INTERACTIVE PROFIT MAXIMIZATION MODELING FOR POULTRY PRODUCTION: A DECISION MODEL APPLICATION TO SOYBEAN AND COTTONSEED MEAL

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RESUMO

A rentabilidade da substituição de farelo de soja (SBM) por farelo de semente de algodão (CSM) é avaliada usando um modelo que otimiza a produção e o processamento de frangos de corte sob condições de mercado variáveis. O modelo incorpora então a formulação de rações, produção e processamento de frangos para determinar que ingredientes produzem o frango mais pesado para ser processado ao custo mais baixo, e que dele se derivam as partes processadas mais rentáveis. A solução ótima é determinada para cenários onde existem duas opções de processamento: carcaça inteira *vs.* partes processadas. Para o estudo de caso analisado, frangos alimentados com CSM resultam em maiores lucros para o processamento em carcaça inteira, enquanto que frangos alimentados com SBM geram maiores lucros para o processamento em partes. Uma análise de mapeamento de preços indica que, para flutuações de preços de CSM e SBM, usando CSM no processamento em partes, também pode ser rentável.

Palavras-chave: maximização de lucros, farelo de semente de algodão, farelo de soja, mapeamento de preços, níveis de proteína.

ABSTRACT

Profitability of substituting cottonseed meal (CSM) for soybean meal (SBM) in broiler feed is evaluated using a model that optimizes broiler production and processing under changing market conditions. The profit maximization model therefore incorporates feed formulation, broiler production, and broiler processing to determine what feedstuffs yield the heaviest birds to be processed at the lowest cost and for the most profitable processed parts. The optimal solution is determined for scenarios where there are two processing options: whole carcass *vs.* cut-up parts. For the case-study prices analyzed, CSM-fed broilers may earn higher profits for whole carcass processing, while SBM-fed broilers earn higher returns for cut-up parts processing. Price mapping analysis indicates that for given fluctuations of CSM and SBM prices, using CSM in cut-up parts processing can also be profitable.

Key words: profit maximization, cottonseed meal, soybean meal, price mapping, protein levels.

JEL classification: C61, Q12, D24.

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1 INTRODUCTION

Currently, use of soybean meal (SBM) combined with corn for poultry feeding has been common in the Brazilian and U.S. industries, the two major competitors in the world poultry markets. SBM prices have shown to be low enough to be used efficiently by Brazilian poultry producers in the South region. On the other hand, soybean annual production has increased considerably in Brazil. However, this has not been always the case and may change in the future. With that in mind, other high protein substitutes are available and have been studied in the past. More recently, the expansion of cotton production in the Southern part of the Northeast Region of Brazil has brought to attention the possible availability of cottonseed meal (CSM) as an alternative for protein in poultry rations.

The Northeast region of Brazil has not benefited from the soybean production frontier expansion experienced in the last years. On contrary, this has resulted in a less competitive industry, because soybeans are not produced in most of the Northeast and transportation costs are significantly high. Cottonseed production has increased significantly in the past years (as shown by Sampaio, Vital and Costa, 2003), and can represent an alternative for producers from that region.

Due to its high protein level concentration, CSM may be used as a protein source for poultry production. In this study, we analyze the use of CSM in poultry production and compare it to the use of SBM from the perspective of a poultry integrator that faces different prices of inputs (*e.g.*, SBM and CSM) and different prices of outputs (whole carcass or cut-up parts of broilers). The emphasis of this study is not only on the technical efficiency obtained by feeding either SBM or CSM, which is important but not the essence of making profits in poultry production. We also stress the economic efficiency obtained from the processing and selling of broilers fed either of the two protein sources into seasonally adjusted markets.

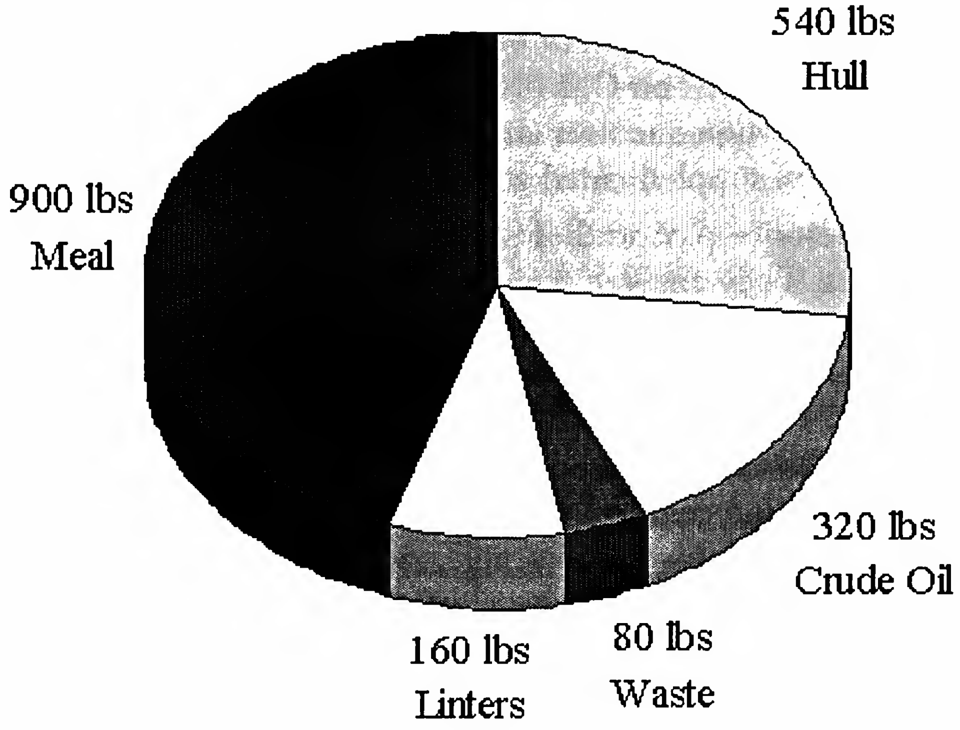
CSM is the second most valuable product (after cottonseed oil) derived from the cottonseed crush. Cottonseed yields 900 pounds (45%) of CSM for each ton that is crushed (National Cottonseed Products Association, NCPA, 1999), as shown in Figure 1. CSM is a high protein level feed ingredient whose first limiting amino acid is lysine. (Grau, 1946, and Anderson and Warnick, 1966). It is commonly known that CSM may be used as an alternative for SBM. In the U.S., for example, the use of CSM is concentrated in feed for livestock and is usually sold between 40% and 42% protein level. (NCPA, 1999). The main obstacle in managing CSM for poultry and livestock rations is the presence of gossypol, due to current processing techniques that cause lysine deficiency. (Fisher and Quisenberry, 1974). In Canada, however, CSM is used as a protein source for broiler chickens in addition to SBM and other protein sources. Canadian analysis of CSM in poultry diets shows that, when supplemented with lysine, CSM reaches productivity levels comparable to SBM. (Campbell, 1988).

