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# **Tillage Systems, Cropping Practices, Farm Characteristics and Efficiency**

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# **Tillage Systems, Cropping Practices, Farm Characteristics and Efficiency**

## **Abstract**

This paper examines the technical efficiency (TE) of a sample of farms in North-Central Kansas practicing conventional and no-till practices. A stochastic frontier production model with technical inefficiency effects is used to obtain individual farm TE values and to explain sources of technical inefficiency. The results indicate that TE is not impacted by no-till practices.

**Keywords: No-Till, Technical Efficiency, Stochastic Production  
Frontier**

## **Introduction**

Conservation tillage practices have gained rapid popularity since the early 1990s. The area under conservation tillage practices in the U.S. has increased from 26 percent in 1990 to 37 percent in 2002, while the area under no-till has increased from 6 percent to 20 percent (CTIC). The rapid growth in the adoption rates of no-till and the growing interest in general for reduction in tillage has been the result of a search for efficiency improvements and the growing importance of environmental concerns. The most commonly attributed economic benefits of switching over to no-till practices are the reduction in machinery costs, labor savings, and possible long-term productivity increases through increases in soil fertility. Increasing government budgetary expansions for conservation spending has also provided economic incentives for no-till adoption in marginal agricultural lands and those prone to soil erosion.

Though several agronomic studies (Schlegel et al.; Weisz and Bowman; Anderson et al.) have documented the effect of conservation tillage on crop yields, studies that examine possible productivity and efficiency gains are not prevalent. Economic studies related to conservation tillage have focused on adoption factors (Fuglie; Fuglie and Kascak; Soule, Tegene and Weibe; Gould, Saupe and Klemme; Rahm and Huffman) and risk (Williams, Llewelyn, and Barnaby; Williams; Helms, Bailey, and Glover).

This paper examines the technical efficiency of individual farm enterprises in North-Central Kansas practicing conventional and no-till practices. The crops considered in the study are wheat, sorghum, and soybean. Results are generated using cross-sectional (3-year average) and panel data and a stochastic frontier production function.

## **Empirical Models**

The history of thought related to technical efficiency dates back to Koopmans (1951), Debreu (1951) and Farrell (1957). Technical efficiency is a measure of a firm's ability to maximize output for a given level of inputs (output oriented) or to minimize input use for a given level of output (input oriented). The stochastic production frontier model this paper uses is based on output oriented technical efficiency.

Several studies abound in industry and agriculture that have examined efficiency issues (technical, allocative, scale and overall) using parametric and non-parametric methods (DEA). Parametric methods most commonly have used production and cost functions. Technical efficiency measurement using a production function received major thrust after Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) independently proposed the stochastic frontier production function. It differed from its deterministic (Aigner and Chu, 1998) counterpart by being able to disentangle the effects of random shocks and measurement errors from technical efficiency effects. In the estimation of a stochastic production frontier, the choice of distributional assumptions for efficiency, estimation method, and the functional form are important considerations (Kumbhakar and Lovell; Coelli, Prasada Rao and Battese).

A stochastic frontier Cobb-Douglas production function model with technical inefficiency effects based on Battese and Coelli (1995) is employed in this paper to estimate individual enterprise level technical efficiencies for farms practicing conventional till and no-till practices and to examine the factors effecting technical efficiency. A number of previous studies (for e.g. Battese and Broca; Audibert) have used a similar model to examine the technical efficiency of a sample of farms.

Our empirical models include labor, capital, and purchased inputs as production function variables. Tillage practice, farm size (total crop acres), enterprise proportion (percent of total crop acres devoted to a particular enterprise), rental ratio (land tenure), and rainfall are used to explain differences in technical inefficiency/efficiency among farms. Since the data used in this analysis are comprised of a panel of observations spread over a small period of time (3 years), we have constructed two models – (1) a cross-sectional model (3-year average model) and (2) a panel data model.

The first model, the cross-sectional model, can be expressed as:

$$(1) \quad \ln(Y_i) = \mathbf{b}_0 + \mathbf{b}_1 \ln(Lab_i) + \mathbf{b}_2 \ln(Cap_i) + \mathbf{b}_3 \ln(PI_i) + V_i - U_i$$

where  $i$  represents the  $i^{th}$  crop enterprise observation;  $Y$  represents the enterprise output value;  $Lab$ ,  $Cap$  and  $PI$  represent the input variables labor, capital and purchased inputs respectively;  $V_i$  is assumed to be an independent and identically distributed random error; and  $U_i$  is assumed to be a non-negative random variable that is associated with technical inefficiency.

