THE IMPACT OF ENERGY PRICES ON OPTIMUM MACHINERY SIZE AND THE STRUCTURE OF AGRICULTURE: A GEORGIA EXAMPLE

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In analyzing the impact of recent energy price increases on agriculture, agricultural economists have suggested the possibility of substitution of labor for farm machinery inputs [3, pp. 881-833] [17, pp. 195-196]. Since large energy input is embodied in farm machinery [14, p. 195], energy-price increases not only raised costs of machinery fuel, but also provided a cost-push effect on other fixed and variable machinery cost components. However, these potential price incentives have not been sufficient to reverse aggregate historical trends towards larger equipment in current machinery purchases [11, 15]. Understanding the nature of recent shifts in optimum machinery size on different farm sizes is important for consideration of future farm size and labor-capital structure of agriculture.

In the past three decades, substitution of machinery and petroleum products for labor in agricultural production has been an important contributing factor to current farm structure. Numerous empirical studies have demonstrated that larger farm machinery contribute to economies of size in farming [2, 9, 12, 14, 18]. These economies of size have contributed to adoption of larger pieces of machinery, increases in farm size and declines in labor inputs.

The purpose of this paper was to examine incentives for investment in smaller machinery sizes in response to changed input prices associated with the energy shortage. A management-decision framework for optimum machinery size was developed. It was applied in an empirical analysis of two representative farm units in South Georgia under 1973 and 1975 prices. Implications of the analysis for impact of input price changes on economies of size structure of agriculture were also considered. The decision framework included multiple objectives, because considerations broader than profit maximization are appropriate for machinery decisions in general. Changes in price incentives due to energy shortages were therefore only a specific case of a more general multiple-objective problem. In addition, the framework could be adapted to other areas of farm management.

A FRAMEWORK FOR CONSIDERATION OF OPTIMUM FARM MACHINERY SIZES

In a static, perfect-knowledge profit maximization analysis, optimum machinery size is simultaneously determined with enterprise levels—subject to available land, labor and other fixed resources. In this framework, the optimum machinery complement is subject to the constraint that field operations be performed on a timely basis with available labor. Timeliness of operation recognizes that field operations are performed during a particular period of time, and that available machinery must have sufficient capacity to perform those operations with available labor resources.

For this paper, the analysis was limited by a basic theorem of production economics—maximum profit input levels meet the expansion path requirement of being minimum cost for the particular output levels. Within this framework, the minimum-cost machinery complement was determined for a particular crop acreage by comparing costs of technically feasible machinery complements. If labor is considered fixed

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for the firm, only machinery costs associated with alternative complements need be considered. However, the sum of machinery and labor costs is an appropriate decision criteria if labor is considered variable. The latter approach was adopted because of the focus on structural adjustments.

Optimum machinery complements determined by profit maximization analysis may not be adopted by farm operators if decisions reflect a multiple goal structure [6, 10]. Two other objectives having particular relevance for farm machinery decisions are leisure and risk aversion. If the farmer values leisure more than income, a higher cost machinery complement may be preferable when less labor is required.

Similarly, a machinery complement which provides more capacity than necessary to complete field operations (under average field conditions) may be preferable to a risk-averse farmer. As Walker and Nelson recognized, excess machinery capacity provides insurance against weather interfering with field operations [19, p. 23]. Therefore, larger machinery capacity than is consistent with profit maximization may be optimal in a multiple-goal framework which considers leisure and risk.

The framework utilized for consideration of multiple objectives in this paper does not generally provide a unique optimal solution. Unlike many methods being considered in farm management research and extension [19], the costs, hours of labor and hours of machine capacity were not weighted with a managerial utility function. With a methodological viewpoint similar to that of cost-effectiveness analysis in public policy evaluation, data related to objectives are summarized in a decision table. This method avoids methodological pitfalls in estimation of preference functions. In addition, results are more readily applicable to managers with varying goal structures. Analogous to cost-effectiveness analysis, the decision table does have the limitation of providing a unique solution only in cases when one alternative dominates all others with respect to all goals.

