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THE IMPACT OF CONSERVATION TILLAGE TECHNOLOGY ON U.S. WHEAT PRODUCTIVITY GROWTH AND REGIONAL COMPETITIVE ADVANTAGE

By

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Abstract: The total factor productivity index for U.S. wheat was 1.5% per year between 1974 and 1983. The conservation tillage productivity index for U.S. wheat was about 1.1% per year during this time period, or about 75% of the T.F.P. North Dakota and Washington were equal in competitive advantage in 1983. Scale economies in U.S. wheat production represented between a six and two percent advantage for very large (2700 acres) and large (1100 acres) enterprises over medium size (650 acres) enterprises in 1983.

Key Words: Wheat, productivity, conservation tillage, soil erosion, competitive advantage, scale economies, index, United States

I. Soil Erosion and Wheat Production and Productivity

Wheat production in the U.S. holds a comparative advantage (or the least comparative disadvantage) in the semi-arid regions of the Great Plains and the Pacific Northwest relative to corn and grazing livestock (Heady, p. 665, Cochrane, p. 223). Once the prairie sod was broken, soil erosion became a ongoing problem in these wheat producing areas (Cochrane, p. 308-9). Given the low rain fall, many western wheat farmers depend on summer fallow to increase soil moisture as well as to store up nitrogen and control weeds (Johnson and Ali, p. 67). However, the benefits of summer fallow come at the expense of the soil erosion (Johnson and Ali, p. 67).

The intense cultivation of continuous cropping, the alternative to summer fallow, also causes soil erosion (Burt, p. 81). As a result, the water storage capacity of the soil decreases as top soil becomes more shallow (Burt, p. 92). So, unless a region has particularly deep topsoil, the long run loss of soil erosion will eventually over take the short run gains from intensive cultivation.

"Conservation tillage" is a new technology that has been developed to address the problem of soil erosion with either continuous and summer-fallow wheat. Conservation tillage substitutes "a stubble drill for a conventional drill and herbicides for tillage operations" (Epplin et al,

p. 1039). If conservation tillage is being adopted in U.S. wheat production, then the reduction in quantity of tillage capital, the increase in herbicides, and the associated change in yield should result in a productivity increase.

What is the relationship between conservation tillage and wheat productivity? Burt suggest the relationship is too complex to determine (p. 86). On the other hand, Taylor and Young state that a clear relationship exits between soil conservation and productivity (pp. 64-66). If there is a relationship between conservation tillage, and productivity, then, over time, regions will have differences in total factor productivity based on their willingness or ability to adopt soil conserving technology. These differences will affect a regions' ability to maintain competitive and comparative advantage of wheat (Heady, p. 664-5). In this paper, the increase in U.S. wheat productivity from conservation tillage is measured using Tornquist indexes of total and partial productivity.

II. A Model of Productivity

Consider a continuous, twice-differentiable, concave, non-decreasing, non-homothetic, logarithmic production function such that yield is a function of input quantities and discrete variables of time, region, and enterprise size.

(1) $\ln Y_{jtru} = f(\ln X_{itru}, T, R, U)$.

Where Y_{jtru} is the yield for commodity j in time t, region r, and enterprise size u. X_{itru} is quantity of input i to produce commodity j. T, R, and U are discrete measures of time, region, and enterprise size.

Diewert has shown that a Tornquist input-quantity index, defined as the geometric mean of the Paasche and Laspeyres input indexes, provides a second-order approximation of a production function. As a result, the ratio of yield to input indexes between points 0 and 1 is an index of productivity, independent of changes in relative prices (pp. 122-23). By applying Diewert's quadratic lemma,

(2) $\ln(Y_{jtru1}/Y_{jtru0}) = \Sigma_i \frac{1}{2}(S_{itru1}+S_{itru0})\ln(X_{itru1}/X_{itru0})$
$+ \frac{1}{2}(\alpha_{t1}+\alpha_{t0})(T_1-T_0) + \frac{1}{2}(\alpha_{r1}+\alpha_{r0})(R_1-R_0) + \frac{1}{2}(\alpha_{u1}+\alpha_{u0})(U_1-U_0)$.

