Determinants of Farm Size and Structure

Proceedings of the program sponsored by the NC-181 Committee on Determinants of Farm Size and Structure in North Central Areas of the United States, held January 7, 8, 9, and 10, 1989, in Tucson, Arizona.

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Ames, Iowa 50011
December 1989

ECONOMIES OF SIZE IN MULTI-OUTPUT FARMS: A MIXED INTEGER PROGRAMMINGAPPROACH*

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Introduction and Objectives

The objective of this paper is to examine size economies for an agricultural crop setting where, as farm size is varied, crop acreages, tractor power units, equipment sets, and labor situations are endogenously determined. A Mixed Integer Programming model is used for the analysis. The model allows for simultaneous selection of inputs and outputs for alternative acreage levels. Integer units are provided for labor situations, primary power units, and equipment. These, along with fixed costing of crop specific equipment, allow for decreasing per unit fixed costs for each crop as acreage of that crop is increased. The result is the optimal or maximum profit crop, labor, and machinery choice for a given acreage and, as acreage is varied, the maximum profit path for varying acreage. Transcribed into cost per unit of output this path becomes a long run average cost function (LRAC). For any labor, power unit, and/or equipment set an associated families of short run average cost (SRAC) functions are developed.

Previous studies of agricultural size economies have estimated LRAC's 1) using cross-sectional cost data of existing firms or 2) from an economic-engineering or synthetic firm approach. Some may describe these two approaches as respectively positive and normative, however the two approaches are described here as econometric and budgeting-programming respectively. It is the programming approach which is emphasized here even though budgeting analysis has been used for nearly all economic-engineering size studies. The availability of Mixed Integer Program algorithms now allows programming analysis to accomplish economic-engineering size studies with several major advantages over budgeting.

Each of these two approaches has its advantages and disadvantages tied to the behavioral assumptions of each approach. As Ryan has stressed, cross sectional estimates of size economies must be interpreted with caution suggesting that reasons other than size may account for big farms having lower costs. There are other theoretical concerns related to the estimation of size economies econometrically. These problems are addressed by Hubbard and Dawson and Vlastuin, et al. Yet, this approach has been employed far more in recent years compared to earlier times. Budgeting-Programming develops an envelope curve from a series of short run average cost functions each developed from an assumed fixity situation. Each short run average cost function demonstrates capacity economics

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*Presented at NC-181 Meeting, Tucson, Arizona, Jan. 7-10, 1989.

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which unfortunately is still sometimes viewed as evidence of size economies. As Johnson warned, the assumption of the fixed input set is critical to the development of the long run average cost function particularly at small units of output. As with the econometric approach, this approach has its deficiencies. Generally, size impacts are isolated by this approach yet longer run aspects are excluded.

The Budgeting-Programming approach examines capacity economies for as many fixity assumptions as can be investigated. Unfortunately, unless the analysis endogenizes these fixity assumptions, the analysis may omit important resource combinations. Similarly, unless the analysis endogenizes the optimum output mix, assumptions regarding the appropriate output at various farm sizes may be less than optimal. Chambers has emphasized the need to consider multi output size economies. Recent literature on scope economies has stressed these important input and output interrelationships which occur at various sized firms. Agricultural production is clearly a multi input-multi output process and demonstrates scope economies components. This analysis, while not directed to the isolation of scope components, identifies the optimum organizations which embody those components.

Previous budgeting-programming size analyses have been strongly assumption driven. Where programming analyses have been employed, decreasing costs per unit arising from fixed inputs have not been incorporated. Hence, there has been little investigation of true costs of small acreages. In fact, most size studies using economic-engineering have examined only one activity. Further, past budgeting-programming studies have not provided for the potentially large number of choices resulting from interrelations between 1) labor situations, 2) primary power units, and 3) implement choice. Here, these are endogenized so that at changing acreages profit maximizing solutions involve changing combinations of these factors. In addition, at higher acreages it may be more profitable to substitute lower labor using activities rather than change labor or machinery sets.

Programming and the LRAC

The estimation of agricultural long run average cost functions has occurred with some uneasiness and tentativeness related to economic theory. Long run average cost functions are usually depicted at L or U shaped formed as an envelope of short run average cost functions. The expected behavior of SRAC functions conforms well to fixity based economic theory. Short run average cost functions which are U shaped do not require production functions which exhibit all elasticities of production - greater, equal, and less than one. Important to the SRAC is the level of fixity affecting the average fixed cost per unit.

The relation of the resultant envelope curve to a long run production function is more obscure. The elusiveness of a long run production function led Heady (1984) to suggest the following: 1) long run production functions have constant returns to scale, and 2) the major interest in cost economies lie in a pseudo long run average cost function with associated short run curves relating to different technologies. Limiting the LRAC function to a pseudo function is operational but places severe limits on the understanding of the management, financial, and risk impacts which restrain the duplication of units.

Declining marginal productivity is absent in programming models, however declining fixed costs per unit can occur resulting from the incorporation of integer formulations. This permits downward sloping SRAC functions. Upward sloping SRAC functions arising from programming analysis can occur from two forces. First, if with additional output the model allows for the purchase of higher cost inputs to achieve those outputs, short run costs may rise. In addition if the model is multi output based, resource restrictions may force the firm to vary its output mix once resources are exhausted. That is, as acreage is increased the firm may engage in less resource requiring activities to remain within the resource constraints. Such changing output mixes will eventually involve higher cost per unit of output as acreage is expanded. If neither of these two aspects (purchasing of some additional inputs or provision for multiple outputs) is present, programming models will result in infeasibilities (or slack acreage if allowed to) without experiencing increasing sloped SRAC functions.