When searching for alternative protein sources for poultry or livestock feed, in addition to the feeding response, quality and safety aspects, integrators are also concerned about the availability of the alternative protein source(s), storage and marketing of these alternatives. Among all protein sources, excluding SBM, CSM is the most traded and it is priced in at least seven different major markets in the United States. (Feedstuffs, 2000). The use of CSM for poultry production could become a reality, precipitating welfare losses to areas which currently benefit directly from the production of SBM. Among such areas in the United States, the North-Central region could be impacted the most by reduction in the utilization of SBM in poultry production. In Brazil, the use of CSM may become important in regions that do not have a significant SBM production and that could find CSM as an economical alternative. Regions, such as the Northeast which now import

SBM from the Midwest and South regions of Brazil, may become more competitive, by producing CSM and feeding to their broilers.

Profitable use of CSM requires that its price must be lower than the price of SBM. Not only that, CSM-fed broilers must be as productive as SBM-fed broilers. Or, if not as productive, the price for CSM must be such that it compensates for the lower physical productivity of the CSM-fed broilers. The price difference of protein sources is important, because protein sources in the diets account for approximately 30% of the total diet for high protein level feeds. Historical data on prices show that SBM price has always been higher than the price of CSM for several markets in the United States. (Feedstuffs, 2000).

Figure 1 – Cottonseed products yield per ton of seed crushed



Source: National Cottonseed Products Association.

The profit-maximizing analysis for CSM- and SBM-fed broilers presented in this study is composed of two objectives. First, a profit-maximizing model is developed and used to estimate optimization scenarios of the competing protein sources, where response functions are estimated and price sensitivity analyses conducted. The price sensitivity analysis is then followed by a price mapping analysis on SBM and CSM driven profits that is conducted to determine price combinations of the sources that help the integrator in the decision process of what source can be used most profitably. All these scenarios are estimated for the U.S. industry and presented here with the overall objective of introducing such type of analyses in Brazilian scenarios, where the industry does not vary much from the U.S.

2 RELATED LITERATURE

This section presents technical studies that have compared the use of CSM to SBM in poultry feed rations. Summaries of previous studies that use profit maximization within a mathematical programming context in poultry production and/or feed formulation are also presented.

2.1 Studies on CSM as a protein source for poultry

Extensive production analyses have been applied to finding technically efficient protein substitutes for SBM in poultry production. Peanut and other vegetable oil meals have been cited as protein substitutes for SBM in previous studies, but, according to authors of these studies, these protein sources do not completely replace SBM (*e.g.*, see Heuser, Norris and McGinnis 1946, Carew, Olomu and Offiong 1988, and El Boushy and Raterink 1989). That is, they do not demonstrate greater weight gains, less feed consumed, or better feed conversion than SBM feeds when fed to broilers alone. The interest expressed on CSM is greater than others, because CSM availability decreases shortage risks assumed when one uses an alternative protein source and CSM ensures a higher protein quality level, when supplemented with lysine, than the other sources.

Watkins *et al.* (1993) describe past studies that used CSM in poultry and discuss more recent use of CSM in poultry diets. They analyze the effect of levels of CSM utilization and lysine supplementation on poultry diets and estimate production functions for the effects of CSM levels on feed intake and on feed utilization. They conclude that there does not appear to be any significant relationship between dietary lysine supplementation and response to CSM. Their subsequent study (Watkins *et al.*, 1994) analyzes the influence of assigned metabolizable energy values and supplementation with essential amino acids on the performance of CSM-fed chickens. They compare treatments where SBM is used solely and treatments where levels of CSM are added to the diets. Their analyses reveal that there is no significant difference in body weight for any of the treatments, but that feed consumption is higher for diets with CSM added. However, the use of two protein sources in the same diet makes it difficult to distinguish the effects of each source in the body weight and feed consumption responses of the chickens.

Watkins and Waldroup (1995) study the use of higher concentrated protein in CSM feed formulation (44.96%), which can be obtained from newer extrusion processes in poultry diets. Comparing SBM-fed broilers with diets that contain SBM and levels ranging from 10% to 30% CSM and added necessary amino acid supplements, their results show that CSM is more suitable for finisher diets (21-42 days) than for starter diets. Also, 30% CSM levels in the diet result in birds that weigh less and eat less than in the other treatments.

These studies show promising results for the use of CSM as a complement for SBM in poultry diets, if not as a substitute. This may follow from the belief that higher levels of CSM may not be as efficient as levels used in past studies. Our study uses data obtained by experiments conducted at the University of Georgia[1] that use full substitution of protein sources; *i.e.*, experiments are conducted with diets that contain either SBM or CSM for the collection of information on live body weight, feed consumption and weight of processed parts. This data set, which contains productivity information on each source (SBM *vs.* CSM), is used to estimate the production functions that will be used in the profit maximization model of this study.

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[1] Feed composition and feeding level experiment was conducted by the Poultry Science Department, University of Georgia. The experiment consisted of using four different levels of protein (17%, 20%, 23%, and 26%) and two different sources of protein (SBM *vs.* CSM) to feed broiler chickens until 42 days and collecting body weight, feed consumed and weight of whole carcass and cut-up parts. For more detailed information, contact the authors.

2.2 Profit maximization and cost minimizations models

With the wide-spread adoption of mathematical programming in the 1950's, interest in feed formulation was renewed. For decades, the major objective to be attained in optimal broiler production was to minimize the cost of feed, and little consideration was allocated to other determinants of maximizing 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, 1974).

The adoption of simple cost minimization does not account for differentials in productivity among input sources; *e.g.*, broiler performances in experimental trials of those fed peanut meal protein vs. those fed SBM protein have been shown to differ significantly. (Costa *et al.*, 2001). Adoption of profit maximization techniques later in the 1990's has taken into consideration the multi-factor productivity aspect of economically efficient broiler production. Few models have been developed thus far, and they differ in their approaches to the problem.

