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An economic analysis of coordination strategies of feeder pig finishers

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I. INTRODUCTION

In the last two decades economists have modeled the coordination strategies of individual farm firms and different agricultural processing firms. The use of multi-period linear programming in the analyses of the farm growth strategies was predominant in the economic literature of the 1960's [17, 8, 19]. In more recent years economists have incorporated risk analyses into models of coordination strategies for farm firms and agricultural processing firms [5, 29, 22].

Since a large number of input securing, processing, and marketing alternatives are usually available to the processing firm, programming techniques are especially well-suited for the analysis of a firm's optimal coordination strategy. Processing firms may use different marketing arrangements to obtain the input or firms may integrate the raw material production into its own production processes [1, 21]. In addition, firms may use various production technologies to process the raw material and different marketing arrangements to sell the processed good. Given the firm's objectives, resource contraints, technical efficiency, and degree of risk aversion, modelers derive the optimal input securing, investment, production, and marketing strategy for the processing firm [4, 5].

In many respects, feeder pig finishing firms are agricultural processing firms. Feeder pigs, obtained through various marketing arrangements or produced by the finishing firm, are fed or "processed" to market weight and then marketed as butcher hogs by the firm. The finishing firm must determine a coordination strategy that specifies the marketing or production arrangement used to obtain feeder pigs, the technology employed to finish the pigs, and the method used to market butcher hogs. The production technology used to "process" feeder pigs (confinement versus open lot, feed ration 1 versus feed ration 2, etc.) and the arrangement used to market butcher hogs (direct sales versus forward pricing, etc.) are important components of the firm's total coordination strategy [25]. However, it is assumed that all firms use the same production technology and marketing strategy. This analysis will concentrate on the optimal input securing strategies of feeder pig finishing firms.

Until the recent development of the subsidiary sow farrowing firm, feeder pig finishers have had three basic input securing alternatives: 1) direct purchases in traditional feeder pig markets, 2) private contracting with independent feeder pig producers, and 3) production of feeder pigs by the finishing firm. Since feeder pig futures contracts are not traded in any of the organized exchanges, finishers cannot obtain or price feeder pigs through forward contracting in established markets. The producer and finisher must privately negotiate any forward contract. As a result, contractual arrangements are seldom used by feeder pig finishers. Finishers are forced to rely on direct purchases in established feeder pig markets or produce the feeder pigs within the firm.

Problems exist with both relevant input securing alternatives. Large variations in the price and quality of feeder pigs directly purchased in traditional markets have resulted in large variations in the returns of both producers and finishers. In addition, producers and finishers have not equally shared profits (losses) from butcher hog production. Finally, the search and transactions costs associated with direct purchases may significantly increase the price of directly purchased feeder pigs.

Since the finishing firm is usually a multi-product farm firm, the quantity of labor and capital constrains the number of feeder pigs the firm can produce. The large quantities of specialized labor required for sow farrowing may not be available due to other labor demands, lack of farrowing skills, and/or the work preference of the farm operator. Labor may have a higher valued use in grain production or less time-intensive livestock activities. As a result, the firm is often unable to produce all the feeder pigs that are finished by the firm to maximize net revenue.

Although the coordination strategies of feeder pig finishing firms are similar to strategies of other agricultural processing firms, the number of input securing alternatives available to finishing firms has been less than the number available to other processing firms. In addition, existing input securing alternatives have been inadequate.

The problems associated with direct purchases in traditional feeder pig markets and the infeasibility of incorporating feeder pig production into some firm's production mix have resulted in the demand for a reliable source of quality feeder pigs. Recent changes in both the technology of hog production and the organizational structure of ownership have led to the development of a fourth input securing alternative for feeder pig finishers. The combination of large-scale confinement technologies with collective forms of ownership has produced the subsidiary sow farrowing firm. Local feeder pig finishers collectively invest in the facilities, equipment, breeding stock, and management required to produce feeder pigs for shareholders of the firm. Ownership is distinct from management and the large-scale confinement technology enables the manager to establish routine production procedures that are similar to modern industrial processes. Feeder pigs are sold to shareholders at a price equal to the cost of production. Investment in a subsidiary sow farrowing firm is an alternative to farrowing pigs on the shareholder's own farm or purchasing pigs in established markets.

The purposes of this analysis are to: 1) evaluate the coordination problems of feeder pig finishers that have led to the development of the subsidiary sow farrowing firm, 2) describe and evaluate the subsidiary sow farrowing firm as an input securing alternative, 3) develop a linear programming model to derive optimal coordination strategies for feeder pig finishers, and 4) interpret model results and state the farm management implications that result from parametric analysis of the model.

II. COORDINATION PROBLEMS OF FEEDER PIG FINISHERS

A. Direct Purchases in Traditional Feeder Pig Markets

The first step in analyzing direct purchases of feeder pigs is to establish criteria by which the exchange mechanisms of traditional markets can be evaluated. The price variability and the distribution of gains and losses between buyers and sellers are the first criteria used to evaluate the exchange mechanism of traditional feeder pig markets. Since large price variations increase the probability of exchange inefficiency and require large investments in information generation, less price variation is preferred to more price variation. The second criterion used to evaluate the exchange mechanism of traditional feeder pig markets is the cost of transactions associated with the exchange system. These include physical handling costs (transportation costs and feeder pig shrinkage), search and other information generation costs, and the costs incurred during the exchange (time required of traders).

Traditional market sources of feeder pigs include local livestock auctions and private feeder pig dealers. Since the price established in centralized markets (livestock auctions) represents an alternative price for both producers and finishers, the auction price often guides the price making procedures for other decentralized marketing arrangements. Private feeder pig dealers are forced to price within a small range of the "going price" at the local auction. Thus, the problems that characterize local auction markets are also problems in more decentralized spot markets. In addition, little information is available on the price and quantity of pigs transacted by private feeder pig dealers. For these reasons livestock auctions are the only traditional source of direct purchases considered in this analysis.

Although information on feeder pig transactions is limited, there exist some data on feeder pigs transacted in livestock auctions. The marketing division of the Iowa Department of Agriculture reports weekly feeder pig prices at selected Iowa livestock auctions. From this data average monthly prices for Nos. 1-3 40 lb. feeder pigs sold in Iowa auctions have been calculated.

In addition, two enterprise budgets have been developed at Iowa State University to simulate a feeder pig finishing operation and a farrow-to-finish operation [10, 11]. Researchers assume the feeder pig finishing firm purchases pigs in local livestock auctions at the average monthly price calculated from the data reported by the Iowa Department of Agriculture. Researchers assume a four-month feeding period and feed costs are calculated using average monthly prices for corn, soybean meal, vitamins, minerals, and other feed additives. Since a fixed feed efficiency ratio of 3.85 is assumed, the quantity of feed required by each pig is fixed for all feed periods. Changes in feed costs result from changes in feed prices. Nonfeed expenses include the cost of buildings, equipment, labor, medical, and feed processing services as well as the cost of power and fuel, interest and other miscellaneous costs incurred in finishing the feeder pigs [10].

In the farrow-to-finish enterprise budget researchers estimate the cost of producing 40 lb. feeder pigs based on feed costs of the sow herd and feeder pigs, labor, building and equipment services, and other operating and overhead expense. Finishing costs are calculated in the same way as in the feeder pig finishing budget [11]. Both enterprise budgets have been in operation since January 1974.

Given average monthly feeder pig prices in Iowa auctions and results from the enterprise budgets, a number of quantitative estimates are made to evaluate the exchange outcomes of transactions in local livestock auctions. In general, the per pig return to finishing feeder pigs is algebraically stated as follows:

$$RF = B - FPC - FC$$

where

RF - per pig finishing return

B - sales value of the butcher hog

FPC - cost of the feeder pig

FC - per pig finishing cost.

In addition, the per pig finishing cost (FC) is defined as the sum of feed, labor, and operating and overhead costs. It is algebraically stated as follows:

$$FC = FDC + LC + OOC$$

where

FC - per pig finishing cost

FDC - per pig feed costs for finishing a 40 lb. feeder pig

LC - per pig labor costs for finishing a 40 lb. feeder pig

OOC - per pig operating and overhead costs for finishing a 40 lb. feeder pig.

Finally, the feeder pig cost for pigs directly purchased in livestock auctions is algebraically stated as follows:

$$FPC_M = MP + SC + TC$$

where

FPC_M - total per pig cost of feeder pigs directly purchased in livestock auctions

MP - per pig market price

SC - per pig search costs

TC - per pig transactions cost.

Thus, the finishing return on pigs directly purchased at livestock auctions is:

$$RF = B - MP - SC - TC - FDC - LC - OOC$$

Reference will be made to these variables in the evaluation of direct purchases in traditional feeder pig markets.

Relatively large variations in feeder pig prices (MP) and a poor division of gains (or losses) between producers and finishers have been unsatisfactory elements of exchange outcomes in livestock auctions. From September 1973 to August 1977 the monthly price of feeder pigs sold in Iowa auctions (MP) has ranged from \$16.30 to \$48.59 per head. The average price ($\overline{MP}$) and variance (s^2_{MP}) of feeder pigs in this period were \$32.25 and \$84.50 respectively. The coefficient of variation ($C_{MP} = \frac{s_{MP}}{\overline{MP}}$) was .28.

Estimated returns to producers and finishers were calculated for this same time period from the two Iowa State budgets. If producers and finishers shared profits (losses) equally a large positive correlation between returns is expected. The producer's return was calculated by subtracting the cost of producing 40 lb. feeder pigs, given in the farrow-to-finish enterprise budget, from the price of feeder pigs at Iowa auctions (MP). The finisher's return was obtained directly from the finishing budget (RF). The correlation between returns was -.041. There is no equitable sharing of profits and losses between producers and finishers. In fact, the correlation coefficient for a longer time series may be negative and greater in absolute value. The unusually profitable hog market in late 1975 and early 1976 resulted in relatively large positive gains for both producers and finishers. However, in 23 of the 46 marketing months producers' and finishers' gains have been opposite in sign, i.e., producers have gained at the expense of finishers or finishers have gained at the expense of producers.

In addition to relatively large price variations and inequitable sharing of profit between producers and finishers, a third unsatisfactory element of direct purchases results from the uncertainty of genetic quality of pigs obtained at local livestock auctions. Although genetic quality can be assessed to some degree by inspection, physical appearance is not necessarily an accurate indicator of genetic quality. Genetic quality will determine the rate of gain and feed efficiency of feeder pigs. The average quality and variations in quality will affect the mean and variance of feed costs (FDC) associated with finishing the feeder pig. Variations in finishing costs will result from variations in the <u>price</u> and <u>quantity</u> of feed required to increase hog weight from 40 to 220 lbs. If feeder pig buyers could perfectly assess genetic quality, pigs with low feed efficiency ratios would be priced at a premium and pigs with high feed efficiency ratios would be priced at a discount. A trade-off exists between the market price of feeder pigs (MP) and the feeding costs of finishing the pig (FDC). However, in cases where genetic quality of the feeder pig is unknown and difficult to assess variations in finishing costs will be greater than variations in finishing costs when genetic quality is known. Since the genetic quality of feeder pigs sold in livestock auctions is not known with certainty, the variation in finishing costs is expected to be larger for these pigs than for pigs with known genetic backgrounds.

Thus, direct purchases of pigs in traditional feeder pig markets result in unsatisfactory exchange outcomes due to: 1) large variations in feeder pig prices, 2) poor division of gains between producers and finishers, and 3) large mean and variance of finishing costs that result from the inability to perfectly assess feeder pig quality.

The second criterion used to evaluate the exchange mechanism of livestock auctions is the search and transactions costs associated with these direct purchases. Although most economic analysis assumes perfect information and disregards transactions costs, these costs may be significant for livestock auction transactions. Management labor in a multi-product farm firm is usually a constraining resource. If management labor has a higher valued use in other production activities, large amounts of time spent traveling to and transacting in livestock auctions will result in significant search costs. In addition, physical costs associated with livestock auction transactions such as commissions, transportation costs, and feeder pig shrinkage may significantly add to feeder pig costs. Thus, the level of search and transactions costs (SC and TC) associated with livestock auctions are other unsatisfactory elements of the exchange mechanism.

B. Vertical Integration - Feeder Pig Production by the Finishing Firm

The second input securing alternative is feeder pig production by the finishing firm. The return to farrowing and finishing feeder pigs is:

$$RFF = B - FPC_P - FC$$

where

RFF - per pig return of the farrow-to-finish operation

B - sales value of the butcher hog

FPC_P - per pig cost of feeder pigs produced by the finishing firm

FC = per pig finishing cost.

The cost of pigs produced by the finishing firm is algebraically stated as follows:

$$FPC_P = FDC_F + LC_F + OOC_F$$

where

FDC_F - feed costs associated with farrowing a feeder pig

LC_F - labor costs associated with farrowing a feeder pig

OOC_F - operating and overhead costs associated with farrowing a feeder pig.

The finishing cost is the sum of feed, labor, and operating and overhead costs associated with finishing a 40 lb. feeder pig. The algebraic specification is:

$$FC = FDC + LC + OOC$$

where the terms are defined as before.

Thus, the farrow-to-finish return is:

$$RFF = B - (FDC_F + FDC) - (LC_F + LC) - (OOC_F + OOC).$$

Feed, labor and operating and overhead costs are distinguished for farrowing and finishing the pigs.

