperatives tend to use more of each of these inputs per unit of output compared to all other forms of ownership. For energy resource the picture is somewhat vague. If one looks at the enterprises in the first four categories a clear decline in utilization of energy per unit of output is observed as we move from the least efficient to more efficient enterprises. However, the most efficient enterprises use as much energy as enterprises falling into the 0.5-0.74 efficiency category. This may indicate that in the most efficient enterprises labor is more productive due to more intensive use of machinery, and, consequently, use of more energy resources. All these findings suggest that inefficiency arises from over-utilization of resources rather than from enterprises being resource constrained. Another source of inefficiency is that most of the enterprises operate in the region of decreasing returns to scale and thus produce scale inefficient output. This is relevant for private, state enterprises and agricultural companies, while for cooperatives the opposite pattern is observed: the majority of the cooperatives operate in the region of increasing returns to scale, which implies that cooperatives could gain efficiency by expanding their operations and thus, exploiting economies of scale.

Table 4 contains the results obtained from the estimation of the Grand Frontier. Inefficiency in this case arises only due to ownership structure, which to a great extent captures the effect of management on enterprise performance. Private enterprises are seen to be the most efficient as was expected. Agricultural companies, however, do not lag far behind private enterprises in terms of technical efficiency. There is a noticeable gap between the performance (efficiency) of private and state enterprises. The cooperative form has proven to be the least efficient form of ownership with mean efficiency equaling 0.36 compared to that of private enterprises with 0.82. To avoid confusion with the previously obtained estimates of technical efficiency the following should be warranted. The estimate of mean technical efficiency, for example, for state enterprises is the highest (0.56), while under the assumption of common technology they the least efficient after cooperatives. This means that state enterprises are the most technically efficient within their own environment bur the state enterprise frontier is well below the Grand Frontier, while the private enterprise frontier is below the Grand Frontier but is above the frontier of each ownership form. One possible explanation for our finding might be that there is little real difference between cooperatives and state farms as cooperatives are largely farms that took the easiest possible path when forced to restructure by a Presidential decree at the end of 1999, changing as little as possible except for the formal name and structure of the enterprises. But even though state enterprises and cooperatives are less efficient on average, the best cooperatives are just as good as the best private enterprises because some will have very authoritarian leaders who are able to get a deal out of their farms despite the structural disadvantages.

Estimated allocative and economic efficiencies are reported in Table 5. As can be seen the number of enterprises with allocative efficiency of 1.00 is rather limited for each form of ownership pattern with allocative efficiency below 0.5 for the majority of the enterprises. However, one might be interested in estimating allocative efficiency for all enterprises without discriminating between ownership structures. For this purpose we estimated allocative and economic efficiencies under the assumption of variable returns to scale for the pooled sample of 2482 enterprises. The results are presented in column 4, Table 5. The findings are not impressive: mean allocative efficiency is only 0.36, meanwhile mean economic efficiency is 0.08. Such a low value of economic efficiency tells that enterprises are highly technically and allocatively inefficient. Further, a remark about the efficiency being a relative measure is in place: agricultural enterprises appear to be very heterogeneous and while there are a few allocatively and technically efficient enterprises a huge number of enterprises lie well below the frontier. Removing 1% of the top-ranking observations (considering them as outliers) from the sample we re-estimated the allocative, technical and economic efficiencies. The point estimates, however, increased only slightly: allocative efficiency increased to 0.4, technical efficiency to 0.25 and economic efficiency to 0.11. This finding is of a special value to policy makers and indicates that if policy-makers are interested in increasing average efficiency of agricultural enterprises they should force those highly inefficient enterprises out of business. These are, however, only rough estimates. Recall that in calculating allocative efficiency we made the strong assumption that the price of capital (assets) equals opportunity cost. In reality, while other input prices are paid directly by agricultural enterprises, the capital price is not. Thus, the very low allocative efficiency measured here might be explained by the fact that we made an assumption that is actually inappropriate. Hence, we re-estimate allocative efficiency for the pooled sample but this time with the capital input excluded from the analysis. The results are contained in column 5 of Table 5. As one can see the estimate of technical efficiency does not change significantly (0.21 as compared to the previously estimated 0.23), but average allocative efficiency increased from 0.36 to 0.61 and economic efficiency from 0.08 to 0.12. These estimates are more plausible, and the fact that the omission of capital input does not effect technical efficiency but has a significant effect on the value of allocative efficiency suggests that enterprises primarily emphasize the allocation of non-capital inputs. Nevertheless, to get the best possible estimates of allocative and economic efficiency an inclusion of capital input should be included and a precise measurement of its price is required.

