Chapter 5

Analyzing Packer Costs

The Model

Dramatically increased concentration in cattle slaughter (and increased concentration in hog slaughter) has coincided with the ascendance of large plants in each industry. This suggests that new scale economies may have emerged and driven the increase in concentration. For scale economies to drive consolidation, they must adhere through a range of plant sizes, and not simply appear among very small plants. Moreover, for scale economies to drive increases in concentration, technological change should be scale-increasing—the largest plants should have cost advantages in the 1990's that are larger than those observed in the 1960's and 1970's.

Increased concentration in cattle and hog slaughter occurred along with other developments. Cattle plants moved toward fabrication of carcasses into boxed beef, while hog plants moved from extensive further processing (into hams, sausages, and the like) toward slaughter and simple fabrication. Since fabrication raises plant costs and alters input demands, cost analyses need to take account of product mix. More important, as larger plants often do more fabrication, any analysis of scale economies needs to take account of product mix.

Finally, real wages fell from 1977 to 1992, while wage premiums paid by large plants disappeared. We aim to estimate the effects of wage changes on costs, and so need to separately identify the effects of changes in scale economies and relative wages on large plant costs.

We need a statistical cost model that will allow us to estimate the extent of scale economies over a wide range of plant sizes, and that allows us to identify scale-increasing technological change. The model should identify the effects of factor price changes on costs, and should allow the effects of scale, factor prices, and product mix to change through time.

A Functional Form for Cost Estimation

For our purposes, we need to estimate a statistical cost function that:

(1) estimates the effect of plant scale on costs, and allows the effect to vary with plant size;

(2) estimates the effects of product and input mix on costs;

(3) identifies the effects of input prices on cost, allowing those effects to vary with plant size; and

(4) allows the above effects to vary over time as a way to capture technological change.

We chose a functional form that is widely used in empirical analyses of costs—the translog cost function. The translog is defined as follows:

$$\begin{aligned} \ln C = {} & a_0 + \sum b_i \ln P_i + (\tfrac{1}{2}) \sum \sum b_{ij} \ln P_i \ln P_j \\ & + g_1 \ln Q + (\tfrac{1}{2}) g_2 (\ln Q)^2 + \sum g_{li} \ln Q \ln P_i \\ & + \sum d_k \ln Z_k + (\tfrac{1}{2}) \sum \sum d_{kl} \ln Z_k \ln Z_l \\ & + \sum \sum d_{ik} \ln P_i \ln Z_k + \sum d_{lk} \ln Q \ln Z_k \\ & + \sum a_n T_n + \sum \sum a_{in} \ln P_i T_n + \sum a_{\ln} \ln Q T_n + \sum \sum a_{kn} \ln Z_k T_n \end{aligned} \quad (5\text{-}1)$$

where C is total cost, the P_i are factor prices (in this case, labor, animal and meat materials, other materials, and capital), Q is output, Z represents other plant characteristics, and T is a set of dummy variables for each census year (with 1992 as the base). All continuous variables are transformed to natural logarithms.

We observe slaughter plants operating in 1963, 1967, 1972, 1977, 1982, 1987, and 1992. The model allows for technological change by adding interaction terms between each first-order parameter and each of six different dummy variable (one for each year, with 1992 as the base). In the final form of the cost function, we used 4 factor prices, 3 Z variables, and 1 output variable, so that allowing for time-varying parameters added 48 new parameters to the model.

The translog is a flexible functional form that allows for many possible production relationships, including varying returns to scale, nonhomothetic production (that is, optimal input ratios that vary with the level of output), and nonconstant elasticities of input demand. One can estimate the cost function directly, but parameter estimates are often inefficient because of multicollinearity among the variables on the right-hand side. Gains in efficiency can be realized by estimating the optimal, cost-minimizing input demand, or cost-share equations jointly with the cost function. The equations are derived directly from the cost function as the derivatives of total cost with respect to each input price, and share parameters with the cost function:

$$(\partial \ln C)/(\partial \ln P_i) = (P_i X_i)/C = b_i + \sum b_{ij} \ln P_j + g_{li} \ln Q + \sum d_{ik} \ln Z_k + \sum a_{in} . T_n \quad (5\text{-}2)$$

Because we follow standard practice and normalize all variables (dividing them by their mean values before estimation), the first-order terms (the β_i) can be interpreted as the estimated cost share of input i at mean values of the right-hand variables; the other coefficients capture changes in the estimated factor share over time, and as factor prices, output, and plant characteristics move away from their mean values.