The estimated production cost (FPC_P) from the farrow-to-finish enterprise budget ranged from \$26.13 to \$28.99 for the 1974-77 period. The average cost of production ($\overline{FPC}_P$) and variance ($s^2_{FPC_P}$) were 27.30 and .52, respectively. The coefficient of variation (C_{FPC_P}) was .026. The variation in feeder pig costs is considerably less for production by the firm than for direct purchases in livestock auctions. However, the Iowa State farrow-to-finish enterprise budget assumes a relatively small scale of production and labor skills are not quality differentiated. The operation of a large scale, continuous farrowing facility requires large amounts of skilled management labor. Since management labor in a multi-product farm firm is usually a limiting resource, farrowing pigs may not be an optimal production activity or increasing the scale of the farrowing operation may not be an optimal expansion activity. If management labor has a higher valued use in other production activities the cost of firm-produced feeder pigs significantly increases when the opportunity cost of management labor (LC_F) is added to other production costs. Thus, the quantity of management labor may constrain the number of feeder pigs the finishing firm can produce. Furthermore, many farm operators lack the specific swine management skills to efficiently farrow pigs and the operator may not be able to hire such skilled labor. Finally, many farm operators simply prefer not to farrow pigs. As a result, some finishing firms have been forced to rely on other input securing alternatives (direct purchases in auction markets) which have not been satisfactory.

III. DEVELOPMENT OF THE SUBSIDIARY SOW FARROWING FIRM

A. The Organizational Concept and Characteristics of Iowa Firms

Groups of feeder pig finishers have recently formed subsidiary sow farrowing firms as a fourth input securing alternative to eliminate problems associated with direct purchases of feeder pigs in livestock auctions and feeder pig production by the finishing firm. The subsidiary sow farrowing firm is a collective entity, formed by a group of individual finishers, which constructs a large-scale farrowing facility, purchases breeding stock, and hires the management to produce feeder pigs. The sow farrowing firm sells feeder pigs to shareholders at a price equal to the cost of production. Ownership is distinct from management. Large-scale confinement technologies enable the manager to establish routine production procedures that are similar to modern industrial processes.

In 1977, 88 sow farrowing firms were identified in Iowa. Of the 88 firms, 65 participated in a survey conducted by Iowa State University [24]. Survey results indicate that sow farrowing firms are a relatively new phenomenon. The majority of firms were not organized until 1973 and did not begin production until 1974. Most firms are organized as Subchapter S corporations.

Local feeder pig finishers have invested in subsidiary sow farrowing firms for three principal reasons [24]. First, the sow farrowing firm provided a reliable source of high quality pigs at a price equal to the cost of production. The finisher can eliminate the large variations in feeder pig costs and quality through the investment in the sow farrowing firm. Since feeder pigs are usually sold to members at a price equal to production costs, the variance of feeder pig costs is dramatically reduced. The consistent, high quality pigs produced by the firm reduces both the mean and variance of finishing costs. In addition, the sow farrowing firm provides a reliable source of feeder pigs. Search costs and the time required for exchange are reduced, if not eliminated, from feeder pig costs. Finally, transactions costs are reduced. The direct transfer of feeder pigs from the firm to the finisher's farm reduces physical handling costs and avoids the serious weight (shrinkage) and death loss associated with traditional market transactions.

The second most important reason for organizing sow farrowing firms was to release labor used in farrowing for other production or leisure activities. Investors may have realized that their management labor had a higher valued use in other production or leisure activities. Finally, the third most important reason for organizing sow farrowing firms was to have farrowing supervised by a person with the proper training, skills and interest in hog production. Investors expect economies of scale as a result of both plant size and specialization.

B. Relative Efficiency Among Iowa Firms

Survey results indicate large variations in the economic and technical efficiency among subsidiary sow farrowing firms in Iowa for the 1976 production year [24]. The per pig cost of production, a measure of the economic efficiency of firms, ranged from $16.00 to $37.30 with an average production cost of $27.55. The number of pigs produced per sow, a measure of the technical reproductive efficiency, ranged from 11.52 to 21.60 with an average of 15.18 pigs produced per sow in 1976. The number of litters produced per sow, another measure of technical reproductive efficiency, ranged from 1.40 to 2.58 with an average of 1.82 litters produced per sow in 1976. The large variations in relative efficiency among firms is disturbing and warrants further analysis. Since the organizational concept and confinement technologies are relatively new, some of the variation in economic and technical efficiency may be explained by differences in the organizational structure and production technologies among Iowa firms. In addition, some of the variation in efficiency may be explained by differences in the quality of the management of the firm. Regression analysis is used to explain differences in the economic and technical efficiency among firms in Iowa.

Of the 65 firms surveyed in the Spring and Summer of 1977, 47 had completed at least one full year of production (i.e. had been in production in 1976). Of these 47 firms, 38 had complete data sets. Three additional firms which had missing data for one of the explanatory variables were added to the data set by estimating values for the missing data. Estimates were made by statistical procedures [20, p. 336] or on the basis of personal judgment by the interviewer.

Production statistics from 41 Iowa firms for 1976 are used in the regression analysis. Four equations are fitted in the first run for the different measures of economic and technical efficiency. The per pig variable production cost is used to measure the economic efficiency of the firm. The number of pigs produced per sow, the number of litters produced per sow, and the litter size are used to measure the technical efficiency of the firm. The model contains twelve independent or explanatory variables. The explanatory variables can be classified into four sub-categories: 1) the scale and maturity characteristics of the firm, 2) the investment and labor employed per sow, 3) the organizational structure of the firm, and 4) the human capital characteristics of the manager.

The four specific equations fitted on the first run are:

$$Y_i = B_0 + B_1C + B_2PY + B_3IBE + B_4HPS + B_5PS + B_6MC + B_7ME + B_8MPE + B_9MJT + B_{10}MH + B_{11}CS + B_{12}SC + U$$

$$i = 1 \ldots 4$$

where

Y_1 = PPS - the number of pigs produced per sow in 1976,

Y_2 = LPS - the number of litters produced per sow in 1976,

Y_3 = LS - the average weaned litter size in 1976,

Y_4 = CP - the average variable cost per pig produced in 1976,

C = the capacity of the firm in terms of the maximum number of sows housed,

PY = the number of years the firm has been in production,

IBE = the investment in buildings and equipment per sow adjusted to a 1974 base,

HPE = the number of hours of labor employed per sow in 1976,

PS = the calculated power structure rating of the firm,

MC = the number of management changes per production year,

ME = the number of years of formal education of the manager,

MPE = the number of years experience of the manager in operating a large hog facility,

MJT = the participation (MJT = 1) or nonparticipation (MJT = 0) of the manager in a special job training program,

MH = the average number of hours worked per week by the manager,

CS = the number of different production activities on which the manager received regular consulting services,

SC = the number of short courses attended by the manager in the previous 12 months,

U = random disturbance.

The capacity of the firm (C) is included in the analysis to pick up any scale effects. Since the survey data indicate that efficiency of the firm improved from the first to second production year, the number of years in production (PY) is used as a maturity variable in the analysis.

The amount invested in buildings and equipment per sow (IBE), adjusted to a 1974 base, is included in the analysis as a variable to measure the production technology of the firm. Relatively large per sow investments in buildings and equipment are associated with a more detailed building design and greater control of environmental conditions such as temperature, humidity, odor, and noise. Contractors and promoters maintain that building design and environmental control are crucial elements affecting the conception rates of sows.[1] The amount of

[1]Herman Tripp, Pure Line Hog Company, Columbus, NE., and Dale Keuter, Lamperts, Inc., Mason City, IA., personal communications 1977.

labor employed per sow (HPS) is also included in the analysis. Survey results indicate that the amount invested in buildings and equipment per sow and the amount of labor employed per sow are nearly independent. The correlation between the amount invested in buildings and equipment per sow and the number of man hours employed per sow is .01.

The power structure rating of the firm (PS) and the number of management changes per year of production (MC) are included in the analysis as measures of the organizational structure of the firm. High power structure ratings indicate that management of the firm is decentralized (manager has responsibility for executing most production and some business management decisions) while low power structure ratings indicate that management of the firm is centralized (board or board member has responsibility for executing important production and most business management decisions of the firm). The number of management changes per production year is included as a measure of the organizational stability and as a measure for the ability of the board to cooperatively work with the manager of the firm.

Finally, human capital characteristics of the manager are included in the analysis as measures of managerial ability [6, p. 9]. Nearly everyone contacted in the preliminary research effort agreed that managerial ability is the key factor in determining "success of the firm." However, measurement of managerial ability is complicated. The manager's education, experience, job training, and current channels of information are human capital characteristics of the manager used as measures of managerial ability. The manager's education is measured in terms of the years of formal education. Experience is measured in terms of the number of years that the manager had operated a large confinement facility. Job training is a dummy variable. A value of one is assigned to this variable if the manager participated in a special swine management program. The value is zero otherwise. The number of hours worked per week by the manager is included as a measure of the manager's "willingness to work." Channels of information include the number of swine management short courses or clinics attended by the manager within the past 12 months and the number of production activities on which the manager receives regular consulting services from a swine specialist.

A simple linear model is chosen as the functional form. Plots of the estimated residuals (e) against the independent variables (x) indicate an equal scattering of the estimated errors about zero for the range of x values. First run regression results are presented in Table 1.

The equations used to explain the variation in production efficiency perform better than the equation used to explain variation in economic efficiency among firms. The poor performance of the equation used to evaluate differences in per pig production costs may be the result of measurement error. Since debt retirement schedules differed among firms, board chairmen were asked to give the average variable cost of production. However, some board chairmen may have reported a cost that included a per pig debt retirement payment (i.e. the average total cost of production). The lack of a uniform cost figure may have caused problems in explaining relative economic efficiency among Iowa

Table 1. First run regression results (n = 41)

	PPS	LPS	LS	CP
Intercept	16.16 ***	1.42 ***	10.62 ***	21.15
(t)	(3.40)	(2.67)	(5.71)	(1.65)
C	-.003	-.0005	.0003	-.006
(t)	(-1.13)	(-1.50)	(.28)	(-.77)
PY	-.65 *	-.016	-.237 **	2.13 **
(t)	(-1.84)	(-.41)	(-1.72)	(2.24)
IBE	.004	.0008 **	.001	-.001
(t)	(1.26)	(2.27)	(.809)	(-.15)
HPS	.14	.009	.017	.28
(t)	(1.42)	(.79)	(.43)	(1.06)
PS	.337 ***	.031 **	.045	-.46
(t)	(3.03)	(2.47)	(1.03)	(-1.55)
MC	-2.67 ***	-.17 *	-.69 **	7.37 ***
(t)	(-3.38)	(-1.96)	(-2.24)	(3.47)
ME	-.24	.0003	-.136 **	.66
(t)	(-1.38)	(.014)	(-2.01)	(1.42)
MPE	-.04	-.004	.0008	.6 **
(t)	(-.46)	(-.41)	(.023)	(2.49)
MJT	.03	.04	-.206	1.97
(t)	(.03)	(.35)	(-.54)	(.74)
MH	.003	-.0002	.005	-.17 *
(t)	(.10)	(-.04)	(.35)	(-1.85)
CS	.496 **	.034	.107	-.126
(t)	(2.06)	(1.25)	(1.14)	(.194)
SC	-.15	-.007	-.041	-.02
(t)	(-1.43)	(-.64)	(1.037)	(-.07)
R^2	.631	.483	.396	.448
F	3.996	2.18	1.531	1.893
Prob F	.001	.044	.1713	.0803

* Significant at .10 level.
** Significant at .05 level.
*** Significant at .01 level.

firms. Thus, the equation used to explain variation in economic efficiency was dropped from the analysis.

Equations used to explain differences in the number of pigs and litters produced per sow in 1976 perform reasonably well. The number of pigs produced per sow per year is the product of the number of litters produced per sow and the average litter size. All three are used as dependent variables in the first run. As expected, the model adequately explains variations in the number of litters produced per sow but fails to satisfactorily explain the variation in litter size. The survey of subsidiary sow farrowing firms indicates that low numbers of pigs produced per sow per year resulted from low numbers of litters produced per sow per year rather than from small weaned litter sizes [24]. It follows that the explanatory variables such as building design (measured by the per sow investment in buildings and equipment), managerial ability, and organizational structure of the firm influence the number of litters produced per year (conception rates). Variations in litter size is more likely to result from different genetic characteristics of the breeding stock and other variables that are difficult to measure and not necessarily a concern of this analysis.

Two final regression equations are estimated to explain the variations in the number of pigs and litters produced per sow in 1976. Independent variables which appeared to be insignificant in the first run are excluded in the final run. Final run results are presented in Table 2.

Table 2. Final run regression results (n = 41)

	PPS	LPS
Intercept	11.48 ***	1.47 ***
(t)	(4.81)	(6.36)
C	-.005 **	-.0005 **
(t)	(-2.07)	(-2.17)
IBE	.007 **	.0008 ***
(t)	(2.37)	(2.86)
PS	.315 ***	.028 ***
(t)	(3.20)	(2.95)
MC	-1.95 ***	-.173 ***
(t)	(-2.80)	(-2.57)
CS	.73 ***	.042 *
(t)	(3.30)	(1.93)
R^2	.448	.456
F	6.658	5.863
Prob F	.0002	.0005

* Significant at .10 level.
** Significant at .05 level.
*** Significant at .01 level.

