Cost Efficiency In U.S. Corn, Soybean, Wheat, and Cotton Production

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Abstract

Between 1974 and 1983, intertemporal cost efficiency for U.S. field crops increased about 1.4 to 1.2% percent for corn, soybeans, and wheat and .2% per year for cotton. Competitive advantage in 1983 was held by central Illinois and north central Iowa in corn, central Illinois in soybeans, the Washington Palouse and central North Dakota in wheat, and southern California in cotton relative to the other selected regions in the study. Scale economies exist in corn, soybean and wheat but not in cotton production.

Key Words

corn, soybeans, wheat, cotton, cost efficiency, competitive advantage, scale economies, productivity, index numbers

I. A Question of Cost Efficiency in U.S. Agriculture

Cost efficiency is defined in this study as a comparison of the ratios of inputs to output either between two points in time, two regions, or two enterprises sizes for a given commodity. The commodities examined are corn, soybeans, wheat, and cotton produced in the U.S. The two time periods are 1974 and 1983. Pairwise comparisons are made among four or five regions and three enterprise sizes are for each commodity. Cost efficiency is the inverse of total factor productivity and, in that sense, the terms can be used interchangeably.

Why are measures of cost efficiency or productivity in U.S. agriculture important? There are four reasons. First, an increases in efficiency results in an increase in real income to consumers and resource owner. Increases in efficiency over time from the adoption of new technological is the source of the wealth of nations. Second, increases in regional efficiency is the source of competitive advantage. Competitive advantage indicates the regions that will reduce production the least when output prices are low or the regions that will realize the greatest return on investments when output prices are high. Third, changes in efficiency across enterprise sizes is a measure of scale economies. Scale economies in these major field crops helps determine the number and size of farms that makes up the structure

American agriculture. Finally, each of these changes in cost efficiency in a primary industry like agriculture can have significant impacts on the secondary and tertiary industries that also make up the rural economy.

Size economies are usually assumed away in studies of intertemporal cost efficiency. When this is done, the possibility exists that some or all of the efficiency gains across time may be accounted for by enterprises simply getting bigger and using all inputs more efficiently. Size economies represent a source of error in trying to estimate cost efficiency across time and region. Similarly, changes in efficiency over time represent a potential source of error in the estimation of size economies as well.

II. A Model of Cost Efficiency

Consider a cost function in which average cost per unit is a function of input prices and discrete variables for time, region and enterprise size.

(1) $C_{jtru} = f(P_{itru}, T, R, U)$

where

C_{jtru} is average cost per unit of commodity j, in time t, region r and enterprise size u.[1]

P_{itru} is price per unit of inputs i, i= capital (K), labor (L), energy (E), fertilizer (F), material (M), and land (A) (all factors variable) used to produce commodity j, in time t, region r and size u

T is time

R is region

U is enterprise size.

This model implies a set of assumptions. First, it is assumed that the cost function is the dual of the production function. Second, we assumed that the factor markets are in equilibrium under conditions of perfect competition. Third, it is assumed that there are constant returns to scale within a size category. Fourth, we assume each region has homogeneous-resource endowments relative to producing commodity j.

Equation (1) is approximated using Diewert's quadratic lemma. Diewert's quadratic approximation lemma for a quadratic function f is

(2) $f(z^1)-f(z^0) = \frac{1}{2}[\nabla f(z^1)+\nabla f(z^0)]^T(z^1-z^0)$.

$\nabla f(z^r)$ is the first derivative of f evaluated at r and where 0 is the initial period and 1 is the subsequent period (Diewert, p. 118). This lemma shows that by using only the geometric mean of the first derivatives, a second-order or quadratic approximation of a function can still be obtained.[2]

Diewert's quadratic approximation lemma applied to a logarithmic cost function results in an equation that isolates the effect of changing input prices from changing cost efficiency on average costs (Diewert, p. 117-18). A quadratic translog cost function implies that as an input price increases, unit cost increases at a decreasing rate as less expensive inputs are substituted for the more expensive ones, to the extent possible, to achieve a given level of output (Young et al. p. 7-8).