The technical efficiency effects model is estimated simultaneously with equation (1) and can be represented as follows:

$$(2) \quad U_i = \mathbf{z}_i \mathbf{d} + W_i$$

In equation (2),  $\mathbf{z}_i$  is a  $(1 \times M)$  vector of firm specific variables explaining technical inefficiency effects;  $\mathbf{d}$  is a  $(M \times 1)$  vector of coefficients of the inefficiency variables to be estimated;  $W_i$  is an unobservable random variable assumed to be independently distributed with mean zero and variance  $s^2$ .

In this paper, we specify  $U_i$  as:

$$(3) \quad U_i = \mathbf{d}_0 + \mathbf{d}_1(Tillage_i) + \mathbf{d}_2(FS_i) + \mathbf{d}_3(EP_i) + \mathbf{d}_4(RR_i) + \mathbf{d}_5(Rainfall_i) + W_i$$

where *Tillage* is a dummy variable (0 for conventional till and 1 for no-till); *FS* represents farm size (total crop acres); *EP* represents the proportion of the crop under study in relation to total crop acres; *RR* represents the proportion of the operator's total cultivated land rented; and *Rainfall* represents the precipitation experienced during the crop growing season.

Technical efficiency of the  $i^{\text{th}}$  crop enterprise is given by,

$$(4) \quad TE_i = \exp(-U_i) = \exp(-z_i \mathbf{d} - W_i)$$

The second model, the panel data model, can be expressed as follows:

$$(5) \quad \ln(Y_{it}) = \mathbf{b}_0 + \mathbf{b}_1 \ln(Lab_{it}) + \mathbf{b}_2 \ln(Cap_{it}) + \mathbf{b}_3 \ln(PI_{it}) + V_{it} - U_{it}$$

$$(6) \quad U_{it} = \mathbf{d}_0 + \mathbf{d}_1(Tillage_{it}) + \mathbf{d}_2(FS_{it}) + \mathbf{d}_3(EP_{it}) + \mathbf{d}_4(RR_{it}) + \mathbf{d}_5(Rainfall_{it}) + W_{it}$$

where  $i$  represents the  $i^{\text{th}}$  enterprise observation and  $t$  represents time. All of the other variables in the production function and inefficiency effects model are the same as those in the first model. Equation (5) and (6) are estimated simultaneously.

Technical efficiency for the  $i^{\text{th}}$  enterprise at time  $t$  is given by:

$$(7) \quad TE_{it} = \exp(-U_{it}) = \exp(-z_{it} \mathbf{d} - W_{it})$$

The elasticity estimates of all the input variables used in the production function are expected to be significant and positive. The coefficient estimates of the technical inefficiency effects model can give valuable information about the nature and strength of the explanatory variables under study. Farm structure characteristics like farm size (total crop acres) and enterprise proportion are commonly expected to be positive due to economies of scale and crop specialization. Several empirical studies on conservation tillage adoption have established the positive role of farm size (Fuglie; Soule, Tegene and Wiebe), however the models used here do not relate farm size with technical

efficiency of any particular tillage practice. The impact of rental ratio (share of rented land cultivated) on technical efficiency is hard to determine a priori. Rainfall is likely to have a positive influence on technical efficiency. The tillage variable is expected to reveal the technical inefficiency relationship with the tillage practice observed in the data. No-till practices by virtue of their moisture conserving, soil protecting, and fertility enhancing abilities are expected to improve technical efficiency and so the coefficient on tillage is expected to be positive.

### **Data**

Data on enterprise output, enterprise level input variables, tillage information, farm size, enterprise proportion, and land tenure for the time period 2000 to 2002, were obtained from north central Kansas Farm Management Association (KFMA) records. Monthly precipitation data for the 16 counties the farms in the data represent were obtained from the National Climatic Data Center (NCDC). Labor included hired and unpaid operator labor; capital included machinery and equipment expenses and a land charge; and the purchased inputs variable included seed, fertilizer and herbicide expenses. All the input values were adjusted to 2002 price levels. Rainfall estimates were prepared based on the crop growing period.