The final regression equations are:

$$PPS = 11.48 - .005C + .007IBE + .315PS - 1.95MC + .73CS$$

and

$$LPS = 1.47 - .0005C + .0008IBE + .028PS - 1.73MC + .042CS.$$

Using the likelihood ratio principle, the joint hypothesis that all coefficients of the excluded variables are zero is <u>not</u> rejected at the .05 level of significance.

Both models explain approximately 50 percent of the variation in the number of pigs and litters produced per sow in 1976. The relatively large amount of "noise" in the system may result from differences in disease conditions in the state, differences in the genetic quality of the breeding stock, and the inability to accurately measure the quality of the building design, organizational structure, managerial ability, and other variables that determine the economic and technical efficiency of firms.

In the final runs the variation in the number of pigs and litters produced per sow in 1976 is explained by: 1) the capacity of the firm, 2) the amount invested in buildings and equipment per sow, 3) the power structure rating of the firm, 4) the number of management changes, and 5) the number of production procedures on which the manager receives regular consulting services. The coefficient of the capacity variable (C) is negative and different from zero at the .05 level significance. In 1976 the typical 400 sow unit produced 1.5 more pigs and .15 more litters per sow than the typical 700 sow unit, other things equal. This result indicates that relatively smaller scale units may be more efficient than relatively large scale units in terms of reproductive efficiency. This may also help to explain why 11 of the 15 firms organized in 1976 have a sow capacity less than 550.

The coefficient of the per sow investment variable (IBE) is positive and different from zero at the .05 significance level in the first equation (PPS) and at the .01 significance level in the second equation (LPS). In 1976 the firm that invested $600 per sow in buildings and equipment would produce, on the average, 2.1 more pigs and .24 more litters per sow than the firm that invested $300 per sow in buildings and equipment, other things equal. Larger investments in buildings and equipment per sow may be associated with more detailed building design and greater environmental control which affect the conception rates of sows.

The coefficient of the power structure rating of the firm (PS) is positive and different from zero at the .01 significance level. Firms with high power structure ratings (manager has the responsibility for executing important production and some business management activities of the firm) produce more pigs and litters per sow than firms with low power structure ratings, other things equal. Firms that delegated authority to the manager for executing activities such as hiring additional labor, selecting boars, purchasing minor equipment, and deciding sources of feed purchases are technically more efficient than firms in which the board made these decisions. Of course, this result is dependent on the ability and experience of the manager and it indicates that a qualified manager should be allowed to actively manage the firm.

The coefficient of the number of management changes per year (MC) is negative and different from zero at .01 level of significance. A high rate of management turnover is associated with relatively low numbers of pigs and litters produced per sow. Since each management change requires an orientation period for the new manager to establish production routines, technical performance of a firm with a high rate of management turnover is expected to be less than the performance of a firm with a low rate of management turnover. A low rate of management turnover may be a good indication of managerial ability. In addition, the rate of management turnover may also indicate the willingness of the independent members to work cooperatively in such an organization.

The coefficient of the number of production procedures on which the manager regularly receives consulting services (CS) is positive and different from zero at the .01 level of significance in the first equation (PPS) and at the .10 level of significance in the second equation (LPS). This result indicates that firms which receive consulting services on production procedures such as feeding practices, breeding routines, disease prevention, and waste handling are technically more efficient than firms which receive no or fewer consulting services, other things equal. This is the only variable that was significant in explaining variations in litter size among Iowa firms in 1976. This may have resulted from the fact that more consulting services are associated with the analysis of and recommendations on feeding and breeding practices that may have influenced litter size.

A number of problems exist in the analysis. First, the inconsistency of the per pig production costs reported by board chairmen results in an inadequate explanation of the relative economic efficiency of Iowa firms in 1976. Secondly, the independent variables used in the analysis were proxies for firm characteristics such as building design, organizational structure, and managerial ability that were difficult to objectively measure. Investment in building and equipment per sow, adjusted to a 1974 base, was included as a measure of the production technology of the confinement system, but differences in building and construction costs among suppliers as well as inadequate adjustments to the base period may have caused measurement error in this variable. Nearly everyone associated with the organization of a sow farrowing firm stressed the importance of the management of the firm, yet many of the variables used to measure managerial ability were not significant or had wrong signs in the analysis. Since the survey was conducted in the spring and summer of 1977, 1976 production statistics may not have reflected the human capital characteristics of the current manager if the board had recently made a management change. This may partly explain why human capital characteristics of the manager performed poorly in the regression equations. Finally, the organizational structure of the firm is measured by a power structure rating constructed from the board chairman's assessment of who was responsible for executing nine different production and business management decisions of the firm. The organizational structure of a cooperative firm is difficult to measure, but the power structure rating and the rate of management turnover are used as reasonable estimates for organization structure in this analysis. Although some problems exist in the analysis, the regression results indicate that firm size, the amount invested in buildings and equipment, the power structure of the firm, the number of management changes per year of organization, and the amount of consulting services used by the firm explain nearly half of the variation in the number of pigs and litters produced per sow in 1976.

C. Feasibility of the Organizational Form

The next step of this analysis is to assess the feasibility of subsidiary sow farrowing firms as an input securing alternative for the farm finishing firm. Technical, economic, and institutional feasibility of the sow farrowing firm must be considered in the analysis.

The technical feasibility of a sow farrowing firm depends on the ability of scientists and engineers to adopt swine production from an uncontrolled to controlled environment. The technical feasibility of confinement facilities is fundamental or basic to the institutional and economic feasibility of sow farrowing firms. Agricultural economists have little influence on or input in the technical feasibility of firms, but the number of existing confinement facilities is evidence that hogs can be physically produced in a confined environment. Furthermore, improvements in building design and the genetic quality of breeding stock will enhance the institutional and economic feasibility of sow farrowing firms.

The institutional feasibility of the sow farrowing firm depends on the ability of independent farm operators to cooperatively produce feeder pigs. The independent farm firm has traditionally produced the bulk of raw U.S. agricultural output. Although collective agricultural marketing is not uncommon in U.S. agriculture, the collective organization of the sow farrowing firm is a nontraditional form of agricultural production [26]. Since shareholders of sow farrowing firms are traditionally independent farm operators, the institutional feasibility of sow farrowing firms may be inhibited by the collective nature of production. Traditionally independent farm operators may find it difficult to work together with other independent farm operators. In addition, the nontraditional form of organization may not be accepted within the community of independent farm operators.

Although the collective nature of the subsidiary sow farrowing firm may inhibit its acceptance, the production and financing flexibility associated with the organizational form may facilitate its acceptance among investors. Since shares are transferrable, finishers do not get "locked into" production. If a finisher constructs a confined farrowing facility on his own farm he is usually committed to farrowing pigs. However, the investor in a sow farrowing firm can sell his share of the investment if he wants out of feeder pig production. The finisher does not capitalize the value of the facilities into the value of the farm. In addition, the finisher is more flexible with respect to capital budgeting in his farm operation. A group of farmers can construct a 400-700 sow farrowing unit at an investment per sow which is less than if each farmer constructed a considerably smaller size operation on his own farm [15]. Finally, credit availability may be greater for the group as a whole rather than on an individual basis.

There exist both inhibiting and facilitating institutional considerations that influence the feasibility of the organizational form. Although institutional feasibility is not the primary concern of this analysis, one should be aware that institutional feasibility must be considered along with the economic and technical feasibility of the sow farrowing firm.

The first step in assessing the economic feasibility of sow farrowing firms is to establish criteria by which the investment in a sow farrowing firm is evaluated. The two most common decision rules used in capital budgeting are net present value analysis and internal rate of return analysis [27]. Both criterion require the calculation of net benefits for each period of the investment.

Let $R_t = B_t - C_t$

where

R_t - net benefits or net returns from the investment in period t

B_t - gross benefits in period t

C_t - gross costs in period t

$t = 1, 2, \ldots, T$ where T is the life of the investment in years.

The quality of the investment analysis depends on the estimation accuracy of the cost and benefit stream. Since sow farrowing firms usually price pigs to cover production costs, the firms generate no profit and pay no explicit return to shareholders. The implicit net return on the investment in a sow farrowing firm is the difference between the price paid for the pigs received from the firm and the alternative cost of obtaining the feeder pigs (i.e., the cost of directly purchasing pigs at local livestock auctions or the cost of producing the pigs by the finishing firm). The net return on the investment in a sow farrowing firm will depend on the characteristics of individual feeder pig finishing firms. Since finishing firms vary with respect to size, labor efficiency, and degree of risk aversion, the cost of feeder pigs obtained through different input securing alternatives will vary among firms.

If the alternative value of pigs received from the farrowing firm is the cost associated with direct purchases at livestock auctions ($FPC_M = MP + SC + TC$), the market price must be adjusted for feeder pig quality and for search and transactions costs. In general, the high quality feeder pigs from sow farrowing firms would be priced at a premium due to high feed efficiencies (i.e., the reduction in finishing costs is reflected in the price paid for the feeder pigs). The alternative cost must be comprehensive and include the search and transactions costs associated with local livestock auction transactions.

If the alternative value of pigs received from the farrowing firm is the cost of producing the feeder pigs by the finishing firm ($FPC_P = FDC_F + LC_F + OOC_F$), the calculation must include the appropriate opportunity cost for the labor used in farrowing. The management of a large swine breeding herd requires relatively large quantities of skilled labor. The alternative value of the feeder pigs purchased from the farrowing firm (B_t) largely depends on the opportunity cost of labor used in search, transactions, and/or production of feeder pigs.

The second component in determining the net return (R_t) is the price paid for pigs received from the farrowing firm (C_t). The economic efficiency, measured by the per pig production costs, varied among farrowing firms in Iowa. This may have resulted from the fact that firms are relatively young and not all of the technological and organizational "bugs" have been worked out. As optimal building designs and organizational structures are formulated, variation in economic and technical efficiency among firms is expected to be reduced. However, a realistic production standard should be used in determining the level of the per pig production cost. Excessive production expectations result in lower expected production costs and bias the net return upward.

The net return in any period is the difference between the alternative cost of the pigs received from the firm and the amount paid to the sow farrowing firm for the pigs. Given a reasonable estimate for the net return, the net present value of the investment is just the sum of the discounted net returns less the initial cost of the investment. The net present value is calculated as follows:

$$NPV = R_0 + \frac{R_1}{(1+r_1)} + \frac{R_2}{(1+r_1)(1+r_2)} + \dots + \frac{R_T}{(1+r_1)(1+r_2)\dots(1+r_T)} - C_0$$

or

$$NPV = R_0 + \sum_{t=1}^{T} \frac{R_t}{\prod_{i=1}^{T} (1+r_i)} - C_0$$

where

NPV - net present value of the project

R_t - net return in period t

r_i - discount rate in period i

C_0 - initial cost of the investment.

If NPV > 0 then the project is economically feasible. The decision rule of net present value analysis is to do the project or group of projects with the highest net present value.

The internal rate of return analysis is similar to the net present value analysis. The internal rate of return is the discount rate for which the sum of the discounted net returns is equal to the initial cost of the project (i.e., NPV = 0). The internal rate of return is the r for which:

$$R_0 + \frac{R_1}{(1+r)} + \frac{R_2}{(1+r)^2} + \ . \ . \ . + \frac{R_T}{(1+r)^T} - C_0 = 0$$

or

$$\sum_{t=0}^{T} \frac{R_t}{(1+r)^t} - C_0 = 0.$$

If the internal rate of return is greater than 0, then the project is economically feasible. The decision rule is to do the project or group of projects with the highest internal rate of return.

The economic feasibility of the investment in a sow farrowing firm will differ among feeder pig finishing firms. In the following section the investment in a sow farrowing firm is included as an expansion activity in a multi-period linear programming model of the overall coordination strategy for a feeder pig finishing firm.

IV. A MODEL OF THE COORDINATION STRATEGIES OF FEEDER PIG FINISHERS

A. Coordination Strategies of the Feeder Pig Finishing Firm

Since the model finishing firm is a multi-product farm firm, an optimal feeder pig securing strategy is just one part of an overall farm coordination strategy. The model firm produces soybeans, corn, feeder pigs, and butcher hogs. Soybeans produced by the firm are directly marketed while the corn produced by the firm is either marketed or used in livestock production activities. Livestock production activities include feeder pig production and butcher hog production (or feeder pig finishing). Feeder pigs produced can be directly marketed or finished by the firm. Feeder pig production and feeder pig finishing are separate activities in the model. In addition, a separate finishing activity is specified for each feeder pig securing alternative. The finishing and marketing of feeder pigs produced by the firm, the finishing and marketing of feeder pigs directly purchased at livestock auctions, and the finishing and marketing of feeder pigs purchased from subsidiary sow farrowing firms are three separate activities in the model. Investment in a sow farrowing firm entitles the finishing firm to purchase a proportionate number of feeder pigs from the subsidiary farrowing firm. Feeder pigs purchased from the sow farrowing firm can be directly marketed or finished by the firm. The firm can purchase additional corn and hire additional nonskilled labor at a constant cost.