Where Si is the factor share of expenditure on input i, and α_t is the first partial derivative of the production function with respect to time, e.g., $\alpha_{t1} = \delta \ln Y_1/\delta T_0$; and similarly for regions (α_r) and enterprise size (α_u).

Solving equation (2) for the indexes of total factor productivity by time, region, and size and taking the antilog transforms the equation into,

(3) $100(e^{1/2(\alpha t1+\alpha t0)(T1-T0)} * e^{1/2(\alpha r1+\alpha r0)(R1-R0)}$
$* e^{1/2(\alpha u1+\alpha u0)(U1-U0)}) = 100((Y_{jtru1}/Y_{jtru0})$
$\div \pi_i(X_{itru1}/X_{itru0})^{1/2(Sitru1+Sitru0)})$.

Equation (3) implies that the product of intertemporal, interregional, and interenterprise changes in productivity equals the yield index divided by the input-quantity indexes at different times, regions and enterprise sizes. An increase or decrease in productivity is measured relative to point 0 ($base_{tru0}$ = 100). If there is no change in productivity, then the yield and input indexes are equal and the productivity index equals 100.

The productivity index of intertemporal, interregional, and interenterprise can be separated among technical change, regional resource endowments, or scale economies derivations, if the other two sources of change are held constant and equal to zero. However, Griliches stated, "... it does not further our understanding of growth to label the unexplained residual changes in output as 'technical change'" (p. 331). Fortunately, these individual productivity measures are the quotient with a yield and an input-quantity indexes. The input-quantity index is, itself, the product of a set of partial factor productivity indexes, which can be used to determine the source(s) of a change in productivity. These partial productivity indexes (including yield) measure the source and contribution of the embodied quality differences in the input categories to either reduce input quantity or increase yield (Griliches, fn 11, p. 334).

III. Firm Enterprise Budget Data for Wheat

The wheat data needed to determine the yield and input indexes are yields, input expenditures, and the quantities of input by time, region, and size. The ten input i categories used are tillage capital (t), application capital (a), planting capital (p), harvesting capital (k), hauling capital (h), labor (l), energy (e), fertilizer (f), materials (m), and land (a). The input expenditure and quantity data comes from the original survey data for wheat enterprises from the USDA/Farm Enterprise Data System (FEDS) survey of 1974, 1978, and 1983. The selected wheat region/variety/cultural practice were 1) western Kansas (area 100) for hard red winter wheat following fallow, 2) northeastern Montana (area 200) for hard red winter wheat following fallow, 3) central North Dakota (area 200) for hard red spring wheat continuous cropping, and 4) the Palouse in Washington (area 400) for soft white winter wheat following fallow. These regions are homogeneous with respect to soil type and rainfall. The data was sorted by total planted acres for the 41 to 70, 71 to 90, and 91 to 100 percentiles. The enterprises were designated as "medium," "large," and "very large" respectively. In total, 36 representative enterprise budgets (3t x 4r x 3u) were developed from the survey data.

IV. Intertemporal and Interregional Wheat Productivity

It was hypothesized in the introduction that if the conservation tillage technology were adopted by U.S. wheat producers, then a decrease in the quantity of tillage capital and an increase in the quantity of pesticide materials would be observed. Also, for conservation tillage to be successfully adopted over time, it must have a positive effect on productivity. A total factor productivity index (T.F.P.) is used to measure all sources of productivity gains. This is compared to a "conservation tillage" index (C.T.Y.), which is used to measure the partial productivity gains from changes in tillage capital, materials, and yield categories only.

Tables 1 shows the Tornquist total factor productivity index (T.F.P.) and the partial productivity indexes for each input category, total inputs and yield. The tillage and materials categories changed more on average than the other eight input categories. The tillage capital and materials indexes confirm the predictions of a general decrease in tillage service hours and an increase in pesticide use. The overall T.F.P. index for U.S. wheat was positive, at about 1.5% per year between 1974 and 1983. This rate is approximately the same as the 1.9% reported by Thirtle for U.S. wheat between 1971 and 1978 (p. 40).

