FARM SIZE AND TRACTOR TECHNOLOGY

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Technology creates changes in agriculture that all segments of the agricultural community need to consider to anticipate the resulting impacts. Objectives of the research were to project the size and number of farming operations in eastern Washington and to examine the implications for farm size of four-wheel-drive tractor technology. Based on Markov chain projections of farm size, enlargements will occur in farms over 1,000 acres. Use of four-wheel-drive tractors will pressure farming operations larger than 2,000 acres to enlarge further.
Keywords: Tractor technology, economies of farm size, Markov chains.

During 1960 to 1975, total farm output increased 25 percent; and extensive factor substitution occurred. The number of farms declined while their average size increased. The largest growth in agricultural inputs took place in chemicals, 176 percent. In contrast, mechanical power and machinery use rose 7 percent, labor decreased 42 percent, and land being farmed declined 4 percent.

The small gain in mechanical power and machinery relative to the large reduction in farm labor can be partly explained by comparing changes in the size of machinery. As late as 1966, only 5.5 percent of retail sales of farm wheel tractors were units having at least 100 power take-off (PTO) horsepower. By 1975, such large power units accounted for 46.7 percent of sales. The adoption of such technology varies by region, depending upon the type of farming.

Changing technology and farm size have significantly altered the agricultural economy, including the agribusiness industries which supply production inputs to agricultural producers. A problem faced by all segments of the agricultural economy is one of anticipating the effects of technological innovation.

The objectives of this article are: (1) to project the number and size of farming operations in a selected area to 1985; and (2) to examine the implications of changes in farm size for changes in tractor technology, particularly the new generation of four-wheel-drive tractors. We define a farming operation as the amount of land farmed by a single entity, such as an individual or a corporation. The land might be entirely or partly owned, rented, or leased.

PROCEDURES

Markov chains (*6*, *7*) were used to describe how the sizes of farm operations have changed over the last 10 years and to analyze how they may change over the next 10 years.[1] We assumed that the farming operations be grouped into various sizes (states) of operations according to acres. Further, the change in size of a farming operation through the various states is a stochastic process; the probability of moving from one state to another is a function of only the two states. To project number and sizes of farming operations, it was assumed that the same forces, economic and noneconomic, will be experienced during the projection period as were experienced during the base period from which the data were obtained.

The feasibility of the projected farm enlargements is appraised in terms of adoption of conventional and new tractor technology. We investigate the economic forces generated by the adoption of the large four-wheel-drive tractors, and the effects of these forces in changing farm sizes.

Sample

Whitman County in eastern Washington was used as the study area. Parallel studies of Lincoln and Adams counties, not reported here, led to the same general conclusions about farm size trends and tractor technology as the Whitman County study (*4*). The major crops in the area are wheat, barley, peas, and lentils. The average rainfall ranges from 12 inches on the western side of Whitman County to about 25 inches on the eastern side. Peas and lentils are raised in eastern Whitman County where rainfall is sufficient.

The records of USDA's Agricultural Stabilization and Conservation Service (ASCS) county office provided the basic data on how farming operations had changed in the study area from 1965 to 1975. The potential new entrants into farming in the study area were assumed to be the males living on farms in the county. Using such a large number of potential entrants approaches the conditions of the perfectly competitive market model which approximately describes the production sector of agriculture (*10*).

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[1] Italicized numbers in parentheses refer to items in References at the end of this article.

Estimated standard deviations of farm sizes were made with the 1969 Census of Agriculture and supplemental information from the ASCS county office. The standard deviation, mean, and total number of farm operators to be sampled were used to determine the sample size required to achieve a coefficient of variation of at least 7.6 percent in statistical estimates for farming operations of less than 2,000 acres. All farm operators in the county with 2,000 or more acres were added to the sample because the greatest adoption of the latest technology in farm machinery (four-wheel-drive tractors) has been observed on these operations. Thus, the overall coefficient of variation is less than 7.6 percent, but it was not possible to estimate the coefficient of variation for the entire population because the largest class interval in the Census of Agriculture was open-ended.