In this study both aspects are included in the analysis. As acreage is expanded, if resource constraints are reached (machinery time) the model can select higher capacity machinery. At the same time the model may forego doing such and change its output mix to a greater proportion of crops which have a lower per acre requirement for constrained resources.

Fixity and Prescriptive Vs. Economic Analysis

A problem of any programming based model is that fixity must be present in some form which implies a model which is less than long run. This obviously creates no problems in developing SRAC functions but does limit the concept of a true LRAC function developed from a programming setting. As discussed before this need not be overly restrictive in that it is usually understood that the LRAC is really of pseudo form.

A more perplexing problem is whether fixity or management models can be useful in economic analysis. In most cases resource fixity models can only be described as management models, useful only to those situations which have those particular resource constraints in the model. Thus, resource constraint driven results are not generally applicable to either a large number of firms or for developing "general economic analysis" even though large amounts of resources have been expended using representative farm based fixity models which have very detailed resource constraints. At the same time agricultural production does exhibit very definite timeliness aspects and with alternative activities differing in labor and machinery timing needs, these constraints would appear very useful to economic analyses of farm firms.

Thus, while programming based models are prescriptive only for those resource situations assumed in the model, what level of model generality will yield results useful in more general economic analysis? This is a complex issue that requires caution in model construction. Here this issue is faced in two ways. First, SRAC functions are developed for fixed combinations of labor, power unit, and crop specific equipment. Families of SRAC's can be developed for fixity situations resulting from four labor situations, four power units, and four sizes of equipment. These can be developed for any specified situation alone or in combination. For example, a SRAC was constructed for a one-person labor situation endogenizing the choice of both power units and equipment. A family of SRAC's was also developed endogenizing only labor by fixing a set tractors and associated equipment.

Alternatively a SRAC could be developed assuming a labor situation as well as a power unit endogenizing only the choice of equipment. Hence, families of SRAC's could be developed for these three major fixed factors alone or in any combination. Machine timeliness constraints and machine capacity provide the major internal constraints in the problem. In all short run cases, the model optimizes the crop mix in association with the fixed factors and remaining endogenized input factors. The SRAC functions are developed as acreage is varied.

Also, a long run model is constructed where all inputs (labor, power units, and equipment) can be selected in integer form in association with the optimal crop mix. These are determined for any acreage and the resultant LRAC is the tangency of SRAC functions described above. Again, this LRAC should be designated as a pseudo-LRAC abstracting from longer run production processes which include risk, finance, and management aspects.

The fixed costs for machine ownership once incurred lead to declining per unit costs with higher acreages. In this study both depreciation and opportunity interest on mid value investment are included as fixed costs. Generally, depreciation should be costed as a use or operating cost rather than an ownership cost. While the use of a machine requires earlier replacement only at a future time, machine use impacts machine values on financial statements and these impacts cannot be ignored. However, for this analysis depreciation is included as a nonoperating cost because depreciation is so often categorized as such.

Labor fixity costs were also provided in the same way. As described later four labor situations were investigated where one labor setting must be chosen in full.

Previous Studies

Economies of Size. A vast set of literature directed to agricultural size economies has been developed. Without being exhaustive (particularly with respect to econometric studies) the following should be noted as among the more important contributions. Reviews of previous studies are described by Jensen, Madden, and Miller, et al. A general discussion of theoretical issues related to size and agriculture is provided by Babb, Gardner and Pope, and Stanton. Heady provided a basis for budgeting and programming of size economies in 1956. Since most size studies have been directed to crop studies the following should be examined: Carter and Dean; Faris and Armstrong; Miller, et al.; Heady and Krenz; and Hoch. Martin as well as Seckler and Young examined policy related to size and acreage limitations. Among livestock studies King's study should be examined. Hall and LeVeen's study assumptions related to labor fixity charges are important. Similarly the study by Young, et al. should be examined in terms of farm size classifications and the implications to size economies. Finally, Kislev and Peterson's noteworthy work on factor prices and the absence of scale economies is of major significance to size researchers and has not received the recognition it deserves.

Optimal Machinery Studies

The issues that surround the problem of identifying an optimal machinery set have been addressed in various forms by many authors. Eidsvig and Olson, for example, did a study (1969) designed to aid North Dakota farm operators in determining the least-cost combination of machinery for various size farms, taking into account the timeliness of operation. In the study, costs (fixed, variable, and total) were calculated at selected acreages for a wide assortment of sizes and types of implements and were calculated on an average per acre basis.

In 1971 Osborne and Barrick developed an analytical computer routine for use in selecting least-cost combinations of farm machinery for various farms (160, 500, and 960 acres) which were representative for irrigated cotton-grain sorghum farms. In addition, their model was used to develop equipment systems under alternative wage rates. The model based its selection of equipment combinations on technical feasibility, time requirements, and annual costs. The results of their study indicated that farmers cannot expect to realize substantial savings from size of equipment.

In 1973, Boisvert and Jensen used a generalized chance-constrained mathematical programming model. In this model, they incorporated data on time available for field work and on yield losses due to untimely field operations for eight cash-grain farm situations in Southern Minnesota. The basic objective of this study was to determine how the availability of hired labor, machinery capacity, and willingness to assume risk affects the decisions of the farmer with respect to farm size, crop enterprise, and scheduling of field operations. The results were presented based on the level of risk aversion exhibited by the farm operator.

