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COST STRUCTURES, PRODUCTIVITIES AND THE DISTRIBUTION OF TECHNOLOGY BENEFITS AMONG PRODUCERS FOR MAJOR U.S. FIELD CROPS

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PURPOSE

The purpose of this paper is to estimate the cost structures and resource productivities involved in production of four major U.S. field crops and to estimate the distribution among producers of benefits from production related technology. These field crops include corn, soybeans, wheat and cotton grown in selected homogeneous soil and rainfall areas of the U.S. The cost structure of each commodity is estimated relative to a Cobb-Douglas cost function. Productivity is assessed across time, regions and size of enterprise. The distribution of technology benefits is determined by region and enterprise size for each commodity.

LITERATURE

This research is related by subject matter and analytical model to the works of Binswanger (1974), Browne and Christensen (1981) and Ray (1982). Each of these studies applies a translog cost functional form to U.S. aggregate agricultural data as a means of estimating such things as productivity, size economies, factor bias, elasticity of substitution and elasticity of demand. One problem these studies share is the very high level of aggregation of the data. Ray's concluding remarks speak directly to this point.

> ...we need to realize that our model with two outputs [crops and livestock] (although a step in the right direction) is not disaggregative enough...Ideally, this study should have used farm level behavioral data. Use of aggregate data here (as in all similar models using economy wide observations) introduces a measure of aggregation bias (p. 497).

A recent attempt to apply a translog cost function to farm level data was made by Hazilla and Kopp (1984). This study used USDA Firm Enterprise Data (FEDS) enterprise budgets published in 1974 and 1978 as the source of data on input prices and expenditure shares.

Hazilla and Kopp proceeded to construct cost functions in corn production for homogeneous soil and rainfall areas in the Corn Belt. They used these cost functions to estimate intertemporal and interspatial productivity. The Hazilla and Kopp approach represents a major step forward in estimating total factor productivity using farm level data that is sufficiently disaggregated to a single commodity grown in relatively homogeneous soil and rainfall areas. However, there are still a couple of problems associated with the Hazilla and Kopp approach that deserve attention. Hazilla and Kopp used the FEDS enterprise budgets as published without correcting for inconsistency in their construction between 1974 and 1978. Changes in the assumptions imbedded in the parameters in the budget generator used to construct these budgets provided a significant impact on expenditure shares. For example, the procedure for determining the opportunity cost of land changed significantly between years.

Further, Hazilla and Kopp assumed constant returns to size in corn production when estimating changes in productivity. Therefore it is possible that some or all of the intertemporal productivity gains may be accounted for by enterprises simply getting bigger and thereby using all inputs more efficiently. Such size economies, if they exist, represent

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"noise" when one is trying to estimate total factor productivity across time. Similarly intertemporal productivity changes represent "noise" in the estimation of size economies. Changes in relative prices presents a similar problem as well.

Chan and Mountain (1983) conclude

> ...some of the observed average productivity increases which we customarily attributed to the rate of technical progress can now be attributed to the increasing returns to scale inherent in the Canadian agricultural production process (p. 667).
>
> ...in a study set up to measure technical economies of size, the factor prices...should remain the same across farm size as long as a resource quality (productivity) remains constant (Jensen, 1982, p. 26).

OBJECTIVES

The objectives of this study are five in number. First, we construct a profile of the individual cost components for the selected commodity-region-size-time period situations considered. Second, we estimate the Cobb-Douglas cost function using the above cost component estimates as data. Third, we construct an index of total factor productivity by time, region and size for each commodity. Fourth, we estimate economic surplus, consumer surplus and economic rent associated with the above estimated changes in total factor productivities. Finally, we estimate the distributional incidence of economic rent (producer surplus) by homogeneous production regions and by enterprise size.

Objectives four and five on estimating the returns to consumers and resource owners from gains in productivity represent an attempt to link the work being done in the area of estimating cost functions to the work previously done in estimating returns to research in agriculture.[1]

PROCEDURE

The procedure for this study begins with the 1974 "Cost of Producing Selected Crops" survey conducted by USDA paid enumerators in the winter of 1975. This survey was undertaken again in the winters of 1983 and 1984 for the '82/'83 crop years. These data are used to provide the underlying production practices and quantity of inputs information for this study. These data were sorted by commodity, homogeneous region for each commodity, and by enterprise size within each region. This sorted data was then applied to summary programs that aggregated the observations into a representative enterprise composite of production practices and input quantities for each commodity-time region-size category. These representative enterprise data were then coded into a format appropriate for the budget generator program. The output from the budget generator provided the basis for estimating price, quantity and expenditure for the reduced capital, labor, energy, fertilizer, materials and land or KLEFMA inputs. The KLEFMA categories represent the cost profile information that can be used as data for the Cobb-Douglas cost function. The cost functions are solved in such a way that the results produce estimates of total factor productivity across time, region and size. These estimates of total factor productivity then become data in the models of economic surplus and consumer surplus. The results from the estimates of consumer surplus and economic rent can then be distributed relative to production regions and enterprise sizes.

SCOPE

As mentioned above the commodities selected for this study include only the field crops of corn, soybeans, wheat and cotton.

The regions for each of these commodities are listed in Table 1 by the associated FEDS three digit area code signifying homogeneity of soil and rainfall. These sample areas were selected purposively based on importance of the area to production and/or to provide variability in farming systems and production technologies. Their geographic locations are shown in Figures 1 to 4.

Enterprise size is based on planted acres, which includes both owned and rented land. These acreages were then arrayed within each area from largest to smallest and three enterprise sizes were designated for study: very large, large and medium (Table 2). The small size category was not included in this study because it included some very small, part-time production units. As a result we felt any resulting depictions of cost category averages were not very representative of the farmers included. Size categories were determined on the basis of percentiles of the arrayed planted acres and the average enterprise size for each category is shown in Table 3.

Table 1. Geographical Production Regions Included in the Study

Commodity	Selected State	Homogeneous Area	Other
Corn	Illinois	300	
	Indiana	101	
	Iowa	201	
	Nebraska	400	Irrigated
Soybeans	Illinois	300	
	Iowa	201	
	Mississippi	100	
	Ohio	101	
Wheat	Kansas	100	Hard red winter following fallow
	Montana	200	Hard red winter following fallow
	North Dakota	200	Hard red spring continuous
	Washington	400	Soft white winter following fallow
Cotton	Alabama	600	
	California	500	Irrigated
	Mississippi	100	
	Texas	200	Irrigated
	Texas	200	

Table 2. Specification of Enterprise Size Categories

Size Category	Percentile of Arrayed Planted Acres
Very large	91-100
Large	71-90
Medium	41-70
Small	0-40 (not included)

