Journal of Agricultural and Applied Economics, 33,3(December 2001):567–581

Production and Profitability Responses to Alternative Protein Sources and Levels in Broiler Rations

Ecio F. Costa, Bill R. Miller, Jack E. Houston, and Gene M. Pesti

ABSTRACT

Profitability of using alternative protein sources in broiler feed is investigated through the development of a two-stage mathematical program that optimizes broiler production. A case study of peanut meal *vs.* soybean meal is examined. Value of marginal product concepts incorporated in this model permit analysis of demand adjustments before decisions on the production process occur. Given reported input and output prices, results indicate that soybean meal is generally more profitable than peanut meal. Peanut meal can be more profitable at higher dietary protein levels fed to broilers processed into whole carcass or at relatively higher prices for soybean meal.

Key Words: *maximum profit, peanut meal, soybean meal, value of marginal product.*
JEL: Q17.

The feed industry in the United States uses soybean meal (SBM) as the protein basis for broiler rations, considering other sources, such as peanut meal (PNM), to be inferior protein ingredients. Outside the United States, however, other protein sources, including PNM, have been more widely used as inexpensive sources of protein in animal rations (Anderson). Peanuts and peanut oil are used mainly for human consumption, while PNM is a by-product of the oil extraction process and is used in animal feed only. PNM protein lacks important nutrients required for broilers, being deficient in at least three amino acids: threonine, methionine, and lysine (National Research Council, NRC). Such deficiencies may be overcome, however, by supplementing purified synthetic forms of threonine, methionine and lysine that are now available commercially at prices that allow their use in livestock feeds. Methionine and lysine have been added to poultry diets for many years; threonine has only recently become available in synthetic form. Because PNM is generally lower in price than SBM, PNM with amino acid supplements may be competitive with SBM in poultry feeds.

Apart from the possibilities of acceptable substitution of protein sources, it behooves the poultry and feed industries to determine the profitability of using PNM or other protein sources from by-products in their broiler rations. Profitability generally will be driven initially by the farm price that a production firm receives for output sold at the farm level. Production decisions on input use will then de-

Ecio F. Costa, Bill R. Miller, and Jack E. Houston are post-doctoral associate, professor emeritus, and associate professor, respectively, in the Department of Agricultural and Applied Economics, and Gene M. Pesti is professor in the Poultry Science Department, all at the University of Georgia.

pend on the productivity of inputs and thus relative costs. Although farm price is generally required for economically optimal production decisions, in fact there is no marketplace or mechanism for discovering broiler price at the farm level in a system vertically integrated through that stage of production. Broiler production/processing firms contract performance standards and feed regimes to producers (or growers) at terms for each consignment (ownership remains with the integrator). Contract price/performance standards are set by the integrator, and the use of most profitable feed sources and production processes are of most interest to the integrators, given the fact that the grower's role is simply to meet the contract signed by both parties. It may thus be useful to estimate an equivalent farm price derived from supply-demand conditions at the processor/wholesale level to prescribe an efficient solution.

Least-cost feed formulation has been the major tool for broiler production economics and profit maximization models. In the 1950s, mathematical programming generated a renewed interest in feed formulation. Since then, the major concern has been to minimize cost of feed, and little consideration has been allocated to other determinants of maximum profit. Least-cost rations minimize the cost of diets, given a certain set of ingredients and their nutritional content. An important assumption of least-cost formulated diets is that every unit of a least-cost formulated ration has the same productivity regardless of ingredient sources (Allison and Baird). However, this assumption may not be true.

Productivity differs among input sources for similar attributes; *e.g.*, broiler performances in experimental trials of those fed PNM protein *vs.* those fed SBM protein have been shown to differ significantly (Costa *et al.*). Further, productivity of inputs also differs among levels of utilization, such as when higher protein use yields heavier broilers in a shorter period. Specific productivity measures must be included in a model that determines the maximum returns to production subject to given levels and sources of inputs. Pesti and Smith have shown that production responses of broilers to dietary energy and protein levels show diminishing marginal returns. This conclusion supports those of Yoshida *et al.*, Pesti, and Pesti and Fletcher. Models that do not consider diminishing marginal returns to inputs, such as protein and energy, can not precisely describe the optimal production process nor determine maximum profit.

In addition to productivity concerns, other important determinants of profit are not fully considered when least-cost feeds are used as the major tool for broiler production. Total feed consumption and the weights and values of broiler parts are also major determinants of profit. Their influence in optimal allocation of profit and production must change the goal for animal nutrition from least-cost feed to a more broadly profit-maximizing feeding ration. Further, a major tenet in the determination of maximum profit that is considered in this study is the level of protein fed to broilers and its impact on important variables that affect profit, such as feed cost, body weight, feed consumption and weights of processed parts.

In the 1990s, studies were developed to determine maximum profit levels instead of least-cost feeds. Gonzalez-Alcorta, Dorfman and Pesti develop a profit maximization model that uses nonlinear programming and separable linear programming to determine the precise energy and protein levels in the feed that maximize profit. Their model is distinguished by the assumption that body weight is not fixed at a predetermined level. Feed cost is not determined by least-cost feed formulation. Rather, feed cost is determined as a variable of the profit maximization model in a way similar to that described in Pesti, Arraes, and Miller. They conclude that the mathematical programming functions applied in their model show that setting energy and protein levels that vary with output and input prices can raise profit compared to fixed diet levels of energy and protein based on previous nutritional guidelines.

Our study evaluates and determines profitable, efficient feed compositions and strategies for broiler production using two feed protein sources (PNM and SBM) and three levels of protein (16 percent, 20 percent, and 24 percent) for each source. Given the prices of broiler carcass and cut-up parts, productivity data, cost of processing, and cost of feed ingredients, the study assesses economically efficient production and processing of broilers. Along with this economically efficient output, important variables—such as growth period, live and processed weight of a broiler and its cut-up parts, feed consumption, feed composition and feed efficiency (unit of feed per unit of output)—are considered within the decision and management framework. The analysis determines what combinations of feed formulation and grow-out processes are most profitable and how much time should be allocated to the grow-out process under varying prices of outputs and inputs.

