Effects of Field Characteristics and Management on Technical, Allocative, and Economic Efficiency of Rice Production in Arkansas

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Abstract

Arkansas is the top domestic rice producer, representing nearly half of total U.S. rice production.

Rice is a high-cost crop relative to other field crops in Arkansas, and production costs for rice

have increased significantly since the mid 2000s due to rapidly increasing fuel and fertilizer

prices. More efficient rice production management is pertinent to maintaining long term

profitability. This study assesses the important factors leading to higher technical, allocative, and

economic (cost) efficiency in rice production using a Tobit model. The data is obtained from the

2005-2011 Rice Research and Verification Program (RRVP). Using a Clearfield hybrid seed was

found to have positive statistically significant effect, as well as relatively large marginal effect on

all three efficiencies.

Introduction

Historically, rice has been of great importance for the Arkansas economy. Arkansas is the top

domestic rice producer, representing nearly half of total U.S. rice production. In 2011

approximately 1.15 million acres of rice were harvested in Arkansas, yielding approximately

67.7 cwt/ac and producing about 78.1 millions cwt of rice. Arkansas's 2011 rice production was

valued at approximately $1.1 billion (USDA, NASS 2012). Rice however is a high-cost crop

relative to other field crops in Arkansas, and production costs for rice have increased

significantly since the mid 2000s due to rapidly increasing fuel and fertilizer prices. Figure 1., shows the increasing trend of fertilizer and fuel prices in the United States in the past decade.

Figure 1: U.S. Historical fertilizer and fuel expenses (2011 Dollars)
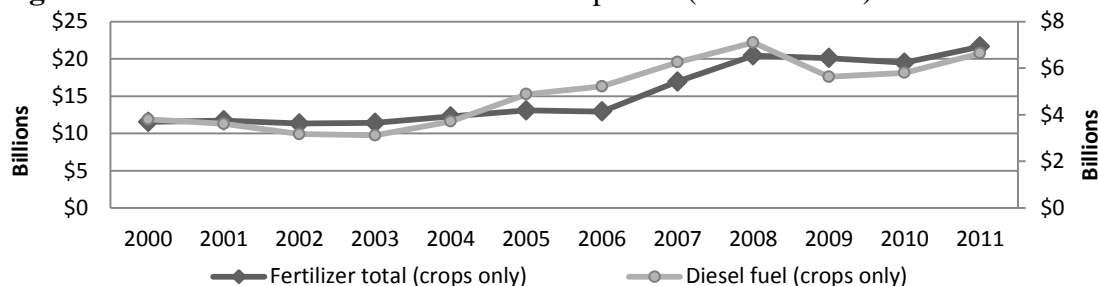
Rice has the highest cost of production inputs of $550.92/acre (Flanders and Dunn, 2012). Production inputs include: seeds, fertilizers, chemicals, custom applications, diesel fuel, electricity, supplies, surveying levees, and labor, but the greatest portion of the costs in rice production comes from fertilizer and fuel costs.

More specifically, 2011 Rice Research and Verification Program (RRVP) study (Runsick et al., 2011) found the average operating expense for the 17 participating fields (used in this analysis) to be $616.56/acre. Fertilizers & nutrients accounted for the largest share of operating expenses on average (23.5%) followed by seed (14.2%), chemicals (13.6%) and irrigation energy costs (12.3%). Although seed's share of operating expenses was 14.2% across the 17 fields, it's average cost and share of operating expenses varied depending on whether a Clearfield hybrid variety was used ($141.33/acre; 22.1% of operating expenses), a Clearfield non-hybrid variety was used ($116.04/acre; 17.3% of operating expenses), or a non-Clearfield, non-hybrid variety was used ($39.13/acre; 6.8% of operating expenses).

Given the increasing input costs rice producers are required to use production inputs in the most efficient manner to minimize production costs and remain profitable. This analysis seeks to identify how different management practices and field characteristics affect technical,

3

allocative, and economic (cost) efficiency of rice production in Arkansas. Technical efficiency refers to using minimum inputs to produce a given level of output. Allocative efficiency occurs when inputs for a given level of output and a set of input prices are chosen to minimize the cost of production assuming the organization is fully technically efficient. Economic (cost) efficiency is the product of both technical and allocative efficiency and refers to the production of a given quantity of output at the minimum possible cost.

This analysis will provide better evidence supporting the use of specific management practices in rice production. Rice producers currently make management decisions based on agronomic factors (high yield, good disease resistance, ease of management). The analysis will provide rice producers with stronger information about the types of management practices and field conditions that improve economic (cost) efficiency in the form of a more efficient combination of inputs and lower input costs.