Table 1 presents the summary statistics of all the variables used in the empirical analysis. The data used in the analysis is comprised of 119 wheat enterprises, 91 grain sorghum enterprises, and 68 soybean enterprises of which 13, 12, and 13 enterprises used no-till practices.



## Estimation and Results

Maximum likelihood estimates of the parameters for both empirical models were obtained using Frontier 4.1 (Coelli, 1994). The results of the two models for the three crops are presented in Table 2. Except for sorghum in the panel data model, the elasticity estimates for capital and purchased inputs were found to be significant across all crops in the two models. Labor was only significant for sorghum in the cross-sectional model.

Table 3 presents the efficiency estimates by crop and model. Because a different sample of farms was used to estimate the models for each crop, it is not possible to compare efficiency across crops. It is possible, however, to compare efficiency across models. Technical efficiency was lower for each crop using panel data. This is as expected. Using panel data rather than cross-sectional averages, increases the variation among farms. This increase in variation leads to more inefficiency.

The  $\eta$  value in table 2 is close to 1 in all the cases, except for the wheat panel data, indicating that a large amount of residual variation is contributed by inefficiency effects. The technical inefficiency effects model, relates the technical inefficiency in production to the explanatory variables in the model. The farm size and the rental ratio variables had consistently negative signs for all the crops indicating the possible presence of economies of scale and efficiency gains corresponding to rental land. The enterprise proportion variable was negative and significant for wheat indicating that for wheat specializing improves technical efficiency.

The rainfall variable was not significant in the 3-year average model, but was significant and negative in the panel data model. The panel data results suggest that

increased rainfall reduces technical inefficiency. In other words, additional rain makes it easier to be technically efficient.

The tillage variable was found to be insignificant in both models. These results suggest that technical efficiency is not impacted, either positively or negatively, by the adoption of no-till practices.

## **Conclusions**

Technical efficiency estimates with the farms practicing conventional and no-till practices have been obtained by the use of two models, a cross-sectional model and a panel data model. Technical inefficiency was significant for both models. There was no evidence of improved technical efficiency with farms practicing no-till practices.

Technical efficiency was significantly related to total crop acres, enterprise specialization, land tenure, and rainfall.

This study focused on specific enterprises. A more comprehensive study that examined whole-farm efficiency and tillage practices would be enlightening. There is an increasing recognition that benefits associated with conservation tillage technologies are related to cropping systems. These benefits could be explored through the use of whole-farm data. Also, cost benefits may accrue to conservation tillage practices even when there is not a yield effect from changing tillage practices. Because of this it would be useful to also examine the relationship between cost efficiency and tillage practice.

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Table 1. Summary statistics of the variables used in the stochastic frontier model<sup>\*</sup>

Variable	Mean	Standard Deviation	Minimum	Maximum
<b>Wheat</b>				
Crop Output	17161.56	12618.68	783.34	83243.58
Labor (U.S. dollars) <sup>**</sup>	13094.47	7356.73	581.64	37197.08
Capital (U.S. dollars) <sup>**</sup>	30283.14	23027.32	700.91	125291.04
Purchased Inputs (U.S. dollars) <sup>**</sup>	13360.78	10213.52	0.00	59829.43
Tillage (CT/NT, 0 or 1)	0.11	0.31	0.00	1.00
Farm Size (acres)	1145.17	693.05	235.50	4443.70
Enterprise Proportion (ratio)	0.43	0.15	0.04	1.00
Rental Ratio (ratio)	0.68	0.31	0.00	1.00
Rainfall (hundreth of inch, annual)	1641.41	425.12	867.00	2531.00
<b>Grain Sorghum</b>				
Crop Output	13068.96	11560.17	258.08	71312.16
Labor (U.S. dollars) <sup>**</sup>	6813.67	4146.26	417.83	25397.56
Capital (U.S. dollars) <sup>**</sup>	15733.92	13817.77	598.22	94673.75
Purchased Inputs (U.S. dollars) <sup>**</sup>	13276.71	11641.26	0.00	83656.00
Tillage (CT/NT, 0 or 1)	0.13	0.34	0.00	1.00
Farm Size (acres)	1122.79	654.86	273.00	4443.70
Enterprise Proportion (ratio)	0.23	0.09	0.03	0.63
Rental Ratio (ratio)	0.69	0.33	0.00	1.00
Rainfall (hundreth of inch, annual)	1856.00	444.69	882.00	3025.00
<b>Soybeans</b>				
Crop Output	3499.49	4215.37	72.97	28134.50
Labor (U.S. dollars) <sup>**</sup>	5813.60	4751.44	282.96	29448.31
Capital (U.S. dollars) <sup>**</sup>	13494.44	14591.26	1185.68	83414.18
Purchased Inputs (U.S. dollars) <sup>**</sup>	9653.37	9517.63	0.00	48071.40
Tillage (CT/NT, 0 or 1)	0.20	0.40	0.00	1.00
Farm Size (acres)	1226.18	765.93	386.00	4443.70
Enterprise Proportion (ratio)	0.19	0.10	0.02	0.50
Rental Ratio (ratio)	0.74	0.31	0.00	1.00
Rainfall (hundreth of inch, annual)	1892.12	436.54	882.00	3025.00