Since marketing strategies are not a concern of this analysis, all agricultural products are sold in decentralized spot markets. The net revenue from the sale of agricultural commodities and borrowing are the two sources of cash flow for the firm. Uses of cash flow include resource supplying activities, investment activities, consumption activities, and debt repayment activities. Expansion or investment activities of the firm include the purchase of additional land and machinery, the construction of additional farrowing facilities, the construction of additional finishing facilities, and the investment in subsidiary sow farrowing firms. Expansion activities increase the grain and livestock production capacities in all future time periods. The investment in a sow farrowing firm entitles the investor to purchase a proportionate share of feeder pigs at a price equal to the cost of production in all future periods. Financial activities include borrowing, repayment of debt, withdrawal of cash for consumption, payment of taxes, and the transfer of cash and debt between periods.

The firm is physically constrained by the number of acres of land, the number of hours of unskilled and management labor, and the initial farrowing and finishing capacity of the firm. The firm is financially constrained by a credit limitation. A detailed explanation of the activities, constraints, and technical coefficients of this model is presented in the following sections.

B. The Linear Programming Model

1. Objectives, activities, and constraints of the model firm

The objective of the firm is to maximize discounted net returns over a five year planning horizon. Net returns from the sale of agricultural commodities are equal to expected gross revenue less the expected variable cost of production. The multi-period analysis allows for firm growth through the generation of investment funds. Internally generated investment funds are the net revenue in excess of consumption requirements, tax liability, and debt and fixed cost payments. In addition, borrowed capital adds to the amount of investment funds. The external borrowing limitation is a function of the net worth of the firm. Investment funds are used to acquire additional resources that increase the production capacity of the firm [2, 8]. Net returns are maximized over the five year period and final period adjustments add the current discounted market value of assets purchased in previous periods to the objective function and substract the amount of outstanding debt from the objective function. The farm firm operator has adequate managerial ability and no internal limits on growth.

Although the matrix for the model contains 103 rows and 142 columns, the yearly sub-matrices are only 20 rows by 24 columns. The activities and constraints of the finishing firm are listed in Table 3 and Table 4, respectively.

2. Determination of technical coefficients

Technical coefficients of the model were determined from three data sources. Production costs and returns were obtained from the 1975-76 edition of "Suggested Farm Budgeting Costs and Returns" which is published by the Cooperative Extension Service of Iowa State University [16]. Investment costs for farrowing and finishing facilities were obtained from the "Pork Industry Handbook" which is also published by the Cooperative Extension Service of Iowa State University [15].

Table 3. Activities of the finishing firm

Production Activities

iPC - produce corn in period i.

iPMSB - produce and market soybeans in period i.

iPFP - produce feeder pigs in period i.

iFFFP - finish and market feeder pigs produced by the firm in period i.

iFDFP - finish and market feeder pigs directly purchased at auction markets in period i.

iFSFFP - finish and market feeder pigs purchased from subsidiary sow farrowing firms in period i.

Marketing Activities

iMC - market corn in period i.

iMFFP - market feeder pigs produced by the farm firm in period i.

iMSFFP - market feeder pigs purchased from subsidiary sow farrowing firms in period i.

Resource Supplying Activities and Management Labor Transfer

iBC - purchase corn in period i.

iHUL - hire additional unskilled labor in period i.

iTML1 - transfer unused April-May-June management labor to unskilled labor category in period i.

iTML2 - transfer unused September-October-November management labor to unskilled category in period i.

iTML3 - transfer unused other management labor to unskilled category in period i.

Table 3. Continued

Expansion Activities

iILM	-	purchase land and machinery in period i.
iIFRC	-	build farrowing capacity in period i.
iIFNC	-	build finishing capacity in period i.
iISFF	-	invest in subsidiary sow farrowing firms in period i.

Financial Activities

iBRRW	-	borrow capital in period i.
iRD	-	repay debt in period i.
iTD	-	transfer debt in period i.
iWCC	-	withdraw cash for consumption and fixed costs payments in period i.
iTC	-	transfer cash in period i.
iPTX	-	pay taxes in period i.

Final Period Adjustment Activities (these add or subtract an amount from the objective function at the end of the final period)

iLAC	-	add discounted current market value of land and machinery purchased in period i.
iFRAC	-	add discounted current market value of farrowing facilities constructed in period i.
iFNAC	-	add discounted current market value of finishing facilities constructed in period i.
iSFFAC	-	add discounted market value of sow farrowing firm shares purchased in period i.

Table 3. Continued

ADDCASH - add discounted value of cash transferred from the final period to the next.

SUBDEBT - subtract discounted value of debt transferred from the final period to the next.

$i = 1, 2, \ldots, 5$

Table 4. Constraints of the finishing firm

Type of Constraint	Initial RHS Value		Physical Constraints
L	320	iL	- acres of land in period i.
L	2400	iUL	- hours of unskilled labor in period i.
E	570	iML1	- hours of April-May-June management labor in period i.
E	570	iML2	- hours of September-October-November management labor in period i.
E	1700	iML3	- hours of other management labor in period i.
L	100	iFRC	- farrowing capacity in period i.
L	3000	iFNC	- finishing capacity in period i.
G	200	iFNMIN	- minimum number of feeder pigs finished in period i.
	transfer rows		
L	0	iCTR	- corn transfer row in period i.
L	0	iFFPT	- firm produced feeder pig transfer row in period i.
L	0	iSFFPT	- sow farrowing firm feeder pig transfer row in period i.
			Financial Constraints
E	10000	iCF	- cash flow in period i.
L	172500	iCRD	- credit availability in period i.
G	0	iMDR	- minimum debt repayment in period i.
	transfer rows		
E	0	iDB	- debt balances transfer row in period i.
E	0	iPT	- tax payment transfer row in period i.
			Accounting Rows
E	0	iLMAR	- land and machinery investment accounting row in period i.

Table 4. Continued

Type of Constraint	Initial RHS Value	
E	0	iFRCAR - farrowing capacity investment accounting row in period i.
E	0	iFNCAR - finishing capacity investment accounting row in period i.
E	0	iSFFAR - sow farrowing firm investment accounting row in period i.
	final period accounting rows	
E	0	CADDCASH - accounts for cash transferred from the final period to the next.
E	0	CSUBDEBT - accounts for debt transferred from the final period to the next.
		i = 1, 2, ..., 5

Finally, the investment cost and production efficiency of subsidiary sow farrowing firms were obtained from a 1977 survey of board chairmen conducted by Iowa State University [24].

A simplified version of the tableau for the first two production years with specific a_{ij} coefficients is presented in Table 5 to illustrate the basic model structure. Returns to finishing activities in Table 5 are calculated assuming the price of hogs equals $.38 per pound.

a. <u>Production, marketing, and input securing activities of the firm</u> The average variable cost (c_j) of producing one acre of corn in the model is $94.30. This includes the cost of variable machinery and power, seed, fertilizer and lime, herbicides and insecticides, and other costs associated with producing an acre of corn. A unit of corn production requires one acre of land and 4.5 hours of labor. Total labor is broken down into unskilled and management categories. Of the 4.5 total hours, 4 hours of unskilled and .5 hours of skilled labor are required to produce an acre of corn. A yield of 115 bushels per acre is added to the corn transfer row. The cash flow of the firm is reduced by the amount of the variable cost of production. Although sophisticated tax structures can be incorporated into linear models [28], a tax rate of .25 is assumed for simplicity. Thus, the firm's tax liability is decreased by 25% of the average variable cost of production. A lower bound of 40 acres is set for the corn production activity to reflect a personal preference of the farm operator.

The net return on producing and marketing one acre of soybeans is $170.70. The gross return per acre is equal to the expected yield times

Table 5. Tableau with input-output coefficients for years 1 and 2 of the model

	1PC	1PMSB	1PFP	1FFFP	1FDFP	1FSFFP	1MFFP	1MSFFP	1ILM	1IFRC	1IFNC	1ISFF	IBRRW	1RD	1TD
OBJ	-94.3	170.0	-80.7	66.6	35.6	39.1	30.0	4.5						-.08	-.08
1L	1	1													
1UL	4	3.5	8.25	.45	.45	.45									
1ML	.5	.5	2.75	.15	.27	.15									
1FRC			1												
1FNC				1	1	1									
1CTR	-115		30	10.75	11	10.25									
1FFPT			-7.5	1			1								
1SFFPT						1		1							
1FNMIN				1	1	1									
1CF	94.3	-170.7	80.7	-66.6	-35.6	-39.1	-30	-4.5	2100	161.8	30.6	1180	-1	1.08	.08
1CRD													1		
1MDR													-.1	1	
1DB													-1	1	1
1PT	23.6	-42.7	20.2	-16.95	-8.9	-9.8	-7.5	-1.1	.57	62.8	2.5	97.35		.02	.02
2L									-1						
2UL															
2ML															
2FRC										-4					
2FNC											-3				
2CTR															
2FFPT															
2SFFPT												-15			
2FNMIN															
2CF															
2CRD														-1.5	1
2MDR													-.1		
2DB															-1
2PT									-6.43	9.52	.38	14.75			

Table 5. Continued

	2PC	2PMSB	2PFP	2FFFP	1FDFP	2FSFFP	2MFFP	2MSFFP	2ILM	2IFRC	2IFNC	2ISFF	2BRRW	2RD	2TD
OBJ	-87.3	158.1	-74.7	61.7	32.9	36.2	27.8	4.12						.074	.074
1L															
1UL															
1ML															
1FRC															
1FNC															
1CTR															
1FFPT															
1SFFPT															
1FNMIN															
1CF															
1CRD															
1MDR															
1DB															
1PT															
2L	1	1													
2UL	4	3.5	8.25	.45	.45	.45									
2ML	.5	.5	2.75	.15	.27	.15									
2FRC			1												
2FNC				1	1	1									
2CTR	-115		30	10.75	11	10.25									
2FFPT			-7.5	1			1								
2SFFPT						1		1							
2FNMIN				1	1	1									
2CF	94.3	-170.7	80.7	-66.6	-35.6	-39.1	-30	-4.5	2205	800	32.10	1239	-1	1.08	.08
2CRD													1		
2MDR													-.1	1	
2DB													-1	1	1
2PT	23.6	-42.7	20.2	-16.65	-8.9	-9.8	-7.5	-1.1	1.10	66.0	2.6	102.2		.02	.02

the expected price. An expected yield of 40 bushels per acre and an expected price of $5.50 per bushel are assumed in the model. The variable cost of producing an acre of soybeans is $49.30. This includes the cost of variable power and machinery, seed, fertilizer, herbicides and other variable production costs. A unit of bean production and marketing requires one acre of land and 4 hours of total labor. Of the total labor, 3.5 hours of unskilled and .5 hours of management labor are required to produce and market beans from one acre of land. Cash flow of the firm is increased by the amount of the net return and the tax liability of the firm is increased by 25% of the net return. A lower bound of 40 acres is also set for the bean production activity.

The average variable cost of producing one litter of 7.8 pigs is $80.67. This includes the cost of supplement and minerals, breeding, veterinary and medical, and miscellaneous costs associated with producing a litter of 7.8 pigs. Each litter requires a total of 11 hours of labor. Of the total labor requirement, 8.25 hours of unskilled and 2.75 hours of management labor are required for the production activity. Each litter requires one unit of farrowing capacity and 30 bushels of corn. Since a death rate of 4% is assumed, 7.5 pigs are added to the firm-produced feeder pig transfer row. Cash flow of the firm is reduced by the variable cost of production and the tax liability is reduced by 25% of the variable cost.

The basic model is solved for three different expected prices of butcher hogs. Return to finishing activities are calculated for the price of butcher hogs equal to $.28, $.33, and $.38 per pound. The gross finishing return is equal to the market weight (220 lbs.) times the expected market price. Since all butcher hogs are sold in decentralized spot markets, the gross return to all three finishing activities is identical. However, differences in the net finishing return result from differences in feeder pig prices and quality which are reflected in the variable finishing cost (the amount of feed, supplement, and medicine) and the death loss associated with each input securing alternative.

The variable cost of finishing one firm produced feeder pig is \$15.64. This includes the cost of supplement and minerals, veterinary and medical, and other miscellaneous costs. A feed efficiency ratio of 3.85 is assumed to calculate the quantity of supplement and corn required per hog. Finishing one firm produced feeder pig requires one unit of finishing capacity and 10.75 bushels of corn. A 2% death loss is assumed. Finishing activities require .6 hours of labor per hog. Of this, .45 hours of unskilled and .15 hours of skilled labor are required to finish one feeder pig. Finishing a firm produced feeder pig reduces the own firm feeder pig transfer row by one and adds one to the finishing minimum. Cash flow is increased by the amount of net revenue per pig and the tax liability of the firm is increased by 25% of the net return.

The variable cost of finishing one feeder pig directly purchased at a local livestock auction is \$44.56. This includes the cost of the feeder pig, supplement and minerals, veterinary and medicine, and other miscellaneous costs. A 4% death loss is assumed for feeder pigs directly purchased at livestock auctions. A feed efficiency ratio of 4 is assumed to calculate the quantity of supplement and corn required per hog. Since directly purchased feeder pigs have poorer feed efficiency ratios, each pig requires 11 bushels of corn. Finishing requires .6 hours of labor per pig and search and transactions require .12 hours of management labor per pig. Thus, .72 hours of labor are required to finish a directly purchased feeder pig. Of the total, .45 hours of unskilled and .27 hours of management labor are required. The finishing minimum is increased by one for each unit of the activity. The cash flow of the firm is increased by the amount of the net revenue and the tax liability of the firm is increased by 25% of the net revenue.