Data and Methods

This study uses RRVP data for 137 rice fields enrolled in the University of Arkansas RREC for the period 2005 – 2011. There are seventeen 2011 fields, twenty two 2010, 2009, 2008 and 2005 fields (each), twelve 2007 fields, and twenty 2006 fields. Efficiency scores for the three efficiency measures are calculated using Data Envelopment analysis (DEA), which is a non-parametric, linear programming approach that measures relative efficiency among a set of decision making units (rice fields in this case). The DEA approach was used and described in another paper Watkins et al. (2012). This paper uses a censored Tobit model to determine the impacts of field characteristics and management practices on each efficiency measure. The efficiency measures were provided by Watkins et al. (2012). The DEA approach followed by a

Tobit model has been extensively used in the past to calculate efficiency scores and analyze the factors that affect different efficiencies.

Kiatpathomchai S. (2008), implemented the same technique DEA followed by a Tobit analysis to assess the economic and environmental efficiency of rice production systems in southern Thailand. This study estimated three efficiency frontiers efficiency, economic and environmental. It was found that farm size and province had positive statistically significant effect while rice variety had negative statistically significant effect on the technical efficiency frontier. Province and rice variety had the same effect on the economic frontier as well.

Brázdik (2006) also assessed the factors affecting efficiency of West Java rice farmers using DEA and Tobit approach, to estimate technical efficiency scores and to explain the variation in the efficiency scores related to farm-specific factors, respectively. The paper found that farm size has negative statistically significant effect on efficiency but the quadratic term can have a positive effect if the size is above the threshold level.

Dhungana, Nuthall and Nartea (2004) analyzed the economic inefficiency of Nepalese rice farmers using the DEA and Tobit approach as well. After using data envelopment analysis of the sample of 76 Nepalese rice farmers the respective average relative economic, allocative, technical, pure technical and scale inefficiencies were found to be 34, 13, 24, 18 and 7 per cent. The only statistically significant factors that affect economic and technical inefficiency were age (its square term) and education. These had the following effect negative (positive) and positive. Education was also found to have a positive statistically significant effect on pure technical efficiency, while the risk attitude was found to have a negative statistically significant effect on the allocative efficiency.

Wu and Prato (2006) also used cost frontier approach to investigate productive efficiency for a sample of Missouri (specialized) crop-only and (diversified) integrated crop-livestock farms. Results suggest that on average diversified farms were as technically and scale efficient as specialized farms however the lower allocative efficiency diluted the technical efficiency gains resulting in greater cost inefficiency for diversified farms than for specialized farms. Farm size was found to have statistically significant impact on allocative (negative), scale (positive), and scope (positive) efficiencies. Hired labor was found to have statistically significant effect on all efficiencies; positive on overall, technical and allocative efficiency, and negative on scope and scale efficiency. Land ownership was found to have negative statistically significant effect on technical and allocative efficiency. Returns to assets was found to have negative statistically significant effect on overall, technical, allocative and scope efficiency. Farm type had a positive statistically significant only on overall and allocative efficiency. The analysis showed that an increase of 1 % in allocative efficiency results in a \$2,433 increase in annual net farm income. Following the DEA approach used to calculate the efficiency scores a Tobit model was used to analyze the determinants affecting efficiency scores. Tobit model was used because of the nature of the dependant variables which are in the 0 to 1 range, which requires a two limit model such as the censored Tobit. The model was first proposed by Tobin in 1958.

The Tobit model is specified as follows (Greene, 2001):

$$y_i = \beta' x_i + \varepsilon_i$$
if $\beta' x_i + \varepsilon_i > 0$ and 0 if not
$$z_i = 1 \text{ if } y_i^* > 0 \text{ and 0 if not}$$
where,
y_i is the latent or dependant variable
β' is the parameter to be estimated
x_i are the independent variables or regressors
ε_i is the error term, assumed to be normally distributed

z_i is the censoring indicator

According to Greene (2001) marginal effects for the Tobit model are estimated as follows:

$$\frac{\partial E[y|x]}{\partial x} = \beta \Phi \left(\frac{\beta'x}{\sigma} \right)$$

Following Dhungana et al.(2004) the marginal effects for the binary variables in this model are calculated as follows:

$$E(y|x_i = 1) - E(y|x_i = 0)$$

The maximum likelihoods for β are obtained by maximizing the log likelihoods (Woolridge, 2006). The log likelihood for the censored regression model is defined as follows (Greene, 2001):

$$lnL = -\frac{n_1}{2}(\ln(2\pi) + ln\sigma^2) - \frac{1}{2\sigma^2} \sum_1 (y_1 - \beta'x_i)^2 + \sum_0 \ln[1 - \Phi(\frac{\beta'x_i}{\sigma})]$$