In interpreting a decision table, identification of the technical tradeoffs between two machinery complements in reference to two goals is helpful to decision makers. If a machinery complement provides more capacity at a higher cost, the cost differential is the insurance premium for that extra capacity. The relationship between leisure and costs can be presented in a break-even framework. While break-even analysis is generally presented in a profit maximization framework [1], David has applied it to machinery decisions. This parallels the analysis in this paper [4, pp. 28-39]. Specifically, if machinery complement A has a higher cost exclusive of labor but requires less labor than B, total labor and machine costs are equal for some wage as follows:

$$M_A + WL_A = MB + WL_B \qquad (1)$$

where

M_A and M_B = machinery costs
L_A and L_B = labor hours, and
W = wage rate.

This break-even wage is determined as follows:

$$W = \frac{M_A - M_B}{L_B - L_A} \qquad (2)$$

If the farmer places a higher value on his labor than the break-even wage, A would be preferable; if not, B would be preferable.

Thus, presentation of a decision table with costs, hours of required labor, machine capacity and the break-even wage provides information for guidance of farmer decisions on optimum machinery size in a multiple goal framework. This information is general enough to encompass many goal structures. It can be interpreted in terms more meaningful to farmers than a framework requiring specification of the goals' structure.

EMPIRICAL FIRM APPLICATIONS[1]

Representative Farm Situations

Two farms with 200 and 500 acres of row crops were considered in the analysis. These farms represented medium to large commercial farms in South Georgia. The enterprise mix on both was 55 percent corn, 20 percent peanuts, 20 percent soybeans, and five percent cotton. These percentages were representative of row crop acreages in Southwest and South Central Georgia for 1973-1975. They were therefore assumed consistent with the current profitability situation. Machine operations for each enterprise were typical for the area and were all performed with owned machines.

Performance levels of particular machines and per-acre costs for each machine were calculated with the Oklahoma State Budget Generator [20].

[1] The empirical results in this paper are presented in more detail in Marable [13].

Machinery prices and cost parameters for 1973 and 1975 were adapted from previously published machinery cost research [16, 6].

Technically Feasible Machinery Complements

In designing machinery complements for analysis, particular sizes of equipment were included with an appropriate size diesel tractor. Traditional farm budgeting methodology was utilized in determining technically feasible complements. Given the timing of specific machine operations for each enterprise and each machine's level of performance, required machine hours for an acre of each crop for various sizes of machines can be determined. For a particular combination of enterprises, farm requirements for machine hours with different sizes can be calculated for any time period. Comparison of time required for different sizes of equipment in each period with available time allows delineation of technically feasible machinery complements for a particular farm size.

For this research, machine requirements for each month were considered. Based on a maximum available time of 250 hours per month for each machine, required hours were adequate for tractors and all machines considered on the 200-acre farm. Available tractor time was exceeded in selected months on the 500-acre farm, so that two tractors were necessary in each complement. However, all other machine requirements were met—two tractors rather than one was the only difference between complements on the farms.

Minimum Cost Complements

Total machinery and labor costs for each farm were calculated from per-acre costs in the enterprise budgets. Cost calculations for each enterprise did reflect annual level of use actually achieved on each farm. Following Kletke's results [8], it was assumed that machines were used for their maximum life. Years of life was defined as the smaller of (1) total hours of life divided by hours of annual use or (2) maximum years owned. Total hours of life and maximum years owned are engineering data.

The cost analysis for technically feasible complements is summarized in Table 1. For the 200-acre unit, the minimum cost complement had the smallest machinery considered in the analysis under 1973 prices. Therefore, no opportunity for substitution of labor for capital existed with the increase in prices to 1975. The 50 horsepower tractor and associated equipment were still minimum cost. For the 500-acre unit, substitution of small equipment was possible, as the least-cost complement under 1973 prices was a medium-sized complement, including 100 and 59