In table 2, the annual T.F.P. index is compared to the C.T.Y. index and its components. The C.T.Y. for U.S. wheat was about 1.1% per year between 1974 and 1983, or about 75% of the T.F.P. index. This reveals that conservation tillage and yield were the dominant changes taking place in wheat productivity over this nine year period.

It was also hypothesized that regions with the highest rates of intertemporal productivity gain will have the greatest improvements in regional competitive advantage. Of the four wheat regions studied, Washington was consistently more or just as productive than its next closest competitor by 0 and 49% (see table 3). As anticipated, the competitive advantage of North Dakota and Kansas did increase, while Montana decreased relative to Washington.

North Dakota ranked fourth in wheat production in 1974, but had caught up with Washington in 1983 by closing a 41 percentage-point gap (see table 4). The improved competitive position of North Dakota can be attributed to yield growth of eighteen percentage points, while input use decreased nineteen percentage points. The differential rate of adopting conservation tillage between North Dakota and Washington explains about half of the change in input use that contributed to a change in competitive advantage. The other half of the change in inputs was an eight percentage point decrease in cost of land as a percentage of total expenditure share in North Dakota compared to Washington.

On average, very large U.S. wheat producers (2700 acres) were six percent more productive and large producers (1100 acres) were two percent more productive than medium size producers (650 acres) in 1983 (see table 5). Thirtle estimated returns to scale in U.S. wheat to be between five and seventeen percent from 1939 to 1978 (p. 40).

Was conservation tillage technology the source of scale economies in U.S. wheat production? The adoption of conservation tillage technology did effect scale economies. See table 6. The effects of conservation tillage on scale, measured as C.T.Y., were more pronounced in 1978 and 1983 (50 to 67% of T.F.P.) than in 1974 (11 to 38% of T.F.P.).

The indexes of scale economies suggest that wheat producers in North Dakota and Washington have almost fully exploited scale economies by 1983. However, very large Kansas and Montana wheat producers enjoyed a nine to eighteen percent productivity advantage over medium producers in 1983. Regions can increase their productivity and competitive advantage by exploiting scale economies. Since producers in these regions do not enjoy a competitive advantage in wheat, one strategy they could adopt is the exploiting of scale economies. Kansas very large wheat producers were larger than any other in 1983 in terms of planted acres and may not have wanted to increase their capital investments for the additional scale economies (see table 7). As for Montana, very large producers might well be expected to increase their enterprise sizes in the future to help make up for the loss in competitive advantage.

V. Warranted Assertions

The tillage capital and materials indexes found in this study confirmed the predictions of a general decrease in tillage service hours and an increase in pesticide use. The overall T.F.P. index for U.S. wheat was positive, at about 1.5% per year between 1974 and 1983. The C.T.Y. for U.S. wheat was about 1.1% per year between 1974 and 1983. index. The first warranted assertion is that conservation tillage and yield was the dominant changes taking place in U.S. wheat productivity over between 1974 and 1983, comprising about 75% of the growth in T.F.P.

No region showed positive intertemporal productivity gains from conservation tillage by decreasing inputs more than the accompanying decrease in yields. Therefore, a second assertion based on the results from this study is that the successful adoption of conservation tillage is possible if and only if it is accompanied by a yield increase.

The North Dakota case shows that besides increases in productivity, a region's competitive advantage in wheat is also a function of the relative cost of its land. Once a parity in competitive advantage is reached, additional productivity may then become capitalized into the land assets. Thus, a third assertion is that regions can achieve a competitive advantage by either increasing productivity or devaluing their resource endowments with the gains in productivity becoming capitalized in the resource endowments as parity is achieved. This suggests that we would expect to see land prices decrease in Montana.