Modeling Framework

A procedure for determining a derived demand price at the farm level, or value of the marginal product to the integrator (Equivalent Farm Price, EFP_B), for broilers is first postulated. Dock prices reflect consumer expectations, but these prices must first be translated to the production level. Farm prices for broilers are not available, due to the vertically integrated system of production and processing. Thus, it is desirable to calculate a derived price that will be equal to the dock price discounted by the costs involved in the transportation, processing, marketing, and other activities that affect integrator profit margins. Although cost is one determinant of market prices, consumers have the option of choosing less-expensive goods. While such a situation forces prices to be discovered in the consumer market, supply adjustment can only be made at the grower level. Therefore, it is necessary to account for derived demand at that level before a supply decision is made. This model will help to determine the most profitable allocation of inputs for the production of broilers given their derived demand prices. The EFP_B of a broiler is thus a key variable in profitable decision-making on the use of inputs such as SBM, PNM, or other substitute ingredients.

Government agencies and private corporations calculate equivalent farm prices for broiler production to estimate integrator profits in the absence of price determination at the production-level. Different approaches can result in alternative measurements for equivalent farm price. We do not attempt to determine an equivalent farm price that will be used in every production process situation. Instead, we calculate an equivalent farm price to be used in the situation represented by a particular production process that is predetermined in the model. Previous studies have examined the technical aspect of producing broilers fed PNM, but they have not analyzed the productivity nor price conditions under which alternative protein sources such as PNM could replace protein from SBM efficiently. The economically efficient adoption of alternative protein levels and/or sources (*e.g.*, PNM) which we model in this study can enhance broiler production and profitability in areas that have high peanut or other oil meal production. Such areas will greatly benefit from using the most suitable alternatives.

A two-stage model that minimizes feed cost in the first step and maximizes integrator profit per bird per unit of time in the second step of a broiler production process is then constructed under the given constraints determined by economic and technical restrictions. Figure 1 describes the flow of processes that transform inputs at the farm level to produce live weight birds and hence to flow to the processing stage, where carcass weight is the basis. Information feed-back, via value of marginal product (*VMP*) concepts, is then used to determine equivalent farm price (EFP_B), feed efficiency, number of days necessary to grow broilers (t), bird live weight (BW), and the maximum level of profit (Π).

Seasonal or other changes in demand can cause fluctuations in price, and costs of processing, among other costs, must be discovered for carcass and cut-up parts. On the other hand, supply adjustment can only take place at the farm level, although the decisions on such adjustments are made by the integrators. This model demonstrates the implications of supply adjustments of birds' live weights to predetermined market prices of whole carcass