Gonzalez-Alcorta *et al.* (1994) develop a profit maximization model that uses nonlinear and separable programming to determine 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, and 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 *et al.* (1986). Gonzalez-Alcorta *et al.* (1994) 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 increase profitability compared to fixed diet levels of energy and protein based on previous nutritional guidelines.

Costa *et al.* (2001) develop a two-step profit maximization model that minimizes feed cost in the first step and then maximizes profits in broiler production and processing in the second step. Their model shows the optimal average feed consumed, feed cost, live and processed body weight of chickens, as well as the optimal length of time that the broilers must stay in the house and other factors, for given temperature, size of the house, cost of inputs and outputs and for a certain, predetermined protein level, source, and set of processing decisions. They conclude that peanut meal can be more profitable than SBM for growing birds to be processed and sold as whole carcasses.

The analysis conducted in our study differs from Costa *et al.* (2001) by developing a model that allows for a single, iterative search procedure that will select the optimal protein level and formulated ration to be fed to the chickens for either protein source. This model generates processing alternatives for selling whole carcass and cut-up parts, but it also indicates what protein source will generate the most profitable feed ration. The model-generated signal of specific protein sources to meet pre-determined marketing options is key to determining the market for feed inputs.

3 MATERIAL AND METHODS

3.1 Model description

The model presented in this study is composed of a generalized set of equations that are applied to all marketing options through specific equations used according to the desired processing strategy. This section lays out the general framework of equations, explaining all variables and their measure, and how the model optimizes interactively to solutions for each market-driven scenario.

The generalized model is summarized by the equations presented next. The objective function maximizes profit per bird per unit of time, Π (Equation 1). Π is equal to total revenue, or derived farm price, DP_{BW}, times live body weight, BW, minus total cost or cost of feed consumed, P_{FC}, times feed consumed, FC, times interest cost, I, divided by feeding time, t, necessary to grow broilers to the time where live bird weight, feed consumed and marketing conditions are optimum. That is,

$$Max\,\Pi = [(DP_{BW} * BW) - (P_{FC} * FC) * I]/t \qquad (1)$$

Subject to:

$$P_{FC} = P_F + DEL \qquad (2)$$

$$P_F = \sum_{t=1}^{n} P_t * X_t \qquad (3)$$

$$\sum_{t=1}^{n} \alpha_i * X_i \geq ME \qquad (4)$$

$$\sum_{t=1}^{n} \beta_t * X_t \geq PR \qquad (5)$$

$$\frac{\sum_{f=1}^{m} \sum_{t=1}^{n} \rho_{ft} * X_i}{\sum_{t=1}^{n} \beta_t * X_t} \geq \eta_f \qquad (6)$$

$$\sum_{i=1}^{n} \mu_i * X_i \geq Ca \qquad (7)$$

$$\frac{\sum_{t=1}^{n} \mu_t * X_t}{\sum_{t=1}^{n} \theta_t * X_t} = 2.0 \qquad (8)$$

$$\sum_{t=1}^{n} X_t = 1.0 \qquad (9)$$

$$X_t \geq 0 \qquad (10)$$

Equations 2-10 account for the feed nutrient and cost constraints of the model. Cost of feed consumed is equal to least cost feed, P_F, plus feed delivery cost, DEL. The cost feed function (3) finds the optimal cost of feed for determined ingredients (X_i) and for their prices (P_i). The constraints meet nutrient requirements for technically efficient growth and are represented by: level of metabolizable energy (4) in the ration has to be at least equal to the pre-determined level (ME), where α_i is the technical coefficient for energy for each ingredient; level of protein in the ration (5) has to be at least equal to the level determined by the model (PR), where β_i is the technical coefficient for protein content of each ingredient; protein ratio (6) of each nutrient to level of protein in the diet has to be at least equal to the level desired (η_j), where ρ_{ji} is the technical coefficient for the nutrient of each ingredient; the sum of all calcium content in the ingredients (7) must be greater than or equal to the desired calcium content (Ca); ratio of calcium to available phosphorus (8) has to be equal to 2.0, where γ_i and θ_i are the technical coefficients for calcium and available phosphorus, respectively; the sum of all ingredients (9) has to be equal to a unit of feed; all ingredients must have a non-negative value in the solution (10). Next,

$$BW = f(FC, FC^2, PR, PR^2, FE) \tag{11}$$

$$FC = f(t, t^2, PR, PR^2, FE) \tag{12}$$

where the production functions (11 and 12) are estimated by ordinary least squares (OLS) analysis on experimental data to provide technical response coefficients to the programming model (or, "optimization"). Live body weight of a broiler, BW, is a function of feed consumed per broiler, FC, its squared term, FC^2, dietary protein level, PR, its squared term, PR^2, and a dummy variable for gender. The equation is estimated for each protein source (soybean meal or cottonseed meal) and is primarily estimated for male birds, i.e., when female birds are used, the coefficient for FE is added to the intercept of the function. Feed consumed per bird is a function of feeding time, t, its squared term, t^2, dietary protein level, PR, its squared term, PR^2, and a dummy variable for gender. The equation is also estimated for each protein source (soybean meal or cottonseed meal) and is primarily estimated for male birds; i.e., when female birds are used, the coefficient for FE is added to the intercept of the function.

Equations 13-16 (in bold) vary according to the decision of what is the product market in which the broilers will be sold. Section 5 will give a detailed explanation on how the equations vary for the pre-determined marketing options. In general, derived average price of a broiler, DP_{BW} is equal to the live value of birds delivered to the plant that are processed into whole carcass, cut-up parts, or to be sold in the live market, LV_k, divided by the number of birds finished in the production process, BF (Equation 13). LV_k equals BF times the average derived price for the marketing option k, ADP_k, times the percentage of birds which are not dead on arrival at the processing plant, (1 - DOA), plus the price for dead on arrivals, P_{DOA}, times the percentage of dead on arrivals, DOA (Equation 14). ADP_k is equal to an average value of the weights of processed carcass or cut-up parts, w_l, depending on the marketing option, k, times the dock price of each processed carcass or cut-up part, P_l, minus processing cost, PRO_l, and catching and hauling cost, CAT_l (Equation 15), where l equals the part to be processed (whole carcass, skinless boneless breast, tenderloin, leg quarters, wings, fat pad or remaining parts of the chicken) divided by the average live weight estimated in Equation 11. Equation 16 presents the production function, or yield function, of each processed part l, where w_l is a function of average live body weight, BW, protein level, PR, its squared term, PR^2, and a dummy variable for female chickens, FE. These variables are estimated the same way as in equations 11 and 12 for each processed part l.