Graphs 7 through 9 present the ratios of inputs. An interesting finding is revealed for agricultural companies. Allocatively efficient agricultural companies use half as many workers per 100 hectares as other ownership forms. At the same time workers seem to be much better equipped with capital, which is supported by capital/labor and energy/labor ratios. Since there are at most 6 enterprises with efficiency scores of 1.00, inferences about the optimal resource mix are made on the basis of enterprises falling into the 0.75-0.99 category. Results for the pooled sample without the capital input variable reveal an optimal number of workers of 9 per 100 ha of land and an optimal energy use of about 2000 kW-hours per worker. For the least allocatively efficient enterprises (excluding fully efficient from consideration) capital/labor and capital/land ratios are much higher than those for the most efficient, which suggests that firms that are more allocatively efficient tend to replace costly capital with cheap labor.

6 Conclusions

In this paper we measure productivity changes and provide a comprehensive analysis of the factors determining the observed development paths in Ukrainian agriculture. The Malmquist index,measure of TFP based on DEA analysis was used for this purpose. The results obtained from this study have important implications for Ukrainian agriculture. First, half of the regions experienced a decline in TFP, which was primarily due to a decline in technical efficiency over 1996-2000 period. This finding indicates that Ukraine has a great potential to increase its agricultural output through improving technical efficiency. 6 regions, all of which are Western regions, (Lviv, Ternopil, Rivne, Ivano-Frankivsk, Chernivtsi and Transkarpathian) experiences technological regress over the entire period. This implies that these are low-technology regions and for agricultural production to be fostered they require technological progress that can be achieved by increasing investments. Generally, if technological change is largely a question of catching up then one would expect that improving technology is closely related to foreign direct investment as a means of transferring innovations and know-how from the West to Ukraine. However, foreign technologies cannot be adopted one to one, but rather must be adapted to Ukrainian conditions. So, the government could contribute by increasing investment into research and education. Investments especially in education could help to ensure that managers are making the best possible use of the available technology and capital stock.

Second, TFP growth is positively related to farm size. Large agricultural enterprises appear to experience greater improvements in technical efficiency and technological progress. This finding is valuable for policy-makers and calls for priorities to large-scale production.

Third, of the four types of farm ownership, collective agricultural enterprises are the least efficient, while private enterprises show the best performance. This suggests that in Ukrainian agriculture structural changes are required to improve efficiency: collective enterprises should be substituted by more efficient forms such as economic partnerships or private enterprises. Mean technical efficiency scores are rather low and inefficiency arises from over-utilization of resources rather than from resource constraints. Hence, even though agricultural enterprises are learning to economize on inputs much remains to be learned. Furthermore, average efficiency scores are being pulled down considerably by the fairly large number of farms that are highly inefficient. Under normal market conditions, bankruptcy and a functioning land market would force such farms to exit, which would increase the average scores considerably.

In this paper we also analyzed allocative and economic efficiency and found that enterprises combine resources in an inefficient way. However, some limitations concerning the estimation of allocative and economic efficiencies must be mentioned. First, the absence of price data on capital input prevented us from estimating allocative efficiency consistently. Omitting this variable from the analysis is not an ideal remedy to get accurate scores of allocative efficiency, since even though agricultural enterprises do not face capital price directly they must somehow take its value into consideration when determining the best resource mix. Therefore, our findings on allocative and economic efficiencies preliminary, nevertheless, they can be used to present a general picture of Ukrainian agricultural enterprises. Based on the results a few policy recommendations may be warranted. First, to increase average allocative efficiency policy-makers should undertake certain steps to eliminate input market imperfections, because competitive markets are more flexible and efficient instruments of resource allocation. For example, the existence of a land market would enable farmers to allocate land to more efficient uses. Second, supporting farmers by, for example, providing subsidized credits would probably result in increased investments in capital and, consequently, technological progress but it would not necessarily increase efficiency in an economic sense, partly because farmers will allocate their efforts to get support from the government and will not concentrate on improving production efficiency.

