

Article

Productive Efficiency of Potato and Melon Growing Farms in Uzbekistan: A Two Stage Double Bootstrap Data Envelopment Analysis

Aziz Karimov

UNU-WIDER, World Institute for Development Economics Research, Katajanokanlaituri 6B, Helsinki 00160, Finland; E-Mail: Karimov@wider.unu.edu; Tel.: +358-9-615-992-31; Fax: +358-9-615-993-33.

Received: 15 April 2013; in revised form: 26 July 2013 / Accepted: 31 July 2013 /

Published: 2 September 2013

Abstract: This article is one of the first to carry out a non-parametric efficiency analysis of crop production in Uzbekistan. The study applies the bootstrap Data Envelopment Analysis (DEA) to compute bias corrected technical efficiency (TE) scores using a sample of farms located in two regions of Uzbekistan. The study also investigates the determinants of TE in potato and melon production. Results indicate that there is room for efficient use of resources. Farmers are found to be more scale-efficient but not productively efficient. Findings from the second stage DEA model display that soil fertility index, farm size, water availability, crop diversification index, dependency ratio, potential to work in large land area, and longer distance to market contribute positively to production efficiency.

Keywords: DEA; double bootstrapping; technical efficiency; scale efficiency

1. Introduction

Improving crop productivity in the farming sector clearly plays a central role in promoting economic growth, increasing food security, and alleviating poverty in the country. As the literature review from developing and transitional countries has shown, efficiency enhancements in using resources positively impact crop productivity [1–3]. Given the various agricultural programs and policies implemented over the years to increase farmers' efficiency and productivity in Uzbekistan, it was necessary to quantitatively measure the current levels of efficiencies and their determining factors. Moreover, as experience from other countries in the developing world shows, quantitative studies such as the present study are needed before developing efficiency enhancing policies. The study contributes

to the efficiency analysis literature of farm households in Uzbekistan. It also contributes to the policy more in terms of empirically showing current efficiency levels and potential factors, which could be taken into account in decision-making.

Frontier efficiency methods are believed to be very practical tools in agricultural research. They are helpful in analyzing micro-farm associated problems, which may be due to externally or internally related factors. They are also useful in making recommendations drawn from the empirical work and the theory of production. Efficiency studies provide information about the need for the adoption of new technologies or whether it is still possible to achieve higher yields with the prevailing technology. With this in mind, the study measures technical and scale efficiency (SE) of farms that produce potatoes (*Solanum tuberosum L.*), honey (*Cucumis melo*) and watermelons (*Citrullus lanatus*)—hereafter H-W melons—utilizing the farm survey data collected from two provinces of Uzbekistan for the 2007 crop growing season.

Increasing resource use efficiency in potato production became vital in the existence of a state order for strategic crops, such as wheat and cotton. Potato production requires less water and more harvest time per hectare than any other subsistence crop. It is the third important food crop after wheat and rice in the country. While the country produced potatoes prior to its independence, it mostly remained dependent on imports from Russia and Belarus. This led to serious problems in the beginning years of independence because of the collapse of complex economic links that were created during the Soviet period. The state prioritized boosting the potato production and reducing the import dependence from other countries. The overall sown areas under potatoes increased from 40 to 70.7 thousand ha, while production increased from 351 to 1693 thousand tons in the years 1991 to 2010 [4]. In the case of H-W melons, the sown area decreased dramatically, but not the production levels due to the introduction of high yield varieties. Olimjanov and Mamarasulov [5] mention that yields of these crops are still low in comparison to other countries with a similar agro-ecological environment, which also stresses the importance of this study.

There are a few studies, which have studied technical efficiency (TE) of potato and H-W melon production in the efficiency literature. Amara *et al.* [6] reported that farmers in Quebec, Canada were 80% efficient in potato production. Adewumi and Adebayo [7] found 47% efficiency in the production of sweet potato using the data from the Kwara State of Nigeria. Nyagaka *et al.* [8] revealed decreasing returns to scale in Irish potato production and found 67% efficiency from the sample of farmers located in Nyandarua North district of Kenya. Ibrahim [9] examined TE and profitability of watermelon in Borno State of Nigeria and found the TE of 86%. The Author reported that agricultural experience, educational level, membership in cooperatives, credit amount and extension contacts significantly impact production efficiency.

The TE in the context of this study is used to quantify resource use efficiency in crop production, while SE is employed to measure optimality in terms of farm size. The two-stage Data Envelopment Analysis (DEA) model is used for estimation [10–12]. Since the study divides the main sample into sub-samples, the sample sizes become smaller and this may undermine the robustness of efficiency findings. This work applies new methodological developments in the area of DEA to improve robustness of efficiency scores.