FIGURE 1

Selected Homogeneous Soil and Rainfall Areas in Corn Production

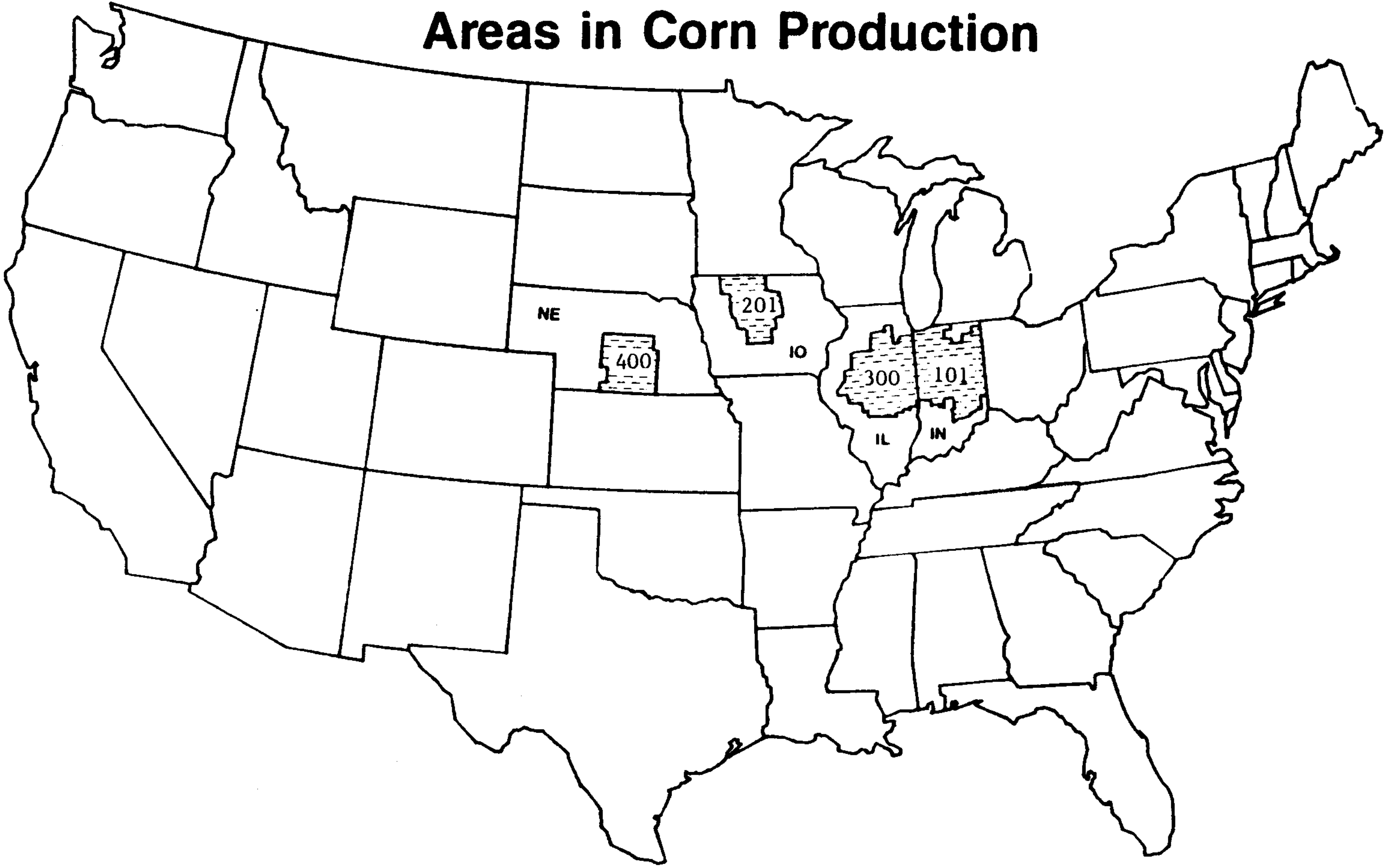


FIGURE 2

Selected Homogeneous Soil and Rainfall Areas in Soybeans Production

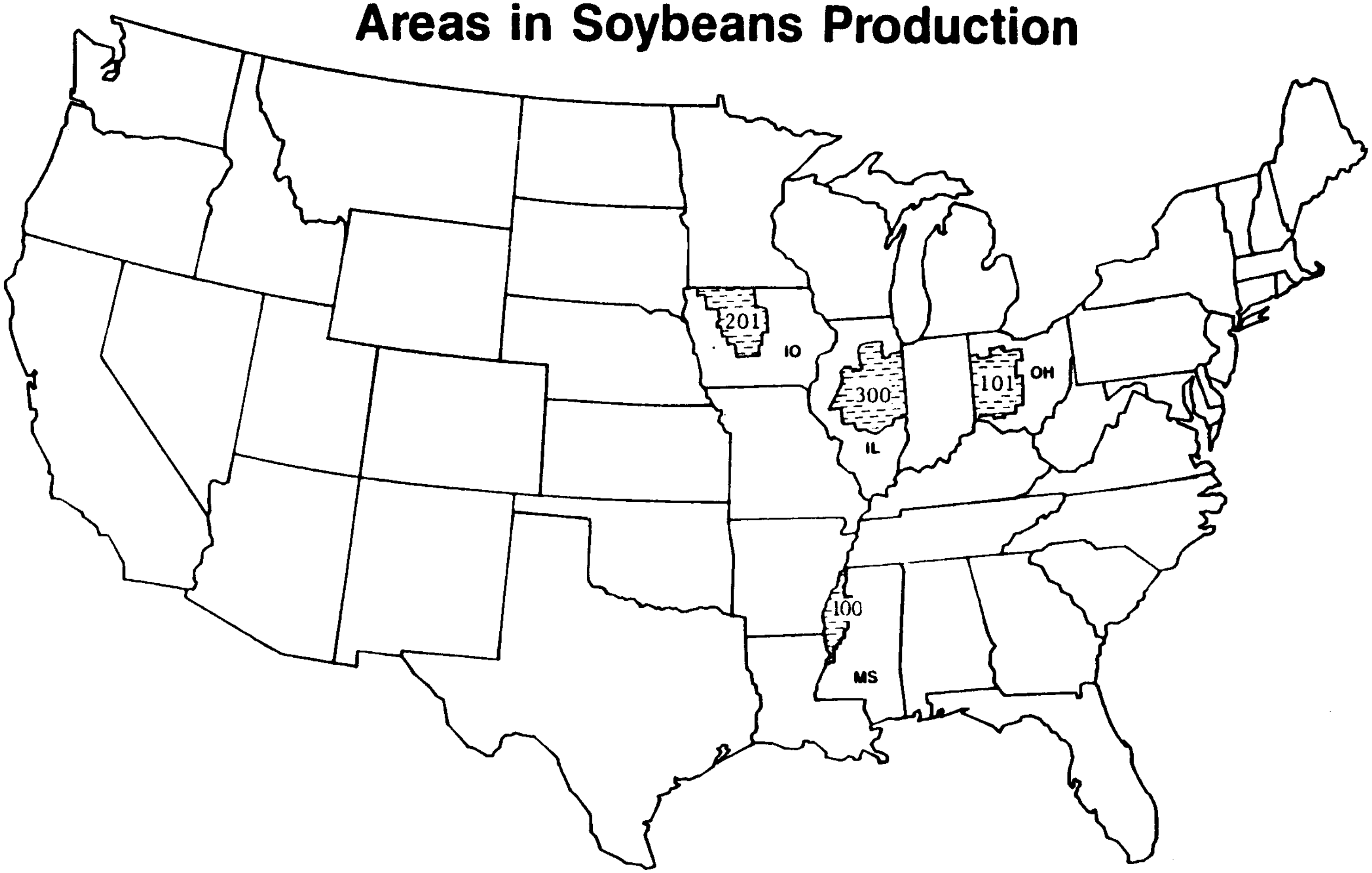


FIGURE 3

Selected Homogeneous Soil and Rainfall Areas in Wheat Production

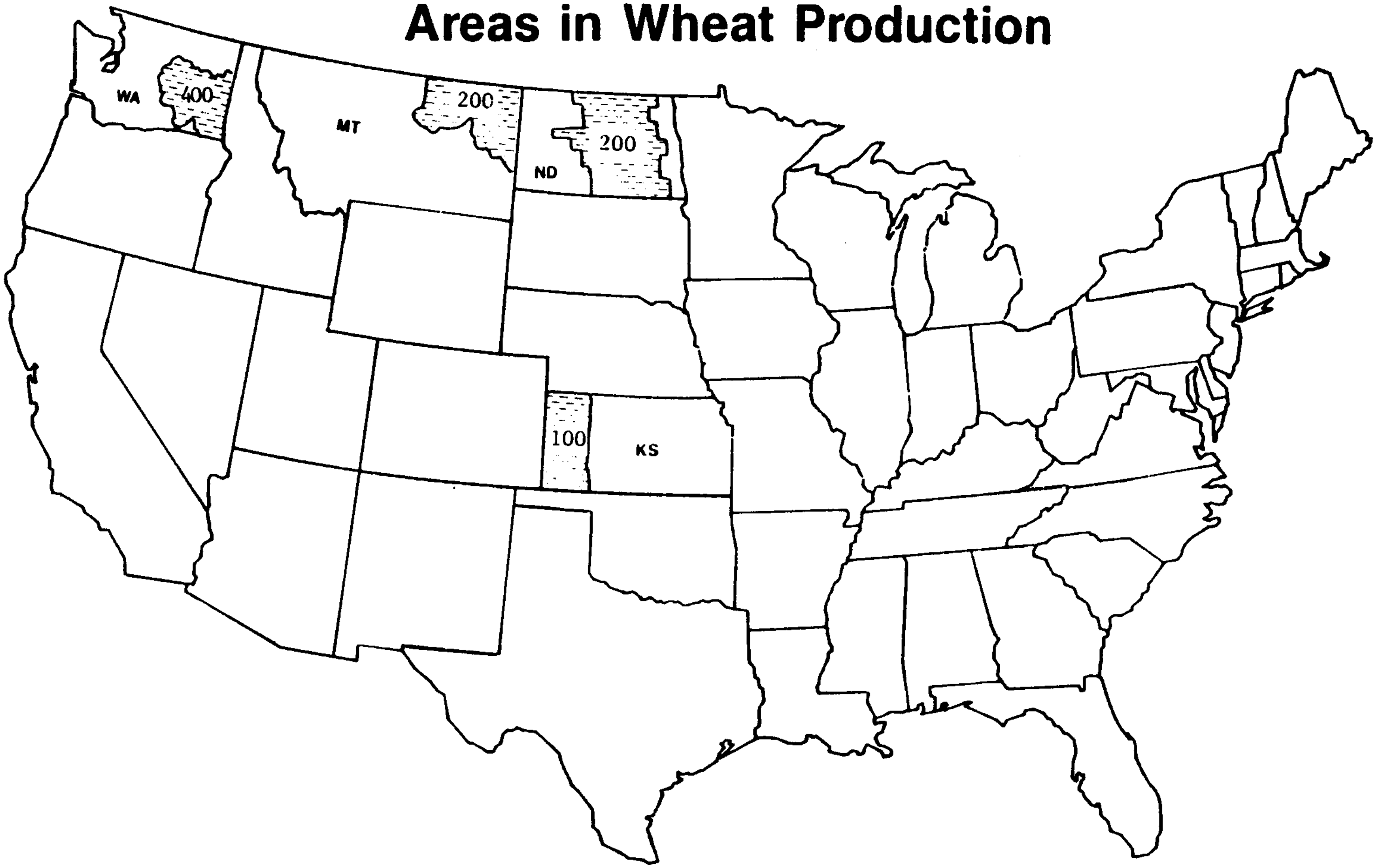


FIGURE 4

Selected Homogeneous Soil and Rainfall Areas in Cotton Production

Table 3. Average Enterprise Size (Planted Acres) by Commodity and Production Region Based on the 1982/83 FEDS Survey

	Corn	Soybeans	Wheat	Cotton	Cotton cont'd
	IL 300	IL 300	KS 100	AL 600	TX 200
VL	1113	684	3909	1842	5920
L	355	418	1429	917	1825
M	246	270	774	568	972
Wt. Ave.[1]	520	388	1796	1049	2714
	IN 101	IO 201	MT 200	CA 500[3]	
VL	903	707	1577	2833	
L	515	341	619	1432	
M	271	210	421	614	
Wt. Ave.[1]	444	291	1093	2237	
	IO 201	MS 100	ND 200	MS 100	
VL	576	1262	1283	2868	
L	249	894	630	1202	
M	170	795	338	754	
Wt. Ave.[1]	314	1050	672	1686	
	NE 400[3]	OH 101	WA 400	TX 200[3]	
VL	1715	897	2388	1707	
L	671	493	1104	929	
M	266	244	753	436	
Wt. Ave.[1]	685	436	1628	971	
	Wt. Ave.[2]	Wt. Ave.[2]	Wt. Ave.[2]	Wt. Ave.[2]	
VL	998	782	2659	2989	
L	403	455	1083	1317	
M	233	299	645	646	
Overall	470	438	1447	1926	

[1] Weights for average enterprise size within an area and across size categories are based on 1982 Census of Agriculture Table 41, "Specified Crops by Harvested Acres" as a ratio of production of this size category to the sum of production across size categories.

[2] Weights for average enterprise size across areas and within size categories are based on 1981-85 average county level SRS data as a ratio of an areas production to the sum of production across areas.

[3] Irrigated.

METHODOLOGY