Another very important point is that in our analysis at the farm level we considered agricultural enterprises in 5 central regions of Ukraine. In Western and Eastern regions climatic and soil conditions are different and land input heterogeneity would have to be modeled somehow. Thus, while our inferences about the efficiency of enterprises in the central part of Ukraine are valid, they cannot necessarily be extended to Ukraine as a whole.

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Appendix

Table 1
Average annual change in TFP and its components

Region	Malmquist index	Efficiency change	Technical change	Pure efficiency change	Scale change
L'viv	0.914	0.930	0.983	0.933	0.996
Rivne	0.914	0.927	0.987	0.932	0.995
Ternopil	0.914	0.920	0.993	0.921	0.999
Khmelnytskiy	0.925	0.925	1.000	0.931	0.994
Ivano-Frankivsk	0.938	0.951	0.986	0.984	0.966
Chernivtsi	0.961	0.965	0.996	0.988	0.977
Vinnytsa	0.977	0.947	1.032	0.990	0.956
Sumy	0.983	0.965	1.019	0.955	1.011
Volyn	0.986	0.948	1.040	0.924	1.026
Transkarpathian	0.988	1.008	0.981	1.000	1.008
Zhytomyr	0.990	0.972	1.019	0.973	0.999
Kyiv	0.999	1.000	0.999	1.000	1.000
Cherkasy	1.001	0.981	1.021	0.983	0.998
Poltava	1.002	1.000	1.002	1.000	1.000
Chernihiv	1.010	0.972	1.040	0.974	0.998
Donetsk	1.032	1.020	1.013	1.018	1.001
Crimea Autonomy*	1.050	1.044	1.006	1.037	1.007
Mykolaiv	1.058	0.994	1.064	1.000	0.994
Kharkiv	1.063	1.000	1.063	1.000	1.000
Luhansk	1.064	1.005	1.059	1.004	1.001
Dnipropetrovsk	1.069	1.020	1.047	1.021	0.999
Odesa	1.070	1.053	1.016	1.068	0.986
Zaporizzya	1.084	1.064	1.018	1.048	1.016
Kherson	1.114	1.055	1.055	1.051	1.004
Kirovograd	1.128	1.037	1.087	1.029	1.007
Average	***1.007***	***0.987***	***1.021***	***0.990***	***0.997***

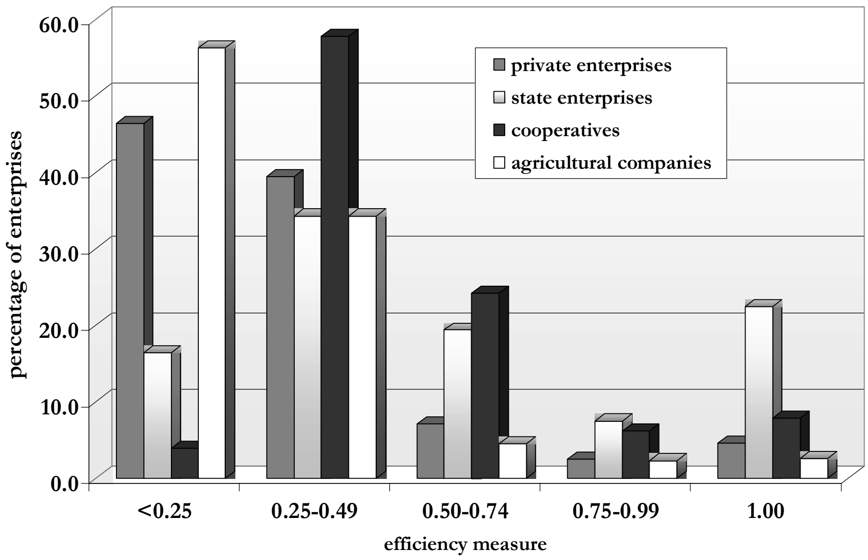
Table 2
Malmquist index summary for annual means

From year t to year t+1	Malmquist index	Efficiency change	Technological change	Pure efficiency change	Scale efficiency
1996-1997	0.998	1.077	0.926	1.038	1.037
1997-1998	0.821	0.805	1.020	0.872	0.923
1998-1999	1.062	1.115	0.952	1.074	1.039
1999-2000	1.184	0.982	1.205	0.987	0.995