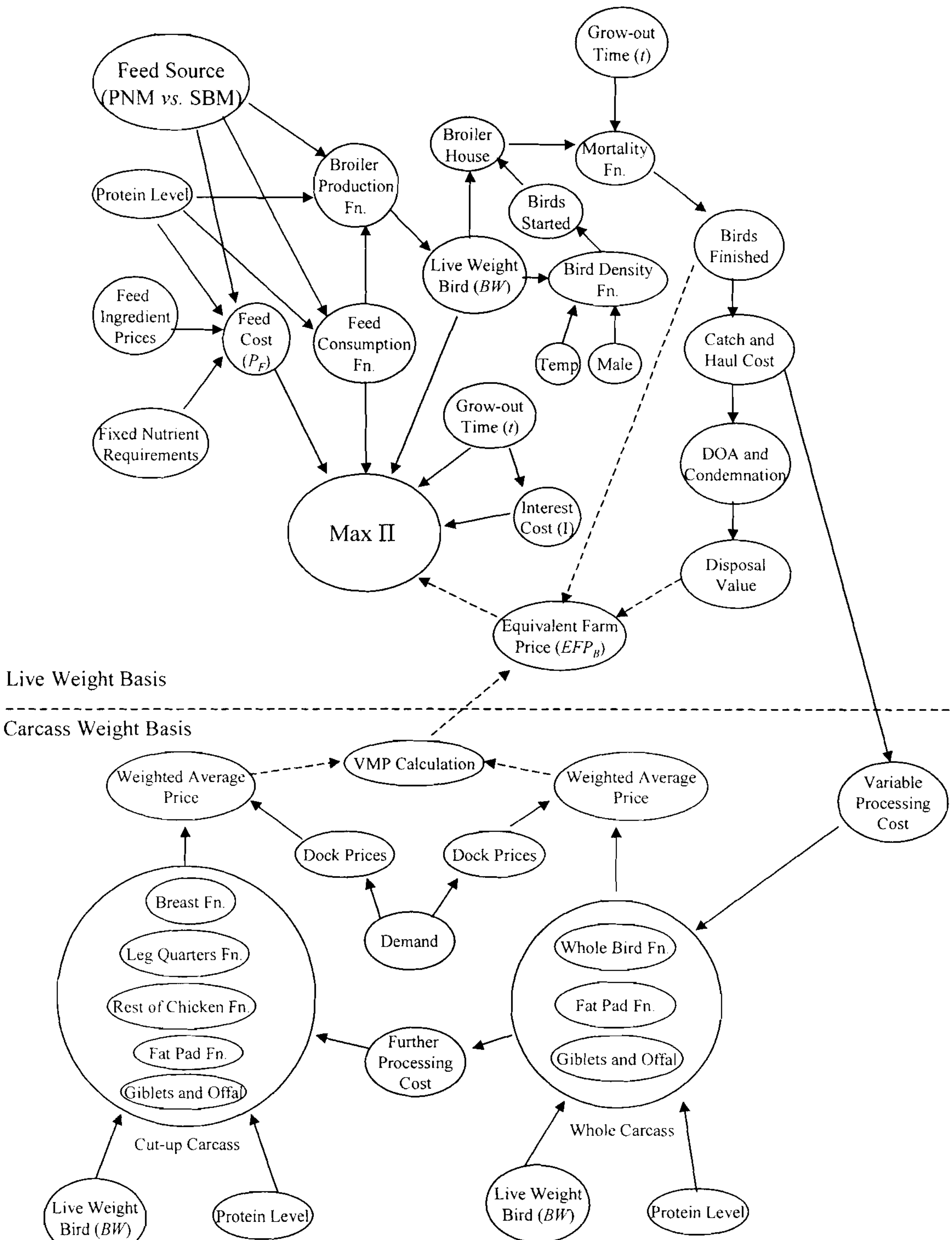

Figure 1. Flow chart of production and processing of broiler decision model used to maximize profits

and cut-up parts. Economic theory, through the concept of *VMP*, makes such implications possible. Solid lines in Figure 1 indicate cause and effect in the model, *i.e.*, flow of feed and chickens through the system. Dotted lines indicate derived demand calculations that, combined with physical flows, determine maximum profit. In the chart, the term *function* means that coefficients are estimated from experimental data or secondary data. Labor and capital costs at farm level and capital cost at plant level must be considered, but these are not included in the current model. Such costs are thus the inputs to production that must be paid from the net revenues that are to be maximized.

The flow chart (Figure 1) depicts the production process, beginning when SBM or PNM is chosen as the protein source at predetermined protein levels for feed formulation. Feed ingredients are determined and fixed nutrient requirements are set for given biological requirements as determined by the NRC. Nutrient requirements, feed ingredients, and ingredient prices are the basis of determination of a least-cost ration (or feed cost, whose price is P_F). This least-cost ration is a minimum cost combination of the predetermined protein source and level and of the other fixed levels of ingredients constrained by nutrient requirements. Feed cost (P_F), equivalent farm price (EFP_B), and feed consumed (F_C) are part of the broiler production function that determines the profitable live weight of a bird (BW). Bird live weight must be produced in the broiler house, where space/bird, a function of average temperature, bird live weight and male percentage, will determine the number of birds to be placed in the house. Mortality function, which is estimated as a function of time, determines the number of birds finished after the grow-out process is completed. Catching and hauling costs are deducted when birds are transported to the processing plant or to the carcass weight basis side where the second stage is started. At that point, dead-on-arrival and field-condemned birds must be subtracted from the number of birds finished, and their disposal value must be added to the calculation of equivalent farm price.

On the carcass basis side, variable processing cost and dock prices of whole carcass and cut-up parts, in conjunction with processing yield functions, determine whole carcass and cut-up parts weights and are used to estimate a weighted average price (or derived demand price) of whole carcass and cut-up parts. The yield functions are determined by feed protein levels and bird live weight. The weighted average price then enters the *VMP* calculation, and the *VMP* and disposal values are used to determine the equivalent farm price, which is part of the profit function.

Endogenous and exogenous/predetermined variables used in this model are presented in Table 1. Since this is an interactive model that uses estimated regression coefficients and is executed in two stages, some variables are determined endogenously in one portion and are later used as predetermined or predicted variables. Using appropriate parameters obtained from analysis of experimental and secondary data, the model has a two-stage solution procedure for each level of protein and each feed ingredient source. Global optimization is achieved by iteration of protein level and ingredient sources. In other words, in the first stage feed must be formulated using linear programming to obtain a minimum cost at a predetermined level of protein and for a particular feed ingredient source incorporating any necessary amino acid supplements. The minimum-cost feed meets all nutrient requirements for broiler production determined by NRC. In the second stage, the formulated feed and its cost are used to find the optimum live and processed bird weights and minimum production time that maximize profit using nonlinear programming. The global optimization is ascertained after model scenarios are analyzed for the protein levels (16 percent, 20 percent, and 24 percent) and ingredient sources (PNM and SBM).

The first stage is summarized by the following equations:

$$(1) \qquad \text{Min } P_F = \sum_{i=1}^{n} P_i \cdot X_i$$

Subject to:

Table 1. Definition of Variables Used in the Model

Variable	Description and Units
Π	Profit, cents per broiler per day
EFP_B	Equivalent farm price, cents per pound
BW	Average live body weight of chicken, pounds
P_f	Feed cost, cents per pound
P_i	Price of each ingredient used in the feed formulation, cents per pound
X_i	Quantity of each ingredient used in the feed, pounds
α_i	Technical coefficient percentage for energy content of each ingredient
ME	Energy level of the diet set by producer, kcal/kg
β_i	Technical coefficient percentage for protein content of each ingredient
P	Protein level, percentage of the diet, set by producer
ρ_{ji}	Technical coefficient percentage for nutritional values of each ingredient
η_j	Fixed Nutritional values set by producer in order to meet NRC requirements, percentage of total protein
μ_i	Technical coefficient percentage for calcium content of each ingredient
Ca	Fixed minimum calcium percentage of all variables
θ_i	Technical coefficient percentage for available phosphorus content of each ingredient
F_C	Feed consumed, pounds of feed
I	Interest cost for the feeding period, cents per pound
t	Number of days necessary to grow broilers up to a maximum profit level
LV_k	Live value of birds delivered to plant in dollars/flock, $k = WB$, or CU for whole carcass or cut-up parts, respectively
BF	Number of birds finished after production period
i	Ingredient used in feed formulation
n	Number of ingredients used in feed formulation
j	Nutrient percentage of ingredient i
m	Number of nutrients determined by the NRC requirements
P_{WB}	Derived weighted average price of a live weight broiler processed into a whole carcass, dollars per pound
P_{CU}	Derived weighted average price of a live weight broiler processed into cut-up parts, dollars per pound
w_l	Weight of part l in pounds, $l = WB, FP, GIB, OFF, BR, LQ$, or RC for weight of whole carcass, fat pad, giblets, offal, breast, leg quarters, and remaining parts of a chicken, respectively
DOC_l	Dock price paid for part l, dollars per pound
PRO_l	Processing cost of part l, dollars per pound
CAT_l	Catching and hauling cost of part l, dollars per pound
BS	Number of birds started in the production period
M	Mortality (number of birds dead in growing process)
L	Livability (1-Mortality)
D	Bird density, or space allocated per bird in the house, square feet per broiler
S	Size of the house, square feet
DUM_{16}	Intercept shifter for 16-percent protein level in diet; equals 1 for 16 percent, 0 else
DUM_{24}	Intercept shifter for 24-percent protein level in diet; equals 1 for 24 percent, 0 else
DOA	Percentage of dead on arrivals and field condemnation
r	Annual interest rate
P_{DOA}	Price of dead on arrivals and field condemnation, dollars per pound
DEL	Delivery cost of feed, cents per pound
$TEMP$	Average temperature in the house, Fahrenheit
$MALE$	Percentage of male chickens in the house