The variable cost of finishing one feeder pig purchased from a sow farrowing firm is $41.15. This includes the cost of the feeder pig, supplement and minerals, veterinary and medicine, and other miscellaneous costs. A survey of sow farrowing firms in 1977 indicates the average price paid for feeder pigs by members is $27.55. Since feeder pigs from sow farrowing firms are of a consistently high genetic quality, a feed efficiency ratio of 3.75 is assumed to calculate the quantity of supplement and corn required per hog. The finishing capacity, the finishing minimum, and the sow farrowing firm transfer row are reduced by one. The corn transfer row is reduced by 10.25 bushels to reflect the better feed efficiency ratio. A death loss of 2% is assumed in the model. The time required to finish one sow farrowing firm pig is .6 hours. Of the total, .45 hours of unskilled and .15 hours of management labor are required to finish one pig. Cash flow of the firm is increased by the amount of net revenue and the tax liability of the firm is increased by 25% of the net revenue.

Corn produced by the firm can be used in livestock production activities or sold by the firm. The net return for marketing corn is $1.90 per bushel. The net price is the expected market price ($2.00) less delivery costs (.10). Marketing corn decreases the corn transfer row by one. Cash flow of the firm is increased by the amount of net revenue and the tax liability of the firm is increased by 25% of the net revenue.

The firm can either finish or market the firm-produced feeder pigs. The net revenue from the sale of firm-produced feeder pigs is $30.00 per pig. The firm-produced feeder pig transfer row is reduced by one. Cash flow is increased by the amount of net revenue and the tax liability of the firm is increased by 25% of the net revenue.

The firm can also finish or market the feeder pigs purchased from the sow farrowing firm. However, the number of feeder pigs that the firm can obtain from the sow farrowing firm is constrained by the number of shares or the amount invested in the farrowing firm. Since pigs from sow farrowing firms are of a consistently high quality, the expected gross revenue is $32.00 per pig. A quality premium of $2.00 per pig is paid for the sow farrowing firm pigs. Since the purchase price is $27.55, the net return is 4.45 per pig. The sow farrowing firm feeder pig transfer row is decreased by one. The cash flow of the firm is increased by the amount of net revenue and the tax liability of the firm is increased by 25% of the net revenue.

The firm can buy corn at $2.00 per bushel. The activity increases the corn transfer row by one. Cash flow of the firm is decreased by the per bushel cost and the tax liability of the firm is decreased by 25% of the per bushel cost.

The firm can hire unskilled labor at $3.50 per hour. The amount of unskilled labor the firm can hire is unconstrained. This activity increases the number of unskilled labor hours by one. Cash flow of the firm is decreased by $3.50 and the tax liability of the firm is decreased by 25% of the labor cost.

Three labor transfer activities are included in the model to incorporate the fact that the farm operator will utilize his own unused management labor in an unskilled capacity before hiring additional unskilled labor.

b. Expansion activities of the firm The investment or expansion activities do not directly influence the objective function. In general, investment activities decrease the cash flow and tax liability of the firm in the investment period, increase resource constraints in all future periods, and decrease the tax liability of the firm in future periods.

The unit of land and machinery investment is one acre. Land and machinery investment decreases the cash flow by $2100 in the initial year of the model. The cost of an acre of land that produces 115 bushels of corn and 40 bushels of beans is $2000. For each acre of land purchased \$100 worth of additional machinery is also purchased. Land and machinery costs increase 5% annually throughout the model. Investment in land and machinery affects the tax liability of the firm in two ways. First, a property tax of \$10 per acre increases the tax liability of the firm in the investment year and in all future periods. Secondly, depreciation on machinery decreases the income tax liability in all periods of the model and an investment credit on machinery purchases decreases the tax liability in the year of the investment. A seven year straight-line depreciation method and a 7% investment credit are used in the analysis. The number of acres of land is increased by one in all years following the investment year.

The firm's farrowing operation is a low investment, low intensity confinement system characterized by simply designed permanent buildings for farrowing, gestation, and nursery care. The investment unit is one sow capacity. The 1977 unit cost of such an investment is \$761.80 per sow capacity [15]. Investment costs increase 5% annually throughout the model. The finishing firm does not farrow pigs during planting and harvesting seasons, but maintains a December, February, June, and August farrowing schedule. Thus, the construction of an additional farrowing unit will increase the annual farrowing capacity by four in all future time periods. Cash flow of the firm is decreased by the per unit investment cost. The tax liability of the firm is decreased by 25% of the amount of depreciation in all periods and by the 7% investment credit in the purchase year. A 20 year straight-line method is used to determine depreciation costs while a 7% investment credit is assumed for the entire farrowing unit.

The finishing facility is an open front shelter with an exposed concrete slab. The investment in finishing capacity includes the shelter, concrete slab, waterers, feeders, gates and fencing required for the finishing operation. The unit of investment is one butcher hog capacity. The 1977 cost of such an investment is $30.60 per butcher hog capacity [15]. Investment costs increase 5% annually throughout the model. Feeder pigs are brought onto the finishing floor at 40 lbs. and are fed for 4 months or less. Thus, the construction of an additional finishing unit increases the annual finishing capacity by 3 in all future time periods. Cash flow of the firm is decreased by the amount of the per unit investment and the tax liability of the firm is decreased by 25% of the amount of depreciation in all future periods. A 7% investment credit decreases the tax liability of the firm in the initial year of the investment. A 20 year straight-line method is used to calculate depreciation costs. The depreciation allowance and investment credit are allowed on the entire investment unit.

The unit of investment in a sow farrowing firm is one sow capacity. A 1977 survey of sow farrowing firms indicates that the per sow investment is $1180 for firms organized in 1977 [24]. Investment costs increase 5% annually throughout the model. Since the investment entitles shareholders to purchase a proportionate share of pigs at a price equal to production costs, the investment increases the sow farrowing feeder pig transfer row in all years after the investment year.

Survey results indicate that firms produce an average of 14 pigs per sow in the first year of production and nearly 15.5 pigs per sow in the second production year. The sow farrowing feeder pig transfer row is increased by 14 in the year after the investment and by 15.5 in all other years following the investment. Cash flow of the firm is decreased by the per unit cost of the investment. The tax liability of the firm is decreased by 25% of the depreciation allowance and by the 7% investment credit in the year of the investment and by 25% of the depreciation allowance in all years following the investment. A 20 year straight-line method is used to calculate depreciation costs.

c. <u>Financial activities of the firm</u> Firm growth results from the investment activities of the firm. Internally generated investment funds and external investment funds (borrowing) comprise the total amount of expansion capital in each period. The unit of borrowing is one dollar. Borrowing adds to the cash flow and debt balances of the firm. The firm can borrow up to an external credit limitation which is a function of the firm's net worth. The firm borrows funds for a ten year period. Thus, one unit of borrowing increases the minimum debt repayment by .10 in the investment year and all years following the investment year.

The repayment of debt reduces the objective function by the cost of the borrowed funds. Funds are borrowed at an 8% rate of interest. The repayment of debt decreases the cash flow of the firm by 1.08 and decreases the minimum debt repayment and debt balances by one. The tax liability of the firm is reduced by 25% of the interest cost. Since the repayment of debt increases the net worth of the firm, the credit constraint is increased by 1.5 in all future periods.

Debt not repaid in the current period is transferred to the next period. However, the firm pays the amount of interest that has accrued on the outstanding debt during the current period. The payment of interest on debt transferred to the next period decreases the objective function and cash flow by .08 for each dollar of debt transferred. The transfer of debt reduces current debt balances and increases debt balances in the next period by one. In addition, the transfer of debt decreases the credit constraint in the next period by one.

Finally, the net revenue generated from production by the firm is used for investment, consumption, the payment of taxes, the repayment of debt, and the payment of fixed costs. Consumption is set at a minimal level of $8000. Increases in consumption level will decrease the amount of internally generated investment funds and thus decrease the rate of firm growth. The payment of taxes decreases the tax liability and cash flow of the firm. Cash not used for investment, consumption, the payment of taxes and fixed costs, and the repayment of debt is transferred to the following period. Idle cash is placed in a savings account that earns 5% interest per year.

3. Initial constraints

The firm owns one-half equity in 320 acres of land and the machinery required to farm the land. The firm has a 25 year equal payments contract on the land and it trades machinery throughout the planning horizon so that a constant fixed cost payment of $15,000 is required for all periods of the model. Since the consumption level is fixed at \$8,000, a lower bounds of \$23,000 is set on the activity to withdraw cash for consumption and the payment of fixed costs. Investment in land and machinery adds to the initial resource constraint while any borrowing to finance the investment adds to the minimum debt repayment of the firm.

The farm operator has two school-age sons who provide 2400 hours of unskilled labor per year. The farm operator can hire an unlimited amount of unskilled labor at a constant cost of \$3.50 per man hour. It is assumed that the farmer has the ability to coordinate and work with a large number of workers.

The farm operator is the only source of managerial labor. Managerial labor is distinguished for three seasonal periods: 1) planting, 2) harvesting, and 3) other off-peak periods. The planting period is a nine week period from mid-April to mid-June. In this period, the manager is willing to work 570 total hours. The harvesting period is a nine week period from mid-September to mid-November. Again, the farmer is willing to work 570 hours during this period. For the other 34 weeks of the year the farmer is willing to work 50 hours per week or 1700 total hours. Management labor not utilized for skilled purposes is utilized in an unskilled capacity before additional unskilled labor is hired.

The initial farrowing facilities consist of a farrowing house with 25 crates, a gestation house, and a nursery large enough to accommodate 60 sows and 250 feeder pigs. The production operation is a low intensity confinement system. The firm farrows sows four times a year in a December-February-June-August sequence. One group of 25 sows farrows in December and June while a second group of 25 sows farrows in February and August. The farrowing schedule is designed to avoid periods of peak labor demand. Feeder pig production by the firm serves as an enterprise to utilize excess seasonal labor and other unused resources. Since the farrowing facility is utilized four times a year, the initial farrowing capacity is 100 sows per year.

The finishing facilities consist of open front shelters with exposed concrete slabs. Feeder pigs, purchased in the open market or from subsidiary sow farrowing firms, or produced by the finishing firm, are brought into the facility at 40 lbs. and fed to market weight. Initial one-time finishing capacity is 1000 pigs. Since three finishing cycles exist per year, the initial annual finishing capacity is 3000 pigs. A constraint is added that requires the firm to finish at least 200 feeder pigs. This reflects a personal preference of the farm operator.

A corn transfer row is included that allows corn produced by the firm to be either fed to livestock or marketed. Similarly, transfer rows for firm-produced feeder pigs and for sow farrowing firm feeder pigs are included that allow for feeder pigs to be either marketed or finished by the firm.

The initial cash flow of the firm is $10,000. The initial credit constraint is one-half of the firm's equity in land, machinery, and hog facilities. The 160 acres of land and associated machinery are evaluated at $2000 per unit and the hog facilities, which are assumed to be owned by the firm, are evaluated at $25,000. Thus, the initial external credit constraint is 172,500. Although most farm operators maintain a margin of unused credit as a form of insurance against variations in yields and prices, the farm operator can borrow up to the external credit ceiling in the initial run [3].

Finally, the tax constraint forces the firm to pay the net tax liability. The net revenue from the sale of agricultural commodities increases the firm's tax liability while the investment credit and depreciation on new assets decrease the firm's tax liability. Since no account is made of the depreciation on existing assets or the property tax on initial land, the amount of taxes paid by the firm in the model does not necessarily reflect the actual tax liability of the firm. However, this analysis does account for differences in the tax liability that result from different investment patterns.

4. <u>Final period adjustments in the model</u>

At the end of the final period adjustments are made in the objective function that: 1) add the discounted final period value of assets purchased during the planning horizon, 2) add the discounted value of cash transferred from the last model period to the next period, and 3) subtract the discounted value of debt transferred from the last model period to the next. In a sense, assets accumulated during the planning period are sold at their market value in the final period. The market value in the final period reflects the future stream of income that is not accounted for in the relatively short planning horizon. Accounting rows for each investment alternative are added in each period of the model so that final period adjustments can be made. The current market value of assets at the end of the planning horizon reflects a 5% annual increase in market value. Thus, all assets except land are discounted back to present value by using a nominal interest rate of 8%. Since land does not depreciate and has been increasing in value through time, an adjusted discount rate is used to calculate the present value of land [27]. Finally, two rows and activities are added to the model that subtract the discounted value of debt and add the discounted value of cash transferred from the final period of the model to a following period. Both activities adjust the final value of the objective function.

V. MODEL RESULTS

The basic model is solved for three different sets of butcher hog prices. In Model A the returns to different finishing activities are calculated assuming the price of butcher hogs is equal to \$.28 per pound. Results of this model are presented in Table 6. In Model B the returns to different finishing activities are calculated assuming the price of butcher hogs is equal to \$.33 per pound. Results of the Model B are presented in Table 7. In Model C the returns to different finishing activities are calculated assuming the price of butcher hogs is equal to \$.38 per pound. Results of Model C are presented in Table 8. All other coefficients remain unchanged in the basic model.

The optimal solution prescribes the yearly production, investment, and financial activities that will maximize discounted net returns over a five year planning period. A general discussion of the results for all three models is presented in the following paragraphs while more specific analysis of each model and parametric variation for each model are presented in later parts of this section.

