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Abstract

Using a non-parametric linear programming approach, our contribution is (1) to examine the impact of incorporating risk in efficiency analysis and (2) to compare the efficiency measures with and without risk for continuous and rotation cropping systems. The model uses Nebraska cropping system data for the period, 1986-2000. Results indicate lower efficiency gains are realized with the incorporation of risk. The t-test at the 5% level of significance examining if efficiency measures are significantly different from one is also reported.

Incorporating Risk in Nonparametric Analysis

Any production related activity or event that is uncertain with probability is defined as risk. Production theory of the firm under risk is well developed and has been traditionally analyzed under price risk (Chambers, 1983; and Sandmo, 1971) or production risk (Just and Pope, 1978). In agriculture for decades, risk has been most strongly identified with production (income) risk and product price risk with less attention to input and input price risk. Variability in production (income) results in the inability to achieve goal. Over time, improvements in technology and production practices have helped decrease risks in agriculture by increase (decreasing) the first (second) moment of yields. Currently farmers deal with risk by controlling or minimizing risk through improved and efficient management practices; reduce variability by making changes such as diversifying and integrating applying updated technology; and finally they transfer production risk to someone else through contracting or purchasing crop insurance.

Here neoclassical production theory along with decision theory is applied to explore the impact of risk on agriculture producers who maximize utility and face production functions. Including risk in efficiency paradigm is relatively an unexplored area of research, specifically estimation of risk jointly with output production function. Data envelopment analysis (DEA), a nonparametric approach to the study of efficiency has had a relatively long history. M.J. Farrell discussed the empirical estimation of efficiency where there are multiple outputs and multiple inputs. The application made was to U.S. agriculture. Another analysis using farm survey data was published by Farrell and Fieldhouse (1962). In 1966 at the Western Farm Management Association four papers were presented (Bressler, Boles, Seitz, and Sitorus) related to issues of different components of efficiency and their measurement. In 1978 Data Envelope Analysis (DEA) was introduced by Charnes et al. and popularized in a more informative and applied way by Färe et al (1994). Lovell (1993) presented a selective overview of the existing techniques and models to estimate productive efficiency. Only recently has efficiency analyses of agriculture using DEA received renewed attention.

DEA utilizes input-output data of output and inputs to establish the efficiency frontier of the units under analysis. Each unit, whether the analysis is of public or private nature, can be evaluated relative to the unit frontier. Further, analysis of the factors leading to high efficiency is often also completed. These generally focus on factors such as unit size. Sometimes there is interest, however, in more specific management characteristics of high efficiency. These are largely vague in conventional DEA studies. It is to this issue of more specific management alternatives that this paper is directed.

Here, specific management aspects (cropping system alternatives) of a farm firm are used as the units upon which to estimate the DEA frontier as opposed to using firms as the DMU (Decision Making Unit). For each system resources required and output achieved are used in constructing the efficient frontier. This allows a general interpretation of the efficiency of alternative cropping systems without having the constraints of specific input-output relationships, price assumptions, and right hand sides used in conventional Linear Programming. Further, the focus of DEA is on efficiency rather than profit maximization. More specifically, attention is directed toward the issue of continuous cropping vs. rotation cropping. It is conventionally thought that rotation cropping is more efficient than continuous cropping because rotation cropping often leads to enhanced yields, reduced fertilizer applications, reduced annual inputs, and reduced capital and labor because peak crop demands for these inputs are reduced. Also, risk is considered to be lower for diversified cropping for which rotations qualify. Reduced risk is an efficiency paradigm, benefit under an assumption that decisions are made under risk aversion.

Risk is generally characterized as an objective perspective based on long run phenomena. In most cases a longer run data source is preferred over a shorter run one. On the other hand, changing technical and economic environments favor shorter run data sets. For example, crop yields of one hundred years ago as part of a crop yield data set can be argued to be irrelevant to a crop yield risk analysis. In addition risk in agriculture is sometimes suggested to be a changing phenomenon as technical and economic environments change. When the issue of behavioral responses to recent events is added the issue of risk, as a changing parameter is even more important. The "recent event" phenomenon suggests that risk is most strongly evaluated by the most recent events experienced. A current crop loss, for example, would be expected to strongly increase perceived risk compared to the same loss a decade ago.