TABLE 1. CHANGES IN COSTS OF MACHINERY COMPLEMENTS 1973-1975, 200- AND 500-ACRE FARMS

Cost Components	Farm Size and Tractor Size[d]: 200 Acres				500 Acres					
	100 Hp.	80 Hp.	70 Hp.	50 Hp.	100 and 80 Hp.	100 and 70 Hp.	100 and 50 Hp.	80 and 70 Hp.	80 and 50 Hp.	70 and 50 Hp.
	(Dollars)									
Variable[a]										
1973	2,161	2,045	2,013	1,590	5,353	5,267	4,904	5,065	4,819	4,910
1975	3,843	3,512	3,009	2,592	9,328	8,860	8,367	8,199	8,074	7,590
Change	1,682	1,467	996	1,002	3,975	3,593	3,463	3,134	3,255	2,680
Ownership[b]										
1973	3,062	2,908	2,749	2,618	3,898	3,744	3,621	3,620	3,510	3,408
1975	6,310	5,963	5,591	5,431	7,406	7,104	6,969	6,836	6,762	6,374
Change	3,248	3,055	2,842	2,813	3,508	3,360	3,348	3,216	3,252	2,966
Capital[c]										
1973	1,898	1,781	1,654	1,548	2,427	2,369	2,227	2,218	2,125	2,004
1975	3,604	3,372	3,113	3,000	4,262	4,066	3,966	3,858	3,799	3,502
Change	1,706	1,591	1,459	1,452	1,835	1,697	1,739	1,640	1,674	1,498
Labor										
1973	1,707	1,836	2,135	2,229	4,267	4,267	4,267	4,590	4,590	5,336
1975	1,921	2,063	2,392	2,541	4,802	4,802	4,802	5,160	5,160	5,980
Change	214	227	257	312	535	535	535	570	570	644
Total										
1973	8,828	8,570	8,551	7,985	15,945	15,647	15,019	15,493	15,044	15,658
1975	15,678	14,910	14,105	13,564	25,798	24,832	24,104	24,053	23,795	23,446
Change	6,850	6,340	5,554	5,579	9,853	9,185	9,085	8,560	8,751	7,788

SOURCE: Table 11 of Marable [10].

[a]Variable costs include fuel, lubrication and repairs.

[b]Ownership costs include depreciation, taxes and insurance.

[c]Capital costs are interest on machinery investments.

[d]Horsepower is defined as P.T.O. horsepower.

horsepower tractors. Under 1975 prices, the minimum-cost complement had decreased in size to the smallest—the 70 and 50 horsepower tractor system.[2]

Changes in cost components of total machinery costs for the 500-acre unit in Table 2 indicate emerging economic incentives for decreasing machinery size. The 100 and 50 horsepower complement had a higher capital investment than did the 70 and 50 one, as expressed in higher ownership and fixed costs under both price situations. In addition, larger equipment had larger fuel, lubrication and repair requirements. Variable costs, then, were higher under both price situations. However, more labor was required with the smaller complement.

Under 1973 prices, additional labor costs of the smaller machinery complement were greater than savings in variable and fixed machine operation costs. The large increase in machine prices and inputs costs, relative to labor between 1973 and 1975, reversed this situation. The 100 and 50 horsepower complement still had lower labor costs (about $1100) than the 70 and 50 one. The former had, however, higher variable costs of about $800, higher ownership costs of about $600, and higher capital costs of about $400. Under 1975 prices, achieving minimum cost total machinery and labor costs therefore requires substitution of labor for capital, relative to 1973 minimum cost complements.

Consideration of Multiple Objectives

In considering the impact of multiple objectives on optimal machinery decisions, the focus is on the 500-acre farm because of emerging costs incentives for decreasing machinery size on this unit. In interpreting 1973 results, multiple objective results are consistent with cost minimization. The least-cost system includes a 100 and a 50 horsepower tractor with intermediate machine capacity and labor requirements. If the farmer wanted more machine capacity, the 100 and 80 horsepower unit would only cost 926 dollars more (Table 1).

Thus, under 1973 prices, cost minimization is consistent with other plausible objectives. However, the cost minimization solution for 1975 is not necessarily consistent with other objectives: the 70 and 50 horsepower complement is the smallest size considered in the analysis and costs nearly 2500 dollars less than the largest complement (Table 1). With this range of possible divergence between various objectives, multiple objective analysis appears to be appropriate.