There are two sets of analytical concepts used in this study. The first is that of estimating a Cobb-Douglas cost function solved in such a way as to estimate total factor productivity across time, region and enterprise size. The second relates to estimating economic surplus using the measure of total factor productivity as a necessary condition and as a datum in the analytical model.

A COBB-DOUGLAS COST FUNCTION

Most cost function models begin with the underlying relationship that total cost is a function of input prices and the level of output quantity.

(1) $TC_i = f(Q_i, P_{Ki}, P_{Li}, P_{Ei}, P_{Fi}, P_{Mi}, P_{Ai})$

where

TC_i = total cost per acre for commodity i
Q_i = yield per acre for commodity i
$P_{Ki} \ldots P_{Ai}$ = Price per unit of input for capital (K), labor (L), energy (E), fertilizer (F), material (M), and land (A) for commodity i

Equation (1) reflects a model of one output (Q_i) and six inputs (K, L, E, F, M, A). Further, equation (1) implies a set of four assumptions. First, the implicit decision rule is that producers act as if they cost minimize subject to an output constraint rather than profit maximize subject to a cost constraint. (For the implication of cost minimization versus profit maximization see Ferguson, p. 158.) In general, the results from cost minimization and from profit maximization are equivalent if the producer is operating at the minimum point on the average cost curve associated with the expansion path.

Second, it is assumed that the factor markets for the KLEFMA inputs are in equilibrium under conditions of perfect competition. This assumption implies that each input is used such that its marginal value product equals the input price and similarly that marginal cost or ratio of input price to its marginal product equals the output price.

