Journal of Agricultural and Applied Economics, 36,1(April 2004):185–198

Measurement and Explanation of Technical Efficiency Performance in Ukrainian Agriculture, 1991–1996

Olga I. Murova, Michael A. Trueblood, and Keith H. Coble

The present study examines technical efficiency patterns in Ukraine's crop sector for 1991–1996. The economic and policy environment in Ukraine has changed since reform began in 1991. Many policy changes have exerted offsetting economic pressures on efficiency. Enterprise privatization and the liberalization of prices and trade put upward pressure on technical efficiency, whereas start-stop land privatization efforts, unpredictable government intervention, and slow developments in the credit and labor markets put downward pressure on efficiency. We found that technical efficiency appears to have improved slightly over the 1991–1996 period, suggesting that the positive forces had more impact.

Key Words: Data envelopment analysis, enterprise privatization, inefficiency, price liberalization, productivity, stochastic frontier analysis, technical efficiency

JEL Classifications: D29, E23, E66, O38, P32

There is significant interest in Ukraine's agricultural sector, which is often referred to as the "breadbasket of Europe" for its role as a food exporter during the early 20th century. Ukraine, the largest country in Europe in geographical area and the fifth most populous country, is home to one-third of the world's rich black soil and is considered to have great agricultural potential. Agriculture is very important to the Ukrainian economy, accounting for 40% of Ukraine's gross domestic product and employing 20% of its total population.

Among the republics of the former Soviet Union, Ukraine was a major producer of many agricultural commodities. For example, Ukraine's total grain production averaged 46 million tons during the period 1988–1990, nearly half the level produced in Russia and approximately one-quarter of total production in the former Soviet Union (Figure 1). However, by 1998–2000, total grain production had declined to an average of 24 million tons. Similar contractions were observed for sugar beets, fluid milk, beef and veal, pork, and poultry; only the production of sunflower seeds has stayed relatively constant.

There are many questions about whether Ukraine can harness its agricultural potential

---

Olga I. Murova is research specialist, Department of Agricultural Economics and Agribusiness, University of Arkansas, Fayetteville, AR. Michael A. Trueblood is economist, Economic Research Service, U.S. Department of Agriculture, Washington, D.C. Keith H. Coble is associate professor, Department of Agricultural Economics, Mississippi State University, Mississippi State, MS.

This study was conducted under cooperative agreement with the Economic Research Service, U.S. Department of Agriculture. The opinions expressed in the present study are those of the authors and do not represent official views of the Economic Research Service, U.S. Department of Agriculture. We thank William Liefert, Stefan Osborne, Arie Oskam, Lyubov Kurkalova, and Anatoliy Skripnichenko, as well as participants at the North American Productivity Workshop, for their helpful comments. We also thank David Sedik for assisting us in our data collection efforts.

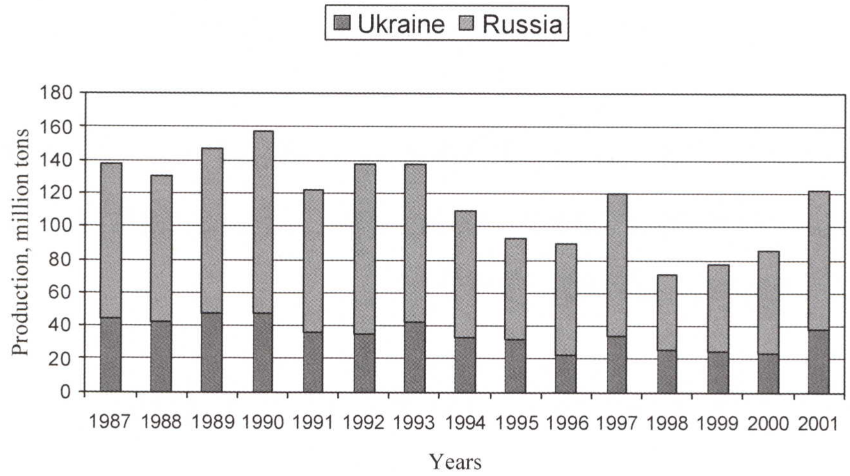

Figure 1. Russian and Ukrainian Grain Production, 1987–2001

and recapture its important role in world markets. At the beginning of reform, it was expected that output would contract initially as the reforms were implemented and real prices fell, but, eventually, the sector was expected to recover as productivity and efficiency improved. Although output has fallen, it is unclear whether efficiency in Ukraine's agricultural sector has improved or whether the sector has shown any clear signs of a rebound.

The objectives of the present study were twofold. The first objective was to highlight some of the economic policies in Ukrainian agriculture, which have an unclear net effect *a priori,* and then to relate these policies quantitatively by measuring technical efficiency performance on corporate and private farms over the 1991–1996 period. We measured technical efficiency as the degree to which producers are able to maximize physical output from given input levels. The second objective was to quantitatively test a particular set of farm level and institutional variables that were found to be important in explaining technical efficiency performance in Ukraine's neighbor, Russia, given that both countries inherited a similar set of policies and circumstances from the Soviet period.

Ukraine's economic environment during the reform period can be characterized as one of drastic price change, as will be highlighted below. This would seem to indicate that it might be more important to measure allocative efficiency (cost minimization, which is a behavioral phenomenon) rather than technical efficiency (a physical phenomenon of producing on the frontier). Although an allocative efficiency study would be welcome in the future (assuming prices are available), there are still good reasons to examine technical efficiency. In Ukraine's case (along with Russia and several other countries in transition), the price liberalization shock was quite severe. For example, fertilizer prices rose dramatically between 1991 and 1996, which is reflected in its quantity of use—a decline of approximately 80% (Table 2 below). Such a sharp change in input markets is bound to lead to a rough transition as producers try to adapt technology to the new price environment. This phenomenon is schematically pictured in Figure 2. Rather than a smooth transition along an isoquant with different input price ratios between points A and B, it is more likely that producers adapted to the new environment in a haphazard path (dashed curved line) away from the production frontier.