A machinery size decision table, discussed in a previous section, was constructed for the 500-acre farm for 1975. Information included in Table 2 is only an example and could be altered under varying situations. Total machinery costs and labor costs were taken directly from Table 1. Total machinery costs

TABLE 2. A MACHINERY SIZE DECISION TABLE FOR A 500-ACRE FARM IN SOUTH GEORGIA, 1975

Tractor Sizes	Total Machinery and Labor Costs[a]	Total Machinery Costs[a]	Annual Labor[a]	Break-Even Wage[a]	Monthly Tractor Hours[b] April	August
(hp.)	(in dollars)	(in dollars)	(in hours)	(in dollars)		
70 and 50	23,446	17,466	2718.2	n.a.	425	360
80 and 50	23,795	18,635	2345.5	3.14	295	360
80 and 70	24,053	18,893	2345.5	3.83	295	360
100 and 50	24,104	19,302	2182.7	3.43	255	360
100 and 70	24,832	20,030	2182.7	4.79	255	360
100 and 80	25,798	20,996	2182.7	6.60	255	360

SOURCES: [a]Adapted from Table 1.
[b]Table 9 of Marable [13].

[2]Smaller tractor sizes were not considered in the analysis because a 50 horsepower tractor is a minimum size for peanut harvesting equipment. With custom harvesting, smaller tractors would be feasible; however, the importance of timing in peanut harvesting severely reduces the feasibility of custom harvesting, even for the small farm.

are derived by subtracting labor costs from the first column. Annual labor reflects labor cost at a wage rate of $2.20 per hour. Data on machinery costs and labor are used to calculate break-even wage as defined in equation (2). Finally, required monthly tractor hours for the two most limiting months, relative to available time, are included in the table; measures of machine capacity for other periods of time or for other machines could also be included.

Interpretation of data in Table 2 varies, depending on the particular analysis under consideration. The situation when an optimal complement would not coincide with minimum cost complement can readily be identified.

For example, the 80 and 50 horsepower complement would be preferable to the 70 and 50 horsepower unit if at least one of the following situations were relevant for the farmer: (1) the extra 130 hours tractor capacity in April was worth the difference in total costs of $349, (2) 372.7 hours of labor savings are worth at least $3.14 per hour or (3) a combination of extra tractor capacity and reduced labor requirements in (1) and (2) are worthwhile to the farmer. If he decides that the 80 and 50 horsepower complement is preferable, a similar comparison with the 100 and 50 horsepower complement would be desirable. It should be noted that the other three complements—80 and 70, 100 and 70 and 100 and 80—would never be optimal in this decision framework: One of the other three complements always dominates each of them in reference to all three goals.

The same data can be interpreted in a structural change framework. Given that the 70 and 50 horsepower complement is a minimum cost complement, could it be expected that farmers would adopt smaller equipment than under previous price situations? For farmers whose sole objective was profit maximization, the analysis would be affirmative. However, if labor were valued at more than $2.20 an hour, or if extra machine capacity were worth the cost differential, machinery size would not be reduced. If it is recognized that farmers have different goal structures, a realistic judgment would be that some would have incentives to decrease machinery size and others would not. The analysis of this section therefore implies that some reduction in machinery size would be expected.

EMPIRICAL IMPLICATIONS FOR FARM STRUCTURE

Since relative output composition is identical for the two farm sizes, impact of cost increases on economies of size from machinery can be evaluated with consideration of per-acre costs. The total farm cost data on least-cost machinery complements from Table 2 are presented on an acre basis in Table 3.

The lower total cost per acre on the 500-acre farm, under both 1973 and 1975 costs, indicated that economies of size in machinery costs exist on farms larger than 200 acres in Georgia. The existence of these economies results from standard cause of technological economies of scale—indivisibilities of capital inputs. The 500-acre farm has the same machinery, excepting one tractor, as the 200-acre farm. In addition, some of that machinery, including all harvesting equipment, is the same size; the only additional machinery investment for a 500-acre farm was a 70 horsepower tractor and a larger plow.[3] Higher investment and lower level of use on smaller farms is reflected in higher fixed machinery costs per acre, which more than compensates for lower variable cost per acre.