Third, it is at least temporarily assumed that there are constant returns to size. This implies that the elasticity of cost with respect to scale of output equals one. Cost is assumed to change in a constant proportion with output change. If there were increasing returns to size then the rate of cost increase would be less than the rate of output increase. If there were decreasing returns to size then the rate of cost increase would be greater than the rate of output increase (Ferguson, p. 80).

Fourth, it is assumed that all observations made over time and between different regions are on the same cost function. This implies that there has been no shift in the cost function due to new technology introduced over time. This also implies that all regions of the U.S. are equally productive (i.e., have homogeneous resource endowments) relative to producing commodity i.

Assumptions three and four are particularly difficult ones to accept. Therefore we can modify our cost function to account for these problems.

(2) $TC_i = f(Q_i, P_{Ki}, P_{Li}, P_{Ei}, P_{Fi}, P_{Mi}, P_{Ai}, T_T, R_R, S_S)$

where

T_T = time period T
R_R = region R
S_S = enterprise size S

With the addition of these discrete variables T, R and S in equation (2), we no longer need to accept assumption four but rather can test it directly and use the test as a way of estimating total factor productivity across time and regions.

We need still to accept a modified version of assumption three. We must assume that there are constant returns to size within a size category. However, we will be testing whether size economies exist between size categories. As with time and region, relative size economies will be measured in terms of total factor productivity.

The functional form is transcendental logarithmic. A "translog" function implies that as an input price increases total cost increases at a decreasing rate as less expensive inputs are substituted for the more expensive ones to the extent possible. Equation (2) can be rewritten as follows (dropping the ith commodity notation):

(3) $\ln TC = f(\ln Q, \ln P_K, \ln P_L, \ln P_E, \ln P_F, \ln P_M, \ln P_A, T_T, R_R, S_S)$.

Transcendental functions such as equation (3) can be approximated using a Taylor's series polynomial expansion (Thomas, 1962, p. 785). A Taylor series expansion takes the general form of

$$f(x) = f(a) + f'(a)(x - a) + 1/2 f''(a)(x - a)^2 + \ldots + \text{remainder}$$

where

$f(x)$ is the transcendental function to be approximated
(a) is the base or reference point (some particular time, region, or size category).
$f'(a)$ is the first derivative of the transcendental function evaluated at the reference point
$f''(a)$ is the second derivative of the transcendental function evaluated at the reference point

A Cobb-Douglas cost function by definition is a "first order" or first derivative approximation of the cost function since a Cobb-Douglas function assumes that the "second order" or second derivative approximation equals zero (Binswanger, 1974b, p. 965).

A first order approximation of the translog cost function (TC_x) evaluated at (time, region or size) reference point (a) equals

$$(4)\quad \ln TC_x = \ln TC_a + \left.\frac{\partial \ln TC}{\partial \ln Q}\right|_a (\ln Q_x - \ln Q_a)$$

$$+ \left.\frac{\partial \ln TC}{\partial \ln P_K}\right|_a (\ln P_{Kx} - \ln P_{Ka}) + \left.\frac{\partial \ln TC}{\partial \ln P_L}\right|_a (\ln P_{Lx} - \ln P_{La})$$

$$+ \left.\frac{\partial \ln TC}{\partial \ln P_E}\right|_a (\ln P_{Ex} - \ln P_{Ea}) + \left.\frac{\partial \ln TC}{\partial \ln P_F}\right|_a (\ln P_{Fx} - \ln P_{Fa})$$

$$+ \left.\frac{\partial \ln TC}{\partial \ln P_M}\right|_a (\ln P_{Mx} - \ln P_{Ma}) + \left.\frac{\partial \ln TC}{\partial \ln P_A}\right|_a (\ln P_{Ax} - \ln P_{Aa})$$

$$+ \left.\frac{\partial \ln TC}{\partial T}\right|_a (T_{Tx} - T_a) + \left.\frac{\partial \ln TC}{\partial R}\right|_a (R_{Rx} - R_a)$$

$$+ \left.\frac{\partial \ln TC}{\partial S}\right|_a (S_{Sx} - S_a)$$

Equation (4) can be simplified in the following way. We know that

$$(5)\quad \frac{\partial \ln TC}{\partial \ln P_K} = \frac{\partial TC}{TC} * \frac{P_K}{\partial P_K} = \frac{P_K}{TC} * \frac{\partial TC}{\partial P_K}$$

From Shephard's lemma we know that

$$(6)\quad \frac{\partial TC}{\partial P_K} = X_K$$ (Binswanger, 1974a, p. 378).

We can see that this is a reasonable result simply by taking the partial derivative of the <u>total cost constraint of a profit function</u> with respect to each of its arguments. The total cost constraint equals

$$(7)\quad TC = P_K X_K + P_L X_L + P_E X_E + P_F X_F + P_M X_M + P_A X_A.$$

The partial derivatives of this cost constraint for each of the KLEFMA input prices equals

$$(8)\quad \frac{\partial TC}{\partial P_K} = X_K;\ \frac{\partial TC}{\partial P_L} = X_L;\ \frac{\partial TC}{\partial P_E} = X_E;\ \frac{\partial TC}{\partial P_F} = X_F;\ \frac{\partial TC}{\partial P_M} = X_M;\ \frac{\partial TC}{\partial P_A} = X_A.$$

Thus, the partial derivatives of the cost function with respect to price can be rewritten as a factor share S of expenditures on input i relative to total expenditures.

$$(9)\quad \frac{\partial \ln TC}{\partial \ln P_i} = \frac{P_i}{TC} * \frac{\partial TC}{\partial P_i} = \frac{P_i X_i}{TC} = \frac{P_i X_i}{\Sigma P_i X_i} = S_i.$$

We can further simplify the first order approximation by incorporating our assumption of constant returns to size within a size category. This assumption implies that the elasticity of the cost function with respect to output equals one. Therefore,

$$(10)\quad \left.\frac{\partial \ln TC}{\partial \ln Q}\right|_a = 1.$$

Finally, we will let time related differences in cost efficiency equal α_a for notational simplicity such that

$$(11)\quad \left.\frac{\partial \ln TC}{\partial T}\right|_a = \alpha_a.$$

We can assume also in this instance that region and size related differences in cost efficiency equal zero. We can assume this if we match up observations across time that are associated with the same region and size categories. Later on we will solve the cost function for regional or size cost efficiency by making the appropriate observational match ups across time-size or time-region. Therefore,

$$(12)\quad \left.\sum_R \frac{\partial \ln TC}{\partial R}\right|_a = \left.\sum_S \frac{\partial \ln TC}{\partial S}\right|_a = 0.$$

We can now rewrite equation (4) such that it incorporates the information and assumptions in equations (9), (10), (11) and (12). Further we can solve equation (4) in terms of the change in productivity across time between 1974 ($x = 74$) and 1983 ($a = 83$), where 1983 is arbitrarily assumed to be the reference time period.

$$(13)\quad \alpha_{83}(T_{74} - T_{83}) = \ln TC_{74} - \ln TC_{83} - (\ln Q_{74} - \ln Q_{83})$$
$$-S_{K83}(\ln P_{K74} - \ln P_{K83}) - S_{L83}(\ln P_{L74} - \ln P_{L83})$$
$$-S_{E83}(\ln P_{E74} - \ln P_{E83}) - S_{F83}(\ln P_{F74} - \ln P_{F83})$$
$$-S_{M83}(\ln P_{M74} - \ln P_{M83}) - S_{A83}(\ln P_{A74} - \ln P_{A83}).$$

Equation (13) is a first order approximation in logs of a rate of cost efficiency between 1974 and 1983 associated with one output and six KLEFMA inputs. This first order approximation implicitly assumes the second order effects are not significantly different from zero. The second order effects are of two types--those relating to technology bias^2 and those relating to the elasticity of input substitution (Binswanger, 1974b, p. 970).

