5. Analyzing Poultry Slaughter Plant Costs: The Model

Production by large chicken and turkey slaughter plants as a share of total output sharply increased while the number of plants with fewer than 100 employees dropped to almost zero between 1967 and 1992. Over the same time period, plant product mix shifted from whole-bird products to traypacks, cut-up and deboned products, and frankfurters, luncheon meats, and other further-processed products. Greater plant size and additional plant processing likely affected factor demand because greater size and additional processing require more bird and labor inputs. Econometrically, changes in factor demand imply that cost analyses must take product mix into account.

Price changes for liveweight bird and unprocessed poultry (poultry input meat) can affect estimated scale economies and the demand for labor and other factors of production through substitution effects. If poultry input meat prices are a small share of total plant costs, then substitution effects would have a small impact on plant costs. Census data reveal, however, that the cost of live birds dominates production expenses, so cost analyses must distinguish between poultry meat input prices and other factor prices. Note that poultry meat input prices include the costs of feed, medicine, chicks and poults, grower payments, etc., regardless of whether birds are purchased from an independent grower or come from a contractor.

A Functional Form for Cost Estimation

The translog cost function used in this report includes variables for factor prices, plant size, poultry meat input mix, bulk output share, time shifts, seasonality, whole-bird output share, and type of plant (single or multi-establishment firm). This cost function model is both flexible and general, and (a) estimates the effect of plant size on costs; (b) controls for differences in share of primary input meat (chicken or turkeys) and product mix; (c) identifies the effect of factor prices on cost, and allows those effects to vary with plant size; (d) evaluates the importance of production seasonality; and (e) permits technological shifts over time. A second-order, four-factor, longrun cost function is defined as follows:

$$\begin{aligned}\mathrm{Ln}\,C = {} & \alpha_0 + \sum_i B_i \ln P_i + \frac{1}{2}\sum_i \sum_j B_{ij} \ln P_i P_j \\ & + \gamma_Q \ln Q_Q + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \sum_i \gamma_{Qi} \ln Q \ln P_i \\ & + \sum_k \delta_k \ln Z_k + \sum_i \sum_k \delta_{ik} \ln Z_k \ln P_i \\ & + \sum_k \delta_{Qk} Z_k \ln Q + \sum_k \sum_l \delta_{kl} \ln Z_k \ln Q \\ & + \sum_m \rho_m T_m + \sum_i \sum_m \rho_{im} T_m \ln P_i \\ & + \sum_m \rho_{Qm} T_m \ln Q + \sum_k \sum_m \rho_{mk} T_m Z_k + \xi\end{aligned} \tag{5.1}$$

where C is total costs, P is factor prices, Q is output, Z is a vector of plant characteristics, T represents dummy variables for each Census year (with 1992 and the base), and ln is the logarithmic operator.

The translog cost function is flexible in that it allows for a variety of possible production relationships, including returns to scale, optimal factor shares that vary with the level of output (nonhomotheticity), and nonconstant elasticities of factor demand. The cost function can be estimated directly, but parameter estimates are often inefficient because of multicollinearity among explanatory variables. Gains in efficiency can be realized by estimating the factor demand equations (cost-share equations) jointly with the cost function. The equations are obtained from the derivatives of the total cost function with respect to each price (equation 5.2).

$$\begin{aligned}\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i X_i}{C} = {} & \mathrm{B}_i + \sum_j \mathrm{B}_{ij} \ln P_j + \gamma_{Qi} \ln Q \\ & + \sum_k \delta_{ik} \ln Z_k + \sum_m \rho_{im} T_m\end{aligned} \tag{5.2}$$

All variables are normalized (i.e., divided by their mean values before estimation); thus, the first-order terms (the β_is) can be interpreted as the estimated cost-share of factor i at mean values. The other coefficients capture changes in the estimated factor shares with changes in other prices, plant output, and other model components. Price elasticities of factor demand can be derived from the coefficients and variables in the share equations.