There have been relatively few studies on the efficiency and productivity of Ukrainian agriculture during the reform period. Our study is different in several ways from an earlier study by Jensen et al. that measured the technical efficiency of Ukrainian agriculture by (earlier versions of that study can be found

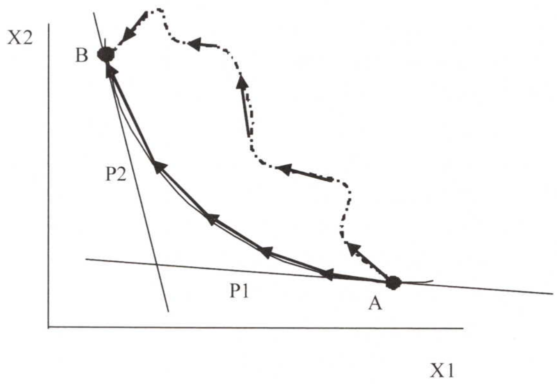

Figure 2. Schematic Transition from One Technology to Another with Extreme Price Change

in Bouzaher, Carriquiry, and Jensen; Johnson et al). The Jensen et al. study was conducted at the farm level for the prereform era (1986–1991) for specific crops, whereas the present study was conducted at the regional (oblast) level for the postreform era (1991–1996) for all crops. Our results show that the average technical efficiency of corporate and private farms did not change very much during this period. Four farm-level variables were found to be important in explaining Ukraine's technical efficiency performance: the number of employees per farm, the percentage of crops marketed to the state, the percentage of private land used in crop production, and terms of trade. These findings link price and trade liberalization, as well as institutional reforms, such as land reform and enterprise privatization, with the technical efficiency performance of Ukrainian farms. We also compared the effects of reforms in Ukraine with those in Russia (Sedik, Trueblood, and Arnade).

The present article is organized as follows. First, policy developments in Ukraine during the reform period are discussed. Then the theoretical model is presented, followed by a review of the data used in the analysis. The technical efficiency results are presented that compare two different widely accepted methods. This is followed by a model that attempts to explain the results with five different explanatory farm-level and institutional variables. The article concludes by relating the overall Ukrainian technical efficiency performance to policy developments.

Policy Background

Since its independence in December 1991, Ukraine has implemented many policy reforms. These have included price and trade liberalization as well as institutional reforms. The various policy changes and economic forces have affected technical efficiency in different and offsetting ways. The net effect on technical efficiency is explored below.

Price and Trade Liberalization

After Ukraine became independent in 1991, the country immediately liberalized prices for most producer and consumer goods at the beginning of reform, except for a few strategic items. By 1996, the Ukrainian government controlled only 11% of all prices (Bjornlund). Like other transition economies, price liberalization led to an initial surge of inflation as the price effects worked through the economy. By 1998, Ukraine reduced its inflation level from triple digits to less than 20% (International Monetary Fund 2000b).

Trade liberalization was also an early part of the reforms. Trade liberalization in Ukraine followed a common path as other countries—the Ukrainian economy experienced a flood of imported food products, which led to an increase in protectionism in the form of higher tariffs to protect domestic producers from less expensive imports. Despite efforts to diversify its trade partners, Ukraine is still highly dependent on other newly independent states (NIS) for trade, especially imports. In 1994, the value of imports from other NIS countries made up 73% of total imports (63% from Russia alone). In 1998, imports from other NIS countries still made up 66% of total imports (48% from Russia) (International Monetary Fund 2000a).

Institutional Reforms

Institutional reforms in Ukraine started with enterprise privatization. The privatization process in agriculture was planned in three stages. The first stage was to reorganize all collective and state farms into collective agricultural enterprises (CAEs). This was done by transferring land into collective ownership of the enterprises. During the second stage, land was titled to the individuals. During the third stage, the CAEs were supposed to be restructured into various types of private enterprises.

By the end of the 1998, almost all collective and state farms had been transformed into CAEs (U.S. Department of Agriculture). These CAEs took the form of cooperatives, joint-stock companies, or peasant associations. However, not much changed in terms of the management or production structure of CAEs. According to recent data, approximately 90% of these CAEs reported losses in 1998. During the second stage of privatization, land was titled to more than 6 million people. According to the presidential decree of 1999, all CAEs had to be transformed into private farms and cooperatives by April 2000; approximately 90% of CAEs met this objective (Radio Free Europe/Radio Liberty).

When traditional large collective farms were reorganized into other collective forms, a new phenomenon was created: the independent family farm. These farms were established on individual land that eventually was to be passed into private ownership. The number of such private farms increased from 0 under the Soviet Union to more than 35,000 by 1997 (Csaki and Lerman). The average farm size for the 1991–1996 period was 24 hectares. Although enterprise privatization reform had some effect on the performance of state and collective farms, independent farmers were influenced by the progress of land reform.

The third type of producer that operates in Ukraine is the producer who uses small household plots, which have an average size of about one-half a hectare. These plots are cultivated mainly by city residents who grow mostly fresh fruits and vegetables. This group of consumers cannot afford the high market prices of these goods because of the production decline on state and collective farms.

Another part of institutional reforms has been the development of land markets. Private ownership of land was legalized in March 1992. Farm members received a certificate guaranteeing their right to a share of land. They had the option of exiting the collective farm and starting their own private farm or remaining in the collective farm (Csaki and Lerman). Most shareholders did not fully understand their rights at that point, so few farmers chose to exit. A 6-yr. moratorium on land transactions was put into place in 1992. This served as a barrier to land sales and was an important impediment to the transition toward functioning land markets. Even though land reform progressed slowly during the early reform period, by 1996, private farms accounted for 12% of the land, whereas the CAEs accounted for 40% of the land and households (private plots) for 38% of the land; other types of farms accounted for 10% of the land (Csaki and Lerman).