There is no way of accounting for technology bias without estimating the second order approximation of the translog function. However, there is a means of dealing with the effects of incorrectly assuming unitary elasticity of substitution when variable elasticity is more nearly the case. Unitary elasticity of substitution between inputs implies that factor shares remain constant over time, regions and enterprise sizes as relative prices change. Conversely, variable elasticity of substitution implies that factor shares change with changes in relative prices.

If we assume that factor shares are constant, when in fact they are changing, then we risk ascribing to technological change productivity gains that are really the effect of changing relative prices. Or conversely, we may ascribe the absence of productivity gains to the absence of technological change when its effect is being offset by changes in relative prices of inputs. Therefore, it is essential that we hold the effect of changing relative prices constant when measuring productivity.

We can hold the effect of relative price change constant by taking the average of the factor share weights between the initial and reference period (time, region or size). If the Cobb-Douglas assumption of constant factor shares is correct then the averaging process leaves factor shares unchanged. If the Cobb-Douglas assumption is incorrect, then the averaging process holds the effect of relative price change constant by changing the factor share weights to equal the average between the two points of reference being considered.

The procedure for determining the average of the factor share weights proceeds in two steps. First equation (13) is re-estimated as before except that the initial and reference periods are reversed such that $x = 83$ and $a = 74$.

$$(14)\quad \alpha_{74}(T_{83} - T_{74}) = \ln TC_{83} - \ln TC_{74} - (\ln Q_{83} - \ln Q_{74})$$
$$-S_{K74}(\ln P_{K83} - \ln P_{K74}) - S_{L74}(\ln P_{L83} - \ln P_{L74})$$
$$-S_{E74}(\ln P_{E83} - \ln P_{E74}) - S_{F74}(\ln P_{F83} - \ln P_{F74})$$
$$-S_{M74}(\ln P_{M83} - \ln P_{M74}) - S_{A74}(\ln P_{A83} - \ln P_{A74}).$$

Second, by subtracting (14) from (13), we can derive the first order approximation of the average rate of cost efficiency between 1974 and 1983 adjusted for changes in relative prices but unadjusted for non-neutral technology bias.

$$(15)\quad 1/2\,(\alpha_{83} + \alpha_{74})(T_{74} - T_{83}) = \ln TC_{74} - \ln TC_{83} - (\ln Q_{74} - \ln Q_{83})$$
$$-\ 1/2\,(S_{K83}+S_{K74})(\ln P_{K74}-\ln P_{K83}) - 1/2\,(S_{L83}+S_{L74})(\ln P_{L74}-\ln P_{L83})$$
$$-\ 1/2\,(S_{E83}+S_{E74})(\ln P_{E74}-\ln P_{E83}) - 1/2\,(S_{F83}+S_{F74})(\ln P_{F74}-\ln P_{F83})$$
$$-\ 1/2\,(S_{M83}+S_{M74})(\ln P_{M74}-\ln P_{M83}) - 1/2\,(S_{A83}+S_{A74})(\ln P_{A74}-\ln P_{A83}).$$

Equation (15) can be reformulated for each set of discrete variables (time, region, size) and the associated combination of initial and reference time periods, regions and size categories. Since there are only two time periods considered in this study for each commodity, then equation (15) is the general equation for measuring productivity across time. There are three size categories for each commodity, which results in two general equations for measuring productivity between enterprise sizes. Using the medium size enterprise as the common denominator then

$$(16)\quad 1/2\ (\alpha_{MD} + \alpha_{VL})(S_{VL} - S_{MD}) = \ln(TC_{VL} / TC_{MD}) - \ln(Q_{VL} / Q_{MD}) - 1/2 \sum_{K} (S_{KVL} + S_{KMD})(\ln(P_{KVL} / P_{KMD}))$$

and

$$(17)\quad 1/2\ (\alpha_{MD} + \alpha_{LG})(S_{LG} - S_{MD}) = \ln(TC_{LG} / TC_{MD}) - \ln(Q_{LG} / Q_{MD}) - 1/2 \sum_{K} (S_{KLG} + S_{KMD})(\ln(P_{KLG} / P_{KMD})).$$

There are three general equations for measuring productivity between regions for corn, soybeans and wheat given that there are four selected regions for each commodity and one region is used as a common denominator for the others. There are four general equations for cotton because four regions were selected and two cultural practices (dryland and irrigation) in the Texas high plains were included. Since the selected regions for each commodity are largely unique to the commodity, we will not present all the associated interregional productivity equations. We will include the three for corn for illustrative purposes. Nebraska area 400 is used as the common denominator.

$$(18)\quad 1/2\ (\alpha_{NE} + \alpha_{IL})(R_{IL} - R_{NE}) = \ln(TC_{IL} / TC_{NE}) - \ln(Q_{IL} / Q_{NE}) - 1/2 \sum_{K} (S_{KNE} + S_{KIL})(\ln(P_{KIL} / P_{KNE}));$$

$$(19)\quad 1/2\ (\alpha_{NE} + \alpha_{IN})(R_{IN} - R_{NE}) = \ln(TC_{IN} / TC_{NE}) - \ln(Q_{IN} / Q_{NE}) - 1/2 \sum_{K} (S_{KNE} + S_{KIN})(\ln(P_{KIN} / P_{KNE})).$$

and

$$(20)\quad 1/2\ (\alpha_{NE} + \alpha_{IO})(R_{IO} - R_{NE}) = \ln(TC_{IO} / TC_{NE}) - \ln(Q_{IO} / Q_{NE}) - 1/2 \sum_{K} (S_{KNE} + S_{KIO})(\ln(P_{KIO} / P_{KNE}))$$

Equations (15) through (20) represent measures of the difference in cost efficiency. Cost efficiency is defined as the ratio of inputs to output. Total factor productivity on the other hand is defined as the ratio of output to inputs. Consequently, difference in total factor productivity is the inverse of difference in cost efficiency. It is perhaps more apparent that these equations represent cost efficiency if, for illustrative purposes, equation (20) is expressed in linear instead of logarithmic terms.

$$(21) \quad \left[\frac{R_{IO}}{R_{NE}} \right]^{1/2(\alpha_{NE} + \alpha_{IO})} = \frac{\dfrac{TC_{IO}}{TC_{NE}}}{\Pi_K \left(\dfrac{Q_{IO}}{Q_{NE}}\right) \left(\dfrac{P_{KIO}}{P_{KNE}}\right)^{1/2\,(S_{KNE} + S_{KIO})}}$$

$$= \frac{\Pi_K \left(\dfrac{q_{KIO}}{q_{KNE}}\right) \left(\dfrac{P_{KIO}}{P_{KNE}}\right)}{\Pi_K \left(\dfrac{Q_{IO}}{Q_{NE}}\right) \left(\dfrac{P_{KIO}}{P_{KNE}}\right)^{1/2\,(S_{KNE} + S_{KIO})}} \approx \frac{\Pi_K \left(\dfrac{q_{KIO}}{q_{KNE}}\right)}{\left(\dfrac{Q_{IO}}{Q_{NE}}\right)}$$ [3]

where

$$\Pi_K \left(\frac{P_{KIO}}{P_{KNE}}\right)^{1/2\,(S_{KNE} + S_{KIO})}$$

is a quadratic mean approximation of the relative price ratio of inputs in corn production between Iowa and Nebraska.

$$\left(\frac{P_{KIO}}{P_{KNE}}\right)$$

is the actual relative price ratio of inputs in corn production between Iowa and Nebraska.