(2) $$\sum_{i=1}^{n} \alpha_i \cdot X_i \geq ME$$

(3) $$\sum_{i=1}^{n} \beta_i \cdot X_i \geq P$$

(4) $$\frac{\sum_{j=1}^{m} \sum_{i=1}^{n} \rho_{ji} \cdot X_i}{\sum_{i=1}^{n} \beta_i \cdot X_i} \geq \eta_j$$

(5) $$\sum_{i=1}^{n} \mu_i \cdot X_i \geq Ca$$

(6) $$\frac{\sum_{i=1}^{n} \mu_i \cdot X_i}{\sum_{i=1}^{n} \theta_i \cdot X_i} = 2.0$$

(7) $$\sum_{i=1}^{n} X_i = 1.0$$

(8) $$X_i \geq 0$$

that is, the least-cost feed function minimizes the cost of feed for pre-determined ingredients (X_i) and their prices (P_i, 1). The constraints meet nutrient requirements for technically efficient growth and are represented by level of metabolizable energy in the ration that must be at least equal to the predetermined level (ME), where α_i is the technical coefficient for energy for each ingredient (2); level of protein (P) in the ration must be at least equal to the level desired by the firm, where β_i is the technical coefficient for protein of each ingredient (3); protein ratio of each nutrient to level of protein in the diet must be at least equal to the level desired (η_j), where ρ_{ji} is the technical coefficient for the nutrient value j of each ingredient i (4); the sum of all calcium content in the ingredients must be greater than or equal to the desired calcium content (Ca, 5); ratio of calcium to available phosphorus must be equal to 2:1, where μ_i and θ_i are the technical coefficients for calcium and available phosphorus, respectively (6); the sum of all ingredients must be equal to a unit of feed (7); and all ingredients must have non-negative values in the solution (8).

The second stage is explained by the following equations:

(9) $$\text{Max} \prod = \{(EFP_B \cdot BW) - [(P_F + DEL) \cdot F_C] \cdot I\}/t$$

Subject to:

(10) $$BW = a_1 + b_1 \cdot F_C + b_2 \cdot F_C^2 + b_3 \cdot DUM_{16} + b_4 DUM_{24}$$

(11) $$F_C = a_2 + b_5 \cdot t + b_6 \cdot t^2 + b_7 \cdot DUM_{16} + b_8 \cdot DUM_{24}$$

(12) $$I = \left(1 + \frac{r}{365}\right)^t$$

(13) $$EFP_B = \frac{LV_k}{BF}$$

(14) $$LV_{WB} = BF \cdot [(1 - DOA) \cdot P_{WB} + DOA \cdot P_{DOA}]$$

(15) $$LV_{CU} = BF \cdot [(1 - DOA) \cdot P_{CU} + DOA \cdot P_{DOA}]$$

(16) $$P_{WB} = (w_{WB} \cdot (DOC_{WB} - PRO_{WB} - CAT_{WB}) + w_{FP} \cdot (DOC_{FP} - PRO_{FP} - CAT_{FP}) + w_{GIB} \times (DOC_{GIB} - PRO_{GIB} - CAT_{GIB}) + w_{OFF} \cdot (DOC_{OFF} - CAT_{OFF}))/BW$$

(17) $$P_{CU} = (w_{BR} \cdot (DOC_{BR} - PRO_{BR} - CAT_{BR}) + w_{LQ} \cdot (DOC_{LQ} - PRO_{LQ} - CAT_{LQ}) + w_{FP} \cdot (DOC_{FP} - PRO_{FP} - CAT_{FP}) + w_{RC} \cdot (DOC_{RC} - PRO_{RC} - CAT_{RC}) + w_{GIB} \times (DOC_{GIB} - PRO_{GIB} - CAT_{GIB}) + w_{OFF} \cdot (DOC_{OFF} - CAT_{OFF}))/BW$$

(18) $$w_{WB} = e^{(a_3 + b_{10} \cdot DUM_{16} + b_{11} \cdot DUM_{24})} \cdot BW^{b_9}$$

(19) $$w_{FP} = e^{(a_4 + b_{13} \cdot DUM_{16} + b_{14} \cdot DUM_{24})} \cdot BW^{b_{12}}$$

(20) $$w_{BR} = e^{(a_5 + b_{17} \cdot DUM_{16} + b_{18} \cdot DUM_{24})} \cdot BW^{b_{16}}$$

(21) $$w_{LQ} = e^{(a_6 - b_{20} \cdot DUM_{16} - b_{21} \cdot DUM_{24})} \cdot BW^{b_{19}}$$