Some restrictions can be imposed on the estimating equations in order to gain further improvements in efficiency (Berndt, 1991). For the cost function to be homogeneous of degree one in prices, the following restrictions must hold:

$$\sum b_i = 0, \quad \sum b_{ij} = \sum g_{li} = \sum d_{ik} = \sum a_{in} = 0 \quad (5\text{-}3)$$

The restrictions reduce the number of parameters that must be estimated, since they imply that some parameters can be derived from combinations of others. Similarly, symmetry is also imposed on the model; under symmetry, the coefficients on all interaction terms with identical components are equal (that is, the coefficients $\beta_{ij} = \beta_{ji}$, and $\delta_{kl} = \delta_{lk}$, for all i,j and all k,l).

We estimate the longrun cost function jointly in a multivariate regression system with the four share equations. Since factor shares sum to one, we dropped the capital share equation to avoid a singular covariance matrix. Each equation could be estimated separately by ordinary least squares, but in order to take account of likely cross-equation correlation in the error terms, we follow standard practice by using a nonlinear iterative seemingly unrelated regression procedure.

Measuring Output

Modern slaughter plants produce many products. Our Census data for cattle slaughter plants define several product categories, including carcasses, hides, boxed beef, ground beef, and byproducts. Each category is itself an aggregate—carcasses may be whole or in halves or quarters, and boxed beef may come in a variety of different cuts.

Multiple outputs create challenges for cost analysis. Suppose two plants slaughter the same number of cattle, but one operates a fabrication line while the other produces only carcasses. They will produce the same physical quantity of output, and so a single product cost function will give them the same output level. But the fabrication plant will hire more workers, carry a larger investment in structures and equipment, and use more energy and materials than the carcass-only plant; it will have higher costs because it will be performing more processing of the carcass. The failure to account for product mix will, in this case, leave some variation in costs unaccounted for. But suppose that the plant that fabricates is also larger, in that it handles more cattle—typical for the modern slaughter industry. Then we may observe higher costs per steer at the larger plant—that is, apparent diseconomies of scale, driven by a failure to account for the different mix of products at the larger plant.

To include multiple products in the cost function, we could simply convert Q in the cost function to a vector, with pounds of each output represented separately in the vector.[17] But since many plants in the data set produce zero amounts of some outputs, and logs are

[17] 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.

undefined at zero, the translog functional form cannot directly be adapted to the multiproduct approach.

Instead, we followed an approach that is commonly used in the extensive literature on the estimation of cost functions 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 (examples include Allen and Liu, 1995, for trucking; Baltagi, Griffin, and Rich, 1995, for airlines; Caves, et al., 1985, for railroads). But the simple measure can be produced in a variety of ways; for example, cost incurred in producing the same simple output can vary if the transport network routes to many different locations (as opposed to a operating a few through-routes) or if the output is produced 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.

We define a single output, pounds of meat produced, but we then add output characteristics to the equation (this is where the Z vector comes from). Our final equation includes a measure of product mix. For cattle, this is defined as one minus the share of carcass shipments in the value of a plant's output. The measure is always defined in the translog, because carcass shipments are never 100 percent of output (byproducts are always positive). Hide and byproduct shipments are nearly constant shares of total output, because they are produced in close to fixed proportions to the number of cattle slaughtered. As a result, the measure varies primarily in proportion to the share of boxed beef in a plant's output; increases in boxed beef mean declines in the share of carcass output. As the cattle product mix variable increases, we ought to see increases in total cost.

Our measure of product mix for hogs was one minus the share of processed products (sausage, hams, etc.) in output. This measure will again always be defined in the translog, as processed product never takes up all of output. This is an inverse measure of processing, and costs should fall as the measure increases.

Each of these choices represents the best fitting option, after some experimentation. We tried several different measures of product characteristics (such as one minus boxed beef). We also tried a multiple-product cost function, with separate entries for pounds of carcass and pounds of boxed beef (setting zero values to low but positive values). But that form did not provide as strong a fit as our preferred alternative, and we preferred not to insert arbitrary values into our model. Finally, we also tried a measure based on the relative value of output, with those plants obtaining a higher value of shipments per pound of output in any year assumed to have a more complex product mix. All product mix and multiple-product measures gave similar qualitative results, but our final choice provided a better fit to the data and a more direct interpretation.

Our final estimating equation includes two other variables in the Z vector, a measure of input mix and a dummy variable for single-plant firms. The measure of input mix is the share of live animals (primarily cattle and hogs) in combined live animal and purchased meat input costs. Some slaughter plants purchase carcasses and other meats from other slaughter plants to supplement their own slaughtered carcasses as inputs to fabrication lines. Plants with significant amounts of purchased meat may have different cost structures than plants that purchase no meats, because those plants will do proportionately more fabrication and less slaughter.