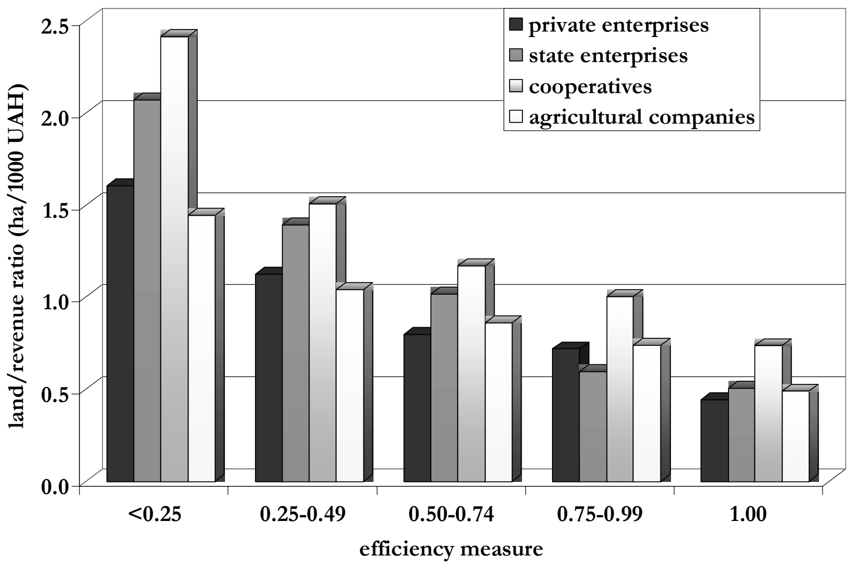
Table 3
Cumulative change in TFP and its components over 1996-2000

Region	Malmquist index	Efficiency change	Technical change	Average farm size, ha
L'viv	0.695	0.746	0.934	414.0
Ternopil	0.697	0.716	0.975	647.7
Rivne	0.700	0.738	0.946	767.9
Khmelnytskiy	0.733	0.733	1.001	983.1
Ivano-Frankivsk	0.773	0.817	0.947	458.0
Chernivtsi	0.854	0.868	0.982	668.1
Vinnytsya	0.912	0.803	1.134	1669.7
Sumy	0.933	0.869	1.076	1442.1
Volyn	0.945	0.808	1.170	572.2
Transkarpathian	0.952	1.031	0.924	425.8
Zhytomyr	0.959	0.891	1.078	756.9
Kyiv	0.994	1.000	0.994	2639.8
Chercasy	1.006	0.927	1.086	1564.0
Poltava	1.008	1.000	1.008	1597.5
Chernihiv	1.040	0.891	1.168	955.8
Donetzk	1.137	1.079	1.051	1620.8
Crimea autonomy*	1.216	1.188	1.022	1903.0
Mykolaiv	1.250	0.975	1.282	1932.7
Kharkiv	1.275	1.000	1.276	1932.8
Luhansk	1.283	1.021	1.255	1157.5
Dnipropetrovsk	1.303	1.084	1.203	2891.4
Odesa	1.310	1.229	1.065	1645.1
Zaporizzya	1.379	1.282	1.076	2504.1
Cherson	1.538	1.241	1.240	1834.6
Kirovograd	1.616	1.157	1.397	1686.5
Average	***1.060***	***0.964***	***1.092***	**-**

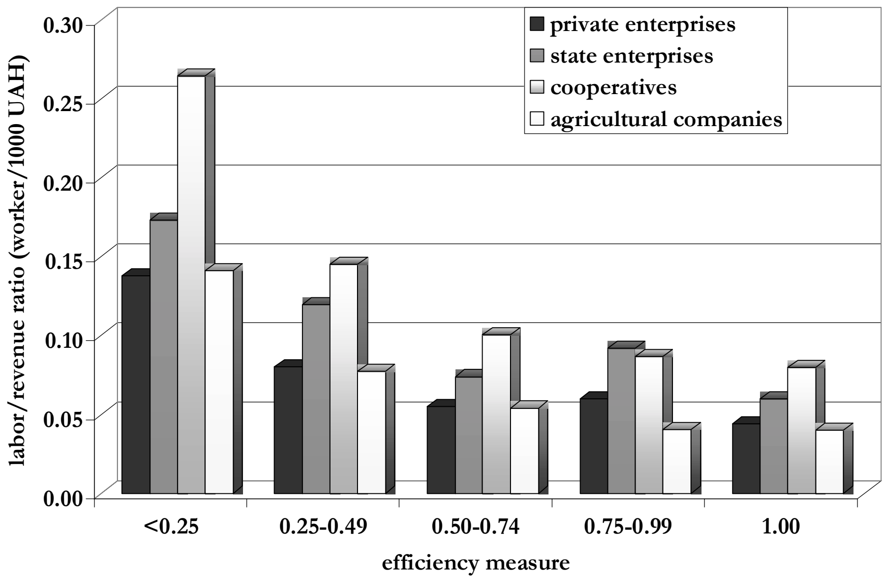
Graph 1
The distribution of the enterprises according to efficiency categories