2. Methods

2.1. Data Envelopment Analysis

Charnes *et al.* [10] introduced the DEA model, which was further developed by Banker *et al.* [13]. In the first stage, DEA uses the linear programming (LP) techniques and constructs the frontier ray, which consists of most efficient farms. The distance between this ray and the location of other farms not in this ray provides the efficiency measure. A regression model is used in the second stage to estimate some exogenous variables, which are assumed to influence TE. An advantage of this method compared to stochastic frontier analysis is that it does not require a functional form, whereas a disadvantage is that it assumes no statistical noise in the analysis. The farm can operate at different returns to scale.

The selection of a particular scale depends on the feature of production under investigation. The article chooses the variable returns to scale (VRS) technology because constant returns to scale (CRS) technology assumes that farms operate at an optimal scale. Because crop production is influenced by many external factors, such as weather, economic shocks and institutional changes, use of VRS technology is more appropriate. The production technology is described via an output orientation. The output-orientation portrays to what extent the output can be increased for given input levels. To demonstrate the model, some basic definitions first need to be described. The following has to be given: the set of s inputs ($x \in \mathbb{R}_+^s$) and q outputs ($y \in \mathbb{R}_+^q$), which constitute a production set T :

$$T = \{(x, y) \in \mathbb{R}_+^{s+q} : x \text{ can produce } y\} \tag{1}$$

This set can be described as an output equivalence set defined as $\forall x \in T$:

$$Y(x) = \{y \in \mathbb{R}_+^q \mid (x, y) \in T\} \tag{2}$$

The study utilizes the Farrell [14] measure of output for the TE measurement. It is the reciprocal value of the Shephard *et al.* [15] output distance function. TE (τ) is defined for some point $(x_i, y_i) \in \mathbb{R}_+^{s+q}$ such that:

$$\tau_i = \sup\{(\tau \mid x_i, \tau \mid y_i) \in T, \tau \neq 0\} \tag{3}$$

Estimation of output oriented TE under VRS (TE_{vrs}) involves solving the following LP model:

$$\begin{aligned} & \text{Max}_{\tau_i, \lambda_j} \tau_i \\ & \tau_i y_{qi} \leq \sum_{j=1}^n \lambda_j y_{qj} \\ & x_{si} \geq \sum_{j=1}^n \lambda_j x_{sj} \quad (s=1,2,3,\dots,6 \text{ inputs}) \\ & \sum_{j=1}^n \lambda_j = 1 \\ & \lambda_j \geq 0 \end{aligned} \tag{4}$$

Where n is the number of farms, which produce a single output utilizing m production factors. Here, i -th farm produces y_{qi} units of output using x_{si} units of s -th inputs. τ_i describes the proportional rise in outputs which can be acquired by the i -th farm given input vector x_i . λ is an intensity variable utilized to obtain all potential linear mixes of observations from the sample. TE under CRS (TE_{crs}) can be calculated by removing the convexity constraint ($\sum_{j=1}^n \lambda_j = 1$) from Equation (4). SE gives information about returns to scale in crop production. It is calculated by dividing TE_{crs} by TE_{vrs} [16] and measured using the following formula, which results in a score between zero and one:

$$SE = TE_{crs} / TE_{vrs} \quad (5)$$

Full SE is achieved at the score of 1. Farms are considered scale inefficient when SE is less than 1. TE under the non-increasing returns to scale (TE_{NIRS}) can be calculated by replacing convexity restriction from Equation (4) with $\sum_{j=1}^n \lambda_j \leq 1$. If TE_{vrs} and TE_{NIRS} are unequal and SE is less than one, the farm is said to be operating under increasing returns to scale (IRS). In contrast, if these scores are equal and SE is less than one, the farm is said to be operating under decreasing returns to scale (DRS).

2.2. Truncated Regression

The Tobit regression is commonly used in the second stage of the DEA. Contrarily, Simar and Wilson [17] mention that the error term is not censored but truncated. Taking this critique into account, the study adopts the truncated maximum likelihood (ML) regression as follows:

$$\hat{\tau}_i = z_i \beta + \varepsilon_i \quad (6)$$

where $\hat{\tau}_i$ is the TE_{vrs} score for each farm i , z_i is the vector of factors which are assumed to impact on TE_{vrs} (dependent variable). β is the vector of parameters and ε_i is the continuous, and identically and independently distributed random variable, $N(0, \sigma_\varepsilon^2)$ with left-truncation at $1 - z_i \beta$.