Markov Chain Analysis

The ASCS data on farming operations in the county were used to develop the probability transition matrix (P) which described how farming operations changed over time among various acreage states:

State	Size	Farms observed 1965	Farms observed 1975
	Acres	*Number*	
S_0	0	412	535
S_1	1-99	176	75
S_2	100-259	225	200
S_3	260-499	452	375
S_4	500-999	483	450
S_5	1,000-1,999	269	400
S_6	2,000-2,999	85	63
S_7	3,000 and over	11	15

Each element (p_{ij}) in the probability transition matrix (P) in table 1 is an estimate of the probability of a firm moving from one state to another. Because each row in the P matrix constitutes a probability vector, the premultiplication of the P matrix raised to the n^{th} power by the row vector defining the states in the base period results in a row vector of the projected number of farming operations in each state in the n^{th} future period. In general, $S^n = S^oP^n$ where S^o refers to the base period vector and S^n is the row vector of the future number and size of farming operations in the n^{th} time period.

In this study, we examine only the situation where n equals 2; that is, we project the 1965-75 transitions to 1985. We did not estimate an equilibrium solution of the process or an index of farm operation mobility in terms of changing size. There were no absorbing chains in this study. Estimating these various other facets arising from Markov chains would have implied unrealistic assumptions concerning future technology.
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PROJECTED FARM SIZE

Between 1975 and 1985, 22 percent of the farming operators are expected to enlarge their operations (table 2). Of these 471 operators, 62 are expected to be in the size groups larger than 2,000 acres. Over one-half (55 percent) of the total enlargements will be farming operations in the size groups of 1,000 acres or larger. Table 2 shows the average size of the farming operation of the sampled farms for each farm size category. The table does not show how many farmers will reduce the size of their operations during 1975-85. It is the number of enlarging farms that has implications for adopting new tractor technology.

OPTIMUM MACHINERY SELECTION

One force causing farms to enlarge is excess capacity of farm power units. While the use of farm machinery increased only 7 percent during the decade studied, the number of farm tractors rating above 140 horsepower increased from less than 1 percent in 1970 to nearly 10 percent in 1974. All else equal, increases in tractor horsepower will result in excess capacity and frequently in a larger per unit cost (*9*).

Table 1.—Transitional probability matrix for farming operations in Whitman County, Washington, 1965 and 1975

State	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7
S_0	0.8656	—	0.1292	—	—	—	0.0052	—
S_1	.6219	.3731	—	—	—	—	.0050	—
S_2	—	—	.5556	.2222	.1111	.1111	—	—
S_3	.0553	—	—	.7190	.2212	—	.0046	—
S_4	.1035	—	.0518	—	.6211	.2070	.0145	.0021
S_5	—	—	—	—	.0929	.8364	.0706	—
S_6	—	—	—	—	—	.5882	.3647	.0471
S_7	—	—	—	—	—	—	.0909	.9091

Table 2.—Farming operations expected to change farm size in Whitman County, Washington between 1975 and 1985

Item	Farm size group (acres)								Total
	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	
	0	1-99	100-259	260-499	500-999	1,000-1,999	2,000-2,999	3,000+	
					Number				
Distribution of farming operations, 1985	551	49	200	271	399	555	70	20	2,115
					Acres				
Average size of farming operations, 1975	0	44	175	358	756	1,464	2,344	5,520	---
					Number				
Total farming operations in each State as a result of enlargements			7	57	149	196	54	8	471
					Percent				
Farming operations in each size group enlarging as a percentage of all farms enlarging			1	12	32	42	11	2	100
Farming operations enlarging as a percentage of farming operations, size group total			4	21	37	35	77	40	22

Source: (*4*, tables 3, 5, and 7).