Measures of Scale and Scope Economies

The estimated cost function yields a natural measure of scale economies, the elasticity of total cost with respect to output, Q:

$$\in_{CQ} = (\partial \ln C)/(\partial \ln Q) = g_1 + g_2 \ln Q + \sum g_{li} \ln P_i + \sum d_{lk} \ln Z_k + \sum a_{\ln} T_n \qquad (5\text{-}4)$$

Values of the cost elasticity, $\in_{CQ}$, that are less than 1 indicate economies of scale. For example, a value of 0.90 indicates that costs increase by 0.9 percent for every 1.0-percent increase in output (in turn, average costs fall as output increases). Values in excess of 1 show diseconomies of scale. Because the variables are all divided by their sample mean values before estimation, the first-order term, γ_1, can be interpreted directly as the 1992 estimate of scale economies for plants at the sample mean size.

Equation 5-4 shows the value of a flexible functional form for our purposes, because it allows the estimated cost elasticity to vary with changes in output, factor prices, plant characteristics, and time. The parameters on the interaction terms between Q and years (the α_{1n}) show how the mean cost elasticity changes through time, while the parameter on the the ln Q term (γ_2) shows how the elasticity varies as we move away from the mean plant size to larger or smaller plant sizes. Finally, the other coefficients allow the estimated degree of scale economies to vary with factor prices and other plant characteristics.

We can also define a cost elasticity with respect to changes in product mix. Define Z_p as our measure of product mix in cattle plants (one minus the share of carcasses). Then the product mix parameter is:

$$\in_{CZp} = (\partial \ln C)/(\partial \ln Z_p) = d_p + \sum d_{kp} \ln Z_k + \sum d_{ip} \ln P_i + d_{ip} \ln Q + \sum a_{pn} T_n \quad (5\text{-}5)$$

The first-order term in the cost elasticity, δ_p, provides a direct measure of the effect of increases in boxed beef production on costs in 1992, given the physical volume of output, at sample means for all variables. The interaction terms on T (the time periods) show how that elasticity changes as one moves back in time, while the coefficients on the Z interaction terms show how the product mix elasticity varies as product mix, input mix, and ownership type vary. Finally, the coefficient on physical output, δ_{1p}, provides a direct estimate of scope economies. Positive values indicate that expanding product mix is more costly, per pound, in larger plants than in small, while negative values indicate that expanding product mix is less costly in larger plants than in smaller plants.

Measures of Input Substitution and Demand

The translog functional form can be used to derive measures of substitution elasticities among inputs, as well as measures of own-price and cross-price input demand elasticities. Some models assume a particular structure of input demand in slaughter industries; for example, "value-added" cost function models assume that there is no substitution between animals and other inputs in the production of meat. Our specification allows us to test that assumption.

How is it possible to substitute other factors for animals in the production of meat? Of course, at any one plant, purchased carcasses can be substituted for animals in the fabrication process. But even without purchasing carcasses, yields—the amount of meat produced from a carcass of a given size—do vary across animals, plants, and time, and some of that variation may be systematic, due to more intensive use of labor, machinery, and other materials. On the other hand, variation in yields does not necessarily imply that variations in input prices were driving variations in input substitution. That is an empirical issue, and translog parameter estimates allow us to test for the actual existence of substitution, and to estimate its extent.

Substitution among labor, capital, and materials is more likely, and the translog estimates will allow us to identify the extent of substitution among those inputs, and to estimate price elasticities of input demand. In turn, those estimates can be used as parameters in models that aim to simulate the response of the industry to changes in public policy or the industrial environment.

The Allen partial elasticities of input substitution for any inputs i and j, as derived from the translog function, are equal to:

$$s_{ij} = (g_{ij} + S_i S_j)/(S_i S_j), \quad (5\text{-}6)$$

while price elasticities of input demand can be written as:

$$\in_{ij} = (g_{ij} + S_i S_j)/S_i \quad (5\text{-}7)$$

and

$$\in_{ij} = (g_{ii} + S_i^2 - S_i)/S_i \quad (5\text{-}8)$$

where the S's are the factor shares of the ith and jth inputs, and γ_{ij} is the coefficient on the jth input price in the demand equation for the ith input (equation 5-2); it is also the coefficient on the interaction term between the ith and jth factor prices in the cost equation (5-1). The coefficient γ_{ii} is the coefficient on the ith input's price in the demand equation for that input, and is also the coefficient on the squared input price term in the cost function. Because, according to equation 5-2, predicted factor shares will vary with output, time, factor prices, and plant characteristics, estimates of equations 5-6 to 5-8 should use fitted shares at representative data values, and reported elasticities are also representative values, which can vary with the data.

Data and Variable Definitions

Table 5-1 provides definitions for the variables in the translog longrun cost functions estimated for cattle and for hogs. All data are derived from the LRD files of the 1963-92 Census of Manufactures. Explanatory variables include input prices (labor, animals and meat, other material, and capital) and plant output. To these standard explanatory variables, we add product mix, input mix, time shifts, and establishment type variables.