2.3. Bootstrapping in DEA

The performance of farms can be affected by several errors related to measurement. While DEA assumes no statistical noise, there is still uncertainty because of the variability of the selected sample (*i.e.*, efficiency scores are sensitive to sampling errors). A sampling error arises because the DEA constructs the frontier from the sample not from the population. Simar and Wilson [18,19] recommend bootstrapping DEA efficiency scores. Greene [20] emphasizes that the bootstrapping is a necessary step in the “absence of a statistical underpinning”. In the bootstrapping technique, the data generating process is continually simulated by re-sampling. The original estimator is applied to every sample that is simulated, so that the original estimator’s sampling distribution mimics the resulting estimates. The article adopts the double bootstrapping (algorithm #2) offered by Simar and Wilson [17] to test and strengthen the validity of statistical inference. While empirical studies have shown that there is not much difference between single and double bootstrapping procedures, double bootstrapping improves statistical efficiency in the second stage.

3. Data

The data used in this study was collected in three steps. The first step comprised a purposeful selection of districts to capture the adequate representation of each province. For the analysis, eight districts from Khorezm and seven districts and two crop producing cities from Fergana province were selected. The second step comprised a purposeful selection of those villages, which specialized in vegetable production within the chosen districts. The study used secondary information to obtain general information on vegetable production from both provinces. For that informal meetings were arranged with village leaders to have an idea about farmers' crop portfolios. In the third step, crop producing farms were randomly selected from each chosen village. The final analysis (*i.e.*, after adjusting for missing cases and outliers) included 178 and 145 potato and H-W melon producing farms. Model variables are at plot level because this helps to minimize the omitted variable bias that would confound a household-level analysis.

A statistical summary of input and output variables utilized in the DEA model is detailed in Table 1. One output and six inputs are used in the first stage of the DEA. It is worth noting that because of data unavailability, inputs have not been adjusted for quality. Output includes the quantities of production both sold and kept for self-consumption. Inputs consist of land, labor, seeds, nitrogen fertilizer, diesel and other expenses. Land input (ha) is defined as the crop grown area. The labor input is measured in person days. One working day is set to eight hours. The seeds variable (kg) consists of seeds purchased from the market and produced by the farmer. Nitrogen fertilizer input (measured in kg) is derived by calculating the share of nitrogen in the content of each fertilizer. The diesel fuel input is also included and measured in kg. "Other expenses" is an aggregated variable, which consists of the sum of expenses on Water User Associations (WUAs—Renamed to the Water Consumers Association [WCA] in 2009), chemicals (other than chemical fertilizers) and organic manure, all measured in monetary units.

Table 1. Summary statistics of variables used in the analysis.

Variable	Units	Potatoes		H-W Melons	
		Mean	SD	Mean	SD
Output	Tons	20.4	17.76	9.45	8.75
Land	ha	1	0.8	0.5	0.5
Labor	Man-days	906	729.6	450.5	457
Seeds	Kg	3125	2536.8	2.5	2
Nitrogen fertilizer	Kg	184	150.4	43.5	49
Diesel fuel	Kg	299	244	94.5	98.5
Other expenses	1000 UZS	76	62.4	34	32.5

The DEA model is categorized by location (pooled sample and two provinces), crop-grown area, and bonitet scores, under CRS and VRS technologies. The bonitet score is a composite soil fertility index, which includes several soil related indicators. It is expressed as an index on a scale of 1 to 100. The farmer gets the bonitet value of land when he leases it from the state. The larger the index value, the more fertile is the land.

The findings are presented in the next section. The study utilized the FEAR package introduced by Wilson [21] in the R platform and Stata 12 for the analysis.

4. Results and Discussion

4.1. Technical Efficiency

The results are presented in Table 2. In the first and second columns, findings from TE_{crs} and TE_{vrs} technologies are shown. The third column reports the percentage of farms that constitute a frontier under TE_{vrs} . The fourth column reports the bias corrected TE_{vrs} which was derived using a single bootstrapping procedure as described by Simar and Wilson [19]. The fifth and sixth columns show confidence intervals (CIs) of bias corrected TE_{vrs} . In all cases, the bias-corrected TE_{vrs} are less than the original ones. It shows that the initial TE_{vrs} scores are overestimated, which in turn leads to bias results.

Table 2. Technical efficiency estimates.