The firm produces soybeans rather than corn as a cash grain crop. In all three models, the number of acres of corn produced enters the solution at its lower bound of 40 acres. Furthermore, all additional land purchased by the firm is used for soybean production. The firm purchases the additional corn required to finish or produce feeder pigs.

Investment activities follow a similar pattern throughout the planning horizon in all three models. The firm increases its farrowing capacity in the first period of the model to utilize off-season

Table 6. Solution of Model A (price of hogs equals $.28 per pound)

Value of the Objective Function: $561,300

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	297
4	40	315
5	40	333

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	550	200	0	0	200
2	5320	200	0	0	200
3	5320	200	0	0	200
4	5320	200	0	0	200
5	5305	200	0	0	200

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	159	0	0
2	17	0	0	0
3	18	0	0	0
4	18	0	0	0
5	18	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	550	0	93993	3199
2	19634	4277	0	21526
3	19634	4347	0	22492
4	19634	4408	0	23460
5	19634	4471	0	24427

Table 7. Solution of Model B (price of hogs equals $.33 per pound)

Value of the Objective Function: $620,500

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	300
4	40	321
5	40	342

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4770	0	0	4770
3	0	4770	0	0	4770
4	0	4770	0	0	4770
5	0	4770	0	0	4770

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	134	585	0
2	20	0	0	0
3	21	0	0	0
4	21	0	0	0
5	21	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	83394	6221
2	65549	5895	0	23400
3	65549	5976	0	24480
4	65549	6049	0	25558
5	65549	6119	0	26632

Table 8. Solution of Model C (price of hogs equals $.38 per pound)

Value of the Objective Function: $1,107,700

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	279
2	40	280
3	40	280
4	40	322
5	40	366

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4350	920	1204	6474
3	0	4350	278	2355	6983
4	0	4350	98	2479	6927
5	0	4350	0	2480	6830

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	120	1160	86
2	0	0	171	73
3	42	0	0	1
4	44	0	0	0
5	44	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	172500	3612
2	82107	6449	0	31186
3	86894	6680	0	41036
4	86461	6829	0	43528
5	85404	6934	0	45544

managerial labor. The scale of the farrowing operation is constrained by the quantity of off-season managerial labor. This quantity reflects the farm operator's skill level and work preference. The investment in farrowing facilities is largely financed through borrowing in the first period. Later period investments are entirely financed out of internally generated investment funds.

In Model A (price of hogs equals \$.28 per pound) the firm markets all feeder pigs produced except for 200 head which are finished to fulfill the minimum finishing constraint. However, in models B and C (price of butcher hogs equals \$.33 and \$.38 per pound, respectively), the firm finishes all firm produced feeder pigs. The total number of feeder pigs finished by the firm is equal to the number of feeder pigs produced by the firm, the number of feeder pigs directly purchased at livestock auctions (traditional market source), and the number of feeder pigs purchased from subsidiary sow farrowing firms (nontraditional market source). Direct purchases at livestock auctions are the primary source of feeder pigs finished by the firm in the first period of models B and C. However, by the final period the number of direct purchases at livestock auctions is reduced to zero in both models. In Model B the firm produces all feeder pigs that are finished after period one. In Model C the firm produces approximately two-thirds of the pigs finished by the final period of the model while it purchases the remaining one-third from subsidiary sow farrowing firms.

In period one of models A and B the firm constructs farrowing facilities to utilize off-season management labor. In all following periods of models A and B the firm uses internally generated investment funds to purchase additional land and machinery which are used for soybean production. Only in Model C (price of butcher hogs equals $.38 per pound) does the firm expand finishing activities beyond the point where feeder pig production and finishing are means to utilize off-season management labor. In periods one and two of Model C the firm substantially invests in subsidiary sow farrowing firms while in the remaining periods the firm expands the scale of its farming operation. This is the only model in which investment in subsidiary sow farrowing firms is an optimal expansion activity.

A more detailed explanation and a parametric variation of Model A, Model B, and Model C are presented in the following sections. Four parametric operations are performed on each model. First, the initial scale of the farm operation is varied from 160 to 800 acres in increments of 160 acres. Secondly, the number of hours of off-season managerial labor is varied from 1190 to 2550 by increments of 340. Variations in the number of hours of off-season managerial labor reflect differences in swine management skills and work preference of farm operators. Thirdly, the credit constraint is varied from $20,000 to $172,500 in increments of $38,125. Variations in the credit constraint reflect differences in the risk aversion of farm operators. Farm operators impose internal credit constraints to create a margin of credit that serves as insurance against price and production variations. Finally, the three models are solved varying the production efficiency of sow farrowing firms from 12 to 20 pigs per sow per year by increments of two. Since a large number of solutions were obtained from the parametric analysis, only the solutions for extreme values are presented in tables. However, the text contains a general discussion of the results from the parametric analyses for each model.

A. Parametric Analysis of Model A

The value of the objective function for Model A is \$561,300. This represents the discounted value of net revenue generated throughout the model plus the discounted final-period value of assets acquired during the planning horizon minus the discounted value of outstanding debt.

The firm expands the farrowing capacity in period one, but feeder pigs are directly marketed rather than finished by the firm. The initial investment is largely financed through borrowing. The number of hours of off-season managerial labor constrains the scale of the farrowing operation of the firm. The firm invests in land and machinery in all periods after the first out of internally generated investment funds. As the scale of the farm operation increases, the number of litters farrowed decreases to release managerial labor for grain operations.

The solutions of Model A for various scale farm operations are presented in Tables 9 and 10. Regardless of the initial scale of the farm operation, the firm will expand feeder pig production to utilize off-season managerial labor. However, since the 160 acre farm firm generates less investment funds from cash grain operations, the firm constructs farrowing facilities in the first two periods of the model. The firm

Table 9. Solution of Model A for 160 acre farm operation

Value of the Objective Function: $337,400

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	120
2	40	120
3	40	120
4	40	128
5	40	136

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	550	200	0	0	200
2	3760	200	0	0	200
3	5380	200	0	0	200
4	5380	200	0	0	200
5	5380	200	0	0	200

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	107	0	0
2	0	54	0	0
3	8	0	0	0
4	8	0	0	0
5	8	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	550	0	75272	0
2	13417	1358	29413	9590
3	19859	3720	0	15257
4	19859	3752	0	15825
5	19859	3781	0	16396

Table 10. Solution of Model A for 800 acre farm operation

Value of the Objective Function: $1,196,500

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	760
2	40	760
3	40	808
4	40	856
5	40	904

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	550	200	0	0	200
2	5140	200	0	0	200
3	5140	200	0	0	200
4	5133	200	0	0	200
5	5118	200	0	0	200

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	153	0	0
2	48	0	0	0
3	48	0	0	0
4	48	0	0	0
5	48	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	550	0	16129	25609
2	18953	5948	0	41513
3	18953	6138	0	43700
4	18886	6308	0	45862
5	18825	6477	0	48000

finances the investments through borrowing in the first two periods. In addition, firms with small scale farm operations construct slightly larger farrowing facilities since less labor is needed for the cash grain operations. Relatively large debt repayments and small amounts of internally generated investment funds constrain the increase in the scale of the farm operation.

Firms with large scale farm operations construct the appropriate size farrowing facility in the first period to utilize off-season managerial labor. The investment is financed through borrowing and investment funds internally generated by the firm. However, as the initial scale of the farm operation increases, the firm relies less on borrowed funds for financing the construction of farrowing facilities. The 800 acre farm firm generates nearly all the investment funds through the profitable soybean production activity. Since larger scale farm firms generate more investment funds, they quickly expand the scale of farm operations.

The solutions of Model A for various initial amounts of off-season managerial labor are presented in Tables 11 and 12. The number of hours of off-season managerial labor reflects the operator's level of swine management skill and/or the operator's work preference. In addition, the number of hours of off-season managerial labor could reflect the number of laborers with managerial ability. For example, many farms are father-son or brother-brother operations. One of the two partners may specialize in swine operations while the other may specialize in the cash grain operation. Since feeder pig production is the major activity

Table 11. Solution of Model A for 1190 hours of managerial labor

Value of the Objective Function: $511,300

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	296
4	40	312
5	40	328

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	550	200	0	0	200
2	3610	200	0	0	200
3	3610	200	0	0	200
4	3610	200	0	0	200
5	3610	200	0	0	200

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	102	0	0
2	16	0	0	0
3	16	0	0	0
4	16	0	0	0
5	17	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	550	0	46855	7706
2	12835	2295	0	19870
3	12835	2360	0	20693
4	12835	2417	0	21513
5	12835	2475	0	22328

Table 12. Solution of Model A for 2550 hours of managerial labor

Value of the Objective Function: $633,600

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	280
4	40	302
5	40	324

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	550	200	0	0	200
2	6520	200	0	0	200
3	8140	200	0	0	200
4	8140	200	0	0	200
5	8140	200	0	0	200

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	199	0	0
2	0	54	0	0
3	22	0	0	0
4	22	0	0	0
5	22	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	550	0	127457	0
2	24460	5197	0	19570
3	30960	7583	0	25341
4	30960	7670	0	26564
5	30960	7746	0	27779

to utilize off-season labor, the number of hours of off-season managerial labor determines the scale of the firm's farrowing operation. The firm operated by a manager with a high level of swine management skills or with a strong preference for work will construct a large scale farrowing facility. For example, the firm with 2550 hours of off-season managerial labor farrows 1112 litters per year while the firm with 1190 hours of off-season managerial labor farrows 508 litters per year. The firm markets all feeder pigs produced except 200 head which are finished to satisfy the minimum finishing constraint.

The firm primarily finances the investment in farrowing facilities through borrowing in the first period. In later periods the firm invests in land and machinery out of internally generated investment funds. Firms with larger scale farrowing operations generate more investment funds and expand the scale of farm operations at a faster rate than firms with smaller scale farrowing operations.

The solutions of Model A for various initial credit constraints are presented in Tables 13 and 14. Although the amount of external credit extended to the farm firm is a function of the firm's net worth, individual farm operators may impose personal or internal credit contraints to create a "margin of credit" by which they can insure themselves against variations in price and yield. Thus, the internal credit constraint reflects the operator's degree of risk aversion. When the internal credit constraint limits the amount of borrowing below the optimal level of $93,993, the firm is forced to expand the farrowing operation at a slower rate. When credit is constrained to $20,000, the

Table 13. Solution of Model A for $20,000 credit constraint

Value of the Objective Function: $535,800

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres
1	40	280
2	40	280
3	40	280
4	40	288
5	40	308

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	550	200	0	0	200
2	2650	200	0	0	200
3	4330	200	0	0	200
4	5350	200	0	0	200
5	5350	200	0	0	200

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	70	0	0
2	0	56	0	0
3	8	34	0	0
4	20	0	0	0
5	21	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	550	0	20000	10273
2	8962	364	5000	15875
3	15625	2807	0	19249
4	19646	4313	0	23135
5	19646	4386	0	24084

Table 14. Solution of Model A for $58,125 credit constraint

Value of the Objective Function: $552,400

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	283
4	40	302
5	40	321

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	550	200	0	0	200
2	4030	200	0	0	200
3	5320	200	0	0	200
4	5320	200	0	0	200
5	5320	200	0	0	200

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	116	0	0
2	3	43	0	0
3	19	0	0	0
4	19	0	0	0
5	19	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	550	0	58125	6628
2	14460	2381	0	17777
3	19628	4286	0	22373
4	19628	4362	0	23348
5	19628	4430	0	24311

firm does not produce the optimal number of litters (740) until the fourth period of the model and when credit is constrained to $58,125 the firm does not produce the optimal number of litters until the third period. For credit constraints greater than or equal to $93,993 the firm constructs a 160 unit farrowing house and produces 740 litters in the second period of the model. As a result, firms in which the operator imposes a personal credit constraint do not expand the scale of farm operations as fast as firms with no internal credit constraint.

The solutions of Model A are identical for various levels of production efficiency of sow farrowing firms. An initial production efficiency of 14 pigs per sow in the first year and 15.5 pigs in all following years (a 15.5 production efficiency) is assumed in the model. Investment in subsidiary sow farrowing firms does not enter the optimal solution for production efficiencies of 18 or 20 pigs per sow per year.

B. Parametric Analysis of Model B

The value of the objective function for Model B is $620,500. In Model B the firm again expands the scale of the farrowing operation to utilize off-season managerial labor, but the feeder pigs are finished rather than directly marketed by the firm. In addition, the firm expands the finishing capacity so that all of the feeder pigs produced can be finished by the firm. The composition of finishing activities changes from the first to second period of the model. In the first period, the firm purchases 2250 feeder pigs (75% of total pigs finished) at local livestock auctions while the firm produces all the feeder pigs finished in the remaining periods of the model. The firm largely finances the investment in farrowing and finishing facilities through first period borrowing. After the firm expands farrowing and finishing capacities in the first period, it then expands the scale of its farm operation through investments in land and machinery in all following periods.

The solutions of Model B for various scale farm operations are presented in Tables 15 and 16. All firms, regardless of the initial scale of operation, expand the farrowing and finishing capacities in the first period to utilize off-season managerial labor. The 160 acre firm generates less internal investment funds and cannot expand the finishing capacity to match the increase in the number of firm produced feeder pigs. As a result, the 160 acre firm is forced to market 1217 of the 4800 firm-produced feeder pigs while it constructs additional finishing facilities in the second period. The 800 acre firm markets 67 feeder pigs in the fifth period of the model to release managerial labor for the expanding farm operation. These are the only two cases where feeder pigs are marketed rather than finished by the firm.