(3) $\ln C_{jtru1} - \ln C_{jtru0} =$

$\Sigma_i \frac{1}{2}(S_{itru0}+S_{itru1})(\ln P_{itru1}-\ln P_{itru0})$

$+ \frac{1}{2}(\alpha_{t0}+\alpha_{t1})(T_1-T_0) + \frac{1}{2}(\alpha_{r0}+\alpha_{r1})(R_1-R_0)$

$+ \frac{1}{2}(\alpha_{u0}+\alpha_{u1})(U_1-U_0)$, (Cooke and Sundquist, p. 1005).

Where:

S_{i0} is the change in unit cost for a change in initial input prices and equals the factor share of total expenditures on input i in the initial time period (Shephard, p. 11).

S_{i1} is the change in unit cost for a change in subsequent expenditures on input i in the subsequent time period.

α_{t0} is the change in unit cost for a change in initial technology, e.g., $\alpha_{t0} = \delta \ln C_0/\delta T_0$; and similarly for regions (α_{r0}) and enterprise size (α_{u0}).

α_{t1} is the change in unit cost from a change in subsequent technology, e.g., $\alpha_{t1} = \delta \ln C_1/\delta T_1$; and similarly for regions (α_{r1}) and enterprise size (α_{u1}).

Equation (3) states that the difference in the cost per unit to produce commodity j is equal to the difference in inputs prices, and the differences in efficiency across time, between regions and by enterprise size. Equation (3) is then solving for the changes in cost efficiency.

$$(4)\quad \tfrac{1}{2}(\alpha_{t0}+\alpha_{t1})(T_1-T_0) + \tfrac{1}{2}(\alpha_{r0}+\alpha_{r1})(R_1-R_0) + \tfrac{1}{2}(\alpha_{s0}+\alpha_{s1})(U_1-U_0) = \ln(C_{jtru1}/C_{jtru0}) - \Sigma_i \tfrac{1}{2}(S_{itru0}+S_{itru1})\ln(P_{itru1}/P_{itru0})$$

Equation (4) is the measure of change in cost efficiency by time, region, and size in logarithms. Taking the antilog translates the results into the base 10.

$$(5)\quad e^{1/2(\alpha t1+\alpha t0)(T1-T0)} * e^{1/2(\alpha r1+\alpha r0)(R1-R0)} * e^{1/2(\alpha u1+\alpha u0)(U1-U0)} = (C_{jtru1}/C_{jtru0}) \,/\, \pi_i(P_{itru1}/P_{itru0})^{1/2(Sitru1+Sitru0)}.$$

Equation (5) can be used to determine changes in cost efficiency by time, region or size by segmenting the data, so that two of the three sources of change in cost efficiency are held constant. For example, if region and size are held constant, then equation (5) reduces to a measure of intertemporal cost efficiency (Diewert, p. 127).

$$(6)\quad e^{1/2(\alpha t1+\alpha t0)(T1-T0)} = (C_{jt}{}^{1}/C_{jt}{}^{0}) \,/\, \pi_i(P_{it1}/P_{it0})^{1/2(Sit1+Sit0)}.$$

Equation (6) implies that any difference between the ratios of average cost and input prices can be attributed to change in cost efficiency across time. The price index $\pi_i(P_{it1}/P_{it0})^{1/2(Sit1+Sit0)}$ is an exact measure of inflation. (Between regions, the price index is a measure of regional price differences. Among enterprises, it is a measure of pecuniary economies.) If there has been no change in intertemporal cost efficiency, then the ratios of average cost to input price will equal one.

Equation (5) can be similarly reduced to measure scale economies or competitive advantage. The type of information required to estimate cost efficiency in each case is total cost, yield, factor shares, and input prices.