	Initial TE_{CRS}	Initial TE_{VRS}	% of farms with TE_{VRS} = 1	Bias- Corrected TE_{VRS} Single	Lower- Bound 95% CI Single	Higher- Bound 95% CI Single
Potato Producing Farms						
Location						
Pooled Sample	0.63	0.67	8.43	0.59	0.58	0.66
Khorezm Region	0.64	0.68	9.57	0.59	0.57	0.67
Fergana Region	0.68	0.75	25.4	0.68	0.65	0.76
Grown Area						
Up to 1.0	0.67	0.73	34.62	0.64	0.62	0.72
1.1 and Above	0.64	0.74	24.1	0.60	0.59	0.73
Bonitet Score						
Up to 50.0	0.80	0.80	33.33	0.71	0.67	0.79
51.0–60.0	0.63	0.66	7.46	0.55	0.54	0.65
61.0 and Above	0.69	0.75	14.67	0.66	0.63	0.74
H-W Melon Producing Farms						
Location						
Pooled Sample	0.78	0.84	29.66	0.76	0.72	0.83
Khorezm Region	0.82	0.85	33.9	0.77	0.73	0.85
Fergana Region	0.81	0.91	51.85	0.80	0.73	0.90
Grown Area						
Up to 1.0	0.78	0.84	28.68	0.75	0.71	0.83
1.1 and Above	0.86	1.00	89.00	0.99	0.98	1.00
Bonitet Score						
Up to 50.0	0.83	0.88	52.78	0.75	0.69	0.87
51.0–60.0	0.79	0.86	36.96	0.75	0.69	0.85
61.0 and Above	0.86	0.91	44.44	0.85	0.80	0.91

Results from the pooled sample show that TE (under VRS and CRS) is lower in the case of potato producing farms. Since the highest efficiency is obtained at a score of 1.0, the findings indicate room for efficiency gains with the current technologies, especially in potato production. Constructing the production frontier for each region brings about similar results, but with varying efficiency scores. Fergana has a higher TE_{vrs} than farms in Khorezm in the production of potatoes and H-W melons. This

suggests that there is a provincial divide in resource utilization in the country. Results indicate that most of the productivity gap arises from the inefficient use of inputs, which could be because of social, demographic, economic, organizational and institutional constraints. When the study categorized the crop-grown area into two size groups and estimated efficiency, results in potato production did not change as greatly as in H-W melon production. This suggests that H-W melon farms remain inefficient because of problems related to farming and because of the scale of operations. When crops are categorized by bonitet levels, a difference across the three bonitet groups varies in both crops.

The initial TE_{vrs} results are bootstrapped to improve the robustness of the results and are reported in the fourth column (Table 2). Findings show that the initial results are considerably different in all cases across all categories except the potato growing area. When efficiency scores in the category of the potato growing area are compared, TE is slightly higher (0.64 *versus* 0.60) in the group with a potato growing area of one ha or less. The difference between the initial and bias corrected efficiency scores is also highest in this group (0.74 *versus* 0.60). This also suggests that potato farms are the most inefficient farmers in the given sample. All these results illustrate how much output can be increased if farm resource endowments are used efficiently, following a best-practice farmer. It should be noted that policy recommendations must be based on bias corrected efficiency scores, because of the large differences between the two indicators (initial *versus* bias corrected). For instance, the initial TE_{vrs} for the pooled sample in potato and H-W melon production suggest that farms could increase their output by 49.2% and by 19%, respectively, if full efficiency were achieved, whereas, the bias-corrected TE_{vrs} estimates suggest output expansion in the order of 19% and 32% under a given input set and technology. Similar comparisons can be illustrated in the case of other categories.

4.2. Scale Efficiency

The results from conventional DEA reported in Table 3 illustrate the percentage of farms with IRS, DRS and CRS technologies. The farmers in Fergana have some scaling problems in the production of potatoes and H-W melons, with the SE of 0.89 and 0.90, respectively. This indicates that farmers have to concentrate more on improving the management of crop production, while farmers in Fergana must also increase their SE. Findings show that farms in both regions mostly operate under DRS.

Table 3. Scale efficiency estimates (% of farms).