Cost-function symmetry and homogeneity of degree one can be imposed in order to gain improvements in efficiency (Berndt, 1991). Symmetry means that the coefficients on all interaction terms with identical components are equal (that is, the coefficients $\beta_{ij} = \beta_{ji}$, $\delta_{ki} = \delta_{ik}$, $\rho_{im} = \rho_{mi}$, and $\rho_{km} = \rho_{mk}$ for all i, j, k, and m). The omitted variables are not reported because they are implied. Homogeneity of degree one means that if all factors are doubled, then output would also double. This characteristic means that the number of parameters that must be estimated would be reduced because some parameters can be derived from combinations of others. It requires the following:

$$\sum B_i = 0, \sum B_{ij} = \sum B_{ji} = \sum \gamma_{Qi} = \sum \delta_{ik} = \sum \rho_{im} = 0 \qquad (5.3)$$

Measuring Output

Bugos reports a rapid convergence toward use of the integrator organizational form of contracting poultry growing, and almost complete industry convergence by 1967. Other sources reveal a shift in product output mix from whole birds to cut-up and deboned poultry packed in bulk containers, traypacks, and further-processed products (table 4-6); more homogeneous poultry meat input mix, i.e., liveweight of single-species birds versus multiple-species birds and unprocessed poultry meat inputs (table 4-2); and less production seasonality in turkeys (table 4-6).

New plants were sometimes built to accommodate broader product lines and faster line speeds, but usually cut-up and deboning, packaging, and, to a lesser degree, further-processing operations were added to existing whole-bird production lines, raising both the cost and value of a single pound of poultry output. These changes are accounted for by including the following variables as plant characteristics (the Z vector in equation 1): bulk output share (BULK), whole-bird output share (WHOLE), poultry meat input mix (BIRD), seasonality of production (SEASON), and single-plant firm status (MULTI).

The failure to account for product mix variables in a cost model leads to a specification error and inaccurate cost estimates. Suppose two plants slaughter the same number of chickens, but one produces traypacks and the other produces whole birds. Both plants will have the same physical quantity of output, and, using the estimated coefficients from a regression not controlling for differences in product mix, will have the same predicted costs. Yet, the traypack plant will hire more workers, carry a larger investment in structures and equipment, use more energy and materials, and, in general, have higher costs than the whole-bird plant because it will conduct more processing per pound of chicken.

Cost-function analysis provides a framework for accommodating differences in product mix by extending the cost function to the multiproduct framework (Baumol, Panzar, and Willig, 1982). In this framework, Q in the cost function is converted to a vector, with pounds of each output represented separately.[16] But since many plants produce zero amounts of some outputs, and logs are undefined at zero, the translog functional form cannot directly be adapted to a multiproduct poultry slaughter model.

Instead, the approach taken is one commonly used in the extensive literature on cost-function estimation for transportation firms (railroads, trucking, airlines, shipping). In that literature, analysts often have simple measures of output, defined in terms of ton-miles (for freight) and passenger-miles for trucking (Allen and Liu, 1995), for airlines (Baltagi, Griffin, and Rich, 1995), and for railroads (Caves, Christensen, Tretheway, and Windle, 1985). But the simple measures can be produced in a variety of ways; for example, costs incurred in producing the same simple output can vary if the transport network goes to many different locations (as opposed to operating only a few through routes) or if the output is shipped in many small deliveries (as opposed to a smaller number of large shipments). Transport cost functions often include measures of route and output characteristics in the cost function in order to capture the effect of network characteristics on costs.