Since firms with large scale farm operations generate large amounts of internal investment funds, they expand at a faster rate than firms with smaller farm operations. As large scale firms continue to expand farm operations, the amount of off-season managerial labor required for cash grain operations increases. Since cash grain operations are relatively more profitable than feeder pig finishing activities, the firm produces and finishes fewer feeder pigs.

Table 15. Solution of Model B for 160 acre farm operation

Value of the Objective Function: $406,000

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	120
2	40	120
3	40	125
4	40	136
5	40	147

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	1217	3583	0	0	3583
3	0	4800	0	0	4800
4	0	4800	0	0	4800
5	0	4800	0	0	4800

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	135	196	0
2	5	0	405	0
3	11	0	0	0
4	11	0	0	0
5	11	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	96173	0
2	53221	4629	0	15481
3	66284	5378	0	17379
4	66284	5416	0	18059
5	66284	5455	0	18744

Table 16. Solution of Model B for 800 acre farm operation

Value of the Objective Function: $1,247,000

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	760
2	40	760
3	40	811
4	40	862
5	40	913

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4620	0	0	4620
3	0	4620	0	0	4620
4	0	4620	0	0	4620
5	67	4531	0	0	4531

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	129	533	0
2	51	0	0	0
3	51	0	0	0
4	51	0	0	0
5	51	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	1150	8125	27654
2	63311	7510	0	43314
3	63311	7714	0	45609
4	63311	7892	0	47876
5	62452	8045	0	56100

Relatively small firms finance the initial investment in farrowing and finishing facilities through borrowing, but as the scale of the farm operation increases the firms rely less on borrowing to finance initial investments.

The solutions of Model B for various initial amounts of off-season managerial labor are presented in Tables 17 and 18. In all cases the firms again expand farrowing and finishing capacities in the first period of the model to utilize off-season managerial labor. However, the number of hours of off-season managerial labor constrains the scale of the farrowing facility constructed in the first period. The firm operated by a manager with 1190 hours off-season labor will produce 440 litters per year while the firm operated by a manager with 2550 hours of off-season labor will produce 1012 litters per year. In all cases the firm expands the total number of pigs finished, but the composition of finishing activities changes from the first to second period of the model. In the first period the firm purchases 2250 feeder pigs at livestock auctions while in the second period the firm produces all feeder pigs that are finished. Firms with large amounts of off-season managerial labor will construct large farrowing facilities and produce more feeder pigs than it will finish. In this case the firm markets approximately one-third of the feeder pigs that are produced. Firms that construct large scale farrowing facilities borrow large amounts of capital to finance the investment. After the first period the firm invests in land and machinery out of internally generated investment funds.

Table 17. Solution of Model B for 1190 hours of managerial labor

Value of the Objective Function: $568,200

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	299
4	40	318
5	40	337

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	3300	0	0	3300
3	0	3300	0	0	3300
4	0	3300	0	0	3300
5	0	3300	0	0	3300

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	85	99	0
2	19	0	0	0
3	19	0	0	0
4	19	0	0	0
5	19	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	26746	11623
2	44064	3394	0	21661
3	44064	3472	0	22585
4	44064	3540	0	23501
5	44064	3607	0	24408

Table 18. Solution of Model B for 2550 hours of managerial labor

Value of the Objective Function: $701,700

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	297
4	40	320
5	40	344

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	4030	3560	0	0	3560
3	2765	4825	0	0	4825
4	2765	4825	0	0	4825
5	2765	4825	0	0	4825

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing irm (sow capacity)
1	0	228	186	0
2	17	0	421	0
3	23	0	0	0
4	24	0	0	0
5	24	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	148355	0
2	63977	8468	0	24855
3	77562	9292	0	27446
4	77562	9374	0	28771
5	77562	9457	0	30100

The solutions of Model B for various initial credit constraints are presented in Tables 19 and 20. When credit is internally constrained below the optimal level of \$83,394 the firm requires two periods to reach the optimal farrowing and finishing capacity. The firm that severely limits the use of credit expands its farrowing capacity in the first two periods but does not significantly increase its finishing capacity. This firm directly markets nearly one-third of the feeder pigs that it produces. Firms that do not limit their use of credit expand the finishing capacity to accommodate the increase in farrowing capacity. The firm invests in land and machinery in later periods of the model.

The solutions of Model B are identical for various levels of production efficiency of sow farrowing firms. Investment in subsidiary sow farrowing firms does not enter the optimal solution for production efficiencies of 18 or 20 pigs per sow per year.

C. Parametric Analysis of Model C

The value of the objective function for Model C is \$1,107,700. The substantial increase in the objective function results from the increased profitability of feeder pig finishing activities. The firm expands the scale of its hog operation through large investments in farrowing facilities, finishing facilities, and subsidiary sow farrowing firms in the first period of the model. As in the two previous models, the firm expands the scale of its farrowing operation to utilize off-season managerial labor. The firm increases the number of litters farrowed

Table 19. Solution of Model B for $20,000 credit constraint

Value of the Objective Function: $605,000

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	280
4	40	303
5	40	326

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	180	3000	0	0	3000
3	1563	3417	0	0	3417
4	1563	3417	0	0	3417
5	1563	3417	0	0	3417

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	81	0	0
2	0	60	139	0
3	23	0	0	0
4	23	0	0	0
5	23	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	20000	12265
2	40371	2524	5000	17558
3	52075	5419	0	24210
4	52075	5510	0	25285
5	52075	5591	0	26338

Table 20. Solution of Model B for $58,125 credit constraint

Value of the Objective Function: $615,800

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	290
4	40	312
5	40	334

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	1560	3000	0	0	3000
3	0	4770	0	0	4770
4	0	4770	0	0	4770
5	0	4770	0	0	4770

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	127	0	0
2	10	7	583	0
3	22	0	0	0
4	22	0	0	0
5	22	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	58125	8620
2	45870	4541	0	20993
3	65497	5929	0	24405
4	65497	6016	0	25494
5	65497	6093	0	26567

from 100 in period one to 580 in all other periods of the model. All feeder pigs produced are also finished by the firm.

Since finishing activities are relatively profitable in Model C, the firm substantially invests in subsidiary sow farrowing firms in the first and second periods of the model. The total number of feeder pigs finished by the firm more than doubles from the first to second period of the model, but the composition of finishing activities changes throughout the planning horizon. The number of direct purchases at livestock auctions <u>decreases</u> from 2250 in the first period to 0 in the final period of the model while the number of feeder pigs purchased from subsidiary sow farrowing firms <u>increases</u> from 0 in the first period to 2480 in the final period. Over the five year period the firm substitutes purchases from subsidiary sow farrowing firms for purchases from local livestock auctions as a source for nearly one-third of the total number of feeder pigs finished by the firm. In the final period feeder pigs finished by the firm are either produced by the firm or purchased from subsidiary sow farrowing firms.

Only in Model C does the investment in subsidiary sow farrowing firms enter the optimal solution. The firm invests in 86 units or shares of a sow farrowing firm in the first period. Five to ten finishing firms usually organize subsidiary sow farrowing firms which range in size, measured in terms of sow capacity, from 400 to 700 sows. Thus, the value of 86 shares is a reasonable amount to invest in a sow farrowing firm. For example, seven finishing firms may organize a subsidiary 600 unit farrowing firm to produce feeder pigs for all the investing firms.

If all finishing firms invest equal amounts each firm will be entitled to one-seventh of the feeder pigs produced or the pigs produced per year from approximately 86 sows. The number of pigs and the price paid for the pigs will depend on the production efficiency of the farrowing firm.

The firm also expands the scale of the finishing operation in the first period to accommodate the increase in the number of feeder pigs produced by the firm and purchased from subsidiary sow farrowing firms. Although both the cash grain and finishing operations generate a substantial amount of investment funds, the firm primarily finances the large first period investments through borrowing. The firm borrows $172,500, the maximum external credit limit, in the first period.

Since both the cash grain and livestock operations are profitable activities in Model C, the firm internally generates large amounts of investment funds in later periods of the model. Once the firm reaches the optimal scale livestock operation, it then uses the internally generated funds to expand the scale of the farm operation.

The solutions of Model C for various scale farm operations are presented in Tables 21 and 22. All firms, regardless of the scale of farm operations, again expand farrowing operations to utilize off-season managerial labor. All feeder pigs produced by the firm are also finished by the firm in Model C. Firms with smaller scale farm operations finish more feeder pigs and invest in more shares of subsidiary sow farrowing firms than firms with larger scale farm operations. The 160 acre firm invests substantial amounts in sow farrowing firms in the first three periods of the model. As a result, over 40% of the feeder

Table 21. Solution of Model C for 160 acre farm operation

Value of the Objective Function: $914,000

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	120
2	40	120
3	40	120
4	40	120
5	40	155

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4298	1566	770	6634
3	0	4298	769	2211	7278
4	0	4298	222	3196	7716
5	0	4298	81	3285	7665

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity
1	0	118	1214	55
2	0	0	212	97
3	0	0	146	60
4	35	0	0	0
5	36	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	158082	0
2	83993	5896	53938	21812
3	89934	6183	0	27951
4	94011	6380	0	36646
5	93581	6501	0	38709

Table 22. Solution of Model C for 800 acre farm operation

Value of the Objective Function: $1,637,500

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	760
2	40	760
3	40	826
4	40	896
5	40	965

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4530	238	210	4978
3	0	4530	0	331	4861
4	0	4388	0	341	4729
5	0	4223	0	341	4564

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	126	662	15
2	66	0	0	7
3	70	0	0	0
4	69	0	0	0
5	68	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	1150	0	34320
2	67090	7654	0	56273
3	66081	7873	0	59868
4	63611	7798	0	62223
5	61166	7732	0	64498

pigs finished by the firm are purchased from subsidiary sow farrowing firms by the final period in the model. All firms substitute purchases from subsidiary sow farrowing firms for purchases from livestock auctions in the composition of finishing activities. However, large firms only slightly expand finishing activities beyond the point of utilizing off-season managerial labor. Once firms reach the optimal scale of livestock activities, they use internally generated investment funds to expand the scale of the farm operation. As the scale of farm operation increases, demands on managerial labor increase. Firms with large scale farm operations decrease the number of litters farrowed in later periods of the model to release labor for cash grain operations. Finally, firms with initial large scale farm operations do not expand finishing capacity beyond the capacity required to finish the firm produced feeder pigs.

Firms with relatively small scale farm operations largely finance investments through borrowing while farms with relatively large scale farm operations internally generate a greater portion of the investment funds. In fact, the 800 acre firm internally generates all investment funds used for expansion in the model.

The solutions of Model C for various amounts of off-season managerial labor are presented in Tables 23 and 24. Although the initial amount of off-season managerial labor constrains the scale of the farrowing facilities constructed, all firms expand farrowing capacity in the first period to utilize off-season managerial labor. Firms with relatively small amounts of off-season managerial labor produce fewer

Table 23. Solution of Model C for 1190 hours of managerial labor

Value of the Objective Function: $1,035,900

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	280
4	40	280
5	40	320

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	2460	2378	1764	6602
3	0	2460	1532	3283	7275
4	0	2460	921	4378	7759
5	0	2460	761	4480	7701

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	57	1196	126
2	0	0	226	95
3	0	0	163	68
4	40	0	0	0
5	41	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	172500	3616
2	75707	4394	43125	24710
3	82011	4698	0	30063
4	86563	4918	0	39845
5	86077	5056	0	42136

Table 24. Solution of Model C for 2550 hours of managerial labor

Value of the Objective Function: $1,150,600

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	327
4	40	373
5	40	419

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	6060	0	0	6060
3	0	5963	0	0	5963
4	0	5850	0	0	5850
5	0	5738	0	0	5738

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	177	1024	0
2	47	0	0	0
3	46	0	0	0
4	46	0	0	0
5	45	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	104945	10058
2	84962	7759	0	42508
3	83315	7714	0	44273
4	81682	7670	0	46022
5	80066	7226	0	47735

feeder pigs, purchase more pigs at livestock auctions, invest in more shares of subsidiary sow farrowing firms, and finish a larger number of feeder pigs than firms with relatively large amounts of off-season managerial labor. These firms primarily finance large first period investments through borrowing. Investments in subsidiary sow farrowing firms provide an important source of feeder pigs for firms with relatively small quantities of off-season managerial labor. By the final period of the model these firms purchase well over half of the total number of feeder pigs finished from subsidiary sow farrowing firms. Only after the firm reaches the optimum scale and mix of finishing activities does it expand the scale of farm operations.

Firms with relatively large amounts of off-season managerial labor construct large scale farrowing and finishing facilities in the first period of the model. However, these firms do not expand feeder pig finishing beyond the level required to finish the pigs produced by the firm. Firms with relatively large amounts of off-season managerial labor do not invest in subsidiary farrowing firms and they do not purchase feeder pigs in livestock auctions after the first period of the model. These firms invest in land and machinery out of the net revenue generated from the cash grain and livestock operations in all periods after the first.

Solutions of Model C for various initial credit constraints are presented in Tables 25 and 26. If the firm imposes severe internal credit constraints, expansion of livestock and grain operations is delayed until the firm can internally generate the investment funds.