The financial and credit systems have only very recently been undertaking the major changes that are essential for the restructuring and privatization of agriculture. Before 1992, there was no borrowing, but lending began with the new wave of private farming in 1992. Nearly all farmers experienced difficulties obtaining access to credit. According to a credit survey in 1996, 90% of all respondents indicated that they could not borrow what they needed, mainly because the interest rate was too high (the median rate was 45% per year) and because a shortage of credit in general led banks to reject 25% of all applications (Csaki and Lerman). The interest rate increased over time from 1990 to 1996. The average interest rate on loans in the survey sample rose from 13% per annum in 1990–1991 to 111% per annum in 1995–1996 (Csaki and Lerman). One major obstacle for issuing loans over this time period was that land could not be used as collateral. This issue continues to be a problem today—at present, farmers guarantee their loans with capital, equipment, or future harvests.

The government has not adequately addressed policies to help with labor mobility issues. For the agricultural sector, it is widely believed that policies that increase labor mobility might lead to a rapid outmigration from agriculture and cause social disruption. To avoid this potential problem, the government continues to ration housing units as a means to control labor flows. This is an important issue—the World Bank has argued that agricultural labor productivity has declined, which could be addressed by releasing labor (World Bank). The World Bank argument is based on the casual observation that output has declined but the number of laborers has remained fairly constant. We argue that, although the number of laborers has stayed constant, the number of hours worked has declined, leading to an increase in labor productivity (i.e., hours worked declined at a faster rate than output).

Other Factors Affecting Efficiency

Government intervention has added to the risky economic environment that farm managers face in Ukraine. The government has not had a structured plan or position on market reforms. It has intervened unpredictably, making it difficult for private producers to function. Private producers have felt trapped when they have been suddenly required to make in-kind payments or to respond to some other unexpected policy intervention.

There has been little new investment in market infrastructure in Ukraine between the beginning of the reform period and 1996. Infrastructure such as transportation, storage, processing, and retail facilities were inherited from the Soviet economy and are considered to be inadequate for the functioning of a free market economy.

Summary of Policy Changes

It is unclear what impact these policy changes have had on technical efficiency. Market prices and trade liberalization have increased prices and competition, therefore motivating private producers to achieve more output while having the same amount of resources. This may have increased technical efficiency. Enterprise privatization got off to a slow start. On the one hand, it could have brought the development of ownership rights and marketing channels, which would have improved economic performance. On the other hand, enterprise privatization could have reduced efficiency because of the necessity of learning new processes and losses of time. Land privatization would have contributed positively to improvements in technical efficiency if it had been strongly and effectively implemented, but the process seems to have been initially misunderstood and was later halted by the 6-yr. moratorium. Thus, it is unclear what effect land privatization policies in this case had on technical efficiency. Other factors, such as slow credit and labor market developments and intermittent government interventions, probably have hurt efficiency.

Theoretical Model

Measuring Technical Inefficiency

To understand the net effects of these policy changes in Ukraine on agricultural technical efficiency, we attempted to measure and explain technical efficiency performance during the period 1991–1996. Two well-established approaches for measuring technical efficiency were used and compared: data envelopment analysis (DEA) and stochastic frontier analysis (SFA). DEA is a linear programming approach, whereas SFA uses econometric techniques. Both approaches provide a static measure of Farrell technical efficiency while estimating the production possibility frontier and the distances from each observation unit to this frontier (Farrell). Both methods have advantages and disadvantages over each other, which is why both methods were used. Some advantages of DEA include the fact that it does not assume that firms are not fully efficient and does not require a functional form to be specified in the model. The SFA method, on the other hand, accounts for noise and can be used to conduct conventional hypothesis tests.

With the nonparametric DEA approach, technical efficiency is estimated with either an input or an output orientation (Charnes, Cooper, and Rhodes). We estimated technical efficiency with an output orientation with primal data. With the output orientation, a producer's level of input is held fixed, so that technical efficiency (θ) is measured as a ratio of observed output to the maximum level of output to reach the frontier ($0 \leq \theta \leq 1$). If there are constant returns to scale, then the output orientation scores are equivalent to input orientation scores (Färe, Grosskopf, and Lovell). We checked returns to scale econometrically and found constant returns to scale, so the output scores were inverted to be comparable with the SFA scores.

The output-oriented technical efficiency measure is calculated with the program

$$(1) \qquad F^{O}(\mathbf{x}_i, \mathbf{y}_i | C) = \max_{\theta, z} \theta$$
$$\text{s.t.} \qquad \theta \mathbf{y}_i \leq z\mathbf{M} \qquad z_i\mathbf{N} \leq \mathbf{x}_i \qquad z_i \geq 0,$$

where F^{O} $(\mathbf{x}_i, \mathbf{y}_i | C)$ is the Farrell output-oriented technical efficiency score under constant returns to scale (C), $\mathbf{x}_i$ is input for producer i, $\mathbf{y}_i$ is output for producer i, θ_i is efficiency score for producer i, $\mathbf{z}$ is a $K \times 1$ vector that denotes the intensity variables or weights for the inputs that are used to construct piecewise linear production frontiers, $\mathbf{M}$ is an $I \times M$ matrix of outputs for a set of producers i, and $\mathbf{N}$ is an $I \times N$ matrix of inputs for a set of producers i.

The SFA approach also was used to estimate static technical efficiency. Its general estimation form for the panel data is

$$(2) \qquad y_{it} = \exp[\mathbf{x}_{it}\beta + v_{it} - u_{it}],$$

where y_{it} is the total value of output for the crop sector for oblast i in the year t, $\mathbf{x}_{it}$ is a vector of inputs for oblast i in the year t, β is a vector of parameters to be estimated, v_{it} is the random error term, and u_{it} is a nonnegative measure of technical inefficiency.