III.USDA Farm Enterprise Data

The data for the enterprise budgets used in this study were taken from the "Cost of Producing Selected Crops" surveys conducted by USDA in 1975 and 1983/4. The 1974 and 1982/3 national survey data for each commodity were limited to four regions,[3] and then further segmented into three enterprise size categories. The enterprise data within each of the 102 categories were aggregated into representative enterprise budget for that category ($4_j*2_t*4_r*3_u+6_{tu}$). These budgets represent a composite of production practices and input quantities for each commodity-time-region-size category. There are 24 budgets each for corn, soybeans, and wheat ($1_j*2_t*4_r*3_u$) and 30 budgets for cotton ($1_j*2_t*5_r*3_u$). The enterprise budgets were used as the source of information needed to construct cost efficiency indexes.

The selected regions for these commodities are listed in table 1 by the associated farm enterprise data system (FEDS) three digit area code signifying homogeneity of soil and rainfall. These sample regions were selected purposively based on importance of the region to production or to provide variability in farming systems and production technologies. In corn production, there were about 32,000 producers in the selected regions producing about 20 percent of U.S. corn for grain, on an average enterprise size of about 470 acres. In soybean production, there were about 33,000 producers in the selected regions with an average enterprise size of almost 440 acres. There were just under 5,600 wheat producers in the selected sample regions producing about 9.1 percent of the nation's output on an average enterprise size of just under 1460 acres. Though different types of wheat are produced in the sample regions, for some purposes comparisons are still of interest. There were about 2,600 cotton producers in the sample regions who grow about 50 percent of the U.S. cotton crop, with an average enterprise size of over 1900 acres.

The average enterprise size in 1983 is presented in table 2. Enterprise size is based on planted acres, which includes both owned and rented land. These acreages were arrayed within each area from largest to smallest and three enterprise sizes were designated for study: very large, large, and medium. Size categories were determined on the basis of percentiles of the arrayed planted acres and the average enterprise size for each category. The very large size is the 91 to 100 percentile; the large size is 71 to 90 percentile; the medium size is 41 to 70 percentile; the small (not used) is 1 to 40 percentile.[4]

The representative enterprise budgets were developed using the USDA budget generator from which fixed capital costs are expressed as a flow in each production period. 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.[5] The KLEFMA input and yield data provides sufficient information on input prices and factor shares and per unit cost to determine cost efficiency by time, region, and size.

IV. Results

The estimates of cost efficiency for corn, soybeans, wheat, and cotton across time, region and enterprise size are presented in tables 3 through 6. Between 1974 and 1983, average intertemporal cost efficiency for both corn and soybeans increased about 1.4% percent per year, for wheat 1.2% per year, and for cotton about .2%. Ray estimated technological change for U.S. crops and livestock form 1939 to 1977 to be 1.8% per year (p. 496). Schultz estimated a 1.35% average annual increase in U.S. agricultural productivity 1910-1950. (p. 109). Thirtle determined biological and mechanical technical change in the U.S.

between 1939 to 1978 to be 8% for corn, 3.6% for soybeans, 3.9% for wheat, and 5.2% for cotton (p. 38). If it is assumed that mechanical changes are largely over, then Thirtle's biological estimates alone are 1.7% for corn, 1.1% for soybeans, 1.5% for wheat, and .5% for cotton.

In 1983, competitive advantage in corn production was held by east-central Illinois and north-central Iowa (6 to 33%) over northern Indiana and south-central Nebraska (irrigated). Competitive advantage in soybean production belonged to east-central Illinois (9 to 80%) relative to north-central Iowa, western Ohio, and the Mississippi Delta. Competitive advantage in wheat production went to the Washington Palouse and central North Dakota (15 to 96%) compared to western Kansas and northeastern Montana. In 1982, competitive advantage in cotton production was maintain by south-central California (11 to 186%) relative to the Mississippi Delta, northern Alabama, and the Texas High Plains. 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 (Cooke, 1991). For 1974, Hazilla and Kopp ranked Iowa over Illinois over Indiana in corn production (p. 225). They had the same ranking as this study for 1974 soybean production of Iowa over Illinois over Ohio (p. 225).