Interest cost, I, is determined by annual interest rate, r, and feeding time, t (Equation 17). Number of birds finished, BF, equals the ratio of Size of the broiler house, S, and density

$$DP_{BW} = \frac{LV_k}{BF} \tag{13}$$

$$LV_k = BF * [(1 - DOA) * ADP_k + DOA * P_{DOA}] \tag{14}$$

$$ADP_k = \frac{\sum_l (w_l * (P_l - PRO_l - CAT_l))}{BW} \tag{15}$$

$$w_l = f(BW, PR, PR^2, FE) \tag{16}$$

of birds in the house, D, times the livability of birds, or 1 - M, the mortality of birds (Equation 18). M is determined as a function of feeding time, t (Equation 19). In other words, number of birds finished in the house at the end of the production process is equal to the number of birds started, discounted by the mortality of birds as a function of time. Density of birds in the house (Equation 20) uses estimated parameters from data obtained from a national survey on broiler producing houses (Agri Stats) to describe the function in terms of live broiler weight, BW, temperature, $TEMP$, and the percentage of males in the house, $MALE$. Other constraints include: live broiler weight must be greater than or equal to 3.52 lb (Equation 21), feed consumption per bird must be greater than or equal to zero (Equation 22), and feeding time must be greater than or equal to 25 days (Equation 23).

$$I = (1 + \frac{r}{365})^t \tag{17}$$

$$BF = \frac{S}{D} * (1 - M) \tag{18}$$

$$M = f(t) \tag{19}$$

$$D = f(BW, BW^2, TEMP, MALE) \tag{20}$$

$$BW \geq 3{,}52 lb \tag{21}$$

$$FC \geq 0 \tag{22}$$

$$t \geq 25 \tag{23}$$

State variables to this model, or given variables, are: dock prices of cut-up parts and whole carcass, P_l, percentage of dead on arrivals and field condemnation, DOA, processing cost of whole carcass and parts, PRO_l, catching and hauling cost, CAT_l, annual interest rate, i, price of dead on arrivals and field condemnation, P_{DOA}, delivery cost of feed, DEL, temperature, $TEMP$, male percentage, $MALE$, size of the house, S, and clean out time, CT. Control variables are: profit, Π, Derived farm price, DP_{BW}, live body weight, BW, feed cost, P_F, feed consumed, FC, protein level, PR, interest cost, I, feeding time, t, live value of birds delivered to plant, LV_k, number of birds finished, BF, derived weighed average price of a live weight broiler processed into a whole carcass or cut-up parts, P_k, weight of each processed part, w_l, mortality, M, density of birds in the house, D, broiler house revenue, BHR, and Annual Profit, Π_a.

Parameters coefficients are estimated from regression analysis of experiments, nutrient composition data, and costs and prices data. The model thus seeks an interactive solution for a given marketing option and protein source. Global optimization is achieved by iteration of production function information, prices, and ingredient nutrients. In other words, after determining the marketing option and protein source, feed must be formulated using linear programming to obtain a formulated feed, and costs are used to find the optimal live and processed bird weights and production time that maximize profit using nonlinear programming. The global optimization is achieved after all different protein levels are iterated and the optimal level of protein is found.

Apart from the equations developed in the model, accounting processes make it possible to calculate net revenues for the whole production process and annual profits for the same broiler house throughout the year. Equations 24 and 25 calculate production process revenues and annual profits for the broiler house, respectively.

$$BHR = \Pi * t * BF - CHICK * \frac{S}{D} - VAC * BF \tag{24}$$

$$\Pi_a = \frac{365}{t + CT} * BHR \tag{25}$$

Broiler house revenue (*BHR* in Equation 24) is equal to profit per bird per day, A, times feeding time, *t*, times number of birds finished, *BF*, minus the chick cost, *CHICK*, per number of birds started, which is calculated by the ratio of the size of the house, *S*, and density of birds in the house, *D*, and minus the vaccination, miscellaneous and supervising cost, *VAC*, per number of birds finished. Annual profit (Π_a, in Equation 25) is equal to the total number of days in the year divided by the optimal feeding time, *t*, plus the clean out time, *CT*, all this multiplied by the broiler house. This calculation will calculate annual profitability for each market option selected by the integrator.

4 ESTIMATED PRODUCTION FUNCTIONS

Production equations 11, 12, and 16 are estimated by OLS and are presented in Tables 1 and 2. Table 1 shows the estimated coefficients of Equations 11, 12 and 16 (only for estimation of carcass weight in 16) for both CSM- and SBM-fed broilers. Live bird weight (*BW*) increases at a decreasing rate with respect to feed consumed (*FC*) and protein level (*PR*), while feed consumed increases at an increasing rate with respect to feeding time (*t*) and increases at a decreasing rate with respect to protein level (*PR*). Weight of whole carcass (W_{WC}) increases at a decreasing rate with respect to protein level (*PR*).

Estimated coefficients of Equation set 16 (for skinless boneless breast, tenderloin, leg quarters, wings, fat pad, and rest of chicken) are shown in Table 2 for CSM – and SBM-fed broilers. For CSM-fed broilers, weights of skinless boneless breast, tenderloin, wings, and rest of the chicken (W_{BR}, W_{TE}, W_{WI}, and W_{RC}, respectively) increase at decreasing rates with respect to *PR*, while weights of leg quarters and fat pad (W_{LQ} and W_{FP}, respectively) decrease at increasing rates with respect to *PR*. For SBM-fed broilers, weights of skinless boneless breast, tenderloin, leg quarters, wings, and rest of chicken (W_{BR}, W_{TE}, W_{LQ}, W_{WI}, and W_{RC}, respectively) increase at increasing rates with respect to *PR*, while only weight of fat pad (W_{FP}) decreases at an increasing rate with respect to *PR* for this feed formulation. These results concur with those of Pesti and Smith (1984) that show that production responses of broilers to dietary energy and protein levels show diminishing marginal returns.