McIsaac and Lovering in 1976 developed a computer program to be used by Canadian cereal farmers which was designed for finding least-cost implement sizes for tillage and seeding operations. The input data required for this program included prices of equipment, machinery, draft requirements, repair rates, operating efficiencies, acres to be covered, and operations to be performed.

Burrows and Siemens in 1974 designed a computer program to determine the least-cost, number and size of machines for corn-soybean farms in the Corn Belt. The program was developed as an educational tool and for helping farmers with their machinery purchase decisions.

Kletke and Griffin in 1977 used mixed integer linear programming to determine optimum machinery complements for Northcentral Oklahoma wheat farms. In addition, the authors used their study to determine the effects of alternative wage rates on optimal machinery complements.

Pfeiffer and Peterson developed a mixed integer program in 1979 which was used to identify optimum machinery complements for Northern Red River Valley grain (spring wheat and barley) farms. The study also examined how the least-cost machinery complement changed as the probability of timely completion of field operations increased.

In 1984, Helmers and Monji determined the existence of economies of size for large farms and the impact of farmers' risk aversion level on the size of farm machinery selected. The study was conducted on wheat farms in Kimball County in Northwestern Nebraska. The authors found that farms with up to 3000 acres of harvested wheat generally have farm machinery size economies but those economies are more pronounced at smaller farm machinery sizes. In addition, the authors found that at lower farm sizes (2000 or less acres), higher levels of completion probability always resulted in higher machinery costs.

Economies of Scope

While agriculture has obvious multi-output production potential, this characteristic has in the past received scant attention in agricultural size economies studies. Based on works by Panzar and Willig and Kim, the analysis of multi output effects (economies of scope) offers a fruitful area of study for agricultural researchers. The analysis of this paper incorporates the scope effects resulting from multi output decision making while at the same time allowing for inputs to be endogenized.

Procedure

The analysis pertaining to economies of size was conducted using a farm situation in Saunders County, in eastern Nebraska. Four cropping systems were allowed in the study. These systems are 1) corn (C), 2) soybeans (Sb), 3) sorghum (Sg), and 4) oats (O). Associated with these systems are machinery complements for field preparation and planting that consist of two tractors, two tandem disks, two field cultivators, two planters, and two drills. In addition, four farm family labor situations were allowed. These situations are 1) a part-time family operator who can work only five hours on a field working day, 2) one full-time family operator who can work ten hours on a field working day, 3) a part-time and a one full-time family operator with a total of fifteen working hours per one working day, and 4) two full-time family operators each working ten hours per one working day. The opportunity costs for these labor situations were computed at $7,000, $14,000, $21,000, and $28,000 respectively. The long-run average costs that this study generate include cash production costs such as seed costs, fertilizer and chemicals (Jose et al.), custom operations [such as cost of harvesting (Duey, 1987)], machinery repair and maintenance, machinery fuel and lubrication (Reff).

In addition, the long-run average costs include machinery costs such as machinery replacement (including interest) costs, taxes on machinery, and machinery insurance. These annualized machinery costs were calculated using appropriate formulas (Reff) representing an average cost for a specific piece of machinery. These ownership costs were incorporated in the model in integer form whenever machinery was selected. Once costed, subsequent acreage incurs no additional ownership costs. Existing 1983 published price listings were used in the computation of ownership and variable costs (Duey, 1983). In calculating the ownership costs related to depreciation and interest, the capital recovery method was used. The real interest rate that was used in this method was that of 1987, i.e. 4.71 percent. Purchase prices were discounted 6.5 percent from list prices and salvage values based on 10 years of economic life for both tractors and implements were calculated. Ownership costs for sales tax, insurance, and housing were combined and assumed to be equal to 2 percent of average investment. All tractors were assumed to be powered by diesel, which according to county estimates, cost 56 cents per gallon.

Also included in the long-run average cost is the rental cost of land which was $58 per acre. This was included in the model as a "rental" cost for acres in the right hand side of the matrix of technical coefficients. This amount reflects the average rental rate of an acre of farm land in Saunders County in 1987 (Johnson and Hanson). Not included in the long-run average cost are the imputed costs of equity capital, overhead, management, and entrepreneurship and hence are considered as the residual claimants.

The yields for the four crops and their corresponding average state price levels were obtained from the Estimated Crop and Livestock Production Costs (Jose et al.) and from the Crop and Livestock Prices for Nebraska Producers (Wellman and Lutgen, 1977-1987).

Model and Situation

While Linear Programming has been used in economies of size studies (Miller et al., Davis and Madden), this paper uses a zero-one mixed integer programming model instead. The advantage of using this type of technique is that it eliminates problems associated with indivisibilities and rounding-off of machinery decision variables and family labor situations.

Mathematically (adapted from Pfaffenberger and Walker), the optimization technique can be described as

Maximize $z = c'x$

Subject to $A x < b$

$xi > 0 \quad i = 1,2,\ldots,n$

xi integer for $i\ I$

where I is the subset of indices from the set i = 1, 2, ..., n associated with the integer decision variables. The integer decision variables are for the machinery and implements and for family labor situations and are used as proxies for their corresponding fixed costs. The variable costs of machinery such as fuel, lubricants, etc., along with other costs such as cost of production or the returns per acre of the crops, are considered as the continuous decision variables of the model.

The method used to calculate the economies of size required the following:

Workdays Model

Available field working time is defined as the working days in a scheduled period in which field operations can be performed. Such classification of a working day depends on the trafficability of the surface of the soil.