Total factor productivity, on the other hand, equals the inverse of (21)

$$(22) \quad \left[\frac{R_{IO}}{R_{NE}} \right]^{-1/2(\alpha_{NE} + \alpha_{IO})} \approx \frac{\left(\dfrac{Q_{IO}}{Q_{NE}}\right)}{\Pi_K \left(\dfrac{q_{KIO}}{q_{KNE}}\right)}$$ [3]

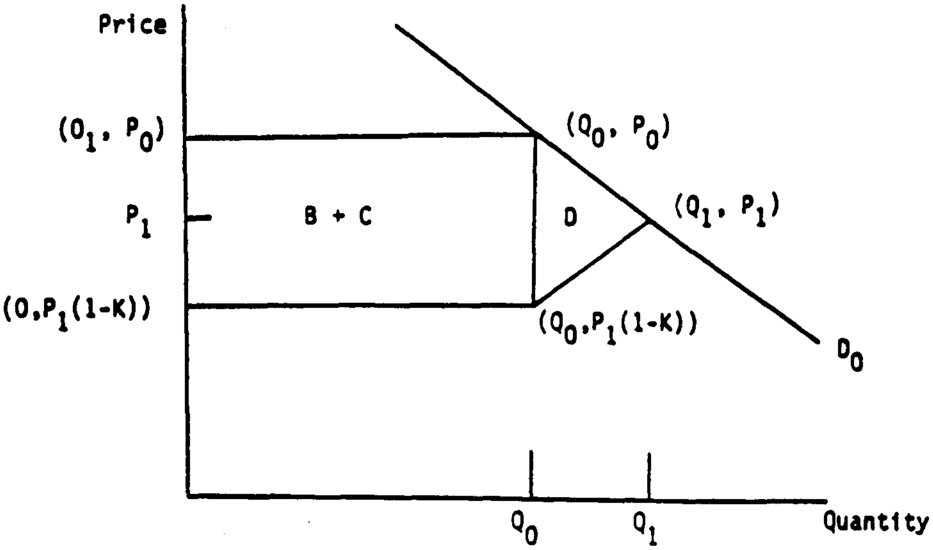
The expression $(1/2 \sum_K (S_{KNE} + S_{KIO})(\ln(P_{KIO} / P_{KNE}))$ in equation (20) is itself a price index calculation needed, in this case, to hold the relative prices of inputs constant between Nebraska and Iowa.

ECONOMIC SURPLUS

The second analytical concept used in this study involves estimating economic surplus. Total factor productivity is needed to estimate the economic surplus associated with a gain in productivity. Economic surplus is defined as the sum of consumer surplus and economic rent. Consumer surplus is defined as a cardinal measure of compensation consumers are able (if not willing) to give up subsequently and still be as well off as initially. Similarly, economic rent is defined as the compensation resource owners are able to forego and be as well off as initially (Cooke, 1985, p. 100).

The estimation of economic surplus for the commodities in this study required an *ex post* price and quantity (presumably in equilibrium), the elasticity of demand and supply and, finally, total factor productivity change. The measure of change in economic surplus (ΔES) is outlined by Lindner and Jarrett (1978), Rose (1980) and Cooke (1985). Economic surplus equals area B + C and area D in Figure 5 below.

FIGURE 5



(23) $\Delta ES = \text{Area } B + C + D$

(24) $\text{Area } B + C = 1/2\ Q_0[P_0 - P_1 + 2KP_1]$

and

(25) $\text{Area } D = 1/2\ [P_0(Q_1 - Q_0) + P_1(1 - K)(Q_0 - Q_1)]$

where

P_1 = the equilibrium price *ex post*
Q_1 = the equilibrium quantity *ex post*
P_0 = the equilibrium price *ex ante*
Q_0 = the equilibrium quantity *ex ante*
K = the difference in total factor productivity expressed as a ratio (Rose, 1980, p. 834)

The values of the ex ante equilibrium price and quantity are estimated using the equations developed by Pinstrup-Andersen, Londono and Hoover (1976, pp. 132-134).

(26) $P_0 = P_1 / [1 - KE / (E + N)]$

and

(27) $Q_0 = Q_1 / [1 + KEN / (E + N)]$

where

P_1, Q_1 and K are the same as defined above
E = the elasticity of supply
N = the absolute value of the elasticity of demand

The change in consumer surplus is measured as

(28) $\Delta CS = 1/2\ (Q_0 + Q_1)(P_0 - P_1)$

where

Q_0, Q_1, P_0 and P_1 are the same as defined above

Economic rent equals economic surplus less consumer surplus

(29) $\Delta ER = \Delta ES - \Delta CS$.

RESULTS

Next we turn to the actual estimates of total factor productivity across time, region and enterprise size as well as the associated economic surplus for corn, soybeans, wheat and cotton. In corn production, (Table 4) there are about 32,000 producers in the selected areas who produce about 20 percent of U.S. corn for grain, on an average enterprise size of about 470 acres. Illinois area 300 has a competitive advantage in corn production followed by Iowa area 201, Indiana area 101 and with Nebraska area 400 a distant fourth. Average intertemporal productivity in corn production increased about 15 percent between 1974 and 1983 or about 1.7 percent per year. Economic surplus from this increase in productivity over the period 1974 to 1983 is about $800 million (about $80 million per year) of which about 75 percent went to consumers and 25 percent went to resource owners. Size economies (Table 8) appear to exist in corn production both between medium and large size enterprises and between large and very large enterprises. Resource owners in Indiana area 101 were in a position to capture a greater amount of the economic rent per acre than in the other areas (Table 4). Also very large enterprise resource owners captured more economic rent per acre than large or medium size enterprise owners (Table 8). Total rents for the 1974 to 1983 period can be converted to an annual basis by dividing by 10.

In soybean production (Table 5), there are about 33,000 producers in the selected areas with an average enterprise size of almost 440 acres. Illinois and Iowa have a competitive advantage in soybean production relative to Ohio and Mississippi. Intertemporal productivity gain is about 15 percent on average across the selected areas and about the same as for corn production during the same period. Size economies in soybean production (Table 8) exist for very large enterprises relative to large and medium size ones in the selected areas. Very large and large enterprises received about the same share of economic rent per acre. Resource owners in Mississippi, Illinois and Ohio all received substantially higher economic rent on a per acre basis than those in Iowa.