SFA estimates technical inefficiency as a nonnegative random variable, u_i, which is assumed to be i.i.d. (Aigner, Lovell, and Schmidt; Meeusen and Van den Broeck). The two most common assumptions made about the distribution of technical inefficiency used in empirical research are the half-normal (Aigner, Lovell, and Schmidt) and truncated normal distribution (Stevenson), although the γ distribution also has been proposed (Greene). The most common functional forms include the Cobb-Douglas and translog production functions. The random error, v_i, can be positive or negative, so stochastic frontier outputs vary about the deterministic part of the frontier model, $\exp(x_i\beta)$.

Explaining Technical Inefficiency

We also attempt to explain technical efficiency with SFA, which is a useful approach for investigating the forces causing inefficiency. We used a model developed by Battese and Coelli that conditions the efficiency measures on exogenous policy or institutional data. This model has been used previously in both micro- and macrolevel applications. For example, Tian and Wan used the same model for analyzing China's production of rice, wheat, and corn.

The goal of this model is explain technical efficiency performance with economic and policy variables that were found to be important in Russian agriculture (Sedik, Trueblood, and Arnade). Some of these variables included the number of employees per farm, the share of crops marketed through state channels, the share of subsidiary plot output, the percentage of privately owned land used in crop production, and the terms of trade. To estimate this model, the following Cobb-Douglas function was used:

$$(3) \qquad \ln(y_i) = \sum \beta_i \ln x_i + v_i - u_i, \qquad i = 1, 2, \ldots, n,$$

where $\ln(y_i)$ is the logarithm of the total value of output for the crop sector for farms in region i, $\ln \mathbf{x}_i$ is the logarithm of input quantities in region i, v_i is a random error $v_i \sim N(0, \sigma_v^2)$, and u_i is the measure of technical inefficiency, $u_i \sim N(\mu, \sigma^2)$, truncated from the left at zero.

This stochastic frontier model allows simultaneous estimation the causal factors which explain technical inefficiencies, u_i:

$$(4) \qquad u_i = \mathbf{z}_{it}\boldsymbol{\delta} + w_{it},$$

where $\mathbf{z}_{it}$ are the exogenous variables that help explain inefficiencies, which can be farm characteristics and/or policy variables, $\boldsymbol{\delta}$ is a vector of parameters to be estimated, and w_{it} is a random variable.

The FRONTIER (4.1) software program developed by Coelli was used for estimation. The program uses the Battese and Corra technique that replaces the error variances σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$ (note that $\gamma \in [0, 1]$). The closer γ is to one, the more error variance is attributable to inefficiency; if $\gamma = 0$ and is statistically significant, then an ordinary least-squares model would be appropriate. Technical efficiency under the half-normal distributional assumption was estimated with maximum-likelihood techniques. The program assumes that technical efficiency grows or decays exponentially—that is, $u = u_i\exp[-\eta(t - T)]$, where η is a time trend parameter to be estimated.

Data

The data for this analysis were collected from Ukrainian Ministry of Statistics sources. Panel data for 25 Ukrainian oblasts (equivalent to provinces or states) were collected for the 1991–1996 period, the most recent period available. The year 1995 was excluded from the analysis because of missing observations for some variables. The data include both the corporate and the private sectors of Ukrainian agriculture and demonstrate the importance of including private farmers and private household plots in the Ukrainian model of crop production. In 1996, private household plots and private farms together accounted for 50% of total land and produced 96% of total potato production, 82% of all vegetable production, and 12% of all grains in Ukraine (Csaki and Lerman; Institute of Agrarian Economy). Our analysis is limited to the crop sector and excludes the livestock sector because of (1) the availability and quality of data are considerably better for crops and (2) the small percentage of output in the livestock industry relative to the crop industry.

The variables used to estimate technical efficiency included total crop output, land (adjusted for quality), labor, fertilizers, fuel, electricity, and machinery. Output was measured by the value of total crop production in 1996 rubles. Land was measured as the total agricultural land in farms in each oblast, multiplied by a soil-climatic index (described below), to adjust for quality, in thousand hectares. Labor was measured as the total hours worked for crop-related activities, in thousand man-hours. Fertilizer was measured as the amount of mineral fertilizers used in agriculture in each oblast in thousand tons. Fuel was measured as the sum of benzene and diesel fuel used by all agricultural enterprises, in thousand tons. Electricity was measured as the amount of electricity consumed in collective, interfarm agricultural enterprises and state farms, in thousand kilowatt-hours. Machinery was measured as the total capacity of tractors' engines in all farms, in thousand horsepower.

Weather and soil conditions are important quality factors that should be incorporated into efficiency analysis. Weather has been found to explain approximately 10% of production in the countries of Central and Eastern Europe in 1989–1995 (Macours and Swinnen). Because temperature and precipitation numbers were not available for the present study, a soil-climatic index was used with the goal that it would capture the effect of these two variables. The land soil-climatic index was developed by the Institute of Agrarian Economics at the Ukrainian Academy of Agrarian Science. The index is based on soil-climatic conditions for each oblast. The index can take values from 0 to 1, where 0 indicates the worst soil and climatic conditions in the oblast and 1 is the most propitious conditions for crop production.[1]

The Ukrainian Ministry of Statistics collected the data used in the present study. Procedurally, the annual data for the collected variables are reported from the regional statistical offices to the central office. The Ministry does not check the quality of the data but instead relies on the regional statistical offices

[1] Inclusion of other chemical inputs and irrigation variables would have been desirable. Unfortunately, these data were not available for all years of analyses.