For this reason the issue of the evaluation of the impact on cropping system efficiency of risk is evaluated here using risk as a long run objective variable as well as a shorter run measure giving greater weight to recent events. This is accomplished here using the entire length of the series to the point of analysis for the former and an annually adjusted short run risk measure for the latter. In the first case (termed cumulative) more recent time periods have a larger risk since an additional year is added to the risk calculation for each year of efficiency analysis.

Nonparametric Risk Model

The technology that transforms input vector $x = (x_1, \ldots\ldots, x_n)$ into desirable outputs (gross returns) $y = (y_1, \ldots\ldots, y_m)$ and risk (variation in gross returns) $r = (r_1, \ldots\ldots, r_o)$ can be represented by output set. The output set is effectively utilized in the computation of the risk accounted efficiency measure using the primal approach. Risk endogenized as an undesirable output with a weak disposability assumption is modeled to compute the efficiency measure. Under a weak disposability risk assumption, a reduction in risk requires a reduction in desirable output with a fixed input or requires an increase in input usage to maintain the same desirable output.

Following Fare et al. (1989, pp. 92-93), a weak disposal output reference set satisfying constant returns to scale, strong disposability of desirable outputs and inputs, and weak disposability of risk can be defined as:

(1) $$P_w^T(x) = \{ y : x \text{ can produce } (y_g, R) \text{ in year } T; \quad 0 \le \theta \le 1 \text{ implies } \theta(y_g, R) \in P_w^T(x), RN < R \Rightarrow \theta(y_g, RN) \in P_w^T(x) \},$$

where $P_w^T(x)$ is a weak disposable output set.

The weak disposable output set can be represented by the output distance function and the nonlinear programming problem used to calculate the output measure can be evaluated for each year *t* as:

$$(2) \qquad D_o^T(x^t, y_g^t, R^t)^{-1} = \max_{\theta,z} \{\theta: (x^t, \theta\, y_g^t, \theta^{-1} R^t) \in P_w^T(x^t)\}$$

or

$$\begin{aligned} \max_{\theta,z} \theta \quad s.t. \quad \theta\, y_g^t &\leq Y_g z & \text{where} \quad Y_g &= (y_g^1, y_g^2, \ldots, y_g^T) \\ \theta^{-1}\; n^t &= R\,z & R &= (r^1, r^2, \ldots, r^T) \\ x^t &\geq X\,z & X &= (x^1, x^2, \ldots, x^T) \\ z &\geq 0 \end{aligned}$$

From (2), ***z*** is a *{Tx1}* vector of intensity variables with $z \geq 0$ identifying the constant-return-to-scale boundaries of the reference set, and the equal sign on the second constraint indicates the weak disposability assumption on environmental pollution with a less than (greater than) sign representing the strong disposability of desirable output (input).

Cost of Production Data

A field trial experiment conducted in eastern Nebraska involving seven basic cropping systems allowed a DEA analysis to be performed (Varvel). Three continuously cropped systems were corn (C), grain sorghum (G), and soybeans (B). Two two-crop rotational systems were corn-soybeans (CB) and grain sorghum-soybeans (GB). Two four-crop systems involving corn, grain sorghum, soybeans, and oats differed from each other only in the sequencing of crops. The first was grain sorghum-soybeans-corn-oats (GBCO) while the second was corn-soybeans-grain sorghum-oats (CBGO). Three nitrogen fertilizer levels for nitrogen at 0, 80, and 160 lb./ac. for corn and grain sorghum and 0, 30, and 609 lb./ac. for soybeans and oats were involved in the overall yield response study. However, to keep the system analysis at manageable size, only data for the medium fertilizer level for each crop was used except for soybean for which zero nitrogen was used.