The model for this analysis is defined as:

$$y_i^* = \beta_0 + \sum_{m=1}^{k} \beta_m x_{im} + \varepsilon_i \, , \, \varepsilon_i \sim IN(0, \sigma^2)$$

where,

y_i^* is latent variable representing technical, economic (cost), or allocative efficiency score of field j;

β is a vector of unknown parameters;

x_{im} is a vector of explanatory variables m (m = 1,…, k) for field i which is known constant and hypothesized as determinants of efficiency;

μ_i is an error term that is independently and normally distributed, with mean zero and a constant variance σ^2.

z_i the censoring indicator is set between 0 and 1

The independent variables are the same in the three models, while the dependant variable changes between technical, economic (cost), and allocative efficiency, assuming variable returns to scale for all efficiency scores.

Table 1 provides a complete description of all variables used in the analysis.

Table 1: Descriptive analysis of variables used

Acronym	Description	Mean	StDev	CV	Min	Max
TEVRS	Technical Efficiency assuming Variable Returns to Scale	0.89	0.16	17.48	0.46	1
EEVRS	Economic (Cost) Efficiency assuming Variable Returns to Scale	0.62	0.19	30.20	0.32	1
AEVRS	Allocative Efficiency assuming Variable Returns to Scale	0.70	0.16	22.45	0.32	1
FLDSIZE	Field Size (acres)	61.14	33.08	54.11	9	183
YR11	Year 2011	0.12	0.33	269.12	0	1
YR10	Year 2010	0.17	0.38	223.44	0	1
YR09	Year 2009	0.16	0.37	229.75	0	1
YR08	Year 2008	0.17	0.38	223.44	0	1
YR07	Year 2007	0.08	0.27	349.19	0	1
YR06	Year 2006	0.14	0.35	251.52	0	1
YR05	Year 2005	0.17	0.38	223.44	0	1
NE	Northeast (NASS Crop Reporting District 3 counties)	0.37	0.49	129.86	0	1
CW	Central West (Grand Prairie counties of Arkansas, Lonoke, and Prairie in NASS Crop Reporting District 6 counties)	0.20	0.40	201.73	0	1
CE	Central, East (Non Grand Prairie counties in NASS Crop Reporting District 6 counties)	0.19	0.39	206.70	0	1
SE	Southeast (NASS Crop Reporting District 9 counties)	0.15	0.36	236.49	0	1
OL	Other Location (Non-eastern Arkansas counties)	0.08	0.28	331.56	0	1
CONV	Conventional Variety	0.47	0.50	107.53	0	1
MG	Medium Grain Variety	0.09	0.29	316.12	0	1
CL	Clearfield Variety	0.10	0.30	302.44	0	1
HYB	Hybrid Variety	0.07	0.25	369.59	0	1
CLHYB	Clearfield Hybrid Variety	0.27	0.45	163.07	0	1
SLOAM	Silt Loam Soil Texture	0.63	0.49	77.60	0	1
CLAY	Clay Soil Texture	0.37	0.49	129.86	0	1
SB	Previous crop was Soybeans	0.66	0.47	71.39	0	1
RICE	Previous crop was Rice	0.23	0.42	184.19	0	1
OCROP	Previous crop was neither soybeans nor rice (corn, grain sorghum, fallow)	0.11	0.31	290.20	0	1
CONTUR	Contour Levee field topography	0.42	0.50	118.00	0	1
STRAIT	Straight Levee field topography	0.47	0.50	107.53	0	1
ZERO	Zero-Grade Field topography	0.11	0.32	279.16	0	1
WELL	Irrigation water supplied by well	0.82	0.39	47.54	0	1
SURFACE	Irrigation water supplied by surface water source	0.18	0.39	211.96	0	1
MI	Field has Multiple Inlet Irrigation	0.32	0.47	146.13	0	1
NOMI	Field does not have Multiple Inlet irrigation	0.68	0.47	68.96	0	1

The following variables were omitted from the model as those are base comparisons: year 2011 (YR11), Central West geographical region (CW), conventional variety of rice (CONV), silt loam

soil (SLOAM), previous crop soybeans (SB), contour levees (CONTUR), well irrigation (WELL), and not multiple inlet (NOMI).