Graph 2
Land-revenue ratio for different efficiency groups



Graph 3
Labor-revenue ratio for different efficiency groups



Graph4
Energy-revenue ratio for different efficiency groups

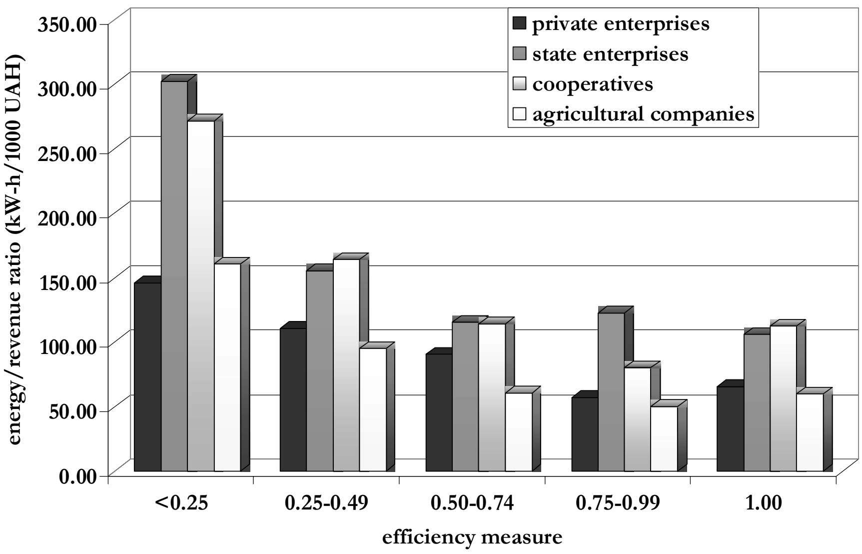


Table 4
Distribution of enterprises according to the Grand Frontier Analysis

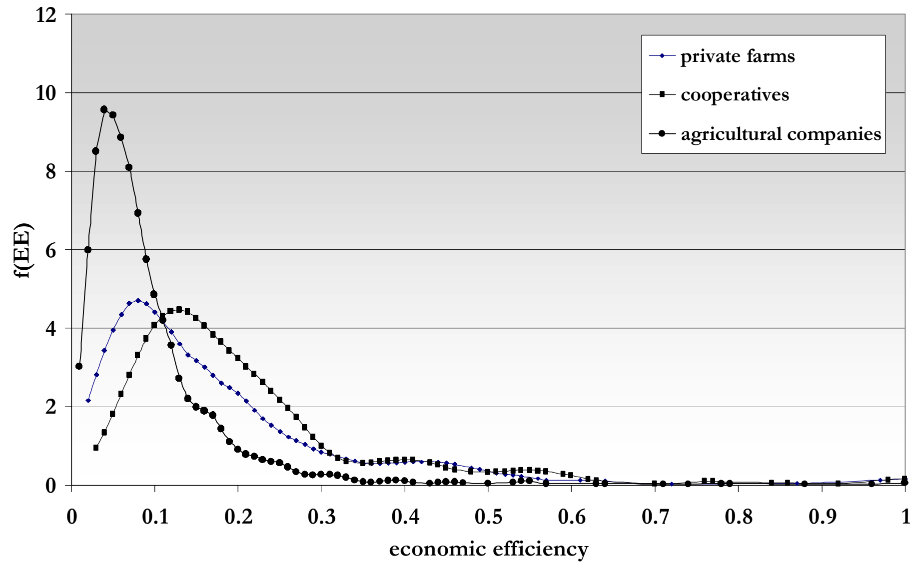
Efficiency measure	Percent of private enterprises	Percent of agricultural companies	Percent of state enterprises	Percent of cooperatives
1.00	7.6	4.9	3.0	0.5
0.75-0.99	66.8	70.9	3.0	0.0
0.50-0.74	21.2	21.6	43.3	1.3
0.25-0.49	3.9	2.0	44.8	94.3
<0.25	0.5	0.5	6.0	3.9
mean efficiency	***0.82***	***0.81***	***0.50***	***0.36***