There are just under 5,600 wheat producers in the selected sample areas (Table 6) producing about 9.1 percent of the nation's output on an average enterprise size of just under 1460 acres. We recognize that the wheat produced in these several sample areas is not the same commodity (see Table 1). Yet for some purposes interregional comparison's are still of interest. The Palouse region of Washington State has a competitive advantage in wheat

Table 4. Corn Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Illinois Area 300	Indiana Area 101	Iowa Area 201	Nebraska Area 400 (Irrigated)	Total/ Average
Percent of U.S. production[1]	%	7.54	4.50	5.34	2.64	20.02
Number of enterprises[2]		14,000	3,190	11,870	2,260	31,920
Enterprise size[3]	acres	520	444	314	685	470
Yield '72-'76[4]	bu/acre	113.1	100.2	102.5	116.6	109.2
Yield '81-'85[5]	bu/acre	126.7	114.9	123.3	130.7	123.7
TFP (Region)		.75	.80	.78	1.00	
TFP (Time)		.08	.15	.22	.22	.15
Elasticity of demand[6]		-.30	-.30	-.30	-.30	-.30
Elasticity of supply[7]		.31	.31	.31	.31	.31
P_1 '81-'85[8]	$/bu	2.72	2.72	2.72	2.72	2.72
Q_1 '81-'85[9]	1000 bu	558,317	337,477	365,721	194,469	1,455,983
Economic surplus	$1000	174,392	185,579	294,254	156,572	810,797
Consumer surplus	$1000	125,501	138,592	227,811	123,897	615,801
Economic rent	$1000	48,892	46,987	66,443	32,675	194,996
Rent/Ent (Region)	$	1,310	6,980	1,400	4,150	1,960
Rent/Acre (Region)	$	6.40	33.00	17.80	21.00	13.00

(See footnotes following Table 7.)

Table 5. Soybean Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Illinois Area 300	Iowa Area 201	Mississippi Area 100	Ohio Area 101	Total/ Average
Percent of U.S. production[1]	%	7.79	5.25	1.93	3.42	18.39
Number of enterprises[2]		14,800	10,450	1,000	6,470	32,720
Enterprise size[3]	acres	388	291	1,050	436	438
Yield '72-'76[4]	bu/acre	34.5	33.6	21.4	30.0	31.3
Yield '81-'85[5]	bu/acre	39.5	36.8	23.6	35.5	34.2
TFP (Region)		.91	.93	1.70	1.00	
TFP (Time)		.21	.04	.15	.21	.15
Elasticity of demand[6]		-.85	-.85	-.85	-.85	-.85
Elasticity of supply[7]		.25	.25	.25	.25	.25
P_1 '81-'85[8]	\$/bu	6.23	6.23	6.23	6.23	6.23
Q_1 '81-'85[9]	1000 bu	157,384	99,566	38,086	70,560	365,594
Economic surplus	\$1000	190,749	29,067	35,541	88,118	343,475
Consumer surplus	\$1000	51,050	7,589	9,437	23,619	91,696
Economic rent	\$1000	139,699	21,478	26,104	64,499	251,779
Rent/Ent (Region)	\$	9,440	2,050	26,000	9,970	7,700
Rent/Acre (Region)	\$	24.50	7.00	24.75	22.90	17.80

(See footnotes following Table 7.)

Table 6. Wheat Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Kansas Area 100	Montana Area 200	North Dakota Area 200	Washington Area 401	Total/ Average
Percent of U.S. production[1]	%	3.47	1.02	1.68	2.94	9.11
Number of enterprises[2]		1,490	800	2,230	1,070	5,590
Enterprise size[3]	acres	1,796	1,093	672	1,628	1,457
Yield '72-'76[4]	bu/acre	27.4	24.8	18.4	40.4	28.6
Yield '81-'85[5]	bu/acre	30.0	18.4	27.9	47.2	32.4
TFP (Region)		1.31	1.72	1.33	1.00	
TFP (Time)		.22	-.25	.47	-.06	.06
Elasticity of demand[6]		-.30	-.30	-.30	-.30	-.30
Elasticity of supply[7]		.20	.20	.20	.20	.20
P_1 '81-'85[8]	$/bu	3.49	3.49	3.49	3.49	3.49
Q_1 '81-'85[9]	1000 bu	87,889	22,063	45,139	77,927	233,018
Economic surplus	$1000	75,337	-32,405	69,907	-27,250	85,589
Consumer surplus	$1000	41,270	-13,987	41,459	-12,134	56,608
Economic rent	$1000	34,067	-18,418	28,449	-15,116	28,982
Rent/Ent (Region)	$	22,830	-23,000	12,740	-14,200	5,200
Rent/Acre (Region)	$	12.70	-21.00	19.00	-8.70	3.60

(See footnotes following Table 7.)

Table 7. Cotton Productivity Differentials and Associated Total Gains in Income in the Sample Production Regions from 1974 to 1983.

	Units	Alabama Area 600	California Area 500 (Irrigated)	Mississippi Area 200	Texas Area 200 (Irrigated)	Texas Area 200	Total/ Average
Percent of U.S. producion[1]	%	1.70	22.60	7.98	9.88	7.43	49.59
Number of enterprises[2]		220	560	400	950	500	2,630
Enterprise size[3]	acres	1,049	2,237	1,686	971	2,714	1,926
Yield '72-'76[4]	lbs/ acre	399.8	981.2	501.4	383.6	286.1	505.0
Yield '81-'85[5]	lbs/ acre	654.9	1,053.3	762.3	353.9	234.5	725.0
TFP (Region)		.72	.49	.60	1.09	1.00	
TFP (Time)		.63	.08	.60	-.19	-.29	.10
Elasticity of demand[6]		-1.84	-1.84	-1.84	-1.84	-1.84	-1.84
Elasticity of supply[7]		.25	.25	.25	.25	.25	.25
P_1 '81-'85[8]	\$/lbs	.588	.588	.588	.588	.588	.588
Q_1 '81-'85[9]	1000 lbs	119,949	1,317,658	507,259	550,003	413,280	2,908,148
Economic surplus	\$1000	27,915	61,380	115,580	-84,793	-120,276	-194
Consumer surplus	\$1000	3,727	7,891	15,401	-10,482	-14,368	2,169
Economic rent	\$1000	24,188	53,490	100,178	-74,311	-105,908	-2,363
Rent/Ent (Region)	\$	109,100	96,000	250,000	-78,000	-212,000	-900
Rent/Acre (Region)	\$	104.00	43.00	148.00	-80.00	-78.00	-.50

(See footnotes following Table 7.)

Footnotes for Tables 4-7

[1] Source: USDA/SRS data tapes on county level production 1979-1983 and USDA/ERS Ag. Info. Bull. No. 471 "Corn: Background for 1985 Farm Legislation," Appendix Table 7 on U.S. aggregate production 1979-1983. Also No. 472 "Soybeans;" No. 467 "Wheat;" No. 476 "Cotton."

[2] Source: 1982 Census of Agriculture Table 41 "Specified Crops by Harvested Acres" data reflects number of farms associated with very large to medium size categories only. The area-to-state production ratio is used to determine the number of enterprises within the area and across size categories.

[3] Source: Mean of USDA/ERS FEDS survey planted acres for very large, large and medium size enterprises.

[4] Source: USDA/SRS data tapes on county level harvested acres and production for 1972-1976.

[5] Source: USDA/SRS data tapes on county level harvested acres and production for 1981-1985.

[6] Source: George P.S. and G.A. King, "Consumer Demand for Food Commodities in the United States with Projections for 1980." Giannini Foundation Monograph No. 26, March 1971, University of California, Berkeley. p. 51.