To determine the extent to which farm enlargements were made and will continue to be made possible by the excess capacity, we defined the maximum acreage that can be handled by one person within a given time using both conventional and four-wheel-drive tractor technology. The time constraint was twofold: (1) the constraint on field time available for completing a specific tillage operation; and (2) the total field time available during a crop season. The maximum acreage is determined in the following set of equations:

$$USS_i = FS*T_i/(AS*IS_i*FE_i/825) \qquad (1)$$

$$D_i = DI_i + WGT_i*S \qquad (2)$$

$$USS_i \leqslant H_j \qquad (3)$$

$$\sum_{i}^{n} USS_i \leqslant TH \qquad (4)$$

$$D_i \leqslant TL_k \qquad (5)$$

Where:

USS_i is the hours required to complete the i^{th} tillage operation on a given farm size;

825 equals (square feet in 1 acre ÷ feet in 1 mile) (100) = (43,560 ÷ 5,280) (100): serves to convert a linear distance into an area;

TH is the total number of hours available for field work during the crop production season;

H_j is the number of hours available for field work in the j^{th} time period ($j = 1, 2, \ldots, m$);

FS is defined as the farm size in acres of cropland in rotation;

T_i is the number of times the i^{th} implement is pulled over the cropland;

AS is the average speed of the tractor in miles per hour;

IS_i is the width in feet of the i^{th} implement being pulled;

FE_i is the field efficiency of the i^{th} implement in percent;

TL_k is the pounds of drawbar pull available in the k^{th} gear for the tractor ($k = 1, 2, \ldots, r$);

D_i is the total draft requirements of the i^{th} implement, composed of the forces parallel to the direction of travel including soil resistance and the component of implement and tractor weight parallel to the slope;

n is the number of different tillage operations required in the crop rotation scheme;

DI_i is the component of total draft, composed of the soil and crop resistance of implement i;

WGT_i is the sum of the weights of implement i and the tractor being used;

S is the sine of slope angle a used to compute the component of implement and tractor weight forces parallel to the slope.

Equation (1) specifies the number of hours required to complete the i^{th} tillage operation. Equation (2) determines the draft requirement for the i^{th} tillage implement. The equation for draft requirements was developed from information given by Hunt (*5*, pp. 24-46). The restrictions imposed on equation (1) by inequality (3) limit the number of hours available to complete the i^{th} tillage operation to not more than the hours of field time available during the j^{th} time period. Inequality (4) limits the total hourly requirements for all tillage operations in the crop rotation to not more than the total hours of field time available during the cropping season. Inequality (5) restricts the draft requirements for the i^{th} implement to not more than the amount of tractor power available.

The coefficients for equations (1) and (2) were developed from engineering data. Draft requirements for each implement were developed using information contained in the 1975 *Yearbook of Agricultural Engineers* (*1*). The information for pounds of drawbar pull available by tractor size was taken from the Nebraska test data modified as suggested by Hunt (*5*, pp. 29-30).

The calculations of the costs of owning and operating each item on the machinery complement necessary for various types of crop rotations were:

$$\text{Annual depreciation} = \frac{\text{New cost minus salvage value}}{\text{Years of operation}} \tag{6}$$

$$\text{Average annual investment cost} = \left(\frac{\text{New cost plus salvage}}{2}\right)(\text{Interest rate}) \tag{7}$$

$$\text{Average annual property tax} = \left(\frac{\text{New cost plus salvage}}{2}\right)(\text{Average assessment})(\text{Tax rate}) \tag{8}$$

$$\text{Average annual insurance cost} = \left(\frac{\text{New cost plus salvage}}{2}\right)(\text{Cost of insurance}) \tag{9}$$

$$\text{Annual storage cost} = (\text{Square feet of storage required})(\text{Cost of storage foot}) \tag{10}$$

$$\text{Hourly implement repair and maintenance costs} = \frac{(\text{New cost})(\text{Implement repair factor})}{\text{Total normal operating hours}} \tag{11}$$

$$\text{Hourly implement preparation cost} = \frac{(\text{New cost})(\text{Implement preparation factor})}{\text{Annual operating hours}} \tag{12}$$

$$\text{Fuel cost per acre} = \frac{(\text{Average fuel consumption/hours})(\text{Fuel cost/gallon})}{\text{Acres per hour}} \tag{13}$$