Table 5
The distribution of agricultural enterprises according to the magnitudes of allocative and economic efficiencies

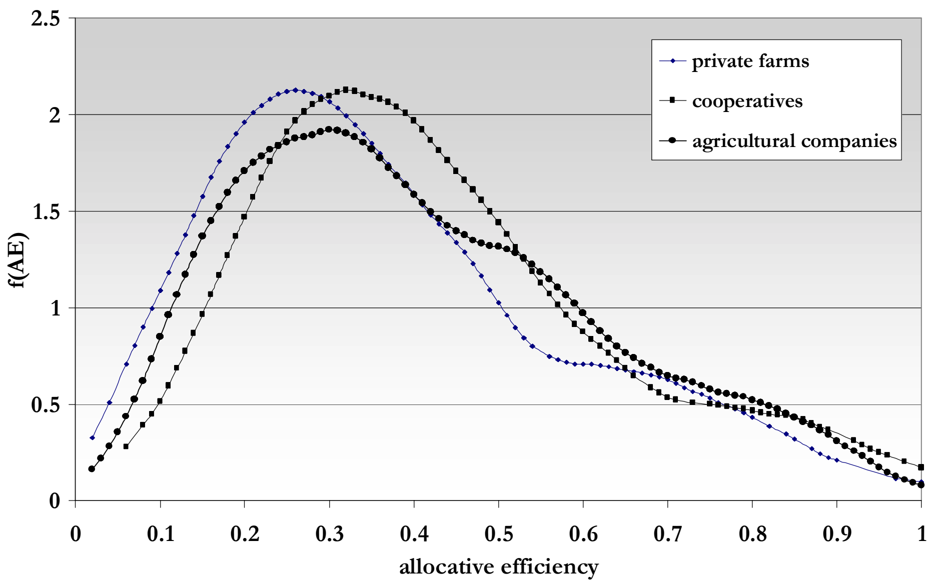
Efficiency measure	The number of private enterprises			The number of cooperatives			The number of agricultural companies			Pooled sample			Pooled sample 1*		
	TE_i	AE_i	EE_i	TE_i	AE_i	EE_i	TE_i	AE_i	EE_i	TE_i	AE_i	EE_i	TE_i	AE_i	EE_i
1.00	31	6	6	23	4	4	37	3	3	44	4	4	24	4	4
0.75-0.99	32	37	3	18	38	7	27	136	4	33	135	3	23	639	2
0.50-0.74	108	94	16	104	72	18	56	344	13	76	404	9	62	1098	14
0.25-0.49	324	245	93	233	199	72	306	619	61	478	1052	81	437	628	89
<0.25	54	167	431	8	73	285	1054	378	1399	1784	820	2318	1869	46	2306
Total number	549	549	549	386	386	386	1480	1480	1480	2415	2415	2415	2415	2415	2415
mean efficiency	0.45	0.38	0.18	0.50	0.43	0.22	0.24	0.41	0.10	0.23	0.36	0.08	0.21	0.61	0.12

* - assets variable has been excluded from the analysis

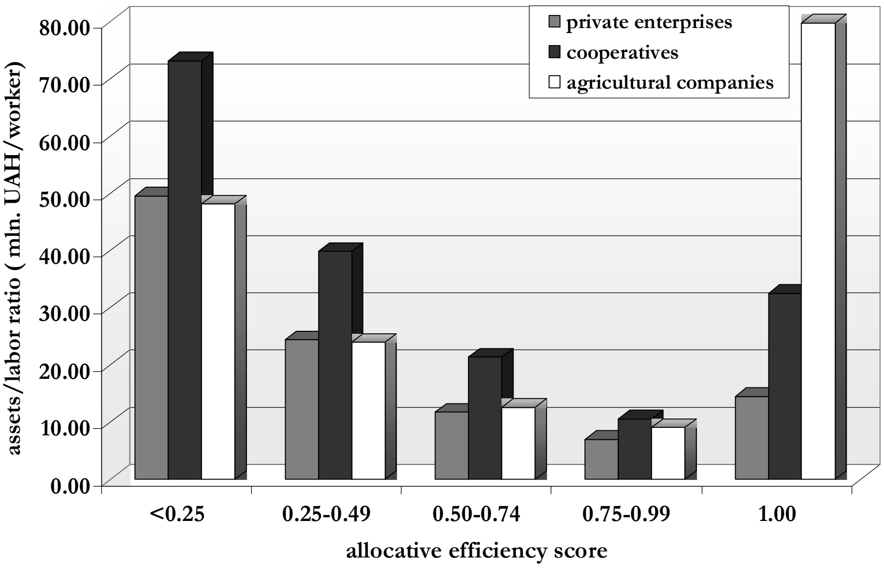
Graph 5
Distribution of economic efficiency scores