<sup>\*</sup>Data represents 119, 91 and 68 wheat, grain sorghum and soybean farms ( of which 13, 12 and 13 are no-till)

<sup>\*\*</sup>Labor, Capital and Purchased Inputs variables values in real 2002 dollars

Table 2. Maximum-likelihood estimates of the parameters of the stochastic frontier production model with inefficiency effects

		<b>Model 1:</b> 3-Year Average (Cross-sectional)						<b>Model 2:</b> Panel Data Model					
Variable	Parameters	Wheat	t-ratio	Sorghum	t-ratio	Soybean	t-ratio	Wheat	t-ratio	Sorghum	t-ratio	Soybean	t-ratio
<i>Stochastic Frontier</i>													
Constant	$\beta_0$	3.3497	5.3479	0.7864	9.8074	0.0382	0.0623	4.9730	10.4254	0.7027	0.7012	0.7617	1.4965
ln (Lab)	$\beta_1$	0.0304	0.6236	0.1882	10.5967	-0.0710	-0.6656	0.0610	1.5477	0.2117	0.6768	0.0861	0.7367
ln (Cap)	$\beta_2$	0.4323	8.3722	0.4634	42.5768	0.6106	5.5570	0.4063	10.1944	0.4918	1.6045	0.5331	4.9448
ln (PI)	$\beta_3$	0.2417	17.7173	0.3092	61.5043	0.3490	3.0767	0.0789	2.8726	0.2798	3.5644	0.2731	3.9519
<i>Inefficiency Model</i>													
Constant	$d_0$	1.5206	6.6057	1.8641	3.1381	2.5344	1.7833	2.2687	14.0505	2.2174	2.1323	3.4100	7.5675
Tillage*	$d_1$	0.0107	0.1743	0.0264	0.1669	0.4329	1.3110	0.0137	0.2970	-0.2921	-0.2972	0.1454	0.7531
FS*	$d_2$	-0.0003	-6.1069	-0.0004	-2.5190	-0.0004	-1.2105	-0.0005	-7.6885	-0.0004	-1.3505	-0.0002	-1.2546
EP*	$d_3$	-0.9400	-5.0657	-1.0126	-1.3151	-1.8621	-1.1363	-1.2819	-8.2428	0.4867	0.4913	-1.2528	-1.3895
RR*	$d_4$	-0.2390	-2.9212	-0.5228	-3.2455	-0.4571	-1.4303	-0.1797	-2.9534	-0.4158	-0.4144	-0.2899	-1.1058
Rainfall*	$d_5$	0.0000	0.5509	-0.0004	-1.1451	-0.0008	-1.0424	-0.0001	-3.5607	-0.0008	-1.8775	-0.0009	-4.3982
$s^2$		0.0342	18.7838	0.1338	3.7902	0.1499	1.7227	0.0565	11.7941	0.5948	1.8596	0.3668	5.1015
?		1.0000	3.35E+02	1.0000	9.63E+06	0.8446	8.1955	0.5997	3.3249	0.8632	9.8940	1.0000	2.68E+05

\*Variables explain inefficiency

Table 3. Mean Technical Efficiencies

	<b>Model 1:</b> 3-Year Average (Cross-sectional)			<b>Model 2:</b> Panel Data		
	Total	Conventional Till	No-till	Total	Conventional Till	No-till
Wheat	0.516	0.522	0.469	0.461	0.466	0.426
Grain Sorghum	0.686	0.686	0.691	0.610	0.597	0.627
Soybean	0.748	0.756	0.720	0.398	0.406	0.366