Annual costs calculated in equations (6) through (10) were converted to an hourly rate by dividing by annual hours of use. The hourly rate was used to compute the cost per acre for each implement used in the rotation. The hourly implement repair, maintenance, and preparation costs factors used in equations (11) and (12) were taken from a study by Oehlschlaeger and Whittlesey (*8*). The factors relate to maintenance and repair over the entire useful life of the machine. The preparation factor relates to preparing the tractor for field service. For motorized equipment, both equations (11) and (12) were used; for nonmotorized equipment, only equation (11) was necessary.

Fuel consumption and fuel cost per acre were functions of field slope, maximum fuel requirements of the engine, and power required for each task. The average fuel consumption per hour used in equation (13) was determined by calculating the portion of time the tractor spends at each slope times the portion of maximum drawbar pull being used (the draft required divided by the drawbar pull) times the maximum fuel consumption. The relationship was (*10*):

$$\text{Average fuel consumption} = (\mathrm{F}) \sum_{i}^{k} \mathrm{R}_i \mathrm{P}_i \ (1.15) \qquad (14)$$

Where:

F is the maximum fuel consumption per hour;

R is the portion of time the tractor spends at a given slope in a representative field;

P_i is the portion of the maximum available drawbar pull actually used (never less than 0.5);

The factor 1.15 is suggested by Hunt to adjust the fuel consumption to reflect the less than ideal conditions that exist in the Nebraska tests (*5*, p. 31).

The estimated changes in machinery inventory and operating costs of farming operations moving from an assumed size of 629 acres to 1,304 acres; from 1,206 acres to 1,347 acres; or from 2,066 acres to 3,587 acres, are shown in table 3 for an operation with a winter wheat-pea-fallow rotation.[2] The illustration is in terms of (1) a common size of conventional crawler tractor; and (2) a commonly purchased four-wheel-drive tractor. The data in table 3 compare the 90 drawbar horsepower (dbhp) crawler tractor with a 228 dbhp four-wheel-drive tractor for selected enlargements in the farming operation.

Per acre costs are less if the 90 dbhp tractor is kept as opposed to obtaining the large tractor when the farming operation increases from 629 to 1,304 acres and from 1,206 to 2,347 acres. This results from the lumpiness of machinery inputs.

The greatest advantage in using the large tractor is on the larger acreages. If acreage is increased from 2,066 to 3,587 acres, economies can be gained in both labor and machinery using the larger four-wheel-drive tractor compared with the conventional 90 dbhp tractor. One tractor with its associated equipment is saved, resulting in the labor savings of one person for a total of 980 hours with the 228 dbhp tractor compared with the 90 dbhp tractor. The machinery costs excluding labor are lower by $3.54 per acre, indicating substantial economies in both labor and machinery operating costs for the larger four-wheel-drive tractor compared with the conventional crawler tractor.

[2] These are the average beginning and ending sizes of the sampled farming operations for Whitman County.

OPTIMUM MACHINERY SELECTION AND PROJECTED FARM SIZE

The effects of enlargement in farming operations on the machinery investment and operational costs for the farming operations illustrated in table 3 are shown in table 4. The additional cost of owning and operating the larger tractor on the smaller acreages is much higher per acre than that of the smaller tractor. The enlargement can be made on the largest farm size with the large 228 dbhp four-wheel-drive tractor at a lower machinery cost per acre ($3.54) and a lower total investment ($35,174.00). In addition, the change can be made without additional labor. Savings are also available in other types of farming operations in the study area. As with the wheat-pea rotation, the greater savings are always at the larger sizes of farming operations.