Two product-mix variables are included in the model: bulk output share and whole-bird output share. The use of these variables depended on data availability. Census data contain several broad product classes for each chicken slaughter plant, including wet- and dry-ice broilers and cut-up parts packed in bulk containers, chicken traypacks, other broilers and old hens, roasters and capons, frankfurters and other further-processed products, and nonclassified items. Turkey slaughter

[16] See Morrison (1998) for an approach along these lines. Her data included more precisely defined outputs for a more limited set of plants, as well as a different functional form for cost estimation, and so was better suited to that method.

categories include roaster birds, whole young birds, whole old birds and turkey parts packed in bulk containers, further-processed products, and nonclassified items. Using these data, we defined bulk output share as one minus the combined shares of traypack and further-processed poultry shipments for chicken slaughter and one minus the share of further-processed poultry products for turkey slaughter. These measures were never zero because traypacks and further-processed poultry as shares of total output were never one and thus were always defined (there were no logs of zero). Since the residual of cut-up and deboned poultry and whole birds packed in wet or dry ice in bulk containers divided by total output (bulk output share) requires fewer inputs than traypacks and further-processed products, total costs should drop as bulk output share increases.

Census data do not distinguish between cut-up and deboned poultry (parts) and whole birds packed in bulk containers; yet there was a sharp increase in parts production at chicken slaughter plants over the 1963-92 period (table 2-2), and most of these parts were shipped in bulk to other countries as exports, to retailers and wholesalers for repackaging, or to further-processors for the production of poultry hams, sausages, etc. Since parts production is a more labor-intensive operation than simple whole-bird production, plant costs would likely be biased upward without controlling for it; thus, publicly available annual poultry parts data were used to construct a variable defined as one minus parts share of output.[17] The residual, mainly whole birds, is indistinguishable between plants; thus, two plants are assigned the same whole-bird share if they exist in the same year even if one plant produces almost no parts and the other plant produces almost all parts. Despite this shortcoming, whole-bird share does accommodate the temporal changes in product mix toward greater poultry parts production.

The final regression excludes the quadratic whole-bird share term because it does not vary across plants. The final regression also excludes the interaction of whole-bird share with bulk output share and poultry meat input mix terms because these variables had no effect on model fit.

Several other product mix variables that could either replace or supplement bulk output share were tried. These included one minus byproducts; one minus broiler parts and whole birds packed in wet or dry ice; and, one minus further-processed poultry for chicken slaughter plants. We also tested a measure based on the assumption that the value of shipments per pound of output has a more complex product mix. None of these specifications provided as good a model fit as that obtained with bulk output share. A multiple-product cost function with separate entries for pounds of whole birds, and traypacks and further-processed products (setting zero values to low but positive values) was also tried, but it was rejected because it did not provide as strong a fit as the preferred alternative, and it required the use of arbitrary zero values.

Census data provide information on the types of poultry used as production inputs. This poultry could be in the form of raw, unprocessed poultry input meat or the liveweight of whole chickens or turkeys. Some plants slaughtered both chickens and turkeys, others only chickens or turkeys, and some slaughtered both birds and used raw unprocessed poultry. Differences in poultry meat input mix may cause costs to rise if it means less plant specialization, or it may cause prices to drop if it means less processing effort; thus, we have included the variable BIRD in the model. We did not use liveweight turkey as a share of total poultry input meat for turkey slaughter because it was not significant.

Technological change, permitting increases in line speeds and improvements in other operations, likely reduced slaughter plant costs over time, suggesting the need for time-shift variables. However, the use of annualized whole-bird output share prevents the use of time-shift variables and their corresponding time-varying parameters because there is insufficient model variance due to the presence of two industry-level variables: time shifters and whole-bird output share. Failure to control for industry technological change may bias results, but, since the basic integrator system of production was well-established by 1967 (Bugos), the amount of bias should be modest. Additionally, many of the changes after 1967 came in the form of greater processing at the plant level, as well as faster line speeds, which are accounted for in the bulk output share, whole-bird output share, and production output variables, while changes in prices are accounted for with the factor price terms.