The effect of field size on efficiency scores is important because it is significant to know the optimal filed size to achieve the optimum efficiency. Given management practices experience has shown farms of about 50 acres tend to be the most efficient to manage. Years 2005-2011 are expected to capture mainly the weather effects and special conditions of each year, therefore compared to 2011, it is expected for years 2005 and 2010 to have a negative impact whereas 2008 is expected to have a positive statistically significant impact on efficiency scores. Years 2005 and 2010 were years with extremely dry weather conditions, while in 2008 crop prices skyrocketed. The different geographical regions will provide good comparison of efficiency scores compared to Grand Prairie Counties (Central West). Rice varieties such as hybrid and Clearfield hybrid are expected to have a positive effect on all efficiencies compared to the conventional varieties due to higher rice yields. Clay soil texture is expected to have a negative effect on efficiency scores relative to silt loam soil. Rice grown on clay soil requires more nitrogen than rice grown on silt loam soil. Previous field crop being rice or any other crop (except soybeans) in the rotation is expected to have a negative effect on efficiency scores compared to cases when the previous crop was soybean. The rice-soybean rotation has been proven to the most profitable. Straight levees and zero-grade are expected to have a positive impact on efficiency scores relative to contour levee. Both zero-grade and straight levee fields are precision leveled to allow for better water delivery than contour levees. Surface irrigation is expected to have a positive impact on efficiency scores compared to well irrigation, because pumping cost for a surface water source is less than from a well. Multiple inlet irrigation is expected to have positive impact on all efficiency scores. Multiple inlet irrigation uses poly pipe

to distribute irrigation water to all paddies simultaneously and allows the field to be flooded up much faster than conventional flood irrigation.

Results/Expected Results

The analysis was conducted using Stata statistical software. Six fields were excluded from the final analysis due to having sandy soil texture (two fields) and furrow irrigation (four fields), resulting in final 131 fields/observations.

Table 2: Tobit regression coefficients (n = 131)

Independent Variables	Regression coefficients β (Standard Errors)		
	TEVRS	EEVRS	AEVRS
FLDSIZE	-0.0017**	-0.0003	0.0003
	(0.0008)	(0.0003)	(0.0003)
YR10	-0.0800	-0.1395***	-0.1367***
	(0.0891)	(0.0326)	(0.0378)
YR09	0.2642**	0.0855**	-0.0089
	(0.1025)	(0.0332)	(0.0385)
YR08	0.4088***	0.1630***	0.0308
	(0.1262)	(0.0369)	(0.0428)
YR07	0.1873	0.0222	-0.0568
	(0.1306)	(0.0429)	(0.0497)
YR06	0.1461	-0.0247	-0.1005**
	(0.1113)	(0.0383)	(0.0445)
YR05	0.0495	-0.1297***	-0.1591***
	(0.1087)	(0.0381)	(0.0443)
NE	0.0820	0.0278	-0.0050
	(0.0695)	(0.0233)	(0.0271)
CE	0.0696	-0.0254	-0.0509
	(0.0808)	(0.0274)	(0.0319)
SE	0.0781	0.0066	-0.0304
	(0.0990)	(0.0331)	(0.0385)
OL	0.0143	-0.0610	-0.0985**
	(0.1131)	(0.0388)	(0.0450)
MG	0.1427	0.1956***	0.1215***
	(0.1093)	(0.0365)	(0.0424)
CL	-0.0342	-0.0110	0.0096
	(0.0979)	(0.0348)	(0.0404)
HYB	0.1604	0.2526***	0.2207***
	(0.1219)	(0.0357)	(0.0417)
CLHYB	0.1674**	0.1646***	0.1108***
	(0.0822)	(0.0250)	(0.0291)
CLAY	0.0176	-0.02348	-0.0337
	(0.0617)	(0.0200)	(0.0232)
RICE	-0.0043	-0.0576**	-0.0565*
	(0.0765)	(0.0256)	(0.0297)
OCROP	0.0240	-0.0039	-0.0037
	(0.0816)	(0.0279)	(0.0324)
STRAIT	0.0002	-0.0072	-0.0157
	(0.0592)	(0.0198)	(0.0229)
ZERO	0.0266	0.0923**	0.1004**
	(0.1227)	(0.0374)	(0.0435)
SURFACE	0.0257	-0.0080	-0.0337

	(0.0784)	(0.0256)	(0.0298)
MI	0.0241	0.0466**	0.0410*
	(0.0622)	(0.0197)	(0.0229)
Constant	0.8557***	0.5697***	0.7260***
	(0.1154)	(0.0405)	(0.0470)

Asterisks *,** and ***, represent 10, 5 and 1 % statistical significance

The results show that technical efficiency is positively and significantly affected by year 2009 and 2008 compared to year 2011. It is also positively and significantly affected by the usage of Clearfield Hybrid rice types compared with the conventional rice type. The only variable that has a negative statistically significant effect to the technical efficiency is field size.