Prices of inputs and outputs are collected for the profit maximization analysis. The prices data consist of prices of ingredients available for the ration formulation, including major feedstuffs and synthetic amino acids that supplement the deficiencies of major alternative protein sources such as CSM. Prices received in Georgia (or the Southeast) for the outputs are considered in the analysis, as well as other costs considered in the production and processing.

Table 1 – Estimated body weight, feed consumed, and carcass weight for CSM- and SBM-fed broilers

	Body Weight		Feed Consumed		Carcass Weight	
Variable	CSM	SBM	CSM	SBM	CSM	SBM
Intercept	-1.192** (0.394)	-1.698** (0.542)	-1.900** (0.947)	-1.107 (0.854)	-318.362** (147.302)	-409.280** (179.164)
FC	0.634** (0.023)	0.692** (0.034)	-----	-----	-----	-----
FC^2	-0.035** (0.005)	-0.043** (0.007)	-----	-----	-----	-----
t	-----	-----	0.015 (0.019)	0.004 (0.017)	-----	-----
T^2	-----	-----	0.002** (0.001)	0.002** (0.001)	-----	-----
BW	-----	-----	-----	-----	0.720** (0.010)	0.753** (0.013)
PR	0.117** (0.036)	0.158** (0.050)	0.140* (0.079)	0.086 (0.071)	20.815 (14.085)	25.523 (17.158)
PR^2	-0.002** (0.001)	-0.003** (0.001)	-0.003* (0.002)	-0.002 (0.002)	-0.436 (0.326)	-0.546 (0.397)
FE	-0.082** (0.013)	-0.061** (0.017)	-0.337** (0.027)	-0.240** (0.024)	6.391 (6.726)	7.760 (7.890)
R^2	0.9945	0.9899	0.9939	0.9946	0.9820	0.9703
N	72	72	72	72	144	144

Standard errors are in parentheses. * indicates parameter estimate is statistically significant at 0.10 level; ** indicates parameter estimate is statistically significant at 0.05 level. Body Weight and Feed Consumption functions are estimated in kg; Carcass Weight function is estimated in grams.

Table 2 – Effects of live weight, protein level, and sex of bird on weights of cut-up parts of CSM- and SBM-fed broilers

	Breast		Tenderloin		Leg Quarters		Wings		Fat Pad		Rest of Chicken	
Variable	CSM	SBM	CSM	SBM	CSM	SBM	CSM	SBM	CSM	SBM	CSM	SBM
Intercept	-196.509*	-221.257*	-61.380**	-80.876**	-34.145	-29.088	-28.607	-50.023	37.789	189.252**	-31.835	-251.526**
	(110.377)	(118.450)	(30.716)	(26.624)	(113.019)	(136.867)	(48.000)	(44.314)	(56.381)	(49.484)	(114.933)	(111.971)
BW	0.160**	0.184**	0.035**	0.044**	0.353**	0.336**	0.079**	0.083**	0.038**	0.035**	0.055**	0.067**
	(0.007)	(0.008)	(0.002)	(0.002)	(0.007)	(0.010)	(0.003)	(0.003)	(0.004)	(0.003)	(0.008)	(0.008)
PR	13.479	12.058	4.136	4.530*	-1.661	-0.264	2.939	4.384	-3.692	-17.122**	5.678	25.750**
	(10.551)	(11.385)	(2.936)	(2.560)	(10.804)	(13.155)	(4.588)	(4.259)	(5.390)	(4.756)	(10.987)	(10.762)
PR^2	-0.285	-0.234	-0.080	-0.083	0.001	-0.008	-0.068	-0.100	0.044	0.327**	-0.057	-0.531**
	(0.244)	(0.263)	(0.070)	(0.059)	(0.250)	(0.304)	(0.106)	(0.098)	(0.125)	(0.110)	(0.254)	(0.249)
FE	7.096	13.237**	4.749**	6.119**	-6.754	-17.239**	3.883*	0.835	13.570**	9.590**	-17.840**	-6.338
	(5.051)	(5.216)	(1.406)	(1.172)	(5.172)	(6.027)	(2.197)	(1.951)	(2.580)	(2.179)	(5.260)	(4.930)
R^2	0.8403	0.8212	0.7533	0.8412	0.9604	0.9268	0.8608	0.8738	0.4585	0.5685	0.5482	0.5236
N	144	144	144	144	144	144	144	144	144	144	144	144

Standard errors are in parentheses. * indicates parameter estimate is statistically significant at 0.10 level; ** indicates parameter estimate is statistically significant at 0.05 level. All functions are estimated in grams.

5 MODEL INTERACTIONS

With the model developed above, we estimate the profitability of four base scenarios: broilers are produced and sold using either SBM or CSM as the protein source, and for each protein source, broilers are sold either after being processed into whole carcasses or into cut-up parts. Initially, comparisons are made directly between SBM *vs.* CSM results for each broiler product marketing alternative. Then, prices of inputs (SBM and CSM) are varied for input price sensitivity analysis. Lastly, a price mapping is extracted to indicate the impact on decisions of seasonal and other price variations that justify using CSM or SBM as the more profitable protein source. The optimal solutions report broiler weight, feed consumption, feeding time, and feed composition that maximize profit under certain production function estimation, market option, and input/output prices. All optimal formulated rations meet all nutrient requirements from the National Research Council (NRC) for nutrient requirements in poultry production. Baseline scenarios use 2002 prices.

Each optimized ration is fed to broilers for an optimized number of days in order to obtain a target weight that is to be processed and sold to a specific market, given the prices of outputs (processed parts) and inputs (feed ingredients, mainly), and other costs integrated in the model, as illustrated by the case/example scenario in Figure 2. Assume in Figure 2 that the current price of SBM has increased considerably. Assume also that whole carcass prices are higher at this same time of the year, because consumers are seasonally desiring more whole carcass, or rotisserie-type products. The integrator faces these two aspects of the input and output markets and employs the decision model to get an optimal solution for the given input and output market situations. Thus, these prices of outputs and inputs are then entered in the model data set, which uses previously entered information and relationships on production and returns to carcass weight broilers fed CSM, nutrient requirements determined by the National Research Council (NRC, 1994), size of the house information, temperature, chicks' gender, and other production costs. The model then searches for an optimal solution, which determines that the integrator must use broilers fed CSM and processed into whole carcass to obtain maximum profits in this period. The optimal solution set that is generated by the model goes first to decisions in the broiler house (i.e., contracts with the feeding unit for this intermediate output), where optimal feed composition, composed of CSM as protein source, and optimal feeding time are set to deliver a live body weight of broilers. The live body weight produced in the broiler house is delivered to the processing plant, where a profit-maximizing whole carcass product is the outcome.