	Khorezm Region (North-Western)				Fergana Region (Eastern)			
	SE	SE = 1	DRS	IRS	SE	SE = 1	DRS	IRS
Potatoes	0.96	39.1	53.9	7	0.89	9.5	74.6	15.9
H and W Melons	0.96	35.6	39.8	24.6	0.9	29.6	48.1	22.2

4.3. Factors Explaining Differences in DEA Efficiency Scores

The results of the truncated ML regression are reported in Table 4. As Simar and Wilson [17] point out, explanatory variables with a positive sign in the double bootstrapping models reflect a negative effect on TE_{vrs} , while positive coefficients reflect negative impacts on TE_{vrs} . Appendix Table A1

describes variables used in the regression model. The study checked explanatory variables for collinearity using the correlation matrix. In the case of potato production, the variable “chemicals” has a strong correlation with the variable “bonitet score”. This suggests that farmers extensively use chemicals on low fertility lands. Since weeding is a major problem on the lands with low bonitet scores, this could be the one reason.

Moreover, in the case of H-W melon producing farms, the variable “obsolete canal” had a high correlation with the variable “farm size”, which suggests that large farms had less obsolete canal conditions. Since yield losses from large farms can be substantial, H-W melon producing farms invest capital to maintain adjacent canals. Because of high correlation, the study excluded the “chemicals” variable from the regression related to potato and the “obsolete canal” variable from the regression related to H-W melon production.

Table 4. Results from the double bootstrapping procedure.

Variable	Potato		H–W Melons	
	Parameter Estimate (S.E.) (95% C.I.)		Parameter Estimate (S.E.) (95% C.I.)	
Constant	4.229 ***		1.91 ***	
	0.579		0.342	
Region	3.108	5.349	1.288	2.892
	0.115		0.141	
Bonitet score	0.189		0.134	
	−0.243	0.444	−0.289	0.398
Farm size	−0.017 **		−0.011 **	
	0.007		0.005	
Water availability	−0.0321	−0.004	−0.019	0.05
	−0.009 *		0.004	
Crop diversification index ^a	0.005		0.003	
	−0.018	0.002	−0.01	0.01
Dependency ratio ^b	−0.711 ***		−0.326 ***	
	0.239		0.117	
	−1.149	−0.254	−0.535	1.956
	−0.452 **		−0.079	
	0.182		0.097	
	−0.798	−0.115	−0.227	0.226
	−0.416 **		−0.103 *	
	0.175		0.061	
	−0.769	−0.1	−0.203	0.569

Table 4. Cont.

Variable	Potato		H-W Melons	
	Parameter Estimate (S.E.) (95% C.I.)		Parameter Estimate (S.E.) (95% C.I.)	
Potential to work in larger land area	-0.064 *		0.109	
	0.035		0.105	
Distance to market	-0.13	0.004	-0.304	0.341
	-0.173 *		0.0001	
Chemicals	0.097		0.018	
	-0.343	0.034	-0.039	0.049
Obsolete canal			0.248 **	
	0.057		0.113	
	0.173		-1.423	0.451
	-0.278	0.368		

Note 1: ***, **, * indicates significance at the 1%, 5%, 10% levels, respectively; Note 2: ^a The study used the Shannon diversity index to capture farmer’s crop diversification and it is calculated by the following formula:

$$\text{Shannon diversity index} = -\sum_{i=1}^J (P_i * \ln P_i) \tag{7}$$

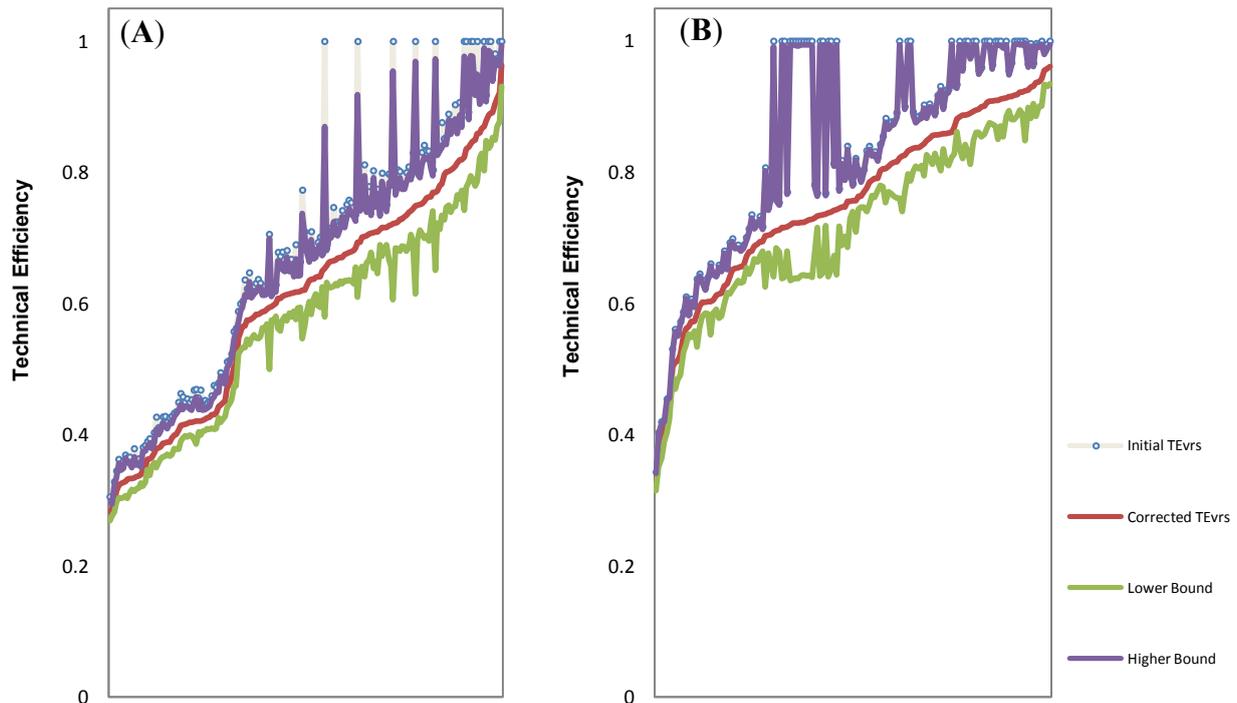
The symbol *J* stands for the number of grown crops. The term *P_i* is the proportion of the area used for a particular crop. *ln* is the natural logarithm. An index is zero if there is only one crop. It increases with the number of cultivated crops; Note 3: ^b Ratio of family dependents aged below 15 and above 60 compared to the number of family adults who are of working age.

In Figure 1, farms are ranked from the lowest to the highest bias-corrected *TE_{vrs}* (see the continuous and smooth red line). CIs are illustrated with purple and green lines, whereas initial *TE_{vrs}* are shown with a dot. Strong accuracy is provided with the CIs, which can be observed in the wide interval estimates. It is also found that the initial *TE_{vrs}* do not provide a smooth line as it does in the case of bias-corrected *TE_{vrs}*.

The results from the truncated regression disclose some remarkable findings. The relationship between efficiency and bonitet score are positive and significant in both cases. In good fertile lands, farmers achieved higher *TE_{vrs}* in the production of potato and H-W melons. Since these are the cash food crops, which are in high demand by the population, farmers tried to use inputs in the most efficient way.

The effect of farm size is significant and positively correlated with efficiency in potato production, which implies that large farms are better able to manage their resources. Farmers who report positive relationship with *TE_{vrs}* also illustrate positive correlation with the willingness to work on larger farm lands. This shows the farmers’ tendency to obtain more land from the state. Since land is a very valuable asset in rural areas, having more land increases the wealth of rural households. The study also finds that access to irrigated water is positively correlated with efficiency which underlines the importance of WUAs that provide enhanced access to irrigation water. WUAs have the responsibility of delivering irrigated water to farm gates and monitor the irrigation flow to farm fields. However, water delays are common [22] because of administrative and financial barriers.

Figure 1. Initial and bias corrected Technical efficiency scores (A) Potato farms (B) H-W melon farms.



The relationship between the crop diversification index and TE_{vrs} is positive and significant in the case of potato production. The results show that farmers with a larger index are more efficient in the use of resources. This may be related with the fact that farmers who diversified their crop portfolio had additional income, which could be used in the purchase of high quality inputs. It also allows for investing in land and employing mechanization services on time. It gives a chance to get additional labor during the season and harvest period for weeding and other agronomic activities.

Farmers who have higher dependency ratios also achieved higher TE_{vrs} in potato and H-W melon production. Relatively larger income generation from these crops and the larger consumption of potatoes and H-W melons by families may increase the efficient use of resources. Since the production of these food crops are promoted by the state, farmers can obtain high yielding seeds from state organizations and apply for the privileged credit. These reasons provide incentives for big families to be efficient in the use of resources. Surprisingly, the variable related to market distance indicates that, as the market distance decreased, farmers display a more inefficient use of resources in the production of potatoes. It can be argued that farmers located in close proximity to local markets experience larger incentives to diversify their crop portfolio, which can lower TE_{vrs} in potato production. Moreover, closer location to markets creates job opportunities, which divert time from potato production to other activities. In the case of the use of chemicals in H-W melon production, it has a negative impact on TE_{vrs} . Chemicals are one of the inputs that are very expensive to obtain. Since they also require additional labor and technologies, more finances are required from the farmer. While, in general, the application of chemicals may increase H-W melon yields, the use of chemicals in substantial amounts may worsen the conditions of land. This decreases the productivity of H-W melons.