There was a major shift in both the chicken and turkey industries away from single-plant firms to multiplant firms over the 1967-92 period; thus, we included a dummy variable (MULTI) for single-plant firm status. However, since it was not significant to model fit for either turkey or chicken slaughter, it does not enter the

[17] Plant-level data for turkey parts exist only for 1987 and 1992 and, thus, could not be used in the analysis.

final regression equation. There was also a change toward balanced year-round production in turkeys (table 4-2). This change implies that plants were operating their facilities at capacity on a year-round basis by 1992. To account for any effects on plant costs, a seasonality variable (SEASONAL) is included.

Measures of Scale and Scope Economies

The elasticity of total costs with respect to output provides a natural measure of scale economies by showing how costs change as plant size increases. Mathematically, it is defined as the derivative of the cost function with respect to output:

$$\in_{CQ} = \frac{\partial \ln C}{\partial \ln Q} = \gamma_Q + \gamma_{QQ} \ln Q + \sum_i \gamma_{Qi} \ln P_i + \sum_k \delta_{Qk} Z_k + \sum_m \rho_{Qm} T_m \qquad (5.4)$$

where values of the cost elasticity, $\in_{CQ}$, that are less than 1 show scale economies and values above 1 show scale diseconomies. For example, a value of .90 indicates that costs increase by 0.9 percent for every 1.0-percent increase in output (average costs fall as output increases). Because the variables are all divided by their sample means before estimation, the first-order term, δ_Q, can be interpreted as estimated scale economies for plants at the sample mean size.

Equation 5-4 allows the estimated cost elasticity to vary with single-plant firm status, whole-bird output share, time, bulk output share, poultry meat input mix, seasonality, output, and factor prices. The parameter on the lnQ term (γ_{QQ}) shows how the elasticity varies with plant output, and the parameters on the factor price terms show how scale economies vary with factor prices. The other coefficients illustrate how scale economies vary with plant characteristics.

The cost elasticity with respect to changes in bulk output share indicates how changes in bulk output share affect costs, i.e., a 1-percent change in the bulk product output share leads to a corresponding percentage change in costs:

$$\in_{CB} = \frac{\partial \ln C}{\partial \ln B} = \delta_B + \sum_k \delta_{kB} \ln Z_k + \sum_j \delta_{jB} \ln P_j + \delta_{QB} \ln Q + \sum_m \delta_{mB} T_m \qquad (5.5)$$

The first-order term in the cost elasticity, δ_B, provides a direct measure of the effect of increases in the bulk product share of output on production costs at the sample mean. The other terms show how elasticity changes with various firm characteristics (single-plant firm status, whole-bird output share, poultry meat input mix, seasonality, and bulk output share), factor prices, production output, and time. The coefficient on physical output, δ_{QB}, provides a direct estimate of scope economies: negative values suggest that average costs decline as plant size increases for a given bulk output share, and positive values suggest that average costs rise.

Measures of Factor Substitution and Demand

The translog functional form can be used to derive the own- and cross-price elasticities of factor demand and the Allen elasticities of factor substitution. These elasticity estimates allow examination of industry responsiveness to changes in public policy or the industrial environment.

The own-price factor demand elasticity indicates how a given change in the price of factor j affects demand for factor j. A cross-price elasticity shows how a given percent change in the price of factor j affects demand for factor k. A positive sign means that the two factors are complements, and a negative sign indicates that they are substitutes. The Allen elasticity of factor substitution indicates the degree to which a given percent change in factor k can substitute for a percent change in factor j—a higher positive number indicates greater substitutability.