This study uses a procedure developed by Meng to determine the number of working days for the critical periods of production. (period I is April 15-May 12 and period II is May 13-June 9). Meng's model chooses soil moisture as the indicator of trafficability and is multiphased. Since soil continually losses water through surface run-off, evapotranspiration, and drainage events, the model simulated this daily process. This process can be expressed as follows:

$$SM(i) = SM(i-1) + Ps = Pr + I + C - Q - ET - D$$

where SM(i) = soil moisture content on i'th day, Ps = precipitation from snow, Pr = precipitation from rainfall, I = irrigation water, C = capillary rise, Q = run-off, ET = evapotranspiration, and D = drainage.

In this model, Meng divided the soil profile into six layers, each 1.97 inches deep. By applying field working day criteria (which he defines as a soil moisture percent field capacity) to the simulated soil moisture contents, the suitability of days for field work were identified. If the soil moisture contents of the top two layers are above this criterion (90.7 percent for layer 1 and 96.5 percent for layer 2 for the soils of this study), a day is considered to be a working day. According to Meng, the results of this procedure were validated and were found to be cite specific. Associated with the number of field working days are levels of timeliness. This study considers one of these levels which was set at 90 percent.

Tillage System

Based on surveys by Dickey et al. 69 percent of the farm operators in the study area use disking as their primary tillage practice. The authors mentioned in their study that 31 percent of fields in the disk tillage system had three rather than four operation. In order, these were: 1) disking, 2) a secondary tillage operation such as field cultivation or disking, and 3) planting. This paper uses disking as its primary tillage method since it comprised the largest share of all tillage systems. Also, the same sequence of operations were used in this analysis with the exception of substituting a field cultivator instead of a disk in the secondary tillage instead of a disk. Since this tillage system does not require a fall moldboard plowing operation or any other kind of tillage practice, this system hence can be perceived as conservation tillage. Since this study utilizes two four-weeks periods, it was necessary to determine in which period each operation or percentage of operation occurs. This information was obtained from the Nebraska Crops and Weather, 1982.

The procedure used to match the size of ground engaging implements to tractor power and to calculate field capacities is given in the Agricultural Engineers Year book (ASAE, 1971). This study assumes that a tractor can be engaged to an implement of a proper match or to an implement that is of smaller size.

The data from the weather model was used to restrict the total number of working days available under certain timeliness levels for each specific period, as well as the upper limit on time available for implements and for labor availability. This study assumes that tractor hours equals 1.1 times implement hours and labor hours equal 1.1 times tractor hours (Kletke et al., and Pfeiffer et al.). This data, along with the data on field capacity that were calculated from the Agricultural Engineers Yearbook were use as input- output coefficients for various for various sized machines.

In order to generate the long run average cost curve, all the relevant information pertaining to resource restrictions were endogenized, hence making all resources variable. The only nonzero number left in the RHS column was the level of farm size that needs to be rented. By varying this level at equidistant increments, more points on the long run average cost curve can be generated. The short run average cost curves, for example, can be generated by taking the machinery complement and the operator's labor situation (or only the operator's labor) at a particular farm size and then forcing them to enter the basis. By rerunning the problem at other farm sizes, more points on the short run curve can be attained. Points on both the long run and the short run cost curves are generated by dividing total costs by their corresponding gross incomes. This optimization model uses a system of transfer rows and transfer activities to tie the fixed cost activities that are associated with the machinery complement to their corresponding variable cost activities.

Results

Table 1 presents the long run average cost model results where the labor, power unit, and equipment set are all endogenized. The analysis of Table 1 is where only two tractors, disks, field cultivators, and planters are available. It can be noted that the LRAC rapidly declines to 240 acres and drops at a decreasing rate between 240 and 1040 acres (approximately .11 over the interval), and then increases over the 1040 acre to 1440 acre interval. Through 320 acres a part time labor situation is selected. For 400 to 720 acres a one person situation is selected and for 800 to 1040 acres a one plus part time labor setting is selected. A two person setting is selected thereafter.

Tractor or power unit size generally increases with acreage although increased labor offsets tractor size in one instance. Moving from 320 acres to 400 acres the optimum labor choice moves to a one person setting rather than a part time one. This allows for a reduction in tractor size over this range (T2 to T1). This same phenomenon occurs between tractor choice and machinery sets. Three times one or more equipment items (disk, field cultivator, and planter) involve reduced size for an 80 acre increase in farm size. For example, moving from 720 to 800 acres increased labor allowed tractor size to remain constant but all equipment was reduced in size. These equipment size reductions always occurred when a labor situation changed.

Soybeans dominated the solutions. The solutions are nearly all specialized in soybeans choosing to meet timeliness constraints with labor and machinery adjustments rather than by selecting multiple crop acreages. Toward the "upper end" of three of the labor settings selected, multiple crops were selected (720 acres - one, 1040 acres - one+, and 1360 and 1440 acres - two). Tables 2 and 3 present SRAC functions for 8 fixity situations which were investigated. The fixity involved both operator labor, tractor, and machinery. For example, the optimum long run solution for 240 acres involved part time labor (one-) as well as a T1D1F1P1 machinery set. This labor and machinery set were forced into the program across the 80 to 320 acre range allowing the model to select the optimal crop mix. At the upper acreage in this range the SRAC departed from the LRAC (SRAC higher) and then became infeasible. Notice the increasing portion of each SRAC function. These increased cost solutions involved multiple outputs compared to specialization on the LRAC. Clearly with fixity in labor and machinery, increased acreage necessitated adjustments in crop acreages as resources became constraining. Of course, labor and machinery sets larger than that optimal for any acreage involved higher costs per unit than the optimal set.