Table 1. Summary Statistics of Ukrainian Data

Variable	Mean	SD	Minimum	Maximum
Scalar Output	920.09	274.55	280.00	1,540.20
Land	1,048.75	446.18	165.35	1,706.16
Labor	67,400.32	32,802.72	1,994.75	132,027.00
Fertilizer	424.71	842.52	5.82	7,845.00
Fuel	118,456.50	64,817.45	31.00	248,802.10
Electricity	247.87	185.55	14.40	1,224.00
Machinery	1,690.25	549.14	413.00	2,552.00

Note: SD is standard deviation.

to review their quality. There is a strong possibility that some data were overestimated at the beginning of the study period, when subsidies for some inputs like fuel and fertilizer were still in place. Overestimation of labor was also a common practice in the former Soviet Union. However, with the reduction of agricultural subsidies at the national level in the reform period, there has been less incentive at the farm level to misreport output and input levels in the hope of receiving such subsidies. As a result, farms have changed their reporting practices and become more truthful over time. Overall, these data can be considered as the most accurate data available in Ukraine at the date of their collection.

Table 1 provides descriptive statistics of the primary inputs used for technical efficiency measurement, and Table 2 shows the trends in national aggregates of the inputs and output of Ukrainian crop production over the 1991–1996 period. The total value of crop output declined by 19.1% during 1991–1996. All inputs were reduced significantly, with the exception of land, which has stayed relatively constant. Labor hours and fertilizer use have contracted the most—57% and 79%, respectively.

Policy variables chosen for the present analysis were found to be influential in previous studies that explained the performance of transition economies. In one study of Russian corporate farm performance, variables connected with land and enterprise privatization policy helped to explain technical efficiency performance. This included the number of employees per farm, the value of private crop production, and the percentage of agricultural land on private farms (Sedik, Trueblood, and Arnade). Another study of transition economies in Eastern Europe found that relative price changes as a result of price and trade

Table 2. Aggregate Levels of Inputs and Output in Ukrainian Crop Production for the Years 1991–1996

Year	Total Value of Output in 1996 Prices (Mil. Rubles)	Land (1,000 ha)	Labor (million man days)	Fertilizer (1,000 tons)	Fuel (1,000 tons)	Elec. (million kw/h)	Machinery (1,000 HP)
1991	20,256	32,591	2,006	4,155	3,805	4,711	42,724
1992	20,379	33,177	1,890	2,999	3,274	4,138	44,064
1993	22,588	32,699	1,823	2,021	2,717	3,910	43,159
1994	17,452	32,965	1,657	1,162	2,497	3,569	43,159
1996	16,386	32,883	871	860	2,510	2,687	38,175
Cumulative percent change, 1991–1996							
	−19.1	0.9	−56.6	−79.3	−34.1	−43.0	−10.7

Note: Data for 1995 are incomplete or missing.

Table 3. Stochastic Frontier Cobb-Douglas Production Function Estimates

Variables	Model 1	Model 2
X variables		
Intercept	2.6731* (4.3120)	0.7398**** (1.9231)
Land	0.3473* (3.9307)	0.3349* (6.7084)
Labor	0.0969 (1.2394)	0.2609* (3.8258)
Fertilizer	0.1084** (2.7256)	0.2213* (7.4753)
Fuel	0.0325 (0.9731)	0.0271 (0.8809)
Z variables		
z_0—Constant	—	0.2208* (3.5785)
z_1—Employees per farm	—	−0.1599*** (−2.0227)
z_2—Percent of crops marketed to the state	—	0.1211**** (1.7782)
z_3—Percent of subsidiary crop output	—	0.1227 (1.4770)
z_4—Percent of private land in crop production	—	−0.5271* (−5.1013)
z_5—Terms of trade	—	0.0104**** (1.5969)
Other variables		
η	0.0532	—
γ	0.6067**	0.9999**
σ^2	0.0443**	0.0282**
Likelihood ratio	60.5189	57.4014

Notes: The *t*-values are shown in parentheses. * denotes significance of the values at the 1% significance level, ** at the 5% significance level, *** at the 10% significance level, and **** at the 20% significance level.

liberalization explained 45% of the output decline. Also, privatization and land reform were found to significantly influence economic performance (Macours and Swinnen).

Unfortunately, much of the data needed to create these variables were not available in all Ukrainian oblasts for our study. The following are five variables for which data were available for all oblasts: the number of employees per farm (z_1), the percentage of crops marketed to the state (z_2), the percentage of total crop production by subsidiary small garden plots (z_3), the percentage of private land used in crop production (z_4), and terms of trade (the ratio of prices received to prices paid by farmers; z_5).

Results

Measuring Technical Efficiency Performance

The FRONTIER (4.1) software program was used to estimate the SFA model. This program uses the maximum likelihood technique for estimation. The translog functional form model was considered first. However, when it was compared and tested against the Cobb-Douglas functional form model, the hypothesis that a Cobb-Douglas model is appropriate was not rejected, so the model was assumed to be Cobb-Douglas. The *F*-statistic for Cobb-Douglas model, 1.93, was less than the critical value of 2.32 at the 1% significance level.

High collinearity was observed between machinery and fuel, which led to unsatisfactory initial SFA results. Several procedures have been proposed to address multicollinearity. The approach that we took was to drop the machinery variable. Model 1 in Table 3 shows the final test statistics and the magnitudes of the Cobb-Douglas coefficients. The test statistic γ is equal to 0.61 and is statistically significant, rejecting the hypothesis that technical inefficiency was not present. The elasticity of output with respect to land was found to be statistically significant and equal to 0.3473.

Table 4. Comparison of the Means of Technical Inefficiencies Using Stochastic Frontier Analysis and Data Envelopment Analysis

Year	SFA	DEA-C
1991	0.694	0.826
1992	0.706	0.841
1993	0.718	0.827
1994	0.731	0.836
1996	0.742	0.751

Note: DEA is data envelopment analysis, and SFA is stochastic frontier analysis.