[7] Source: Cochrane, W.W., "Conceptualizing the Supply Relation in Agriculture." JFE, 37(5), Dec. 1955.

[8] Source: USDA/ERS Ag. Info. Bull. No. 471 "Corn: Background for 1985 Farm Legislation," Appendix Table 7 on U.S. aggregate production 1979-1983. Also No. 472 "Soybeans;" No. 467 "Wheat;" No. 476 "Cotton."

[9] Source: USDA/SRS data tapes on county level production 1979-1983.

Table 8. Distribution of Economic Rent from Technology by Enterprise Size Across the Selected Areas from 1974 to 1983.[1]

Commodity	Very Large	Large	Medium	Total/Average
Corn				
Number of Enterprises	2,248	8,028	21,644	31,920
TFP	.88	.94	1.00	NA
Economic Rent ($1,000)	$50,541	$63,134	$18,322	$194,996
Rent/Enterprise	$22,500	$7,900	$3,750	$6,100
Rent/Acre	$22.50	$19.60	$16.10	$13.00
Soybeans				
Number of Enterprises	1,942	7,467	23,311	32,720
TFP	.94	.98	1.00	NA
Economic Rent ($1,000)	$50,886	$102,749	$98,144	$251,779
Rent/Enterprise	$26,200	$13,750	$4,200	$7,700
Rent/Acre	$33.50	$30.20	$14.00	$17.80
Wheat				
Number of Enterprises	763	1,401	3,426	5,590
TFP	.98	1.01	1.00	NA
Economic Rent ($1,000)	$-1,785	$8,036	$22,730	$28,982
Rent/Enterprise	$-2,350	$5,750	$6,650	$5,200
Rent/Acre	$-.90	$5.30	$10.30	$3.60
Cotton				
Number of Enterprises	429	779	1,423	2,630
TFP	.98	.99	1.00	NA
Economic Rent ($1,000)	$46,316	$-20,828	$-27,852	$-2,363
Rent/Enterprise	$108,000	$-26,700	$-19,600	$-900
Rent/Acre	$36.10	$-20.30	$-30.30	$-.50

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[1] The study period for cotton enterprises was 1974 to 1982. See footnotes following Table 7 for explanation of weighting and distribution procedures.

production relative to western Kansas, central North Dakota and northeastern Montana. The intertemporal total factor productivity gain between 1974 and 1983 is about 6 percent on average across the selected wheat regions but the situation differs greatly between regions. We have, however, tried to minimize the effects of annual weather variability on productivity by averaging crop yields over 5-year periods centering on 1974 and 1983. Resource owners in North Dakota area 200 received the largest positive economic rents per acre during this period as did those on medium size enterprises. There is little indication of size economies (Table 8) in wheat production on average in the selected areas.[4]

There are about 2,600 cotton producers in the sample area who grow about 50 percent of the U.S. cotton crop, with an average enterprise size of over 1900 acres (Table 7). Producers in the Southern California and the Mississippi Delta sample regions have a competitive advantage in cotton production relative to northern Alabama and the Texas High Plains. Total factor productivity gain between 1974 and 1982 is about 10 percent in cotton production, again with some very large differences between regions. A combination of adverse weather and pest conditions combined with declining water resources in the Texas High Plains region resulted in productivity losses for that region during the period studied. The largest positive economic rent per capita goes to resource owners in the Delta area of Mississippi and to very large enterprise owners. Very large enterprises capture the largest portion of economic rent per acre, although technical size economies (Table 8) in cotton production appear to be rather fully exploited by the medium size farms in the selected areas. This suggests that even in the absence of size economies beyond the medium-size cotton enterprise, very large producers are still exploiting available technology for a total income advantage.

CONCLUSIONS

This study has applied the Cobb-Douglas cost function to farm level data. These data were stratified by enterprise size and cost estimates generated using a consistent set of assumptions for both the 1974 and 1982/83 FEDS survey data.

Methodologically, we have estimated a Cobb-Douglas cost function across regions, size and time. We have extended the first order approximation of the cost function to include a measure of the difference in total factor productivity between enterprise sizes. In so doing, we have separated out the effect of changes in productivity associated with factor endowment (interregional) adoption of new technology (intertemporal) and fuller exploitation of existing technology (size economies).

The results indicate that central Illinois in corn, central Illinois and north central Iowa in soybeans, the Palouse of Washington in wheat and southern California and the Mississippi Delta in cotton have competitive advantage relative to the other selected areas. Relative to the enterprise size categories specified in this study, size economies exist in corn and soybean production but not in cotton. The case for size economies in wheat production is uncertain given the data problems in the Palouse area of Washington. Intertemporal productivity for field crops between 1974 and 1983 is about 15 percent for corn and soybeans, and 6 percent for wheat. Between 1974 and 1982 it is about 10 percent for cotton. Regions with competitive advantage did not always receive the highest amount of economic rent per acre for resource owners. Except for wheat, very large enterprise owners received the largest amount of economic rent even on a per acre basis.

Future research in this area should include estimating the second order approximation of the cost function. That is, instead of assuming a unitary elasticity of substitution function (Cobb-Douglas), we could estimate a variable elasticity of substitution function (second order translog function) as well as estimating the associated concept of factor bias. The data problems associated with yields in the Palouse by enterprise size should be addressed as a step toward estimating size economies in wheat production. The measures of intertemporal productivity and economic surplus are gross measures of benefits of new technology. However, we have not specified a measure of the costs, either private or public, of research and development to compare against these benefits. Moreover, additional effort is needed to update the supply and demand elasticities for individual commodities if the estimates of economic surplus are to have empirical credibility in more than a "relative" sense.

The analyses presented in this paper indicate that when adequate farm level cost data are available, it is now feasible to measure differentials in total factor productivity in the production of individual commodities over time, between production regions and by size of enterprise. These differentials provide important analytical insights into the distributional impacts of expenditures for research and development and the technical change that they generate. They also provide insights into the competitive position of producers by size and location. If, in addition, cost and output data can be provided for the "whole farm" units involved, alternative allocations of overhead costs among enterprises can be explored and, in addition, the economics of "farming systems" can be analyzed. We believe it is important that the national agencies involved in providing cost data for U.S. agriculture provide a continuing sample data set that permits the estimation of the economic measures referred to above.

FOOTNOTES

1 The work in returns to research includes an extensive body of literature and includes but is not limited to that done by Ayer and Schuh (1972), Duncan and Tisdell (1971), Evenson (1968), Griliches (1958), Lindner and Jarrett (1978), Peterson (1966), Rose (1980), Schmitz and Seckler (1970) and Wise and Fell (1980).

[2] Technology bias, in the Hicksian sense refers to the phenomenon in which "the factor ratio does not stay constant at a constant factor price ratio" (Binswanger, 1974a, fn p. 377).

[3] These measures of total factor productivity are approximations only in the sense that factor bias has not been accounted for. On the other hand, these are exact Cobb-Douglas measures of productivity.

[4] Data problems regarding yield by enterprise size in the Palouse area of Washington prevented an accurate measure of size economies in wheat production. The Palouse area has a very steep increasing rainfall gradient from west to east. This is complicated by the fact that larger enterprises are situated in the western portion while smaller ones predominate in the eastern portion. This situation shows up in the data as smaller enterprises having much higher yields.

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