More importantly for structural farm charges, cost increases associated with energy price increases have increased economies of scale for the larger farm. In 1973, the cost advantage of the larger farm was about ten dollars per acre, which had increased to over twenty dollars per acre in 1975. The source of this difference is the increase in fixed-cost components, as labor and variable costs increased less on the 200-acre farm. The greater increase in fixed costs is related to previously discussed indivisibilities in machinery use: the increase in machine prices and fixed cost factors is spread over fewer acres on the 200-acre unit than on the 500-acre unit.

Increasing cost disadvantages of the 200-acre farm help reconcile observed behavior of farmers with analysis of the previous section. Incentives to purchase smaller machinery, which existed on the

TABLE 3. MACHINERY COSTS PER ACRE FOR LEAST COST MACHINERY COMPLEMENTS FOR 200- AND 500-ACRE FARMS, 1973 AND 1975

Cost Components	200 Acre		500 Acre	
	1973	1975	1973	1975
	(dollars)			
Variable	7.95	12.96	9.81	15.18
Ownership	13.09	27.15	7.24	12.75
Capital	7.74	15.00	4.45	7.00
Labor	11.14	12.70	8.53	11.96
Total	39.91	67.82	30.04	46.89

[3]Different tractor sizes were included in the complement to allow flexibility in matching tractor sizes and power needs for particular operations. While this factor was not considered in the analysis, Carter and Youde suggested that such management yields fuel savings [2, p. 882].

500-acre farm in 1975, suggest that at least some farmers would be purchasing smaller machinery than currently owned. However, analysis of this section suggests that smaller farms would have an increasing cost disadvantage if they operated with new machinery; hence, smaller farms would have more of an incentive than previously to organize their farm operation without new machinery. The trend to larger machinery in recent purchases, therefore, could result from a combination of smaller machinery for each farm size and a concentration of new purchases among larger farms.

CONCLUSIONS AND IMPLICATIONS

This analysis implies that input price increases associated with machinery costs are providing incentives for a unique combination of increased farm size and substitution of labor for capital on larger farms. Due to inherent limitations of synthesized budgets, relative magnitudes of results must be stressed rather than particular absolute values. With this interpretation, the most important result of the analysis for 1973 is that cost differences between different complements were small. For both farm sizes, annual total costs differentials between the most expensive complement and the minimum cost one was less than $1000 (Table 1).

Farmers would have incentives to purchase larger, more expensive equipment as insurance against risks of unfavorable weather conditions, and to reduce labor requirements. Inasmuch as 1973 results are consistent with historical cost patterns, past machinery-size decision strategies would include indifference among sizes, or preference for larger sizes. Under 1975 price structures, cost differentials between machinery sizes had increased to more than $2000 on both farms. Insurance provided by larger machinery and the value of reduced labor, therefore, were more expensive than in 1973. Thus, under certain goal structures, incentives to reduce machinery size exist under 1975 price patterns.

A methodological result of this analysis has implications for research beyond farm machinery decisions. In 1973, the 100 and 50 horsepower complement dominated several smaller complements with respect to all three goals considered for the 500-acre unit. However, the goals were in conflict over the full range of sizes in 1975. Thus, cost minimization was a more appropriate sole objective for machinery decisions in 1973 than in 1975. In farm management research, consistency of profit maximization with other goals should be evaluated before multiple goal analysis is adopted. This paper demonstrates that cases exist in which multiple goal analysis is superfluous.

An additional implication of this paper concerns research priorities. Derbertin and his colleagues have suggested that management information obtained from experience has value similar to that obtained from research reports [5]. Considering that cost calculations are more complex for machinery and other fixed investments, this result would not be expected to be as true for fixed asset investment decisions. Inasmuch as this paper suggests emergence of potential changes in past machinery decision strategies, a fruitful current research area is current farm investment decisions.

REFERENCES

[1] Berry, Russell L. "Break-even Analysis: A Practical Tool in Farm Management," *American Journal of Agricultural Economics*, Volume 54:1, February 1972.