The fertilizer elasticity was statistically significant and equal to 0.1084. The elasticities of labor and fuel were statistically insignificant and equal to 0.0969 and 0.0325, respectively. The returns to scale were tested and found to have constant returns to scale.[2]

Table 4 provides a comparison of average technical efficiency scores over time for the SFA and DEA approaches. Because constant returns to scale were found in the SFA analysis, the DEA programs used that assumption as well. The average SFA score was 0.694 in 1991 and increased steadily to 0.742 in 1996. DEA scores were a bit higher than SFA scores, which is consistent with the results of previous research (e.g., Bravo-Ureta and Rieger; Ferrier and Lovell; Hjalmarsson, Kumbhakar, and Heshmati; Neff, Garcia, and Nelson). The DEA scores fluctuated year to year but displayed an upward trend during 1991–1994 and then declined in 1996. Because the data for the year 1995 were missing, the change in technical efficiency was adjusted for the jump from 1994 to 1996 using a procedure implemented by Färe, Grosskopf, and Lovell. The correction was made by raising the efficiency scores by the power ½.

The slight disagreement between the results of the SFA and DEA models about trends in the last few years may be partly attributable to the η^2 exponential time trend parameter used in the SFA model, which assumes that technical efficiency has moved in only one direction over time. In contrast, the DEA models allow year-to-year variation.[3]

Because our goal was to explain how some farm and policy variables affected technical efficiency, it is instructive to review the performance of selected oblasts in light of their agricultural policies (the next section systematically explores the effect of particular quantitative variables representing farm and institutional policies). The outcome or different technical efficiency scores should tell us how effective institutional reforms were in different oblasts. Table 5 shows the technical efficiency scores using two methods of analyses: SFA and DEA in Ukraine by oblast for the observed period of time. Vinnitskaya, Kievskaya, and Ivano-Frankovskaya oblasts exhibited the highest increase in technical efficiency (15%, 9.9%, and 8.8%, respectively). It is important to note that the Western Carpathian oblasts—Lvovskaya, Ivano-Frankovskaya, and Zakarpatskaya—were the first ones to fight for land reform implementation and enterprise privatization. By 1996, Lvovskaya oblast was able to make the most progress by creating 15 private farms (Csaki and Lerman). Kievskaya oblast also was exemplary in initiating all reforms. By 1996, 15 CAEs and 15 private farms existed there. Thus, improvement in the technical efficiency in these oblasts can be explained by enterprise privatization and land reform.

Odesskaya, Donetskaya, and Luhanskaya oblasts showed the largest decrease in technical efficiency during this period of time. Donetskaya oblast is widely believed to be an example of the failed transition. By the beginning of 2000, the Donetsk region was one of the lowest oblasts in the country in terms of the number of privatized companies per person, along with Odesskaya and Poltavskaya

[2] The results show that the returns to scale is 0.85. The results of an F-test indicated that the returns to scale were not statistically significantly greater than one. The restriction that the returns to scale were equal to one returned an F-test of 3.84, whereas the critical value for an F-test with one restriction and 112 degrees of freedom is approximately 3.94.

[3] This is an advantage of DEA in this particular context but is not necessarily an indication of its overall superiority over SFA. Many agricultural economists prefer SFA because of the way it captures random noise, such as weather variations.

Table 5. Technical Efficiency Scores by Oblast, SFA and DEA Methods, 1991–1996

	SFA					DEA				
Oblast	1991	1992	1993	1994	1996	1991	1992	1993	1994	1996
Autonom.Rep.Krim	0.756	0.767	0.778	0.788	0.797	1.000	1.000	0.616	0.830	0.449
Cherkasskaya	0.780	0.791	0.800	0.809	0.818	0.909	0.864	0.935	0.919	0.741
Chernovetskaya	0.555	0.572	0.589	0.605	0.621	0.774	0.893	0.712	0.849	0.741
Chernigovskaya	0.889	0.895	0.900	0.905	0.909	1.000	1.000	0.944	1.000	1.000
Dnepropetrovskaya	0.750	0.761	0.772	0.783	0.793	0.952	0.796	1.000	0.895	0.833
Donetskaya	0.726	0.738	0.751	0.761	0.772	0.923	1.000	0.905	1.000	0.633
Hersonskaya	0.472	0.491	0.509	0.527	0.545	0.522	0.519	0.564	0.447	0.454
Hmelnitskaya	0.749	0.761	0.772	0.782	0.792	0.686	0.770	0.681	0.684	0.521
Ivano-Frankovskaya	0.689	0.703	0.716	0.728	0.741	0.876	1.000	1.000	0.993	1.000
Kievskaya	0.936	0.938	0.942	0.945	0.947	0.792	1.000	1.000	1.000	0.978
Kirovogradskaya	0.603	0.619	0.635	0.649	0.664	0.795	0.673	1.000	0.956	0.779
Kharkovskaya	0.711	0.724	0.734	0.748	0.759	0.734	0.960	0.939	0.816	0.845
Luhanskaya	0.505	0.523	0.541	0.558	0.575	0.829	0.827	0.737	0.608	0.588
Lvovskaya	0.828	0.836	0.844	0.851	0.859	1.000	0.993	0.876	0.906	0.930
Nikolaevskaya	0.482	0.501	0.519	0.537	0.554	0.701	0.522	0.749	0.940	0.728
Odesskaya	0.583	0.599	0.616	0.631	0.647	0.846	0.572	0.690	0.612	0.384
Poltavskaya	0.749	0.761	0.772	0.782	0.792	0.846	0.766	0.898	0.919	0.781
Rovenskaya	0.661	0.675	0.689	0.702	0.715	0.858	0.923	0.677	0.829	0.824
Sumskaya	0.677	0.691	0.704	0.717	0.729	0.826	0.853	0.787	0.769	0.692
Ternopolskaya	0.659	0.674	0.688	0.701	0.714	0.619	0.717	0.661	0.709	0.548
Vinnitskaya	0.865	0.871	0.878	0.884	0.889	0.720	0.790	0.823	0.787	1.000
Volinskaya	0.724	0.736	0.748	0.759	0.771	1.000	1.000	0.835	0.836	1.000
Zhitomirskaya	0.697	0.710	0.723	0.735	0.747	0.693	0.733	0.650	0.713	0.651
Zakarpatskaya	0.689	0.699	0.712	0.725	0.737	1.000	1.000	1.000	1.000	1.000
Zaporozskaya	0.602	0.618	0.634	0.649	0.664	0.747	0.846	0.984	0.875	0.666
Average	0.694	0.706	0.718	0.731	0.742	0.826	0.841	0.827	0.836	0.751

Note: DEA is data envelopment analysis, and SFA is stochastic frontier analysis.

oblasts (Kovaleva). Oblasts in the interior of Ukraine, such as Nikolaevskaya and Kirovogradskaya, showed very insignificant increases in technical efficiency.