The factor demand own- and cross-price elasticities for any factors i and j are equal to:

$$\in_{jj} = \frac{(\Phi_{jj} + S_j^2 - S_j)}{S_j} \qquad (5.6)$$

and

$$\in_{jk} = \frac{(\Phi_{jk} + S_j S_k)}{S_j} \qquad (5.7)$$

and the Allen partial cross elasticities of factor substitution can be written as

$$\sigma_{jk} = \frac{(\Phi_{jk} + S_j S_k)}{S_i} S_j \qquad (5.8)$$

where the S represents a factor share of the jth or kth factor, and Φ_{jk} is the coefficient on the kth factor price

for the jth factor; it is also the coefficient on the interaction term between the jth and kth factor prices in the cost equation 5.1. The coefficient Φ_{jj} is the coefficient on the jth factor's price in the demand equation for that factor, and it is also the coefficient on the squared factor price term in the cost function. Since predicted factor shares may vary with output, factor prices, and plant characteristics, estimates of equations 5.6-5.8 should use fitted shares at representative data. Reported elasticities should also use representative values, which can vary with data.

Estimation and Tests for Model Selection

The longrun cost function is estimated jointly in a multivariate regression system with the four factor demand equations. Since the factor shares add to one, the capital share equation is dropped to avoid a singular covariance matrix. All dependent and explanatory variables are normalized by their sample means; thus, first-order coefficients can be interpreted as elasticities at sample means. Each equation in the system could be estimated separately by ordinary least squares, but to account for likely cross-equation correlation in the error terms, we used a nonlinear iterative, seemingly unrelated regression procedure.

The translog functional form used to estimate plant costs is a second-order Taylor expansion that is a very general functional form that can be specified in various ways to capture an array of potential cost effects. Different specifications allow for alternative ways in which factors can be combined, and a wide range of options by which input and output mixes can affect costs. A Gallant-Jorgenson likelihood ratio test was used to evaluate whether a selected variable affects production costs. A likelihood ratio test is preferable to single-variable statistical significance because translog cost functions have many interaction terms for each explanatory variable, making any single variable a poor measure of variable importance. Hypotheses are tested by comparing a model containing a variable of interest to a model in which that variable is excluded (the restricted model). If the difference in the Gallant-Jorgenson statistic exceeds a critical value, then the hypothesis that the test variable does not affect costs is rejected.

A number of model variations were examined. Model I excludes all plant characteristics and product mix effects, i.e., their corresponding parameters are zero. The remainder of the models test whether various plant characteristics and time affect plant costs. Model II adds bulk output share and poultry meat input mix to Model I for chicken slaughter and bulk output share and seasonality for turkey slaughter. Model III adds whole-bird share to Model II. This model gives the best fit of the data for both chickens and turkeys. Model IV adds seasonality for chicken slaughter and poultry meat input mix for turkey slaughter to Model III and Model V adds single-plant firm status to Model III. Model VI omits poultry meat input mix for chickens and seasonality for turkeys from Model III; Model VII leaves out bulk output share from Model III. Model VIII adds time shifts to Model II. Time shifts could not be included in Model III because both the time shifters and whole-bird output share are constant across plants in a given year, causing model failure.

We examined homotheticity of Model III with Model IIIB by forcing the model to be invariant to output by setting all ρ_{Qj} coefficients to zero. That is, the model drops the interaction terms between output, Q, and factor prices, the P vector.

Data and Variable Definitions

Table 5-1 provides definitions of model variables. All data except the whole-bird output share term come from Bureau of the Census microdata from the 1967-92 Census of Manufactures. Explanatory variables include factor prices (labor, poultry meat input, other material, and capital) and plant output. To these standard explanatory variables we add bulk output share, poultry meat input mix, seasonality, whole-bird share, single-plant firm status, whether the plant is part of a multiplant firm, and time-shift variables.

Labor, poultry meat input, and other material factor prices are defined in a conventional fashion. According to Allen and Liu (1995), capital costs are defined as the opportunity costs of investing in plant and equipment. This definition is imperfect because existing machinery and building costs are reported at book, rather than real, values. Additionally, capacity is a measure of full capacity; yet, it is unlikely that all establishments are producing at full capacity for all years.

Whole-bird output share is defined as one minus the industry bird parts production as a percent of total industry production. Costs should drop as the percentage of whole birds rises because there are fewer processing requirements per pound of poultry for whole birds than for bird parts.