Table 5 shows machinery operating costs per acre by farm and tractor size for the winter wheat-fallow area of eastern Washington, a rotation typical of most farming operations there, and in northern Oregon. If an operator acquires a large four-wheel-drive tractor (225 dbhp and over) for any farm size within the economic feasibility range of the conventional crawler tractor, the per acre machinery cost will increase. This cost can only be reduced by spreading the fixed costs over a larger acreage, increasing the likelihood that farming operations will enlarge to reduce cost to the preacquisition cost. The breaking point between the least-cost machinery costs for the conventional crawler type tractor and the four-wheel drive tractor is a farming operation of approximately 2,000 acres.

IMPLICATIONS

The projections of sizes of farming operations by individual counties via Markov chains indicated that the major enlargements in the farming operations would occur primarily in the group over 1,000 acres, following a trend that existed during 1966-75. The number of farming operations larger than 2,000 acres in the study area is expected to increase by 54 operators between 1975 and 1985.

The projected increases in the sizes of farming operations above 2,000 acres will result partially from the continued economic pressure caused by introduction of the new four-wheel-drive technology. To use a four-wheel-drive tractor economically, farming operations must contain at least 2,000 acres. Per acre machinery costs for both conventional and four-wheel-drive tractors show that the farm operator using the four-wheel-drive technology and anticipating an enlargement from 2,000 to 3,600 acres will incur a smaller cost and be able to enlarge his farming operation with existing labor. The farmer with a conventional tractor may not be able to do so.

Large retail sales of large power units imply that con

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Table 3.—Implements, labor, and machinery cost per acre by farm and tractor size for Eastern Washington farms with winter wheat-pea-fallow rotation

Item	Unit	90 dbhp crawler tractor						228 dbhp 4-wheel-drive tractor					
Ending farming operation size group	Acres	1,000-1,999		2,000-2,999		3,000 +		1,000-1,999		2,000-2,999		3,000 +	
Addition to farming operation	do.	675		1,142		1,520		675		1,142		1,520	
		Beginning	Ending	Beginning	Ending	Beginning	Ending	Beginning	Ending	Beginning	Ending	Beginning	Ending
Power units	Number	1	1	1	2	2	3	1	1	1	2	2	2
Farm size	Acres	629	1,304	1,206	2,347	2,066	3,587	629	1,304	1,206	2,347	2,066	3,587
Moldboard plow	Bottoms	6	11	11	20	18	30	4	7	7	12	12	20
Tandem disk	Feet	14	28	24	48	40	72	10	16	16	28	28	48
Spiketooth harrow	do.	20	35	30	60	60	90	20	20	20	40	40	60
Disk drill	do.	10	12	10	20	20	30	10	10	10	20	20	20
Rodweeder	do.	10	10	10	20	20	30	10	10	10	20	20	20
Springtooth harrow	do.	28	52	48	88	80	132	16	32	32	56	48	88
Unitized weeder	do.	30	30	30	60	60	90	30	30	30	60	60	60
Fertilizer applicator	do.	30	30	30	60	60	90	30	30	30	60	60	60
Labor total	Hours	775	1,097	1,069	2,016	2,010	3,024	581	909	847	1,648	1,530	2,044
Labor/acre	do.	1.11	.78	.82	.84	.91	.84	.83	.65	.65	.69	.70	.57
Machinery cost/acre	Dollars	34.98	23.61	24.91	25.95	26.95	25.95	40.24	25.93	27.10	28.03	29.82	22.41
Total cost/acre	do.	43.00	29.40	31.05	32.16	33.68	32.16	46.06	30.63	31.86	32.97	34.87	26.57

Table 4.—Machinery costs and labor requirements for move to larger farming operation by farm and tractor size, eastern Washington farms with winter wheat-pea-fallow rotation