Explaining Technical Efficiency Performance

To investigate the sources of technical inefficiency, a second SFA model was estimated. This model was estimated with five additional z variables: the number of employees per farm (z_1), the percentage of crops marketed to the state (z_2), the percentage of crop output produced on subsidiary plots (z_3), the percentage of private land in crops (z_4), and the terms of trade (z_5). The results are shown as model 2 in Table 3. The β coefficients for land and fuel in model 2 were similar to those in model 1. The coefficients for labor and fertilizer were noticeably different in model 2. The fertilizer coefficients increased from 0.11 to 0.22, and the labor coefficient increased from 0.10 to 0.26 (in the latter case, the coefficient became statistically significant).

The results of the z variables are highlighted below in numerical order. The sign of z_1, the number of employees per farm, was negative and statistically significant. This indicates that the more employees on each farm, the more efficient the farm. This outcome is likely a result of seasonal labor shortages in Ukraine, as has been found to be true for Russia (Sedik, Trueblood, and Arnade). The sign of z_2, the percentage of crops marketed to the state, was positive and statistically significant. This finding is different than that found for

Russian crop production, that using state marketing channels led to increasing efficiency. Sedik, Trueblood, and Arnade argued that this was a short-run transaction cost phenomenon—that is, it was expected that the search costs of finding new private marketing channels might cause short-run decreases in efficiency but then increases in the long run. In Ukraine, because of a liberalization of prices and trade and various ownership models of land, marketing channels were developing. Farmers were finding that marketing through channels other than state channels was more efficient: less paperwork, better price, and differentiation of quality. Farmers who participated in a marketing survey in Ukraine in 1996 stated that 20% sold directly to processors, 15% to commercial firms, and 5% through their own sales outlets (Csaki and Lerman).

The sign of z_3, the percentage of crop output produced on subsidiary plots (i.e., small garden output), was positive and statistically insignificant. This suggests that workers may have pilfered supplies for their own private output or that the disrepair of corporate farms may have led workers to grow food on private garden plots just to survive. As we mentioned earlier, it is mainly city dwellers who cultivate these plots. It is a very inefficient and labor-intensive production practice.

The coefficient of z_4, the percentage of private land used in field crop production (distinct from the small garden output), was negative and statistically significant, meaning that the more private land is involved in crop production, the less corporate farm inefficiency occurs. This could be interpreted that some regions with favorable natural endowments and economic conditions are conducive to privatization efforts. This outcome underlines the importance of land and enterprise privatization reforms in improving technical efficiency performance.

The coefficient for z_5, the terms of trade, was positive and statistically significant at the 20% level. The terms of trade deteriorated because of the more rapid increase of the input price index relative to the increase in the output price index. The positive coefficient for this variable suggests that the worsening of terms of trade has led to improvements in efficiency. This is consistent with the findings of a study on Russia that found that input price increases led to the more rational use of these previously subsidized inputs, especially fertilizers (Sedik, Trueblood, and Arnade). This result links technical efficiency performances with the policy of price liberalization and the reduction of input subsidies.

To summarize, δ coefficients of the z variables were statistically significant for all variables, with the exception of δ_3 coefficient of crop output produced on small garden plots. Coefficients of all Ukrainian variables showed the same effect on technical efficiency as was found in Russia, except for the variable crops marketed to the state. This variable showed that the usage of state marketing channels led to a decrease in efficiency in Ukraine.

Conclusions

One of our goals was to measure the technical efficiency performance of corporate and private farms in Ukraine over the period 1991–1996, during which the economic and policy environment changed dramatically and little is known about the effects on Ukraine's agricultural productivity and efficiency. Many of the policy changes have exerted offsetting economic pressures in terms of the expected impacts on technical efficiency.

We found that technical efficiency appears to have improved slightly over the 1991–1996 period. This would seem to suggest that the positive forces, such as price and trade liberalization, as well as enterprise privatization, had a greater effect on technical efficiency. This finding of increased technical efficiency might seem surprising, but our data clearly show that some inputs have contracted faster than crop output, particularly for labor hours and fertilizers. Like other countries in transition, fertilizer subsidies in Ukraine have been reduced, which has led to higher real prices and forced farm managers to reduce their use.

A similar study for Russia found that technical efficiency declined over the same time period. This can be explained by the fact the

Russian study included only corporate farms' performance in crop production, whereas we included three types of producers: corporate farms, private farms, and household plots.

Another goal of the present study was to quantitatively test a particular set of farm-level and institutional variables that were found to be important in explaining technical efficiency performance in Russia. The results from the stochastic model with the z variables show how some policies in particular affect technical efficiency. The coefficients for four variables were statistically significant and displayed the same signs as in Russia, except that of marketing to the state. The interpretation of variable z_1, the number of employees on all three types of farms in Ukraine, is that the more employees on the farm, the more efficient the farm. Variable z_2, the percentage of crops marketed to the state, provided an evidence of the positive effect of price and trade liberalization on technical efficiency. Variable z_4, the percentage of private land in crop production, links technical efficiency positively with land reform and enterprise privatization. The last variable, z_5, terms of trade, showed how liberalized prices would worsen terms of trade, which has led to increased technical efficiency.

The availability of data was the main constraint for testing the effect of reforms on technical efficiency in Ukraine. Because land reform is still in progress, it would be interesting to estimate the technical efficiency of private enterprises on the farm level and compare it with the CAEs' performance.