The results of Tables 1 and 2 are presented in graphical form in Figure 1. The four selected SRAC functions from Table 2 are "laid on" the LRAC and become part of the LRAC at particular acreage points (240, 560, 880, and 1280). Both a tractor and machinery set are held fixed as well as a labor situation resulting from the LRAC choice at those acreage points.

In Table 4 SRAC functions are developed under less constraining conditions. Here only labor is specified allowing all machinery choices to be endogenized. This flexibility allows solutions to be found over a wider range of acreages and at lower costs. The results of Table 4 are presented in graphical form in Figure 2.

Conclusions

The endogenizing of labor, machinery selection, and output mix as demonstrated in this study provides a different alternative to study size economies in agriculture. The increased availability of mixed integer programming algorithms allows the inclusion of capacity economies (decreased ownership cost per acre) in output choice problems. This eliminates unrealistic output selections where a few acres of one crop is selected. These situations are caused when the optimizing process does not recognize the true short-run ownership cost relationship arising for machinery unique to one crop. These relationships are also important to long run analysis.

Table 1.

Long run total cost (TC), gross income (GI), long run average cost per unit of output (LRAC) [= cost per dollar of gross income (TC/$GI)], and cropping organization along with the corresponding operator's labor and machinery complement at various levels of farm size (90 percent completion probability).

Acres	Labor	TC	GI	LRAC	Crop (Acres)	Machinery[b]
80	one-	21203.30	15776.00	1.3440	Sb	T1D1F1P1
160	one-	30230.60	31552.00	0.9581	Sb	T1D1F1P1
240	one-	39257.90	47328.00	0.8295	Sb	T1D1F1P1
320	one-	50107.16	63104.00	0.7940	Sb	T2D1F2P2
400	one	64312.49	78880.00	0.8153	Sb	T1D1F1P1
480	one	73339.79	94656.00	0.7748	Sb	T1D1F1P1
560	one	83829.43	110432.00	0.7591	Sb	T2D1F1P1
640	one	93268.33	126208.00	0.7390	Sb	T2D1F2P2
720	one	103761.69	138845.60	0.7473	C,Sb (49,671)[a]	T2D2F2P2
800	one+	117993.76	157760.00	0.7479	Sb	T2D1F1P1
880	one+	127040.69	173536.00	0.7320	Sb	T2D1F2P1
960	one+	136429.49	189312.00	0.7207	Sb	T2D1F2P2
1040	one+	146058.76	203010.02	0.7195	C,Sb (32,1008)	T2D1F2P2
1120	two	161170.14	220864.00	0.7297	Sb	T2D1F2P1
1200	two	170550.36	236640.00	0.7207	Sb	T2D1F2P2
1280	two	182342.79	252416.00	0.7224	Sb	T1T2D1F1F2P2
1360	two	192266.48	265227.83	0.7249	C,Sb (46,1314)	T1T2D1F1F2P2
1440	two	204750.77	274007.12	0.7472	C,Sb,O (18,1313,109)	T1T2D1D2F2P1P2DR2

[a] All the numbers inside the parentheses are rounded to the nearest acre.

[b] The letters and the numbers in the "Machinery" column represent the combination of machinery complement that entered the basis at their respective farm size. More specifically; T, D, F, P, DR stand for tractor, tandem disk, field cultivator, and drill respectively. The combinations hence can be described as follows:

T1,T2 = 65 HP and 85 HP tractors,
D1,D2 = 14' and 16' tandem disks,
F1,F2 = 12' and 15.5' field cultivators,
P1,P2 = 4 x 38" and 6 x 30" planters,
DR1,DR2 = 12'6" and 14' drills.

Table 2.

Long run (LRAC) and short run (SRAC) average cost per unit of output at various levels of farm size. The short run average cost figures are generated by letting farm size vary while holding operator's labor and the corresponding machinery complement (taken from Table 1 above at certain farm sizes) fixed (90 percent completion probability).

Acres	LRAC	SRAC1	SRAC2	SRAC3	SRAC4
		T1D1F1P1- one- (240)[a]	T2D1F1P1- one (560)	T2D1F2P1- one+ (880)	T1T2D1F1F2P2- two (1280)
80	1.3440	1.3440 Sb[b]			
160	0.9581	0.9581 Sb			
240	0.8295	0.8295 Sb	1.0060 Sb		
(250)[c]	0.8191	0.8191 Sb	0.9887 Sb		
(283)	0.8163	0.8275 C,Sb[d]	0.9403 Sb		
320	0.7940	No Solution	0.8979 Sb		
400	0.8153		0.8331 Sb		
480	0.7748		0.7899 Sb		
560	0.7591		0.7591 Sb	0.8228 Sb	
(570)	0.7562		0.7575 C,Sb[e]	0.8185 Sb	
(627)	0.7417		0.7746 C,Sb[f]	0.7962 Sb	
640	0.7390		No Solution	0.7916 Sb	
720	0.7473			0.7674 Sb	
800	0.7479			0.7479 Sb	
880	0.7320			0.7320 Sb	0.7905 Sb
960	0.7207			0.7290 C,Sb[g]	0.7723 Sb
(970)	0.7191			0.7311 C,Sb[h]	0.7702 Sb
(1001)	0.7146			0.7375 C,Sb[i]	0.7642 Sb
1040	0.7195			No Solution	0.7569 Sb
1120	0.7297				0.7430 Sb
1200	0.7207				0.7323 Sb
1280	0.7224				0.7224 Sb
13600	0.7249				0.7249 C,Sb[j]
(1370)	0.7265				0.7265 C,Sb[k]
(1385)	0.7289				0.7289 C,Sb[l]
1440	0.7472				No Solution

[a] The upper line describes the machinery complement which, along with the operator's labor is considered to be a fixed resource. The numbers in parentheses indicate the size of the farm at which this particular combination of machinery complement and operator's labor were determined from the long run solutions of Table 1.