5. Conclusions

The extended methodology illustrates that the use of DEA (with the double bootstrapping method) as a benchmark to set up frontier farmers from a given sample is a useful approach. The study shows that farms have the potential to increase yields by improving resource use efficiency with the given agricultural technology. The results demonstrate that the TE_{vrs} among farmers differs across categories. The bias corrected TE_{vrs} is 0.76 and 0.59 in H-W melon and potato producing farms, respectively. This reveals that output levels could be increased by 32% and 19% using the same amounts of inputs in the production of H-W melons and potato. Since efficiency is lower in potato production in comparison to H-W melon production, there is a need to improve the management of potato production and farmers' knowledge in its cultivation. In terms of the scale of operations, most of the farmers achieved SE, but not TE_{vrs} . This indicates that inefficient management practices contribute more than the farm size to technical inefficiencies. While not significant, farmers in Fergana are more efficient in the production of both potato and H-W melon, whereas farmers in Khorezm are more scale efficient. This shows a regional divide in terms of scale and technical efficiencies, which should be taken into account when making regional policies related to agriculture. Access to irrigation is critical for both crops, as it increases TE_{vrs} in crop production substantially. This suggests further improving conditions of canals and drainage systems. It also stresses the important role of WUA that is responsible for the smooth delivery of irrigation water to farm gates. Not surprisingly, farmers achieved higher TE_{vrs} in more fertile lands, which suggests that further actions should be taken towards preserving the soil quality and improving the land tenure system. The state should continue promoting crop diversification, as it helps farmers generate additional income, provides food security and reduces hunger. The significant dependency ratio and efficiency relationship also highlight the importance of these crops in consumption patterns of households and signals for better efficiency inducing policies.

Future research can concentrate on frontier efficiency analysis, both at the theoretical and empirical levels, in many ways. Since this study works with a static model in a cross-sectional setting, it describes the one particular equilibrium situation and ignores the inter-temporal dependence of farm decisions and alteration of variables over time. Future research can concentrate on dynamic models so that it is possible to understand how the behavior of farmers changes over time due to changing institutions and, most importantly, due to changing economical, political, and environmental policies.

Conflicts of Interest

The author declares no conflict of interest.

Acknowledgements

The research was conducted with the support of the ZEF/UNESCO Khorezm project "Economic and Ecological Restructuring of Land and Water Use in the Region Khorezm (Uzbekistan): A Pilot Project in Development Research" funded by the Federal Ministry of Education and Research (BMBF), Germany (Project Number 339970D) and implemented by the Center for Development Research/Zentrum für Entwicklungsforschung (ZEF), University of Bonn, Germany.