Finally, the trend in agricultural labor productivity remains an important issue to address. The World Bank has argued that casual observation shows that output has declined even though the agricultural labor population has remained stagnant. However, our results show that labor productivity has increased, which may not be a contradiction, given that we measured labor in hours employed in crop activities rather than the agricultural labor population. Both measures suggest that the agricultural labor force may be underemployed and could be better redeployed to other sectors if it were allowed to be more mobile.

[Received October 2002; Accepted July 2003.]

References

Aigner, D., C.A.K. Lovell, and P. Schmidt. "Formulation and Estimation of Stochastic Frontier Production Function Models." *Journal of Econometrics* 6(July 1977):21–37.

Battese, G.E., and T.J. Coelli. "A Model for Technical Efficiency Effects in a Stochastic Frontier Production Function for Panel Data." *Empirical Economics* 20(April 1995):325–32.

Battese, G.E., and G.S. Corra. "Estimation of a Production Frontier Model: With Application to the Pastoral Zone of Eastern Australia." *Australian Journal of Agricultural Economics* 21(December 1977):169–79.

Bjornlund, B. "Ukraine—Issues and Analysis." Internet site: http://www.ers.usda.gov/briefing/ukraine/issues.htm (Accessed March 15, 2000).

Bouzaher, A., A. Carriquiry, and H. Jensen. "The Structure of Ukrainian Agriculture: Comparative Efficiency with International Agriculture and Implications for Policy Reform." CARD Staff Report 94-SR72, Iowa State University, 1994.

Bravo-Ureta, B.E., and L. Rieger. "Alternative Production Frontier Methodologies and Dairy Farm Efficiency." *Journal of Agricultural Economics* 41(May 1990):215–26.

Charnes, A., W.W. Cooper, and E. Rhodes. "Measuring the Efficiency of Decision Making Units." *European Journal of Operational Research* 2(November 1978):429–44.

Coelli, T.J. A Guide to FRONTIER Version 4.1: A Computer Program for Frontier Production Function Estimation, CEPA Working Paper 96/07, Department of Econometrics, University of New England, Armidale, NSW, Australia, 1996.

Csaki, C., and Z. Lerman. "Land Reform in Ukraine: The First Five Years." Discussion Paper No. 371. Washington, D.C.: World Bank, 1997.

Färe, R., S. Grosskopf, and C.A.K. Lovell. *Production Frontiers.* Cambridge, UK: Cambridge University Press, 1994.

Farrell, M. J. "The Measurement of Productive Efficiency." *Journal of the Royal Statistical Society,* Series A, Gen. 125(1957):253–90.

Ferrier, G.D., and C.A.K. Lovell. "Measuring Cost Efficiency in Banking: Econometric and Linear Programming Evidence." *Journal of Econometrics* 46(October/November 1990): 229–45.

Greene, W. "Maximum Likelihood Estimation of Econometric Frontier Functions." *Journal of Econometrics* 13(May 1980):27–56.

Hjalmarsson, L., S.C. Kumbhakar, and A. Heshmati. "DEA, DFA, and SFA: A Comparison." *Journal of Productivity Analysis* 7(July 1996): 303–27.

Institute of Agrarian Economy. "Ukrainian Agrobusiness Complex: Situation and Perspectives for 1990–2000." Institute of Agrarian Economy, Kiev, January 1999. [In Ukrainian]

International Monetary Fund (IMF). *Direction of Trade Statistics.* Washington, DC: IMF, 2000a.

———. *International Financial Statistics Yearbook,* Washington, DC: IMF, 2000b.

Jensen, H., P.G. Lakshminarayan, A. Bouzaher, A. Carriquiry, S.R. Johnson, and P. Sabluk. "A Stochastic Frontier Analysis of Technical Efficiency of Ukrainian Crop and Livestock Enterprises and Implications for Reform." *Ukrainian Economic Review* 2(1996):4–22.

Johnson, S.R., A. Bouzaher, A. Carriquiry, H. Jensen, and P.G. Lakshminarayan. "Production Efficiency and Agricultural Reform in Ukraine." *American Journal of Agricultural Economics* 76(1994):629–35.

Kovaleva, E. "Regional Politics in Ukraine's Transition: Donetsk Elites." Sunderland University, United Kingdom, Internet site: http://www.sunderland.ac.uk/~os0hva/kova.htm (Accessed February 14, 2003).

Macours, K., and J.F.M. Swinnen. "Causes of Output Decline in Economic Transition: The Case of Central and Eastern European Agriculture." *Journal of Comparative Economics* 28(2000): 172–06.

Meeusen, W., and J. van den Broeck. "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error." *International Economic Review* 18(June 1977):435–44.

Neff, D.L., F. Garcia, and C.H. Nelson. "Technical Efficiency: A Comparison of Production Frontier Methods." *Journal of Agricultural Economics* 44, 3(September1993):479–89.

Radio Free Europe/Radio Liberty (RFE/RL). Newsline Vol. 5, No. 208, Part II. Prague, Czech Republic: RFE/RL, 1 November 2001.

Sedik, D., M.A. Trueblood, and C. Arnade. "Corporate Farm Performance in Russia, 1991–1995: An Efficiency Analysis." *Journal of Comparative Economics* 27,3(1999):514–33.

Stevenson, R. "Likelihood Functions for Generalized Stochastic Frontier Estimation." *Journal of Econometrics* 13,1(May 1980):57–66.

Tian, W., and G.H. Wan. "Technical Efficiency and Its Determinants in China's Grain Production." *Journal of Productivity Analysis* 13,2(2000): 159–74.

U.S. Department of Agriculture, Economic Research Service. Ukraine internet briefing room, http://www.ers.usda.gov/Briefing/Ukraine/policy.htm (Accessed April 28, 2000).

World Bank. *Ukraine: Economic Growth With Equity—A Participatory Country Economic Memorandum.* Washington, DC: World Bank, 2000.