Item	Unit	90 dbhp crawler tractor						228 dbhp 4-wheel-drive tractor					
Ending farm operation size group	Acres	1,000-1,999		2,000-2,999		3,000 +		1,000-1,999		2,000-2,999		3,000 +	
Addition to farming operation	do.	675		1,142		1,520		675		1,142		1,520	
		Beginning	Ending	Beginning	Ending	Beginning	Ending	Beginning	Ending	Beginning	Ending	Beginning	Ending
Power units	Number	1	1	1	2	2	3	1	1	1	2	2	2
Farm size	Acres	629	1,304	1,206	2,347	2,066	3,587	629	1,304	1,206	2,347	2,066	3,587
Moldboard plow	Dollars	3,890	7,472	7,472	13,648	12,520	20,472	2,716	5,198	5,198	7,780	7,780	13,648
Tandem disk	do.	3,334	6,667	6,052	12,104	9,529	18,156	2,743	4,102	4,102	6,667	6,667	12,103
Spiketooth harrow	do.	405	709	608	1,216	1,216	1,824	405	405	405	810	810	810
Disk drill	do.	2,938	3,244	2,938	5,288	5,288	7,932	2,938	2,938	2,938	5,876	5,876	5,876
Rodweeder	do.	904	904	904	1,808	1,808	2,712	904	904	904	1,808	1,808	1,808
Springtooth harrow	do.	1,449	2,691	2,484	4,554	4,140	6,831	828	1,656	1,656	2,898	2,484	2,277
Unitized weeder	do.	5,409	5,409	5,409	10,818	10,818	16,227	5,409	5,409	5,409	10,818	10,818	10,818
Tractor	do.	40,500	40,500	40,500	81,000	81,000	121,500	56,570	56,570	56,570	113,140	113,140	113,140
Additional cost	do.		8,767		64,069		69,335		4,669		72,615		11,097
Total equipment cost	do.	58,829	67,596	66,367	130,436	126,319	195,654	72,513	77,182	77,182	149,797	149,383	160,480
Number of workers	Number	1	1	1	2	2	3	1	1	1	2	2	2
Change in investment level of large tractor system	Dollars								9,586		19,361		-35,174

Table 5.—Machinery costs per acre by tractor and farm size, eastern Washington farms with winter wheat-fallow rotation, 12-16 inch rainfall area

Farming operation size (acres)	Cost per acre by tractor size (dbhp)					
	Conventional crawler			4-wheel drive		
	70	90	125	185	225	262
	Dollars					
500	43.48	50.41	54.60	46.61	55.82	55.02
700	35.44	40.75	43.55	36.84	44.28	43.38
900	30.07	34.34	36.98	31.33	37.58	36.60
1,100	26.70	30.20	32.40	27.63	33.19	32.22
1,300	24.52	27.62	28.80	25.07	30.16	29.08
1,500	22.38	25.10	26.02	23.17	27.90	26.75
1,700	21.26	23.50	24.38	21.70	26.14	24.97
1,900	19.78	21.77	22.46	20.54	24.60	23.56
2,000	*	21.50	21.85	19.72	23.97	22.97
2,100		21.07	21.29	19.43	23.45	22.02
2,300		20.30	19.92	18.59	22.27	21.27
2,500		19.70	19.44	17.72	21.44	20.45
2,600		*	19.30	17.44	21.42	20.08
2,700			18.57	17.15	20.81	19.63
2,900			*	16.62	20.11	18.92
3,100				16.23	19.49	18.68
3,300				15.79	18.58	17.91
3,500				16.03	18.09	17.44
3,700				15.43	17.73	16.98
3,900				14.47	17.00	16.25

*Beyond this acreage, the time constraint for one of the tillage operations is violated.

tinued economic forces will cause further increases in sizes of farming operations. The economic force mainly involves spreading the large fixed capital investment costs over larger acreages; that is, achieving lower average fixed costs.

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