References

1. Bokusheva, R.; Hockmann, H.; Kumbhakar, S.C. Dynamics of productivity and technical efficiency in Russian agriculture. *Eur. Rev. Agric. Econ.* **2012**, *39*, 611–637.
2. Swinnen, J.F.M.; Vranken, L. Reforms and agricultural productivity in Central and Eastern Europe and the Former Soviet Republics: 1989–2005. *J. Prod. Anal.* **2010**, *33*, 241–258.
3. Wandel, J.; Pieniadz, A.T. What is success and what is failure of transition? A critical review of two decades of agricultural reform in the Europe and Central Asia region. *Post Communist Econ.* **2011**, *23*, 139–162.
4. Center for Economic Research (CER). *Almanac of Uzbekistan 2011*; Print Media: Tashkent, Uzbekistan, 2011.
5. Olimjanov, O.; Mamarasulov, K. Economic and Social Context of the Vegetable System in Uzbekistan. In *Increasing Market Oriented Vegetable Production in Central Asia and the Caucasus through Collaborative Research and Development*; Kalb, T., Mavlyanova, R.F., Eds.; AVRDC publication: Tashkent, Uzbekistan, 2006; pp. 91–95.
6. Amara, N.; Traoré, N.; Landry, R.; Romain, R. Technical efficiency and farmers' attitudes toward technological innovation: The case of the potato farmers in Quebec. *Can. J. Agric. Econ.* **1999**, *47*, 31–43.
7. Adewumi, M.O.; Adebayo, F.A. Profitability and technical efficiency of sweet potato production in Nigeria. *J. Rural Dev.* **2008**, *31*, 105–120.
8. Nyagaka, D.O.; Obare, G.A.; Omiti, J.M.; Nguyo, W. Technical efficiency in resource use: Evidence from smallholder Irish potato farmers in Nyandarua North District, Kenya. *Afr. J. Agric. Res.* **1984**, *5*, 1179–1186.
9. Ibrahim, U.W. Analysis of Production Efficiency and Profitability of Watermelon in Kaga and Kukawa Local Government Areas of Borno State. Master Thesis, Ahmadu Bello University, Zaria, Nigeria, 2011.
10. Charnes, A.; Cooper, W.W.; Rhodes, E. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* **1978**, *2*, 429–444.
11. Charnes, A.; Cooper, W.W.; Karwan, K.R.; Wallace, W.A. A chance-constrained goal programming model to evaluate response resources for marine pollution disasters. *J. Environ. Econ. Manag.* **1979**, *6*, 244–274.
12. Charnes, A.; Cooper, W.W.; Rhodes, E. Evaluating program and managerial efficiency: An application of data envelopment analysis to program follow through. *Manag. Sci.* **1981**, *27*, 668–697.
13. Banker, R.D.; Charnes, A.; Cooper, W.W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Manag. Sci.* **1984**, *30*, 1078–1092.
14. Farrell, M.J. The measurement of productive efficiency. *J. R. Stat. Soc.* **1957**, *120*, 253–290.
15. Shephard, R.W.; Gale, D.; Kuhn, H.W. *Theory of Cost and Production Functions*; Princeton University Press: Princeton, NJ, USA, 1970.
16. Coelli, T.J.; Prasada Rao, D.S.P.; O'Donnell, C.J.; Battese, G.E. *An Introduction to Efficiency and Productivity Analysis*, 2nd ed.; Springer: New York, NY, USA, 2005.

17. Simar, L.; Wilson, P.W. Estimation and inference in two-stage, semi-parametric models of production processes. *J. Econom.* **2007**, *136*, 31–64.
18. Simar, L.; Wilson, P. Sensitivity analysis of efficiency scores: How to bootstrap in nonparametric frontier models. *Manag. Sci.* **1998**, *44*, 49–61.
19. Simar, L.; Wilson, P.W.A. General methodology for bootstrapping in non-parametric frontier models. *J. Appl. Stat.* **2000**, *27*, 779–802.
20. Greene, W.H. The Econometric Approach to Efficiency Analysis. In *The Measurement of Productive Efficiency and Productivity Growth*; Fried, C.A.H., Lovell, K., Schmidt, S., Eds.; Oxford University Press: Oxford, UK, 2008; pp. 92–250.
21. Wilson, P.W. FEAR: A software package for frontier efficiency analysis with R. *Socio. Econ. Plan. Sci.* **2008**, *42*, 247–254.
22. Tischbein, B.; Awan, U.K.; Abdullaev, I.; Bobojonov, I.; Conrad, C.; Jabborov, H.; Forkutsa, I.; Ibrakhimov, M.; Poluasheva, G. Water Management in Khorezm: Current Situation and Options for Improvement (Hydrological Perspective). In *Cotton, Water, Salts and Soums—Economic and Ecological Restructuring in Khorezm, Uzbekistan*; Martius, C., Lamers, J.P.A., Vlek, P.L.G., Eds.; Springer: Heidelberg, Germany, 2012; pp. 69–92.

Appendix

Table A1. Summary statistics of farm characteristics for DEA model.

Variable	Unit	Potatoes		H-W Melons	
		Mean	SD	Mean	SD
Farm Characteristics					
Region	Dummy (Khorezm = 1; Fergana = 0)	0.65	0.48	0.81	0.39
Bonitet score	Index (1-100)	59	12	60	12
Farm size	Ha	17.3	19	14.6	17.5
Water availability	Dummy (Received Enough Water = 1; Not Enough = 0)	0.66	0.47	0.7	0.46
Crop Diversification index	Index	0.64	0.43	0.79	0.85
Dependency ratio	Ratio	1.09	1	1.1	0.94
Potential to work in larger land area	Dummy (Yes = 1; No = 0)	0.54	0.5	0.57	0.5
Chemicals	Dummy (Yes = 1; No = 0)	0.54	0.5	0.63	0.49
Obsolete canal	Dummy (Yes = 1; No = 0)	0.63	0.48	0.52	0.5
Distance to market	Km	9.61	2.63	9.86	2.92