Nebraska average prices for 1984-98 were used to determine value of output (Wellman). Input costs (operating costs) were assembled from budget cost estimates for each year (Selley, et al.). One input and five inputs (not including risk) are utilized in the efficiency analysis. Fertilizer prices were secured from Agricultural Prices. Since the nitrogen rate for each system was held constant over the experimental period, the only variation in its cost is due to nitrogen prices. Nitrogen price changes are the same for all systems. Thus, nitrogen as an input was excluded from the analyses. Risk is defined as (1) continuous risk –annual standard deviation of gross income is computed with each additional year; and (2) moving risk –a four year moving standard deviation of gross income is computed. The underlying sample in the computation of continuous and moving risk seems to reflect the importance of accounting for only the last four years of variation (particularly the most recent) as supposed to all years up to this point. The definitions of the inputs and outputs are detailed in Table 1. All inputs and outputs are defined in inflation free levels.

The mean and standard deviation of input, output and risk variables used in the computation of efficiency measures is presented in Table 2. On an average, continuous-soybeans had higher field operations cost with the variation in the field operations was greater in grain sorghum-soybean rotation. Similarly higher average (variation) seed cost is observed for grain sorghum-soybeans-corn-oats rotation (soybeans). Higher mean and variation of chemical use (custom/rent) was observed in grain sorghum-soybeans (corn) rotation. In the case of labor, higher mean (variation) was observed in corn (grain sorghum-soybeans). In the case of outputs, higher mean and variation in gross income was observed in corn and grain sorghum respectively. Higher mean and variation in continuous (moving) risk was observed in grain sorghum-soybeans (corn-soybeans-grain sorghum-oats) rotation.

Empirical Application and Results

To examine the efficiency of continuous and rotation crop systems with and without risk, the output distance function defined in equations 2 is estimated for each cropping system. Table 3 presents the mean and standard deviation of efficiency measures with continuous and moving risk, and without risk of all the cropping system for the period, 1986-2000.

In general the mean efficiency measures of all cropping system seem to indicate reduced efficiency measures when accounting for risk. This indicates lower efficiency gains when risk is accounted in the efficiency estimation. Thus, risk does impact efficiency as is not neutral with respect to efficiency. A comparison between continuous cropping systems (corn, grain sorghum and soybeans), and two-crop rotational systems (corn-soybeans and grain sorghum-soybeans) and four-crop systems (grain sorghum-soybeans-corn-oats and corn-soybeans-grain sorghum-oats) indicates higher mean and variation of efficiency for continuous cropping systems. Specifically, the average mean and variation in efficiency measure of continuous cropping system (1.38 and 0.67) is higher than two-crop rotation system (1.24 and 0.36) and four-crop system (1.17 and 0.31) without risk included. Similar trend was observed with inclusion of moving risk, however with continuous risk, higher (identical) mean (variation) efficiency was observed by four-crop system of 1.12 compared to two-crop system of 1.10.

The ranking of most efficient to least efficient changes relatively little among the three risk settings. The three continuous systems generally are the most efficient followed by the two-crop systems that which includes corn and soybeans. The remaining two crop system as well as the two four-crop crop systems change in relative ranking depending on the risk setting. The only exception to this occurs for continuous corn for which its efficiency ranking crops when risk is defined in a cumulative manner. Continuous grain sorghum performs as the most efficient of all systems attesting to its low use of purchased inputs.

The results of the $t-$test examining the null hypothesis that the efficiency measures is equal to one are presented in Table 3. Based on the test statistic and $p-$value for the $t-$test at the 5% level of significance, this test indicates the mean efficiency measures without risk and with cumulative and moving risks are significantly different from one for continuous cropping systems of grain sorghum and soybeans. For corn-soybean (without risk), grain sorghum-soybeans (with cumulative risk) and grain sorghum-soybeans-corn-oats (without risk and cumulative risk) rotation, the efficiency measures are significantly different from one at 5% level of significance. At 10% level of significance, grain sorghum-soybeans (without risk and moving risk) and corn-soybeans-grain sorghum-oats (without risk and moving risk) rotation cropping systems the efficiency measures are significantly different from one at 10% level of significance.