5.1 Selling broilers in the whole carcass market

The first analysis compares selling CSM- and SBM-fed broilers that are processed into whole carcass, with results presented in Tables 3 and 4 (first two columns). In Table 3, the feed formulated for CSM has less corn and more poultry fat than the SBM ration, but more CSM is used than for SBM rations in its composition (as CSM has a lower protein concentration than SBM). Both feed scenarios demonstrate optimal protein levels that are higher than the levels currently fed in the industry. The NRC (1994) recommends that the protein level in the diets used for broilers in the grower phase, from 3 to 6 weeks, should be equal to 20%.

Figure 2 – Example of production and processing decision schematic for integrated broiler profit maximization

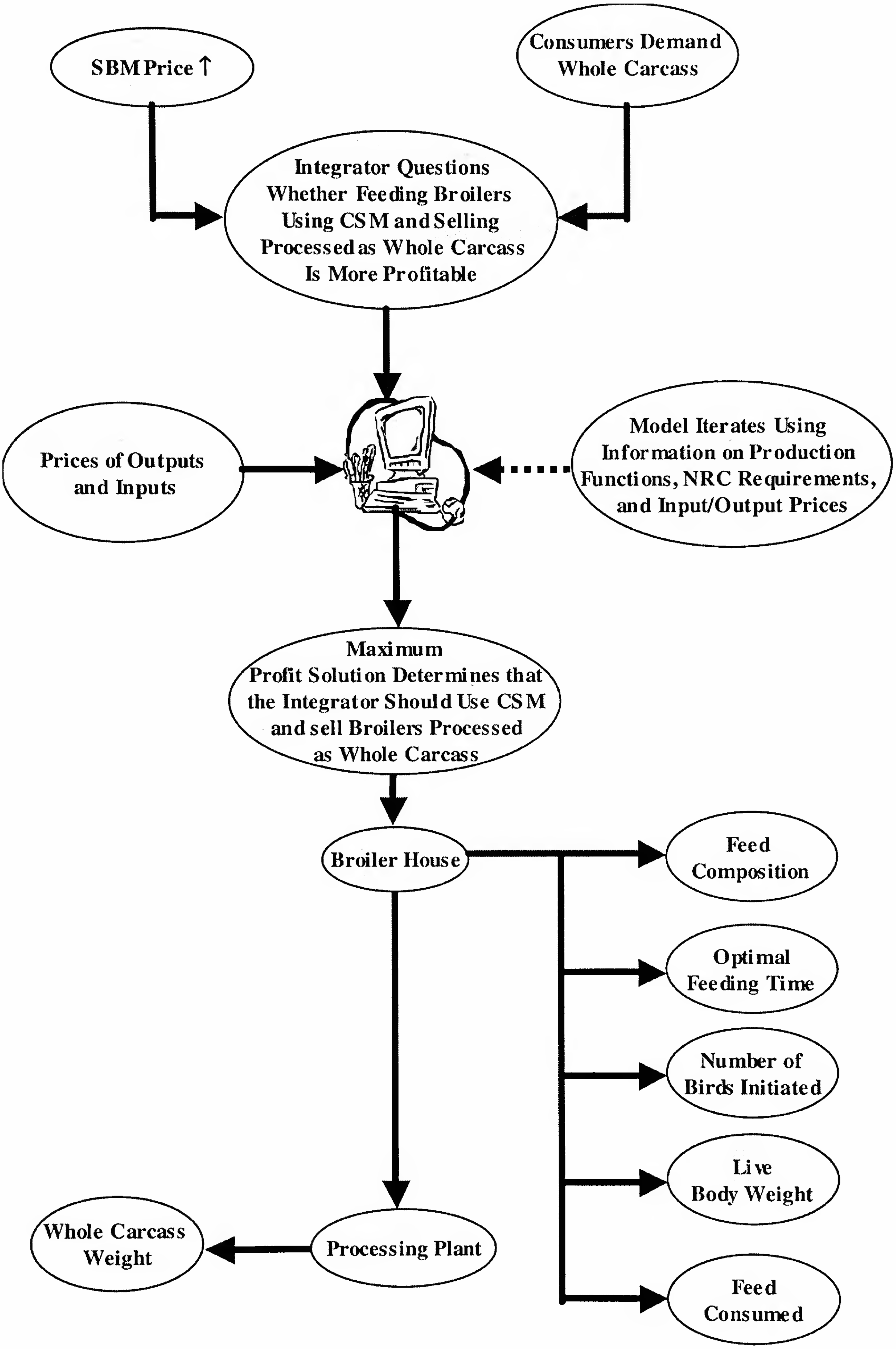


Table 3 – Composition of the optimal solutions rations for SBM and CSM, whole carcass and cut-up parts

Ingredients and Composition	Whole Carcass SBM	Whole Carcass CSM	Cut-up Parts SBM	Cut-up Parts CSM
Ingredients	(%)			
Corn	58.89	49.88	56.43	48.70
Soybean Meal	23.92	---	26.01	---
Cottonseed Meal	---	29.53	---	30.47
Poultry Fat	4.40	7.54	4.78	7.78
Poultry By-Product Meal	4.00	4.00	4.00	4.00
Menhaden Meal	4.00	4.00	4.00	4.00
Meat and Bone Meal	3.00	3.00	3.00	3.00
Defluor. Phos.	0.75	0.67	0.74	0.67
Limestone	0.13	0.25	0.13	0.26
Common Salt	0.30	0.30	0.30	0.30
Vitamin Premix	0.25	0.25	0.25	0.25
Mineral Premix	0.08	0.08	0.08	0.08
Aviax	0.08	0.08	0.08	0.08
Bacitracin	0.05	0.05	0.05	0.05
$CuSO4 - 5H2O$	0.05	0.05	0.05	0.05
DL - Methionine	0.10	0.05	0.11	0.06
L - Lysine	---	0.19	---	0.19
L - Threonine	0.03	0.10	0.03	0.10
Composition by Calculation[1]				
Protein, %	23.12	23.92	23.92	24.23
ME, kcal/kg	3.20	3.20	3.20	3.20
Threonine, %	0.04	0.04	0.04	0.04
Methionine, %	0.02	0.02	0.02	0.02
Lysine, %	0.06	0.05	0.06	0.05

[1] Based on NRC feed composition tables.