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

Product mix (PMIX) in cattle slaughter is defined as one minus the share of carcasses in total physical output; if the weight of hides and other byproducts can be thought of as varying in fixed proportions with total plant slaughter, then this measure should vary largely with variations in boxed beef production. The product mix variable in hog slaughter is one minus the quantity share of processed products (such as hams and sausages). Increases in this measure reflect shifts to less complex processing, and should result in lowered costs.

Table 5-1—Cost function variable definitions

Independent variables	
PLAB	Price of labor = (total plant labor costs) / (total employees).
PMEAT	Price of meat inputs = (purchased animal costs + packed meat costs) / (pounds of live animal meat inputs + pounds of packed meat inputs).
PMAT	Price of other material inputs = (energy costs+packing and packaging cost + other material costs) / (pounds live animal meat inputs + pounds packed meat inputs).
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. Note, machinery rental price is the industry-level cost per dollar of machinery expenditure; building rental price is industry-level cost per dollar of building expenditure.
Q	Output of meat products, in thousands of pounds.
PMIX (cattle)	Product mix: (1 - CARCASS%), where CARCASS% = (pounds of carcass shipments) / (total pounds of meat shipments).
PMIX(hogs)	Product mix: (1 - SAUSAGE%), where SAUSAGE% = (pounds of sausage and ham products) / (total pounds of meat shipments).
IMIX (cattle)	Input mix: (1 - CATTLE%), where CATTLE% = (pounds of live cattle meat inputs) / (total pounds of meat inputs).
IMIX (hogs)	Input mix: (HOGS%), where HOGS% = (pounds of live hog meat inputs) / (total pounds of meat inputs).
ESTAB1	One for single-plant firms and zero otherwise. Shows shift for ownership type.
Dependent variables	
COST	Sum of labor, meat, materials, and capital input costs.
LABOR%	(Salary and wages + supplemental labor costs) / COST.
MEAT%	(Purchased animal costs + packed meat costs) / COST.
MAT%	(Energy costs + packing and packaging cost + other material costs) / COST.
CAPITAL%	(OPPORTUNITY + NEW) / COST. See PCAP above for definitions.

Input mix measures (IMIX) also vary between cattle and hog models. In cattle, the measure is one minus the quantity share (in pounds) of cattle in total animal and meat inputs; that measure will move closer to one as the plant purchases more carcasses from other plants, or as it slaughters other species in addition to cattle. In hogs, the measure is simply the quantity share of hogs in animal and meat inputs, and will move closer to one as the plant specializes more in hog slaughter and purchases fewer carcasses.

Comparison to Other Econometric Models of Slaughter Industries

Our model differs in important respects from four other extant estimations of slaughter cost functions for cattle and hogs. In chronological order, the four are Ball and Chambers (1982), whose model covered the meat products sector for 1954-76; Melton and Huffman (1995), who analyzed costs in cattle and hog slaughter (separately) over 1963-88; Kambhampaty et al. (1996), who estimated a shortrun variable cost function using weekly data for 16 large cattle slaughter plants in 1992; and Morrison (1998), who used the same data source as Kambhampaty et al., to estimate a shortrun variable cost function using monthly data for 42 plants in 1992.

Four features combine to distinguish our study and allow us to investigate some issues that other studies cannot: (1) disaggregated plant-level data covering a wide range of plant sizes; (2) annual observations on plants covering census years between 1963 and 1992; (3) physical measures of output and measures of product and input mix; and (4) a translog specification that allows for technological change by allowing parameter values to shift over census years.

Ball and Chambers (1982) and Melton and Huffman (1995) each use samples that consist of annual time series observations on industry aggregates—for Ball and Chambers, the aggregate is all red meat slaughter and processing. As Ball and Chambers point out, it is quite difficult to disentangle economies of scale from technological change in aggregated time series models. Indeed, each reports estimates of economies of scale that jump very sharply from year to year. Kambhampaty et al. (1996) and Morrison (1998) use data on a relatively small number of large plants, observed at frequent intervals within a year. That data set is better suited to the analysis of pricing and capacity utilization than to economies of scale and technological change.

We contend that changes in product and input mix have been an important feature of technological change in the industry. For example, differences in boxed beef output across plants or over time will affect costs, and omission of a product mix measure will strongly affect estimates of scale economies if product mix is associated with plant size (as chapter 3 strongly suggests). Of the studies mentioned above, only Morrison (1998) accounts for differences in product mix. Kambhampaty et al. rely on a single-product output measure (chilled carcass weight), although the plants in the study produce sharply varying product mixes.[18] The two earlier studies do not control for temporal changes in product mix; chapter 3 shows that such changes were substantial in the periods under study, and correlated with growth in plant sizes.

[18] They do provide separate estimates for plants that specialize in carcass production and those with fabrication capability, but this approach limits the size of their already small sample of plants, and ignores the large differences in fabrication output among fabrication plants.