(22) $$w_{RC} = e^{(a_7 - b_{23} \cdot DUM_{16} + b_{24} \cdot DUM_{24})} \cdot BW^{b_{22}}$$

(23) $$BF = BS \cdot L$$

$$(24) \qquad BS = \frac{S}{D}$$

$$(25) \qquad M = a_8 + b_{25} \cdot t$$

$$(26) \qquad L = 1 - M$$

$$(27) \qquad D = a_9 + b_{26} \cdot BW + b_{27} \cdot BW^2 + b_{28} \cdot TEMP + b_{29} \cdot MALE$$

The objective function, maximum profit per bird per day (Π), is defined as a function of equivalent farm price (EFP_B), body weight (BW), feed cost (P_F), feed delivery cost (DEL), feed consumed (F_C), interest cost (I), and number of days (t) necessary to grow broilers to the point where live bird weight, feed consumed, and marketing conditions are optimum (9).

The constraint set includes live chicken body weight (BW) as determined by feed consumed (F_C), square of feed consumed, and intercept shifters for protein levels, DUM_{16} for 16 percent and DUM_{24} for 24 percent (10). Coefficients a_1, b_1, b_2, b_3 and b_4 are determined by regression analysis on experimental data, and their values depend on whether SBM or PNM is chosen as the protein source. Further, coefficients in equations 10, 11, 18, 19, 20, 21, and 22 are also estimated separately for SBM and for PNM. Coefficient a_1 is modified by dummy variables (DUM_{16} and DUM_{24}) representing the level of protein in the diet. The equation is normalized on a protein level of 20 percent; i.e., when a 20-percent protein level is fed, DUM_{16} and DUM_{24} are equal to zero. Feed consumed is determined by time and the intercept shifters for protein levels (11). Coefficients a_2, b_5, b_6, b_7 and b_8 are determined by ordinary least squares (OLS) regression analysis on experimental trials data, and their values depend on whether SBM or PNM is chosen as protein source. Coefficient a_2 is modified by the dummy variables adjusting for the level of protein in the diet.

Interest cost is determined by annual interest rate and number of days spent by broilers in the house (12). Equivalent farm price of broiler is equal to live value of broilers delivered to plant divided by the number of birds finished per house (13). Live value of broilers delivered to plant for whole carcass (14) or for cut-up carcass (15) equals the number of birds finished in the house times the sum of the value of live birds delivered to the plant and the value of dead on arrivals and field condemnations, where P_{WB} is the weighted average derived price of a bird processed into whole carcass, P_{cu} is the weighted average derived price of a bird processed into cut-up parts, and P_{DOA} is the price received for disposing of DOA's.

Weighted average price of a bird processed into whole carcass (estimated VMP of a live bird) is the sum of the value of the carcass, value of fat pad, value of giblets, and value obtained for offal divided by bird live weight (14). The value of carcass (16) comprises the carcass weight (the difference of dock price for the carcass less processing cost and catching and hauling cost), and accounts for the value obtained for fat pad, giblets, and offal. Processing costs are subtracted from three of the values, with the exception that offal does not have processing cost.

Weighted average price of a bird processed into cut-up parts (or VMP) factors the values of breast, leg quarter, fat pad, rest of chicken, giblets, and value obtained for offal divided by bird's live weight. Value of breast is obtained by the product of breast weight and the difference of dock price for breast weight, processing cost, and catching and hauling cost, shown in the first part of equation 17, and the remaining parts account for the value obtained for leg quarter, fat pad, rest of chicken, giblets, and offal. Processing cost is subtracted from five values, with the exception of offal.

Equations 18–22 are estimated as processed weight, w_l, of each part l derived from a live bird ($l = WB$ for whole carcass, BR for breast weight, LQ for leg quarter, FP for fat pad, RC for rest of chicken, GIB for giblets, and OFF for offal). Sum of all processed parts must be equal to the live weight of the bird. Each equation is estimated as a function of live bird weight and protein level. Coefficients a_3, a_4, b_9, b_{10}, b_{11}, b_{12}, b_{13} and b_{14} are estimated by OLS on experimental trials data, and their values depend on whether SBM or PNM is chosen as protein source, with coefficients a_3 and a_4 modified by the level of protein in the diet. Coefficients a_5, a_6, a_7, b_{16}, b_{17}, b_{18}, b_{19}, b_{20}, b_{21}, b_{22}, b_{23}, b_{24} and b_{25} are determined by seemingly unrelated regressions (SUR), and their values likewise depend on whether SBM or PNM is chosen, with coefficients a_5, a_6 and a_7 modified by the level of protein in the diet.

Number of birds finished (23) equals number of birds started which is determined in equation 24, times livability (25). In other words, number of birds finished in the house equals number of birds started discounted by the mortality of birds as a function of time. Livability (25) is the percent of live birds after subtracting the rate of mortality. Mortality is calculated as percent mortality as a function of time (26). Number of birds started is a function of bird density and size of the house. Bird density[1], or space/bird in the house (27), is an estimated function of live bird weight, temperature, and the percentage of males in the house. As demand may change for broiler size and/or characteristics when expected body weight increases, the space allocated per bird must also be increased and the number of birds started in the production process will decrease for a given house size.

Equivalent farm price is determined at the farm level, because the model takes into account marketing margins as the total of processing costs and other costs to deliver the product to the buyer. Profit is a direct function of the decision for contracting size of bird and other parameters (chiefly the feeding and other production process details). Derived demand price is determined after the dock price is discounted for the marketing margins between grow-out unit and plant. Model construction may be better understood by referring to the estimated value of marginal product (*VMP*) for a live bird. For example, a point estimate of the value of marginal product is equal to the output (carcass weight) produced per input (live weight) used times price per unit of output. Price per unit of output is partially determined by the demand side, that is, by the consumers and the price they are willing to pay for the final product, carcass weight. Carcass weight is initially a function of bird inputs, i.e., protein level and bird live weight. The process of transformation of input (live weight) to output (carcass weight) determines the estimated marginal physical product. Finally, the value of marginal product and the equivalent farm price (EFP_B) are determined from carcass values. Carcass values are partially determined by carcass composition as a function of feed input, i.e., protein levels and bird live weight.