CSM feed costs more per pound than the SBM feed in this product scenario (whole carcass), but the profit generated by supplying CSM to the broilers is higher than the profit generated by SBM-fed broilers (Table 4). This represents the only feeding scenario at observed prices where CSM is more profitable than SBM. SBM-fed birds are fed longer (number of days) than are CSM-fed birds and result in larger birds with higher consumed feed. Yet, profitability is higher for CSM-fed birds when measured as profit per broiler per day, profit per house per period, and profit per house per year.

Table 4 – Baseline scenarios used to analyze the profitability of CSM and SBM in broiler production, whole carcass and cut-up parts

		Whole Carcass		Cut-up Parts	
Variable	Unit	CSM	SBM	CSM	SBM
Protein Level	%	23.92	23.12	24.23	23.92
Feeding Time	days	34.94	39.80	34.94	40.07
Bird Weight	lb	4.24	5.04	4.24	5.10
Feed Cost	cents/lb	7.51	7.50	7.55	7.61
Feed Consumed	lb/bird	6.32	7.97	6.30	8.04
Feed Conversion Ratio	lb/lb	1.58	1.58	1.49	1.58
Profit (Π)	**cents/bird/day**	**2.08**	**1.52**	**2.30**	**2.59**
Derived Price	cents/lb	29.19	29.02	31.00	33.29
Broiler House Revenue	$/house/period	12,778	9,234	14,710	19,622
Annual Profit	$/house/year	116,600	74,898	134,227	159,159
Carcass Weight	lb	2.90	3.55	---	---
Skinless Boneless Breast Weight	lb	---	---	0.597	0.790
Tenderloin Weight	lb	---	---	0.131	0.178
Leg Quarters Weight	lb	---	---	1.335	1.625
Wings Weight	lb	---	---	0.340	0.420

5.2 Selling broilers in the cut-up parts market

Selling broilers processed into cut-up parts generates the highest profits overall (Table 4). Even though this study's procedures differ significantly from the study conducted by Costa *et al.* (2001), the results obtained in this study are similar to theirs regarding the conclusion that feeding SBM to broilers to be sold as cut-up parts generally results in the most profitable scenario.

The protein levels in the optimal solutions remain high relative to current industry practice, and the use of SBM and CSM in the diets for broilers processed as cut-up parts is at its highest level of all three diets formulated for the marketing options simulated here. The feeding process is also the longest for this alternative, and feed costs are the highest of all posited SBM and CSM scenarios for processing alternatives. SBM-fed birds are fed longer than CSM-fed birds and result in larger birds with higher consumed feed. In this case, profitability is higher for SBM-fed birds when measured as profit per broiler per day, profit per house per period, and profit per house per year.

6 PRICE MAPPING ANALYSIS ON SBM *VS.* CSM

At baseline prices for SBM and CSM, optimal solutions in Table 4 show that SBM generates higher profits than CSM when broilers are processed into cut-up parts, while CSM generates higher profits than SBM when broilers are processed into whole carcass. The prices of both sources can and do vary through time and/or seasonally, however. The analysis conducted here determines an equally profitable line for the price combinations of SBM and CSM. The interaction of many possible prices in the model determines at what price combination profits are equalized.

Figures 3 and 4 show the isoprofit lines for the carcass and cut-up parts markets, respectively. Notice that in Figure 3, for considerably higher prices of CSM than SBM, there will be equal profits in the whole carcass product market. CSM-generated profits will be higher for price situations that fall in the southeast area, below and to the right of the line, whereas SBM-generated profits will be higher for price situations that fall in the northwest area, above and to the left of the line. The isoprofit line in Figure 3 is convex relative to the horizontal axis; i.e., CSM will be more profitable than SBM for a larger number of price combinations. In Figure 4, notice that the line approximates a straight line, and for considerably higher prices of SBM than CSM, there will be equal profits. Again, CSM-generated profits will be higher for price situations that fall in the southeast area, below and to the right of the line, whereas SBM-generated profits will be higher for price situations that fall in the northwest area, above and to the left of the line.