In 1983, very large corn enterprises (1000 acres) were about 13% and large enterprises (400 acres) were 6% more cost efficient than medium size enterprises (235 acres). Very large soybean enterprises (780 acres) were 5% and large enterprise (455 acres) were about 3% more cost efficient than medium size enterprises (300 acres). Very large wheat enterprises (2660 acres) were about 6% and large enterprises (1085 acres) about 2% more cost efficient that medium size enterprises (645 acres). In 1982, very large enterprises (3000 acres) are 2% more cost efficient and large enterprise (1320 acres) are 2% less efficient than medium size enterprises (650 acres) in cotton production. Ray found increasing returns to scale in U.S. crop production consistently from 1939 to 1977 (p. 495). Chan and Mountain report statistically significant economies of scale for Canadian agriculture (p. 665). On the other hand, Miller reported that there was "little evidence" of economies of size in U.S. agriculture and that the "medium-size family farms" are as efficiency as the large farms (p. 112).

V. Warranted Assertions

Intertemporal cost efficiency for field crops between 1974 and 1983 increased about 1.4 to 1.2% percent for corn, soybeans, and wheat and .2% per year for cotton. Competitive advantage in 1983 was held by central Illinois and north central Iowa in corn, central Illinois in soybeans, the

Washington Palouse and central North Dakota in wheat, and southern California in cotton relative to the other selected regions in the study. Scale economies exist in corn, soybean and wheat but not in cotton production.

The nonparametric technique used in this study shows that it is possible to measure changes in cost efficiency for individual commodities arithmetically from the data in enterprise budgets. These measures provide necessary information on the impacts of agricultural research and development and the technical change that they generate over time, between regions and by enterprise size.

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. It is important that the national agencies involved in providing cost data for U.S. agriculture provide a continuing sample data set which permits the estimation of these types of economic measures.

Table 1. Selected Regions By Commodity.

Commodity	Selected State	FEDS Area	Geographic Location	Commodity	Selected State	FEDS Area	Geographic Location .
Corn	Illinois	300	East Cent.	Soybeans	Illinois	300	East Cent
	Indiana	101	Northern		Iowa	201	No. Cent
	Iowa	201	No. Cent.		Mississippi	100	Delta .
	Nebraska[1]	400	So. Cent.		Ohio	101	Western.
Wheat	Kansas[2]	100	Western	Cotton	Alabama	600	Northern.
	Montana[2]	200	No. East		California[1]	500	So. Cent.
	North Dakota[3]	200	Central		Mississippi	100	Delta .
	Washington[4]	400	Palouse		Texas	200	High Plains
.					Texas[1]	200	High Plains

1 Irrigated. 2 Hard red winter following fallow. 3 Hard red spring continuous cropping. 4 Soft white winter following fallow.

Table 2. Enterprise Sizes By Commodity And Region (Planted Acres).

Corn	IL 300	IN 101	IO 201	NE 400[3]	Ave.[2]	Soybeans	IL 300	IO 201	MS 100	OH 101	Ave.[2]
VL	1113	903	576	1715	998	VL	684	707	1262	897	782
L	355	515	249	671	403	L	418	341	894	493	455
M	246	271	170	266	233	M	270	210	795	244	299
Ave.[1]	520	444	314	685	470	Ave.[1]	388	291	1050	436	438

Wheat	KS 100	MT 200	ND 200	WA 400	Ave.[2]	Cotton	AL 600	CA 500[3]	MS 100	TX 200[3]	TX 200	Ave.[2]
VL	3909	1577	1283	2388	2659	VL	1842	2833	2868	1707	5920	2989
L	1429	619	630	1104	1083	L	917	1432	1202	929	1825	1317
M	774	421	338	753	645	M	568	614	754	436	972	646
Ave.[1]	1796	1093	672	1628	1447	Ave.[1]	1049	2237	1686	971	2714	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.

Table 3. Corn: Cost Efficiency By Time, Region, And Size.