Scale economies in U.S. wheat production ranged from two to nine percent between 1974 and 1983. Conservation tillage technology accounted for 11 to 67% of the scale economies. A fourth assertion is that conservation tillage is not a scale neutral technology in wheat.

Table 1. A Decomposition of Intertemporal Productivity Indexes for U.S. Wheat (1974=100).

	1983					1978				
Index	Kansas	Montana	N.Dakota	Washington	US	Kansas	Montana	N.Dakota	Washington	US
Tillage	97	91	93	100	96	95	86	95	94	93
Planting	98	96	98	100	98	98	95	98	100	98
Applying	100	100	101	100	100	100	100	100	100	100
Harvest	98	101	96	100	98	99	97	100	100	99
Hauling	98	101	101	101	100	98	100	100	101	100
Capital	91	89	89	100	93	90	80	93	94	90
Labor	96	98	98	100	98	96	96	98	100	97
Energy	99	100	99	100	100	99	98	99	100	99
Fertilizer	99	103	107	102	102	102	106	100	103	102
Materials	102	108	112	112	108	101	108	109	112	106
Land	103	100	100	100	101	104	100	100	99	101
Total Input	90	98	103	114	101	91	86	99	108	96
Yield	111	75	157	114	115	96	86	104	96	96
T.F.P.	123	77	152	100	114	106	99	105	89	99
T.F.P.(Annual)	2.3	-2.9	4.8	0.0	1.47	1.46	-.25	1.2	-2.9	-.25

Interpretation: T.F.P. and C.T.Y. index numbers greater than 100 indicate the extent to which enterprises were more productive in 1983 and 1978 than in 1974 and conversely for numbers less than 100. For the partial productivity indexes, numbers greater than 100 indicate the extent to which input use and yields were greater in 1983 and 1978 than in 1974.

Table 2. Annual Intertemporal Productivity Indexes for U.S. Wheat (1974=100).

Region Year	T.F.P. $Y/(X_i)$	T.F.P. Annual	Tillage (T)	Materials (M)	C.T. (T*M)	Yield (Y)	C.T.Y. Y/(T*M)	C.T.Y. Annual	Difference TFP-CTY
ND 1983	152	4.8	93	112	104	157	151	4.7	0.1
KS 1983	123	2.3	97	102	99	111	112	1.3	1.0
US 1983	114	1.5	96	108	104	115	111	1.1	0.4
KS 1978	106	1.5	95	101	96	96	100	0.0	1.5
ND 1978	105	1.2	95	109	104	104	100	0.0	1.2
WA 1983	100	0.0	100	112	112	114	102	0.2	-0.2
US 1978	99	-0.3	93	106	99	96	97	-0.8	0.5
MT 1978	99	-0.3	86	108	93	86	92	-1.9	1.6
WA 1978	89	-2.9	94	112	105	96	91	-2.2	-0.7
MT 1983	77	-2.9	91	108	98	75	77	-2.9	0.0

Table 3. Interregional Productivity Indexes for U.S. Wheat (Washington = 100).

Index	KS	MT	ND	WA	:	KS	MT	ND	WA
- 1983			T.F.P.					C.T.Y.	
Yield	78	46	71	100	:	78	46	71	100
Input	89	90	71	100	:	100	100	98	100
Productivity	87	51	100	100	:	78	46	72	100
Rank	3	4	1	1	:	2	4	3	1
- 1978									
Yield	87	68	58	100	:	87	68	58	100
Input	95	88	80	100	:	102	102	106	100
Productivity	91	77	73	100	:	85	67	55	100
Rank	2	3	4	1	:	2	3	4	1
- 1974									
Yield	81	70	53	100	:	81	70	53	100
Input	106	100	90	100	:	111	114	107	100
Productivity	76	70	59	100	:	73	61	50	100
Rank	2	3	4	1	:	2	3	4	1

Interpretation: T.F.P. and C.T.Y. productivity numbers less than 100 indicate the extent to which enterprises in a region were less productive than those in Washington. The partial productivity input and yield indexes greater than 100 indicate the extent to which input use and yields were greater in other regions than in Washington and conversely for numbers less than 100.