[b] The letters in the lower line indicate the type of crop that entered the basis.

[c] The brackets were placed in order to show that these solutions were generated for the interval between the farm size at which the solution becomes infeasible due to insufficient machinery-labor capacity (i.e. here at 320 acres) and the previous farm size where such capacity was still sufficient. These extra solutions; the first at 10 acres beyond the 240 acres, and the second, generated at the very last farm size before the solution becomes infeasible, are used to find out the position of the SRAC solutions in relation to the position of the LRAC ones. Both, the LRAC and the SRAC solutions required the same machinery complement, i.e. that of the SRAC's T1D1F1P1.

[d] All 283 acres went into soybeans in the LRAC solution while 29 and 254 acres went into corn and soybeans respectively (numbers are rounded to the nearest acre) in the SRAC solution. The machinery complement for the LRAC solution changed to T2D1F2P1.

[e] All 570 acres went into soybeans in the LRAC solution while 3 and 567 acres went into corn and soybeans respectively in the SRAC solution. The machinery complement for the LRAC solution changed to T2D1F2P1.

[f] 4 and 623 acres went into corn and soybeans in the LRAC solution while 64 and 563 acres went into corn and soybeans in the SRAC solution respectively. The machinery complement for the LRAC solution changed to T2D1F2P1.

[g] All 960 acres went into soybeans in the LRAC solution while 29 and 931 acres went into corn and soybeans respectively in the SRAC solution.

[h] All 970 acres went into soybeans in the LRAC solution while 40 and 930 acres went into corn and soybeans respectively in the SRAC solution. The machinery complement for the LRAC solution changed to T2D1F2P2.

[i] All 1001 acres went into soybeans in the LRAC solution while 74 and 927 acres went into corn and soybeans respectively in the SRAC solution. The machinery complement for the LRAC solution changed to T2D1F2P2.

[j] For both the LRAC and the SRAC solutions, 46 and 1314 acres went into corn and soybeans respectively.

[k] For both the LRAC and the SRAC solutions, 57 and 1313 acres went into corn and soybeans respectively. No change in machinery complement between the two solutions has occurred.

[l] For both the LRAC and the SRAC solutions, 73 and 1312 acres went into corn and soybeans respectively. No change in machinery complement between the two solutions has occurred.

Table 3.

Long run (LRAC) and short run (SRAC) average cost per unit of output at various levels of farm size. The short run average cost figures are generated by letting farm size vary while holding operator's labor and the corresponding machinery complement (taken from Table 1 above at certain farm sizes other than those considered in Table 2) fixed (90 percent completion probability).

		SRAC1	SRAC2	SRAC3	SRAC4
Acres	LRAC	T2D1F2P2-one- (320)	T2D2F2P2-one (720)	T2D1F2P2-one+ (1040)	T1T2D1F1F2P2-two (1360)
80	1.3440	1.5175 Sb			
160	0.9581	1.0150 Sb			
240	0.8295	0.8677 Sb			
320	0.7940	0.7940 Sb	0.9140 Sb		
(330)	0.7873	0.7873 Sb	0.9037 Sb		
(351)	0.7915	0.7915 C,Sb[a]	0.8839 Sb		
400	0.8153	No Solution	0.8458 Sb		
480	0.7748		0.8000 Sb		
560	0.7591		0.7679 Sb		
640	0.7390		0.7435 Sb		
720	0.7473		0.7473 C,Sb[b]	0.7699 Sb	
(730)	0.7540		0.7500 C,Sb[c]	0.7672 Sb	
(735)	0.7513		0.7513 C,Sb[d]	0.7658 Sb	
800	0.7479		No Solution	0.7502 Sb	
880	0.7320			0.7341 Sb	
960	0.7207			0.7207 Sb,	
1040	0.7195			0.7195 C,Sb[e]	0.7570 Sb
(1050)	0.7215			0.7215 C,Sb[f]	0.7552 Sb
(1055)	0.7225			0.7225 C,Sb[g]	0.7543 Sb
1120	0.7297			No Solution	0.7438 Sb
1200	0.7207				0.7324 Sb
1280	0.7224				0.7224 Sb
1360	0.7249				0.7249 C,Sb[h]
(1370)	0.7265				0.7265 C,Sb[i]
(1385)	0.7289				0.7289 C,Sb[j]
1440	0.7472				No Solution

[a] For both the LRAC and the SRAC solutions, 17 and 334 acres went into corn and soybeans respectively.

[b] For both the LRAC and the SRAC solutions, 49 and 671 acres went into corn and soybeans respectively. This result can be checked by comparing the cropping mix of the short run solution with that of the long run solution at farm size equal to 720 acres in Table 1.