Results

Data

Data used in this study are obtained from feeding experiments used by Costa *et al.*; Agri Stats; a confidential survey conducted with a representative company of the poultry industry; and the Georgia Department of Agriculture, Market News Poultry Division (Georgia Department of Agriculture). The feeding experiments collect data on live, carcass, and cut-up weights and feed consumption of broilers. Broilers are fed either PNM or SBM at 16-percent, 20-percent, or 24-percent protein levels, with supplemental amino acids added to both diets to meet the NRC requirements (National Research Council, NRC).

Other data are collected from Agri Stats for the estimation of density and mortality functions. Data on production and processing costs and dock prices of whole carcass and cut-up parts are obtained respectively from the confidential industry survey and from the Georgia Department of Agriculture. Data on ingredient prices are obtained from feedstuffs for the Atlanta or nearest markets.

Coefficient Estimates

Equations used in the model are estimated from experimental data by ordinary least squares (OLS) for *BW*, F_C and W_{WB} functions and seemingly unrelated regression (SUR) for W_{BR}, W_{LQ}, W_{FP}, and W_{RC}, weights of cut-up

[1] In the U.S. industry we would say that bird density is typically measured as square feet per bird. In the rest of the world they would typically measure bird density as birds per square meter. The U.S. industry term is used here, while meaning space/bird.

parts functions. These last four equations are estimated as a system, because the parts of a broiler add up to a whole broiler.

Body weight functions are estimated for each protein source using the feeding experimental data and OLS procedure (Table 2). Live body weight of chickens increases at a decreasing rate with respect to feed consumed for each protein source, although somewhat more rapidly with the SBM diet. As protein level shifts to 24 percent, body weight value is increased by the coefficient of the dummy variable for 24-percent level of protein. Conversely, when protein level shifts to 16 percent, body weight is decreased. All variables are significantly different from zero and signs denote a production behavior that confirms previous studies' production functions (see Pesti, Pesti and Fletcher, and Pesti and Smith).

Feed consumption is analyzed as a function of time and protein levels using the feeding experimental data and OLS procedure (Table 2). Estimation results indicate that feed consumed per chicken increases at an increasing rate with respect to time, again somewhat more rapidly on SBM than on PNM diets. Also, as protein level shifts to 24 percent, feed consumed is decreased by the coefficient of the dummy variable for 24-percent protein level. However, when protein level shifts to 16 percent, feed consumed is not significantly different from that consumed at the 20-percent protein level. All signs were obtained as expected for the productivity relationship as mentioned in the previous paragraph.

Carcass weight equation and cut-up parts equations are estimated for both PNM and SBM. Carcass weight is estimated as a function of live weight of a broiler and protein levels using the feeding experimental data and OLS procedure (Table 2). The effect of protein level on carcass weight is positive (but not significantly different from zero) for higher levels of protein in the PNM model, but negative and significantly different from zero in the soybean model when protein level changes from 20 percent to 24 percent.

Parameter estimates for cut-up parts of broilers using the feeding experimental data are presented in Table 3. Estimates are obtained by using SUR, given that all processed parts of a broiler add up to a whole broiler. All equations depend directly on the total body weight of the chicken. Weight of breast increases as the percentage of protein increases, significantly for all protein level shifts for both PNM and SBM models with the exception of the PNM model from 20-percent to 24-percent protein level (DUM_{24}). Weight of fat pad decreases as the percentage of protein increases. This change is significantly different from zero for protein level shifts from 16 percent to 20 percent (DUM_{16}) for both PNM and SBM models, but it is not significantly different from zero for protein level shifts from 20 percent to 24 percent (DUM_{24}). Weight of rest of chicken decreases as the percentage of protein increases, significantly different from zero for the 20-percent to 24-percent protein level shift. PNM coefficients show more improvement in weight of parts as protein increases than those in the SBM model.

Auxiliary data are used for the estimation of two other important functions in the model. Data on mortality and density functions are collected from a statistical annual report of broiler live production, Agri Stats, that consists of information collected from approximately 116 participants of the broiler industry in the United States. Estimated parameters for density and mortality models are as follows:

$$(26') \quad M = \underset{(0.8721)}{-0.8439} + \underset{(0.0175)}{0.1157}\, t^{***}$$

$$(R^2 = 0.2762,\ N = 116)$$

$$(27') \quad D = \underset{(0.1689)}{0.7093^{***}} - \underset{(0.1275)}{0.2507}\, BW^{*} + \underset{(0.0273)}{0.0794}\, BW^{2***} + \underset{(0.0011)}{0.0033}\, TEMP^{***} + \underset{(0.0003)}{0.0005}\, MALE^{*}$$

$$(R^2 = 0.6048,\ N = 116)$$

(Standard errors in parentheses. * = 0.10, ** = 0.05 and *** = 0.01)

Table 2. Estimated Body Weight, Feed Consumed and Carcass Weight for Broilers Fed PNM and SBM Protein Based Diets