Bulk output share in chicken slaughter is defined as one minus the share of chicken traypacks and further-

processed products. An increase in its value suggests a less complex finishing operation in which plants slaughter chickens and pack them as either whole birds or parts in bulk containers. Bulk output share in turkey slaughter is defined as one minus further-processed turkey products and includes turkey whole birds, parts, and byproducts. An increase in bulk output share should reduce costs because it implies a change to a less complex production operation.

Poultry meat input mix is liveweight chicken as a percent of all liveweight poultry and pounds of unprocessed poultry for chicken slaughter and liveweight turkey as a percent of liveweight poultry and pounds of unprocessed poultry for turkey slaughter. The closer poultry meat input mix is to one, the more likely the plant specializes in the use of its primary poultry meat factor (the slaughter of either chickens only or turkeys only).

Seasonality is defined as total number of employees in the first quarter of the year divided by the total number of employees in the fourth quarter of the year and is used to control for seasonal variation in output, such as the demand for turkeys at the end of the year. As this percentage rises, production becomes less seasonal (it never goes beyond approximately 1.0).

Seasonal plants may require excess plant capacity and/or excess grower capacity to accommodate their needs. Capital investment for these plants is largely for capacity to satisfy the end-of-the-year holiday season and the plants sit idle during much of the year.[18]

[18] Capital costs may not be larger for a seasonal plant than for a year-round plant because these nonseasonal plants must produce non-whole-bird products during the first quarter of the year, meaning that they may have higher capital costs due to additional processing machinery.

Table 5-1: Cost function variable definitions

Independent variables	
PLAB	price of labor = (total plant labor costs) / (total employees)
PMEAT	poultry meat input price = (liveweight poultry costs + unprocessed poultry meat input costs) / (liveweight poultry pounds + unprocessed poultry meat input pounds)
PMAT	cost of other material inputs = (energy costs + packing and packaging cost + other material costs) / (pounds of liveweight poultry + pounds of unprocessed poultry)
PCAP	price of capital = (OPPORTUNITY + NEW) / CAPACITY, where OPPORTUNITY = (machinery rental price) * (machinery book value) + (building rental price) * (building book value); NEW is the cost of new machinery and buildings; CAPACITY is buildings and machinery book value minus all retirements. Machinery (Building) rental prices (Bureau of Labor Statistics) are costs per dollar of machinery (buildings) expenditure.
Q	output of poultry products, in thousands of pounds
BULK	bulk output share = 1 - TRAYPACK% - PROCESSED% for chicken and 1 - PROCESSED% for turkey. TRAYPACK% = (pounds of chicken traypacks) / (pounds of total poultry shipments) and PROCESSED% = (pounds of further-processed poultry, such as poultry sausages) / (pounds of total poultry shipments)
BIRD	poultry meat input mix = (liveweight chicken pounds) / (liveweight poultry pounds + unprocessed poultry pounds) for chicken and (liveweight turkey pounds) / (liveweight poultry pounds + unprocessed poultry pounds) for turkey.
SEASON	seasonality = ratio of first quarter total employees to fourth quarter total employees
WHOLE	whole-bird output share = 1 - (pounds of cut-up and deboned poultry) / (industry pounds of production)
MULTI	one for single-plant firms and zero otherwise. Shows shift for ownership type.
TIME	one in Census year i and zero in other years for all Census years 1972-87 for chicken, and 1967-87 for turkey; 1992 is suppressed, making all results in the context of 1992 values.
Dependent variables	
COST	sum of labor, meat, materials, and capital factor costs
LABOR%	(salary and wages + supplemental labor costs) / COST
MEAT%	(purchased poultry costs + packed meat costs) / COST
MAT%	(energy costs + packing and packaging cost + other material costs) / COST
CAPITAL%	(OPPORTUNITY + NEW) / COST. See above for definitions.