Table 4. A Decomposition of Interregional Productivity Indexes for U.S. Wheat (Washington = 100).

	Kansas			Montana			N. Dakota		
Index	1983	1978	1974	1983	1978	1974	1983	1978	1974
Tillage	100	103	101	99	101	107	99	108	104
Planting	100	101	102	100	100	103	100	101	102
Applying	99	99	98	100	100	99	101	101	100
Harvest	96	97	98	99	96	99	102	107	102
Hauling	100	99	102	99	99	100	98	98	99
Capital	95	99	102	98	97	108	100	115	108
Labor	99	100	103	99	99	102	99	100	101
Energy	100	100	101	100	100	100	99	101	101
Fertilizer	95	95	93	94	93	87	104	98	102
Materials	100	99	110	101	101	107	99	98	103
Land	100	102	98	97	98	98	70	72	78
Total Input	89	95	106	90	88	100	71	80	90
C.T. (T*M)	100	102	111	100	102	114	98	106	107
Yield	78	87	81	46	68	70	71	58	53
T.F.P.	87	91	76	51	77	70	100	73	59

Table 5. A Decomposition of Interenterprise Productivity Indexes for U.S. Wheat (Medium = 100).

	1983			1978			1974		
Index	V Large	Large	Medium	V Large	Large	Medium	V Large	Large	Medium
Tillage	99	100	100	100	100	100	99	99	100
Planting	99	100	100	99	100	100	99	99	100
Applying	100	100	100	100	100	100	99	100	100
Harvest	99	100	100	98	99	100	96	98	100
Hauling	100	100	100	100	100	100	100	100	100
Capital	97	100	100	97	98	100	94	96	100
Labor	100	100	100	100	100	100	99	99	100
Energy	100	100	100	100	100	100	100	100	100
Fertilizer	100	100	100	100	100	100	99	99	100
Materials	99	100	100	100	100	100	101	98	100
Land	100	100	100	100	100	100	100	100	100
Total Input	96	99	100	96	99	100	92	93	100
Yield	102	101	100	102	101	100	101	100	100
T.F.P.	106	102	100	106	103	100	109	108	100

Table 6. Interenterprise Productivity Indexes for U.S. Wheat in 1983, 1978 & 1974 (Medium = 100).

Year	Size	Kansas Area 600	Montana Area 500	N. Dakota Area 200	Washington Area 200	Average T.F.P.	Average C.T.Y.
1983	Very Large	109	118	103	103	106	104
	Large	105	107	103	95	102	101
	Medium	100	100	100	100	100	100
1978	Very Large	105	116	111	100	106	102
	Large	105	100	104	101	103	101
	Medium	100	100	100	100	100	100
1974	Very Large	109	112	120	106	109	101
	Large	109	105	112	107	108	103
	Medium	100	100	100	100	100	100

Interpretation: Numbers greater than 100 indicate the extent to which very large and large enterprises are more productive than the medium size category, and conversely for numbers less than 100.

Table 7. Average Wheat Enterprise Size by Production Region (Planted Acres).

State	Kansas	Montana	N. Dakota	Washington	Weighted	Acre
FEDS Area	100	200	200	400	Average	Index
			Planted Acres			
1983 Very Large	3909	1577	1283	2388	2675	412
Large	1429	619	630	1104	1089	168
Medium	774	421	338	753	649	100
Average	1509	1094	672	1346	1254	193
1978 Very Large	2599	2367	569	1763	1985	334
Large	1418	1101	371	977	1073	181
Medium	728	667	185	597	593	100
Average	1165	1259	390	1057	1020	172
1974 Very Large	1099	1408	757	1765	1328	316
Large	720	624	285	964	743	177
Medium	400	338	148	564	420	100
Average	701	859	460	1098	830	198

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

Weights for average enterprise size across regions and within size categories are based on 1979-85, 1975-80, and 1972-76 average county-level USDA/SRS data as a ratio of a region's production to the sum of production across regions.

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