	Body Weight (BW)		Feed Consumed (F_C)		Carcass Weight (w_{WB})	
Variable	PNM	SBM	PNM	SBM	PNM	SBM
Intercept	0.0971**	0.0448*	−0.8868***	−0.6396***	−0.2147	−0.0267
	(0.0401)	*(0.0231)*	*(0.2030)*	*(0.2006)*	*(0.2477)*	*(0.2414)*
F_C	0.6031***	0.6919***	—	—	—	—
	(0.0432)	*(0.0247)*				
F_C^2	−0.0209**	−0.0309***	—	—	—	—
	(0.0082)	*(0.0047)*				
t	—	—	0.0742***	0.0528***	—	—
			(0.0154)	*(0.0152)*		
t^2	—	—	0.0012***	0.0015***	—	—
			(0.0003)	*(0.0002)*		
BW	—	—	—	—	0.9797***	0.9602***
					(0.0325)	*(0.0317)*
DUM_{16}	−0.2338***	−0.2233***	0.0385	0.0669	−0.0144	−0.0242*
	(0.0297)	*(0.0176)*	*(0.0408)*	*(0.0403)*	*(0.0140)*	*(0.0137)*
DUM_{24}	0.1183***	0.0517***	−0.0921**	−0.1011**	0.0154	−0.0354***
	(0.0297)	*(0.0177)*	*(0.0408)*	*(0.0403)*	*(0.0136)*	*(0.0138)*
R^2	0.9940	0.9981	0.9972	0.9973	0.9436	0.9348
N	36	36	36	36	72	72

Standard errors are in parenthesis.
One, two and three asterisks indicate statistical significance at the 10-percent, 5-percent and 1-percent level, respectively.

Table 3. Effect of Live Weight and Protein Levels on Weights of Cut-up Parts of Broilers Fed PNM or SBM

	PNM				SBM			
Variable	Breast (w_{BR})	Leg Quarters (w_{LQ})	Fat Pad (w_{FP})	Rest of Chicken (w_{RC})	Breast (w_{BR})	Leg Quarters (w_{LQ})	Fat Pad (w_{FP})	Rest of Chicken (w_{RC})
Intercept	−3.0381***	−0.8380**	−4.3753**	−0.8470***	−2.8578***	−0.5198	−5.3969***	−0.4654*
	(0.4797)	*(0.3369)*	*(1.7147)*	*(0.2682)*	*(0.4024)*	*(0.3324)*	*(1.5524)*	*(0.2617)*
BW	1.1609***	0.9078***	1.0578***	0.9589***	1.1499***	0.8681***	1.1491***	0.9106***
	(0.0630)	*(0.0444)*	*(0.2262)*	*(0.0353)*	*(0.0529)*	*(0.0437)*	*(0.5548)*	*(0.0343)*
DUM_{16}	−0.0450*	—	0.2262**	—	−0.1113***	—	0.5548***	0.0117
	(0.0265)		*(0.0968)*		*(0.0220)*		*(0.0848)*	*(0.0126)*
DUM_{24}	0.0328	—	−0.1160	—	−0.0380*	—	−0.1315	−0.0388***
	(0.0257)		*(0.0939)*		*(0.0221)*		*(0.0854)*	*(0.0127)*
R^2	0.8702	0.8568	0.2734	0.9133	0.8924	0.8496	0.5416	0.9083
N	72	72	72	72	72	72	72	72

Standard errors are in parentheses.

One, two and three asterisks indicate statistical significance at the 10-percent, 5-percent and 1-percent level, respectively.

Seemingly Unrelated Regressions give a R^2 for each equation and equations are analyzed together.

Mortality increases linearly and significantly with number of days spent by birds in the house. Thus, M is a cumulative measure of the number of birds that die and the rate is higher because when fed to longer periods, more birds die. Bird density (D, or space/bird) in the house is calculated as the number of square feet per bird allocated in the house. The space allocated per bird increases with respect to BW (due to its quadratic term) because as birds get larger they require more space. Further, as temperature in the house increases more space is needed for the birds. D also increases with male percentage, because male birds are larger, on average, than females. All estimated coefficients are significantly different from zero.

Analysis of Optimization Scenarios

The possibility of using two different protein sources, SBM and PNM, and processing a chicken into a whole carcass or into cut-up parts requires the examination of alternative scenarios. PNM as a protein source is used for the next analysis of different scenarios (Table 4). As protein level in the diets increases from 16 percent to 20 percent and to 24 percent, the number of days necessary to grow broilers decreases in both the broiler-processed-as-a-whole-carcass (BPW) and in broiler-processed-as-cut-up-parts (BPP) scenarios. Bird weight decreases and feed cost increases in both processing scenarios. The increase in feed cost is caused by the increase in percentage of protein in the feed. As protein percentage in the feed increases, more PNM is needed in the composition of the feed and the feed becomes more expensive. Feed consumed and the feed conversion ratio decrease in both processing scenarios. Equivalent farm price increases in both processing scenarios because a higher level of protein produces a more profitable broiler given the fact that less feed is used to produce a bird and the feed conversion ratio decreases, which in turn increases the derived demand prices of the BPW or BPP (Table 4).

Profit increases in both processing strategy scenarios, reaching its maximum for PNM

Table 4. Scenarios Used to Analyze the Profitability of PNM and SBM in Broiler Production Using the Profit Maximization Model

		PNM						SBM					
		Whole Carcass			Cut-up Parts			Whole Carcass			Cut-up Parts		
		Protein Level			Protein Level			Protein Level			Protein Level		
Variable	Unit	16%	20%	24%	16%	20%	24%	16%	20%	24%	16%	20%	24%
Grow-out period (t)	days	46.76	39.18	32.37	54.10	49.76	46.87	42.42	38.56	36.41	47.89	46.07	44.62
Bird weight (BW)	lb	5.32	4.64	3.76	6.43	6.33	6.13	5.14	4.82	4.45	6.04	6.11	5.89
Feed cost (P_F)	cents/lb	8.33	9.35	10.37	8.33	9.35	10.37	8.34	9.47	10.62	8.34	9.47	10.62
Feed consumed (F_C)	lb/bird	11.45	8.41	5.76	14.57	12.57	11.10	9.83	8.16	7.19	12.16	11.22	10.43
Feed conversion ratio	—	2.15	1.81	1.53	2.26	1.99	1.81	1.91	1.69	1.62	2.02	1.84	1.77
Profit (Π)	cents/bird/day	1.96	2.27	2.46	2.17	2.57	**2.78**	2.48	2.66	2.36	2.73	**3.17**	2.81
Equivalent farm price (EFP_B)	cents/lb	36.35	37.07	37.97	38.39	39.87	41.08	37.50	38.23	37.42	39.63	42.33	41.15