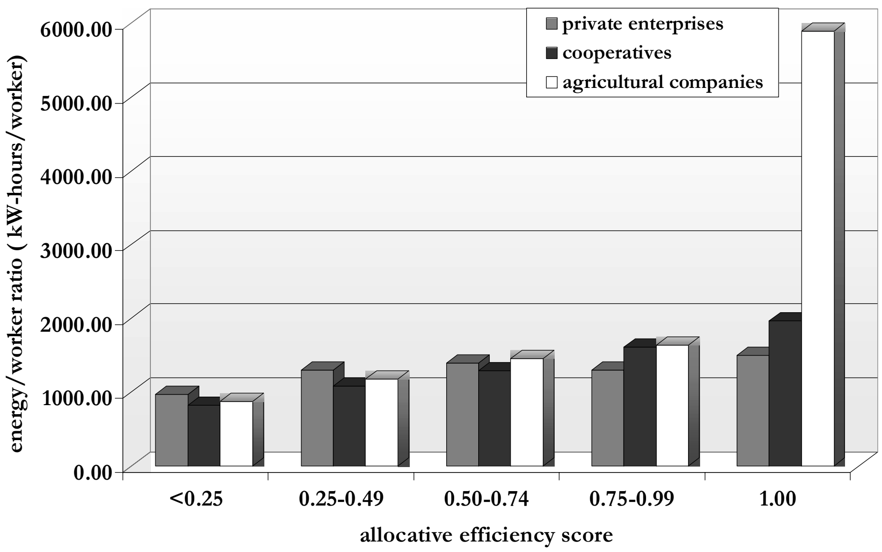
Graph 6
Distribution of allocative efficiency scores



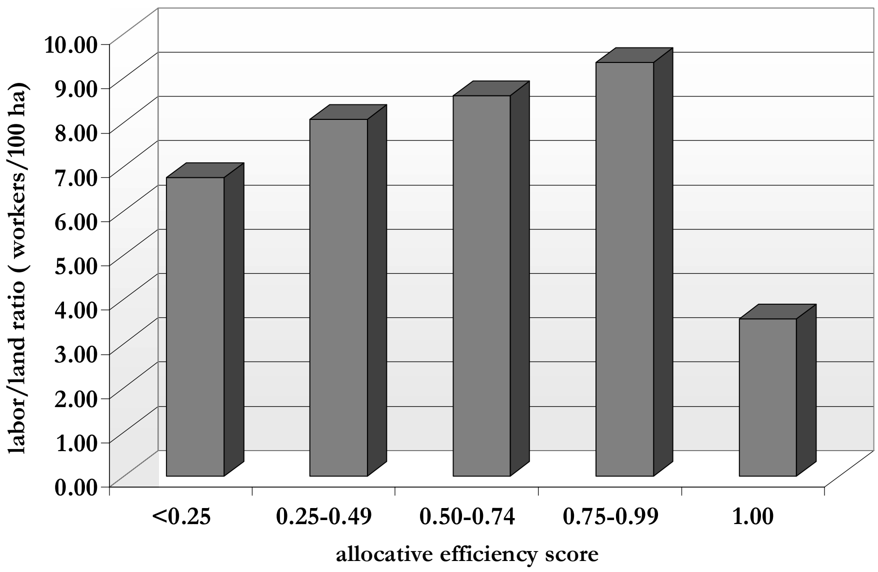
Graph 7
Capital-labor ratio



Graph 8
Energy use per worker



Graph 9
Labor-land ratio*



* - the ratios were obtained from the analysis using the whole sample (without discriminating between ownership forms) with capital (assets) variable dropped