Conclusions

Utilizing the non-parametric linear programming approach, theoretically and empirically we demonstrate -the inclusion of risk in the efficiency analyses would results in lower efficiency gains for continuous and rotation cropping systems. Further for this data, the continuous cropping systems seems to perform better (worse) than rotation cropping systems in terms of mean (variation) efficiency measures. This research is directed only at few continuous and rotation cropping systems for the state of Nebraska.

Where data is available the analysis completed here is useful technique in understanding gains from inclusion of risk. In integration traditional efficiency studies with risk, either aggregate or individual firm data can be employed. Bootstrapping techniques can also be employed in association with DEA analysis to provide still greater confidence regarding the conclusion of these analyses. In addition, a larger data set with greater disaggregation of inputs would aid in deriving broad conclusions.

Table 1. Definitions of the Output, Input and Risk Variables

Variables	Definitions
Output	
Gross Income	Experimental yield multiplied by average price received by year
Risk (cumulative)	Standard deviation for 1986 computed beginning with 1982-1985 gross income observations, the observations increase for each analysis year
Risk (moving)	Risk parameter defined as standard deviation is updated each analysis period by including the most recent gross income observations and deleting the mots distant from a four year data set
Input	
Field Operations	Estimated operating costs of all field operations
Seed	Estimated purchased seed cost
Chemicals	Estimated herbicide and insecticide costs
Custom/Rent	Assumed operations using custom operators or rented equipment
Labor	Estimated labor hours multiplied by an assumed wage rate per hour

Table 2. Mean and Standard Deviation of Output, Input and Risk Variables, 1986-2000 for all the Cropping Systems

Variables		C	G	B	CB	GB	CBGO	GBCO
FIELD OP	mean	80.71	75.61	81.04	79.07	76.98	78.69	78.69
	Std	16.39	18.09	16.76	18.61	19.28	15.84	15.84
SEED	mean	74.80	98.73	102.05	98.68	101.28	109.88	109.88
	Std	8.40	6.30	10.09	5.70	7.55	8.94	8.94
CHEM	mean	86.03	171.95	92.91	151.07	232.43	136.89	136.89
	Std	9.02	105.26	51.52	56.10	121.59	44.58	44.58
CUST/RENT	mean	132.11	85.34	115.88	128.49	94.99	101.30	101.30
	Std	39.40	15.44	36.48	26.31	16.76	14.39	14.39
LABOR	mean	101.36	87.08	93.24	85.05	83.20	89.26	89.26
	Std	7.51	7.71	10.13	12.39	13.35	6.33	6.33
GROSSI	mean	102.07	91.22	77.96	90.28	85.44	90.46	87.38
	Std	24.47	32.37	21.25	21.75	17.60	19.34	16.60
RISKC	mean	65.37	114.33	95.48	220.28	357.94	181.42	230.93
	Std	12.98	10.04	15.40	53.69	109.41	55.91	83.17
RISKM	mean	85.14	105.07	69.79	161.54	260.50	280.24	358.36
	Std	44.98	25.55	22.00	63.47	119.16	172.78	198.71

where GROSSI is the gross income, RISKC is the risk (cumulative) and RISKM is the risk (moving).

Table 3. Mean, Standard Deviation and T-test of Efficiency Measures, 1986-2000 for all Cropping Systems.

Year	C	G	B	CB	GB	CBGO	GBCO
Without Risk							
Mean	1.23	1.58	1.33	1.32	1.15	1.20	1.14
Stdev	0.61	0.94	0.45	0.40	0.31	0.39	0.24
t-test	1.42	2.39*	2.85*	3.11*	1.87**	1.97**	2.32*
With Cumulative Risk							
Mean	1.08	1.28	1.15	1.13	1.07	1.15	1.09
Stdev	0.28	0.41	0.22	0.32	0.12	0.29	0.15
t-test	1.17	2.59*	2.61*	1.54	2.46*	2.01**	2.44*
With Moving Risk							
Mean	1.14	1.36	1.16	1.14	1.12	1.08	1.01
Stdev	0.53	0.47	0.29	0.41	0.26	0.28	0.32
t-test	1.04	2.97*	2.18*	1.28	1.8**	1.17	0.15

where t-test reflect the if the efficiency measures are significantly different from one; *, ** represents significances at 5% and 10% respectively.