[c] All 730 acres went into soybeans in the LRAC solution while 59 and 671 acres went into corn and soybeans in the SRAC solution respectively. The machinery complement for the SRAC solution was T2D2F2P2 while for the LRAC solution, it was T1D1F1P1. In addition, the operator's labor for the LRAC solution changed from one (for the SRAC solution) to one+ (i.e. one full time operator and a part time operator).

[d] For both the LRAC and the SRAC solutions, 65 and 670 acres went into corn and soybeans respectively.

[e] For both the LRAC and the SRAC solutions, 32 and 1008 acres went into corn and soybeans respectively.

[f] For both the LRAC and the SRAC solutions, 43 and 1007 acres went into corn and soybeans respectively.

[g] For both the LRAC and the SRAC solutions, 48 and 1007 acres went into corn and soybeans respectively.

[h] For both the LRAC and the SRAC solutions, 46 and 1314 acres went into corn and soybeans respectively. i For both the LRAC and the SRAC solutions, 57 and 1313 acres went into corn and soybeans respectively.

[j] For both the LRAC and the SRAC solutions, 73 and 1312 acres went into corn and soybeans respectively.

Table 4.

Long run (LRAC) and short run (SRAC) average cost per unit of output at various levels of farm size. The short run average cost figures are generated by letting farm size vary while holding operator's labor fixed.

Acres	LRAC	SRAC1 one-	SRAC2 one	SRAC3 one+	SRAC4 two
80	1.3440	1.3440 Sb			
160	0.9581	0.9581 Sb			
240	0.8295	0.8295 Sb	0.9774 Sb		
320	0.7940	0.7940 Sb	0.8761 Sb		
(330)	0.7873	0.7873 Sb	0.8669 Sb		
(366)	0.8065	0.8065 C,Sb[a]	0.8379 Sb		
400	0.8153	No Solution	0.8153 Sb		
480	0.7748		0.7748 Sb		
560	0.7591		0.7591 Sb	0.8093 Sb	
640	0.7390		0.7390 Sb	0.7796 Sb	
720	0.7473		0.7473 C,Sb[b]	0.7566 Sb	
(730)	0.7540		0.7500 C,Sb[c]	0.7528 Sb	
(735)	0.7528		0.7513 C,Sb[d]	0.7540 Sb	
800	0.7479		No Solution	0.7479 Sb	
880	0.7320			0.7320 Sb	0.7634 Sb
960	0.7207			0.7207 Sb	0.7558 Sb
1040	0.7195			0.7195 C,Sb[e]	0.7418 Sb
(1050)	0.7215			0.7215 C,Sb[f]	0.7402 Sb
(1098)	0.7329			0.7334 C,Sb[g]	0.7329 Sb
1120	0.7297			No Solution	0.7297 Sb
1200	0.7207				0.7207 Sb
1280	0.7224				0.7224 Sb
1360	0.7249				0.7249 C,Sb[h]
1440	0.7472				0.7472 C,Sb[i]

[a] For both the LRAC and the SRAC solutions, 33 and 333 acres went into corn and soybeans respectively.

[b] For both the LRAC and the SRAC solutions, 49 and 671 acres went into corn and soybeans respectively.

[c] All 730 acres went into soybeans in the LRAC solution while 59 and 671 acres went into corn and soybeans respectively. The machinery complement for the SRAC solution was T2D2F2P2 while for the LRAC solution, it was T1D1F1P1. In addition, the operator's labor for the LRAC solution changed from one (for the SRAC solution) to one+ (i.e. 1 full time operator and a part time operator).

[d] All 735 acres went into soybeans in the LRAC solution while 65 and 670 acres went into corn and soybeans respectively. The machinery complement and the labor situation that occurred here are similar to those at 730 acres described in c above.

[e] For both the LRAC and the SRAC solutions, 32 and 1008 acres went into corn and soybeans respectively.

[f] For both the LRAC and the SRAC solutions, 43 and 1007 acres went into corn and soybeans respectively.

[g] All 1098 acres went into soybeans in the LRAC solution. The machinery complement was T2D1F2P1 and the labor situation needed was two full time operators. As for the SRAC solution, 95 and 1003 acres went into corn and soybeans respectively. The machinery complement was T2D2F2P2 (i.e. has changed) and the labor situation has also changed to one+ (i.e. to one full time and one part time operator).

[h] For both the LRAC and the SRAC solutions, 46 and 1314 acres went into corn and soybeans respectively.

[i] For both the LRAC and the SRAC solutions, 18 and 1313 and 109 acres went into corn, soybeans, and oats respectively.