Table 25. Solution of Model C for $20,000 credit constraint

Value of the Objective Function: $1,075,900

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	280
4	40	280
5	40	329

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	3090	2754	0	5844
3	0	4350	1166	756	6272
4	0	4350	458	2027	6790
5	0	4350	262	2155	6767

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	78	951	0
2	0	42	144	54
3	0	0	189	85
4	49	0	0	0
5	49	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	20000	18176
2	71385	4445	5000	28916
3	80277	6360	0	31433
4	85550	6615	0	42857
5	84969	6783	0	45181

Table 26. Solution of Model C for $96,250 credit constraint

Value of the Objective Function: $1,099,900

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	280
4	40	301
5	40	347

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4350	1357	420	6127
3	0	4350	597	1795	6742
4	0	4350	137	2526	7013
5	0	4350	0	2589	6939

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	120	1043	30
2	0	0	203	95
3	21	0	92	42
4	46	0	0	0
5	46	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	96250	10893
2	78854	6292	24063	28665
3	84518	6565	0	36291
4	87051	6773	0	43270
5	86189	6896	0	45430

Since both livestock and grain production activities are relatively profitable in Model C, the firm quickly generates investment funds. Firms with severe internal credit constraints rely on direct purchases of feeder pigs as a means to expand finishing activities in the early periods of the model. However, these firms gradually invest in farrowing facilities and subsidiary sow farrowing firms so that by the end of the fifth period nearly all of the total number of feeder pigs finished are either produced by the firm or purchased from subsidiary sow farrowing firms. Since the firm is able to expand the total number of pigs finished by means of direct purchases of feeder pigs, the value of the objective function is not substantially diminished by imposing an internal credit constraint.

Solutions of Model C for various levels of production efficiency of subsidiary sow farrowing firms are presented in Tables 27 and 28. Regardless of the production efficiency of the sow farrowing firm, the investment pattern of the finishing firm remains unchanged. However, firms that invest in highly efficient sow farrowing firms rely less on direct purchases at livestock auctions and finish more feeder pigs than firms that invest in less efficient farrowing firms.

Table 27. Solution of Model C for 12 pigs per sow production efficiency

Value of the Objective Function: $1,076,600

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	280
4	40	321
5	40	363

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4350	1104	870	6324
3	0	4350	606	1764	6720
4	0	4350	421	1908	6679
5	0	4350	314	1908	6572

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity
1	0	120	1111	87
2	0	0	133	72
3	41	0	0	0
4	42	0	0	0
5	42	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	172500	3610
2	80738	6383	0	30556
3	84447	6562	0	39674
4	84113	6710	0	42003
5	83170	6832	0	44001

Table 28. Solution of Model C for 20 pigs per sow production efficiency

Value of the Objective Function: $1,133,900

PRODUCTION ACTIVITIES OF THE FIRM

Yr.	Produce corn (acres)	Produce soybeans (acres)
1	40	280
2	40	280
3	40	286
4	40	331
5	40	376

Yr.	Market firm produced feeder pigs	Finish firm produced feeder pigs	Finish directly purchased feeder pigs	Finish sow farrowing firm pigs	Total pigs finished
1	0	750	2250	0	3000
2	0	4350	742	1548	6640
3	0	4350	0	2854	7204
4	0	4170	0	2960	7130
5	0	4065	0	2960	7025

INVESTMENT ACTIVITIES OF THE FIRM

Yr.	Purchase land-machinery (acres)	Construct farrowing facilities (sow capacity)	Construct finishing facilities (hog capacity)	Invest in sow farrowing firm (sow capacity)
1	0	120	1207	85
2	6	0	190	63
3	45	0	0	0
4	45	0	0	0
5	45	0	0	0

FINANCIAL AND INPUT SECURING ACTIVITIES OF THE FIRM

Yr.	Purchase corn (bushels)	Hire labor (man hours)	Borrowing	Payment of taxes
1	31212	0	172500	3612
2	83435	6513	0	32984
3	88715	6790	0	42824
4	87303	6665	0	44827
5	85716	6622	0	46647

VI. SUMMARY AND CONCLUSIONS

Until the recent development of subsidiary sow farrowing firms, feeder pig finishers have had only two input-securing alternatives. The finishing firm could either produce the feeder pigs to be finished or directly purchase the pigs at local livestock auctions. The number of input securing alternatives is less than the number available to other agricultural processing firms. In addition, serious problems exist with the two input securing alternatives. Direct purchases in traditional markets (livestock auctions) have been characterized by large variations in both the price and quality of the feeder pigs transacted. Producers and finishers of feeder pigs have not equally shared profits (losses) from butcher hog production. Finally, search and transactions costs associated with direct purchases significantly increase the price of the feeder pigs.

Feeder pig production by the firm is constrained by the quantity of labor and capital of the firm. Although the firm may expand physical capacities through investment, the large quantities of specialized labor required for sow farrowing may not be available due to other labor demands, lack of farrowing skills, and/or the work preference of the farm operator. As a result, the firm is often unable to produce all the feeder pigs finished by the firm.

Problems associated with both traditional input securing alternatives have resulted in the demand for a reliable source of quality feeder pigs. Recent changes in the technology of hog production and the organizational structure of ownership have led to the development of the subsidiary sow farrowing firm as a new input securing alternative.

In this analysis a linear programming model was developed to analyze the coordination strategies of feeder pig finishers. Since finishing firms are usually multi-product farm firms, the feeder pig securing strategy is just one part of an overall farm coordination strategy. In the model the firm can produce corn, soybeans, and feeder pigs. The firm can market or finish the feeder pigs it produces. In addition, the firm can finish feeder pigs directly purchased from livestock auctions (traditional market source) and/or from subsidiary sow farrowing firms (nontraditional market source). The number of pigs the firm can purchase from subsidiary sow farrowing firms is proportional to the amount invested in these firms. Feeder pigs purchased from subsidiary farrowing firms can be marketed or finished by the firm. Other expansion activities of the finishing firm include the purchase of additional land and machinery, construction of additional farrowing facilities, and construction of additional finishing facilities.

The basic model was solved using finishing returns based on the price of hogs equal to \$.28 (Model A), \$.33 (Model B), and \$.38 (Model C) per pound. Parametric analysis was performed on each model that: 1) varied the initial scale of the farm operation, 2) varied the number of hours of off-season managerial labor, 3) varied the initial credit constraint, and 4) varied the production efficiency of subsidiary sow farrowing firms. General results and conclusions are presented below.

The firm produces soybeans rather than corn in all three models. Since a yield of 40 bushels per acre and a price of $5.50 per bushel are assumed in the model, soybean production is a relatively profitable production activity. All additional land acquired by the firm is used in soybean production.

The pattern of investment is similar in all three models. In the early periods of the models the firm increases the farrowing capacity to utilize off-season managerial labor. The firm finances the expansion of farrowing and finishing facilities through extensive borrowing in the early periods of the model. In later periods the farm invests in land and machinery out of internally generated investment funds.

In Model A the firm markets all of the feeder pigs produced by the firm while in models B and C the firm finishes all of the feeder pigs produced by the firm. Direct purchases at livestock auctions are the primary source of feeder pigs in the first period of models B and C. However, by the final period the number of direct purchases is reduced to zero in both models. In Model B the firm produces all the feeder pigs finished after the first period while in Model C the firm produces approximately two-thirds of the pigs finished and purchases approximately one-third of the pigs finished from subsidiary sow farrowing firms by the final period of the model.

In models A and B the firm expands feeder pig production in the first period to utilize off-season managerial labor. In <u>all</u> other periods the firm uses internally generated investment funds to purchase additional land and machinery. Only in Model C does the firm expand finishing activities beyond the point where feeder pig production and finishing is a means to utilize off-season managerial labor. In Model C the firm substantially invests in subsidiary sow farrowing firms. This is the only model in which investment in a subsidiary sow farrowing firm is an optimal expansion activity.

In general, firms with small scale farm operations generate less internal investment funds and are forced to finance a greater portion of early period investments through borrowing. Firms with large scale farm operations generate substantial internal investment funds through the relatively profitable soybean production activity. However, firms with small scale farm operations produce and finish more feeder pigs than firms with large scale farm operations. In Model B firms with small scale farm operations market approximately one-third and finish two-thirds of the feeder pigs produced by the firm. In Model C firms with small scale farm operations finish more pigs and invest in more shares of subsidiary sow farrowing firms than firms with large scale farm operations. These firms purchase over 40% of the total number of pigs finished from subsidiary sow farrowing firms. Firms with large scale farm operations only slightly increase the scale of finishing operations and they do not rely on purchases from subsidiary sow farrowing firms as a major source of feeder pigs. However, these firms do substantially increase their farrowing capacity to utilize off-season managerial labor.

The number of hours of off-season managerial labor reflects the operator's ability to manage a large swine herd and/or the operator's work preference. The amount of off-season managerial labor constrains the scale of the firm's farrowing operation. Firms with large amounts of off-season managerial labor construct relatively large farrowing facilities to utilize this labor. In Model A the firm markets all the feeder pigs produced by the firm. The firm finances the first period investment in farrowing facilities through borrowing and it invests in land and machinery in all other periods of the model out of internally generated investment funds. In models B and C the firm also expands farrowing capacity in the first period of the model. In most cases the firm finishes the feeder pigs it produces. Since the number of hours of off-season managerial labor constrains the scale of the farrowing operation, the composition of finishing activities is largely determined by the initial amount of off-season managerial labor. In Model B the firm relies on direct purchases as the major source of feeder pigs in the first period, but it produces all the feeder pigs finished in the remaining periods of the model. Since a firm with large amounts of off-season managerial labor constructs a large scale farrowing facility, a portion of the feeder pigs produced are marketed by the firm. Firms with large amounts of managerial labor finance the investment in large-scale farrowing facilities through borrowing in the first period of the model. After the first period firms invest in land and machinery out of internally generated investment funds. In Model C firms with small amounts of off-season managerial labor produce fewer feeder pigs and rely on direct purchases from livestock auctions and subsidiary sow farrowing firms as sources of feeder pigs. Firms with small amounts of managerial labor purchase over one-half of the total number of feeder pigs finished from subsidiary sow farrowing firms. These firms finish a larger number of feeder pigs than firms with large amounts of managerial labor. After the firm reaches the optimum scale and mix of finishing activities it expands the scale of the farm operation. Firms with large amounts of off-season managerial labor construct large farrowing and finishing facilities in the first period and they do not invest in subsidiary sow farrowing firms or purchase feeder pigs at livestock auctions.

Since firms generate relatively large amounts of investments funds, internal limitations on credit do not significantly reduce the value of the objective function. Internal limitations on the use of credit affect the rate at which the firm expands livestock and grain operations. The effects of credit restrictions are most severe for Model A in which the livestock production activities are least profitable. In Model B the firm that severely limits its use of credit cannot expand finishing facilities to meet the increase in farrowing facilities. As a result, the firm markets approximately one-third of the feeder pigs it produces. Firms that do not limit the use of credit expand finishing capacity to finish all of the feeder pigs produced by the firm. In Model C the expansion of grain and livestock operations is delayed until the firm can internally generate the investment funds. However, since grain and livestock production activities are relatively profitable in this model, the firm quickly generates the investment funds. In addition, firms with severe internal credit constraints rely on direct purchases of feeder pigs as a means to expand finishing activities in early periods. These firms gradually invest in farrowing facilities and sow farrowing firms so by the end of the fifth period nearly all of the feeder pigs finished are either produced by the firm or purchased from subsidiary sow farrowing firms. In all cases the value of the objective function is not substantially diminished by imposing an internal credit constraint since the firm can expand the total number of pigs finished by direct purchases at livestock auctions.

In models A and B investment in a subsidiary farrowing firm does not enter the optimal solution regardless of the production efficiency of the farrowing firm. In Model C the different production efficiencies have no significant effect on the investment pattern of the finishing firm. However, firms that invest in highly efficient sow farrowing firms rely less on direct purchases at livestock auctions and finish more feeder pigs than firms that invest in less efficient farrowing firms.

The optimal coordination strategy for a particular feeder pig finisher depends on such characteristics of the finishing firm as the scale of farm operation, the amount and quality of off-season managerial labor, and the internal credit limitation of the farm manager. In addition, the expected profitability of feeder pig finishing will determine the scale and composition of finishing activities. This analysis attempts to determine optimal coordination strategies for a number of firms with different characteristics and expectations. Although the results could be applied to make specific recommendations regarding a finishing firm's coordination strategy, the major importance of the study is to develop the appropriate methodology to analyze the coordination strategies of feeder pig finishers.

There are many limitations in the analysis. First, all coefficients in the model are single-valued expectations. Since one of the problems with direct purchases in traditional livestock markets is large variations in the price and quality of feeder pigs, a risk programming analysis which takes into account not only the mean but also the variance of alternative finishing returns would be a more appropriate type of analysis. Secondly, the model is linear and simple. This implies a linear relationship between inputs and outputs for each production activity, i.e., if all inputs are multiplied by a constant output is increased by the same constant (the production function is homogeneous of degree one). It is assumed that such a production function is appropriate over the range of input values in the model. Furthermore, the model is simple in structure. The number of production and investment activities is limited in the model to facilitate the multi-period analysis. Although there are limitations in the analysis, the linear model illustrates the appropriate methodology to analyze the coordination strategies of feeder pig finishers and the parametric analysis provides a reasonable basis for farm management recommendation.

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