[2] Carter, H. O., and G. W. Dean. "Cost-Size Relationships for Cash Crop Farms in a Highly Commercialized Agriculture," *Journal of Farm Economics*, Volume 43:2, May 1961.

[3] Carter, Harold O., and James G. Youde. "Some Impacts of the Changing Energy Situation on U.S. Agriculture," *American Journal of Agricultural Economics*, Volume 56:5, December 1974.

[4] David, Paul A. "The Mechanization of Reaping in the Ante-Bellum Midwest," in *Industrialization in Two Systems: Essays in Honor of Alexander Gerschenkran*, Henry Rosovsky, editor, New York: John Wiley & Sons, Inc., 1966.

[5] Debertin, David L., *et. al.* "Estimating the Returns to Information: A Gaming Approach," *American Journal of Agricultural Economics*, Volume 57:2, May 1975.

[6] Givan, William, *et. al.* Farm Machinery Costs and Performance, 1975, *University of Georgia, Department of Agricultural Economics Faculty Series 75-2, 1975.*

[7] Hatch, Roy E., *et. al.* "Incorporating Multiple Goals into the Decision-Making Processing: A Simulation Approach to Firm Growth Analysis," *Southern Journal of Agricultural Economics*, Volume 6:1, July 1974.

[8] Kletke, Darrel. "Selection of A Farm Machinery Replacement Criterion Using Simulation," *Southern Journal of Agricultural Economics*, Volume 1, December 1969.

[9] Krause, Kenneth R., and Leonard R. Kyle. "Economic Factors Underlying the Incidence of Large Farming Units: The Current Situation and Probable Trends," *American Journal of Agricultural Economics*, Volume 52:5, December 1970.

[10] Lin, William, *et. al.* "An Empirical Test of Utility vs. Profit Maximization in Agricultural Production," *American Journal of Agricultural Economics*, Volume 56:3, August 1974.

[11] McKee, Dean E. "Farm Machinery Market Prospect-1975," in *1975 U.S. Agricultural Outlook*, U.S. Senate Committee on Agriculture and Forestry, Committee Print, 93rd Congress, 2nd Session, Washington, D.C., U.S. Government Printing Office, 1974.

[12] Madden, J. Patrick. *Economies of Size in Farming*, U.S.D.A., E.R.S., Agricultural Economic Report Number 107, Washington, D.C., 1967.

[13] Marable, Ulysses, Jr. "Current Farm Machinery Cost for Row Crop Enterprise on Different Farm Sizes in the Coastal Plain Area of Georgia," unpublished M.S. thesis, Department of Agricultural Economics, University of Georgia, 1975.

[14] Raup, Phillip M. "Economies and Diseconomies of Large-Scale Agriculture," *American Journal of Agricultural Economics*, Volume 51:5, December 1969.

[15] Rodewald, Gordon E., Jr. "The Economies of Size Available with Four-Wheel Drive 140 hp and Larger Tractors in the Eastern Washington Dryland Farming Areas," Contributed paper presented at the AAEA Annual Meeting, Columbus, Ohio, August 1975.

[16] Saunders, F. B., *et. al. Farm Machinery Cost in Georgia*, Georgia Agricultural Experiment Station Research Report 45, 1969.

[17] Schneeberger, K. C., and Harold F. Breimyer. "Agriculture in an Energy-Hungry World," *Southern Journal of Agricultural Economics*, Volume 6:1, July 1974.

[18] Van Arsdall, Roy N., and William A. Elder. *Economies of Size of Illinois Cash-Grain and Hog Farms*, University of Illinois Agricultural Experiment Station Bulletin 733, 1969.

[19] Walker, Odell L., and A. Gene Nelson. "Designing Research and Education Programs Related to Decision-Making Under Uncertainty," Paper presented at the Southern Agricultural Management Research Work Group, Athens, Georgia, January 13-14, 1976.

[20] Walker, Rodney L., and Darrell D. Kletke. *The Application and Use of the Oklahoma State University Crop and Livestock Budget Generator*, Oklahoma State Agricultural Experiment Station Report P-663, 1972.