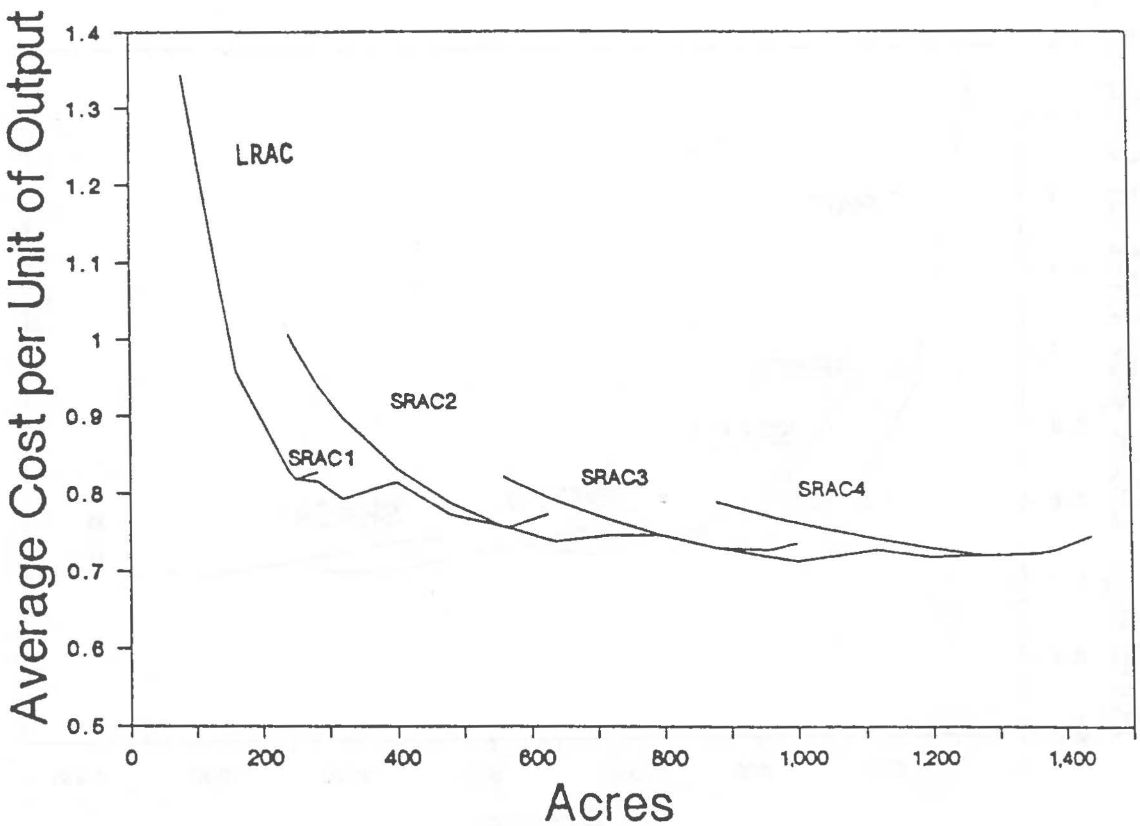

Figure 1.

The Short Run and the Long Run Average Cost Curves When in the Short Run, the Machinery Complement and the Particular Labor Situation are Considered to be Fixed.

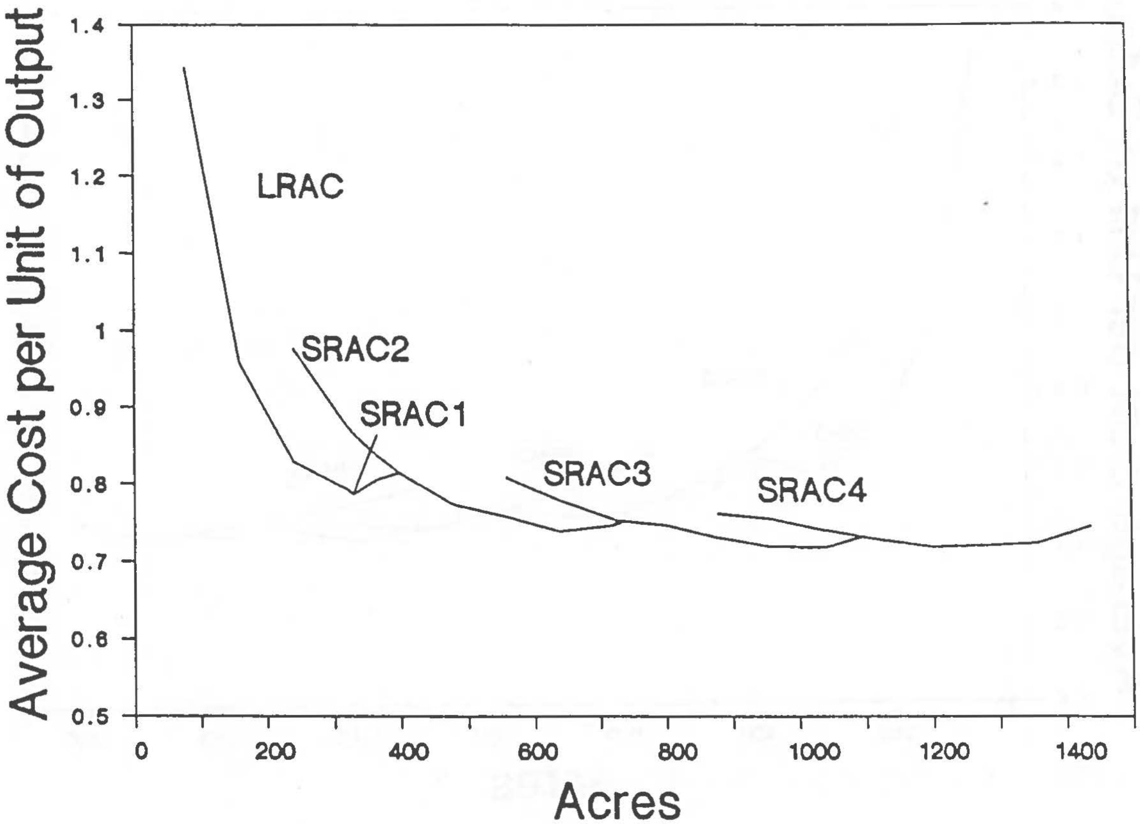

Figure 2.

The Short Run and the Long Run Average Cost Curves When in the Short Run, Only the Operator's Labor Situation is Considered Fixed.

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