Figure 3 – Isoprofit price mapping analysis for whole carcass marketing option

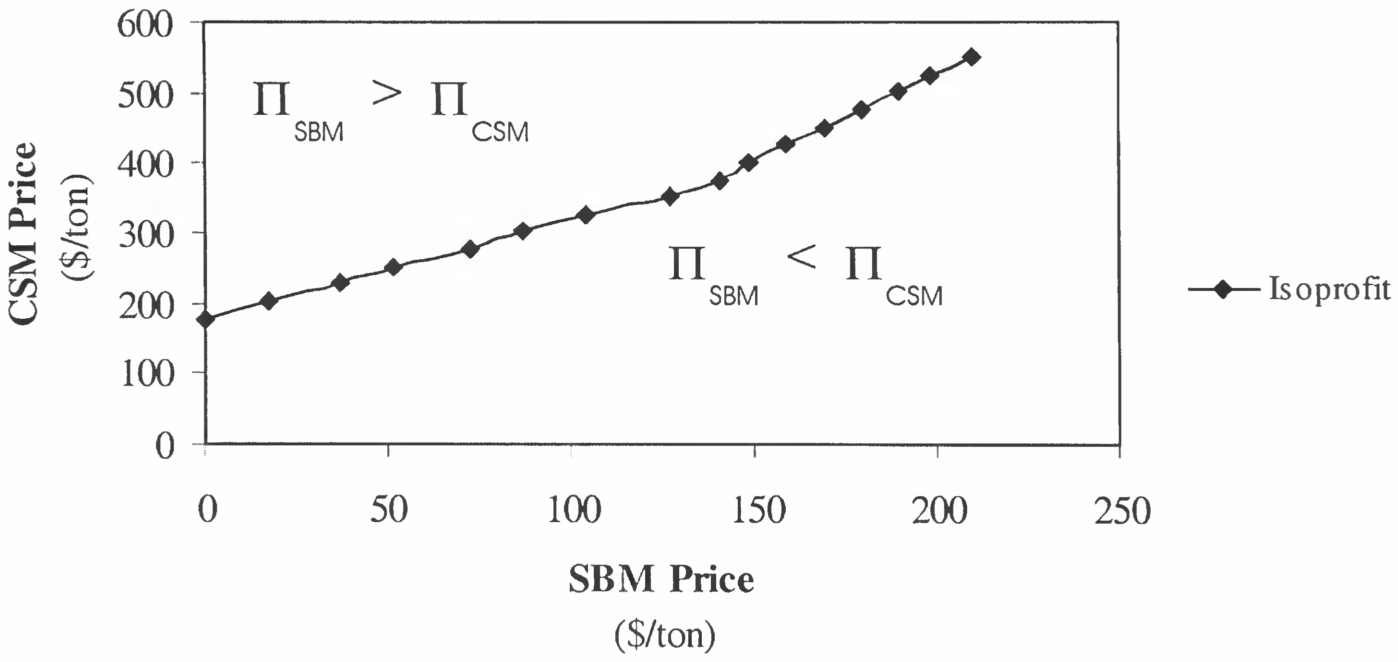
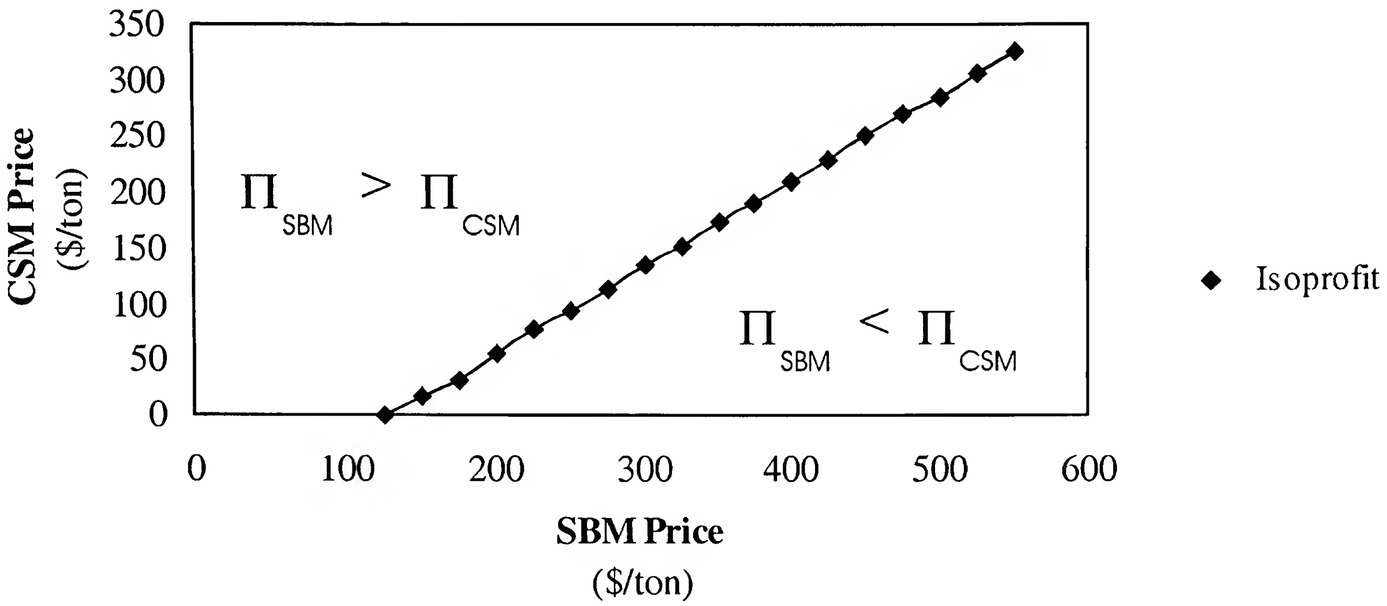


Figure 4 – Isoprofit price mapping analysis for cut-up parts marketing option



7 CONCLUSIONS

This profit-maximization model interactively generates optimal solutions for CSM- and SBM-fed broilers in the whole carcass and cut-up parts marketing options. Feeds formulated for all optimal solutions meet all NRC (1994) requirements for nutrient composition of feed rations. Protein levels of the optimal feed rations indicated by the model are above the average levels reported in the industry and range from 23% to just less than 25% protein level in the diet. Profits are higher for CSM-fed broilers when marketed in the whole carcass marketing option, whereas profits are greater for SBM-fed broilers when marketed in the cut-up parts option. CSM-fed birds are fed for shorter feeding times than are SBM-fed broilers in all directly compared scenarios. Average live body weight and total feed consumed are lower for CSM-fed broilers than for SBM-fed broilers.

A price mapping analysis of SBM *vs.* CSM profits for the whole carcass and cut-up parts markets indicates that there are price combinations at which both sources are equally profitable. The range of prices for which CSM is more profitable than SBM is relatively larger in the whole carcass market, indicating that CSM can more-profitably be used for feeding broilers in that market. On the other hand, the range of prices for which SBM is more profitable than CSM is relatively larger in the cut-up parts market, indicating that SBM is generally more profitable than CSM for feeding broilers in that market. Results for both SBM and CSM formulated rations also show that poultry producers could increase profitability by formulating rations that have higher protein levels than the currently recommended levels.

Solution sets obtained from profit maximization model interactions demonstrate that SBM-based diets are generally more efficient than CSM-based formulations. Moreover, at the set of input and output prices extant, SBM-based feeds are more profitable than using CSM, especially for selling broilers processed into cut-up parts. CSM can be fed more profitably than SBM at these input and output prices only when broilers are sold as whole carcasses. In the U.S. case, CSM may thus have a potentially new market – the protein input market for poultry production in the Southeast region of the United States. That is, given its availability in that region, the results provided in this study demonstrate that CSM may be used profitably as an alternative protein source for SBM in broiler production. If the adoption of CSM for poultry production were to be successfully implemented, gains in the Southeast may be offset by losses to the North-Central region of the United States, and these impacts require further study.

In Brazil, similar results are most likely obtainable for the Northeast region as compared to the Southeast region of the United States. CSM may be fed more profitably than SBM in the Northeast region if one takes into consideration the high transportation costs for SBM from the Midwest and South regions of Brazil. In spite of that, poultry industries are currently dislocating its producing lines from states like Pernambuco to the West part of Bahia searching for a proximity to the soybean producing regions. If CSM is adopted and more used in the Northeast, such migrations would be unseen.

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