Index	Year	Size	Base	Region Illinois Area 300	Indiana Area 101	Iowa Area 201	Nebraska Area 400	Total/ Average
Time	1983	VL	1974 = 100	89	92	80	82	87
		L		92	86	82	91	88
		M		95	92	82	75	88
		Ave		93	90	82	82	88
		Annual		.7%	1.2%	2.2%	2.2%	1.4%
Region	1983	VL	IL = 100	100	109	103	134	NA
		L		100	106	102	134	NA
		M		100	103	97	132	NA
		Ave		100	106	100	133	NA
		Rank		1	3	1	4	
	1974	Ave		100	108	112	144	NA
		Rank		1	2	3	4	
Size	1983	VL	M = 100	84	88	90	84	87
		L		92	95	97	94	94
		M		100	100	100	100	100

Table 4. Soybeans: Cost Efficiency By Time, Region, And Size.

Index	Year	Size	Base	Region: Illinois Area 300	Iowa Area 201	Miss. Area 100	Ohio Area 101	Total/ Average
Time	1983	VL	1974 = 100	87	92	83	79	86
		L		83	93	77	85	85
		M		84	100	97	84	90
		Ave		84	97	84	84	88
		Annual		1.9%	0.3%	1.9%	1.9%	1.4%
Region	1983	VL	IL = 100	100	104	174	108	NA
		L		100	113	186	110	NA
		M		100	108	194	112	NA
		Ave		100	109	180	111	NA
		Rank		1	2	4	3	
	1974	Ave		100	99	182	115	NA
		Rank		2	1	4	3	
Size	1983	VL	M = 100	98	94	88	94	95
		L		97	101	92	95	97
		M		100	100	100	100	100

Table 5. Wheat: Cost Efficiency By Time, Region, And Size.

Index	Year	Size	Base	Region	Kansas Area 100	Montana Area 200	N.Dakota Area 200	Washington Area 400	Total/ Average
Time	1983	VL	1974 = 100		80	128	74	100	90
		L			83	128	63	108	92
		M			82	136	64	97	89
		Ave			82	129	66	101	90
		Annual			2.2%	-2.9%	4.5%	-0.1%	1.2%
Region	1983	VL	WA = 100		110	192	106	100	NA
		L			105	187	94	100	NA
		M			119	213	101	100	NA
		Ave			115	196	100	100	NA
		Rank			3	4	1	1	
	1974	Ave			132	143	170	100	NA
		Rank			2	3	4	1	
Size	1983	VL	M = 100		92	86	96	97	94
		L			95	94	96	105	98
		M			100	100	100	100	100

Table 6. Cotton: Cost Efficiency By Time, Region, And Size.

Index	Year	Size	Region Base	Alabama Area 600	California Area 500	Miss. Area 100	Texas(i) Area 200	Texas Area 200	Total/ Average
Time	1982	VL	1974 = 100	76	95	66	135	115	97
		L		61	90	68	127	164	98
		M		56	97	66	124	155	99
		Ave		66	93	66	129	145	98
		Annual		5.1%	.8%	5.1%	-3.2%	-4.8%	0.2%
Region	1982	VL	CA = 100	145	100	119	303	270	NA
		L		147	100	130	294	303	NA
		M		133	100	101	278	270	NA
		Ave		141	100	111	286	278	NA
		Rank		3	1	2	5	4	
	1974	Ave		182	100	154	182	141	NA
		Rank		4	1	3	4	2	
Size	1982	VL	M = 100	99	96	108	98	90	98
		L		95	100	118	98	97	102
		M		100	100	100	100	100	100

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1 In this study, unit costs (C) equals total costs per acre (TC) divided by yield per acre (Y), i.e., C = TC/Y.

2. Diewert's lemma provides a way to isolate the effect of changing prices on average cost arithmetically. Diewert's lemma is equivalent to a second-order Taylor series expansion of the function (Diewert p.127). A second-order Taylor series expansion is: $f(z^1)-f(z^0) = [\nabla f(z^0)]\,(z^1-z^0) + \frac{1}{2}\nabla^2 f(z^1-z^0)^2$.

3 For cotton production, there were five regions selected in that within the Texas High Plains region both irrigated and dryland production practices were included.

4 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.

5 The assumptions within the budget generator program were at the discretion of the researchers. The key assumption is that all tractors and machinery were fully utilized. Care was taken to make sure that the harvesting machinery was fully utilized for a given enterprise size.