Bold indicates global maximum profit level.

scenarios at 2.78 cents/bird/day in the scenario where a cut-up bird is produced using 24-percent protein level in the diet. This scenario also represents the lowest bird weight (6.13 lbs.) and lowest feed consumed (11.10 lbs.) among the BPP scenarios that use PNM as protein source, but the highest feed cost (10.37cents/lb.) and highest equivalent farm price (41.08 cents/lb.) among all scenarios that use PNM as protein source. The maximum profit scenario does not have the lowest feed conversion ratio (Table 4).

If the firm's strategy changes from producing BPW to producing BPP, at the same level of protein in the diet, the number of days necessary to grow broilers increases considerably. Bird weight also increases. Per-unit feed cost remains the same, since there is no change in the feed formulation stage. Feed consumed and feed conversion ratio also increase as the strategy changes. Equivalent farm price reaches its maximum (41.08 cents/lb) in the same scenario as maximum profit.

Turning to the SBM as a protein source analysis (Table 4), as protein level in the diets increases from 16 percent to 20 percent and 24 percent, the number of days necessary to grow broilers decreases in both processing scenarios. Bird weight decreases in the BPW scenarios. For BPP scenarios, bird weight increases to its maximum level (6.11 lbs.) at 20-percent protein level in the diet and decreases to 5.89 lbs. at 24-percent protein level in the diet. Per-unit feed cost increases in both scenarios. Feed consumed and feed conversion ratio decrease in both processing scenarios. Profit increases, reaching its maximum at 2.66 cents/bird/day at the 20-percent protein level, and falls to 2.36 cents/bird/day at the 24-percent protein level in the BPW scenarios. Similar behavior occurs in the BPP scenarios, where profit peaks at 3.17 cents/bird/day at 20-percent protein level diet and falls to 2.81 cents/bird/day at 24-percent protein.

Equivalent farm price increases, reaching its maximum of 38.23 cents/lb at 20-percent protein level and decreases to 37.42 cents/lb at 24-percent protein in the BPW scenarios. In the BPP scenarios equivalent farm price reaches its maximum (42.33 cents/lb) at 20-percent protein level and falls to 41.15 cents/lb at 24 percent. The scenario that uses SBM as protein source and produces BPP at the 20-percent protein level represents the global maximum profit (3.17 cents/bird/day), highest bird weight (6.11 lbs), highest feed consumed (11.22 lbs.) and highest equivalent farm price (42.33 cents/lb). However, with a feed conversion ratio at 1.84 pounds of feed consumed per each pound of bird weight, this scenario is approximately in the middle range of observed feed conversion (Table 4).

As the firm's strategy changes from BPW to BPP, at the same level of protein in the diet, the number of days necessary to grow broilers increases considerably because bird size is increased when being produced for parts. The least-cost ration is the same, since there is no change in the feed formulation. Total feed consumed increases as the strategy changes, as does the feed conversion ratio. Equivalent farm price also increases, reaching its maximum (42.33 cents/lb) in the same scenario as maximum profit (Table 4).

Comparing the results obtained from the PNM scenarios with the SBM scenarios, the number of days necessary to grow broilers is shorter for SBM scenarios than for PNM scenarios at the same levels of protein with the exception of the scenario where a 24-percent protein level is used in the BPW scenario. Even though feed cost is higher for all the SBM scenarios at the same levels of protein, profit is also higher for the SBM diets when compared at the same protein level with the exception of the BPW scenario at 24-percent protein level. The equivalent farm prices of SBM scenarios are higher in all cases, with exception of the BPW scenario at 24-percent protein. Feed conversion ratios and feed consumed are lower for the SBM scenarios, again with the exception of the BPW scenario at 24-percent protein level. Bird weight is lower in most SBM scenarios, excepting the BPW scenarios at 20-percent and 24-percent protein levels.

Conclusions

The value of marginal product concept that is applied in this model clearly demonstrates that as price of carcass or cut-up parts changes, the number of grow-out days necessary to maximize profit for broilers, final live weight of each broiler, feed consumed, and other variables in the model will vary to make the adjustments necessary to maximize profit for the production/processing integrator. The results obtained from feed experiments and from mathematical programming show that SBM is generally more efficient and, at the set of input and output prices used, more profitable than PNM, especially at lower dietary protein levels. PNM can be more profitable than SBM only when higher levels of protein are fed to broilers processed into whole carcass or at relative prices where SBM is higher than averages in 1997. Analysis of experimental data shows that SBM productivity decreases earlier than does the productivity of PNM, *i.e.*, as higher levels of protein are fed to broilers, PNM continues to add value at a higher rate than SBM. Further analysis may be necessary to determine the level at which PNM protein productivity will decline.

Analysis of weekly prices of carcass and of cut-up parts to determine the seasonal pattern that prices follow may enhance the usefulness of the profit model. That is, feeding rations, production periods, and processing as whole or parts may be altered seasonally to adopt the most profitable production and processing combinations during each period. Although PNM may not be competitive with SBM at some prices, it still may benefit the integrator to alter feeding regimes with SBM (*e.g.*, protein level, days on feed) or processing whole vs. parts to take advantage of seasonality in pricing. This broiler profit maximization model determines the maximum economic profit with respect to resources that are used and have variable costs. A long-run model in which all resources are variable may provide further useful implications to the industry for alternative feed programs.

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