Economic (cost) efficiency, same as technical efficiency, is positively and significantly affected by year 2009, and 2008 compared with year 2011. The used of medium grain, hybrid and Clearfield hybrid seed also has positive and significant effect compared conventional grain. Similarly, zero grade topography compared to contour levees and using multiple inlet irrigation compared to not using it has a positive and significant effect on economic efficiency. Economic (cost) efficiency was found to be negatively affected by the following statistically significant factors: year 2010 and 2005 compared to 2011, and when a previous crop is rice compared to soybeans.

Allocative efficiency is positively and significantly affected by the following factors: using medium grain, hybrid and Clearfield hybrid rice compared to conventional rice, zero-grade topography compared to contour levees and using multiple inlet irrigation compared to not using multiple inlet. Allocative efficiency scores were negatively affected by the following statistically significant factors: year 2010, year 2006, and year 2005 compared to 2011, by the geographical placement of the fields in the Other region (non Easter Arkansas counties) compared to the Central East (Grand Prairie Region), and when a previous crop is rice compared to soybeans.

Table 3 shows the marginal effects of each variable. The statistical software Stata was also used to calculate the marginal effects after each of the three Tobit models. For example, the

results indicate that an increase in farm size of one acre will cause the technical efficiency to decline by 0.002 efficiency units, and the economic (cost) and allocative efficiency to not change. The marginal effect for binary variables represents a discrete change when the binary variable changes from 0 to 1. Binary variables having positive effects on all three efficiency measures are the year 2008, hybrids, Clearfield hybrids, medium grain varieties, zero-grade, and multiple inlet irrigation.

Table 3: Marginal effects after Tobit regression

Independent Variables	TEVRS	EEVRS	AEVRS
FLDSIZE	-0.002	0.000	0.000
YR10*	-0.080	-0.140	-0.137
YR09*	0.264	0.086	-0.009
YR08*	0.409	0.163	0.031
YR07*	0.187	0.022	-0.057
YR06*	0.146	-0.025	-0.100
YR05*	0.049	-0.130	-0.159
NE*	0.082	0.028	-0.005
CE*	0.070	-0.025	-0.051
SE*	0.078	0.007	-0.030
OL*	0.014	-0.061	-0.099
MG*	0.143	0.196	0.121
CL*	-0.034	-0.011	0.010
HYB*	0.160	0.253	0.221
CLHYB*	0.167	0.165	0.111
CLAY*	0.018	-0.023	-0.034
RICE*	-0.004	-0.058	-0.056
OCROP*	0.024	-0.004	-0.004
STRAIT*	0.000	-0.007	-0.016
ZERO*	0.027	0.092	0.100
SURFACE*	0.026	-0.008	-0.034
MI*	0.024	0.047	0.041

(*) dy/dx is for discrete change of dummy variable from 0 to 1

Discussion

The results of the analysis were expected to provide better evidence supporting the use of specific management practices in rice production. Rice producers currently make management decisions based on agronomic factors (high yield, good disease resistance, ease of management). As expected, this analysis has proven that efficiency scores are negatively affected by dry years such as 2010 and 2005, by previous crop being any other crop than soybeans and positively affected by the use of multiple inlet irrigation, the use of hybrid and Clearfield hybrid rice seed types. The magnitude of the marginal effects of the factors also supports the fact that combining appropriate management practices such as using more efficient irrigation practices, specific types of seed, and the appropriate rotation crops will significantly increase the efficiency of rice production in the form of a more efficient combination of inputs and lower input costs.

Field size is an important factor affecting efficiency however, the fields included in the analysis range between 9 and 183 acres with a mean field size of about 61 acres. The average Arkansas rice farm is about 453 acres (Baldwin et al., 2011), implying that the fields participating in the RRVP may be what would be a sample size of a regular rice field, therefore the impact of this factor may be impacted by the field selection. Selecting the same fields and doing continuous research would be optimal however it is virtually impossible in real life.

The importance of irrigation practices in rice production has also been emphasized in this study as well in many other studies. This implies that future studies using correctly measured water usage will be of a great importance to both farmers and scientists.

Including more data observations is also something future studies could do, including data from 2000 till present will definitely provide better insight into the factors affecting efficiency cores.

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