## Chapter 6

# Cattle Slaughter Cost Estimation

We use the cost model to analyze costs at cattle slaughter plants. The data cover Census cattle slaughter plants reporting in the years 1963, 1967, 1972, 1977, 1982, 1987, and 1992, and include a total of 2,541 useable plant observations over the 7 census years.[19] Our primary goals are to identify the extent of scale economies in slaughter, to determine whether scale became more important over time, and to estimate the effect of product mix on plant costs.

## Model Selection

The translog is a general functional form that can be specified in different ways to capture many potential cost effects. Alternative specific forms can allow for changes in cost relationships through time, for different ways in which inputs may be combined, or for different ways in which input and output mix can affect costs. We were not certain of the best form prior to estimation. Model selection tests help to choose the best fitting model among specific functional forms.

Tables 6-1 and 6-2 summarize the set of specific models, and the results of the Gallant-Jorgenson (G-J) tests used to distinguish among them. We began with the most restrictive (I), a translog cost function with four factor prices (labor, capital, animal, and material inputs) and the physical volume of output, but with no measures for input or output mix and no time shifters. It is restrictive in the sense that it imposes the assumptions that input and output mix have no effect on costs and that coefficients do not change through time (no technological change).

Model II adds input and product mix measures but not time shifters; model I is decisively rejected in favor of model II (table 6-2)—input and product mix measures provide statistically significant improvements in fit. Model III adds time shifters to model II; each first-order coefficient is allowed to take on different values in different census years. Model III adds 42 new parameters to be estimated (6 new years times 7 variables); G-J tests again favor the less restrictive model (III) over model II.

Model IV adds a dummy variable for single-establishment firms, and yields a statistically significant (though small) improvement in fit over model III. Models IVa and IVb impose new restrictions on model IV. Model IVa drops variables involving input mix, but that model is rejected; input mix variables, while individually not significant, together provide a statistically significant improvement in fit. Finally, model IVb imposes homotheticity, by eliminating the interaction terms between factor prices and output volume (forcing factor shares to be invariant with respect to output). J-G tests reject homotheticity, and Model IVb, in favor of model IV. The best fitting model (IV) shows the importance of input and product mix, and technological change in determining cattle slaughter costs.

## Summary of the Best Model

Because of the large number of estimated coefficients in model IV, we have organized them into two tables. Table 6-3 reports first-order coefficients for 1992 and changes in those coefficients in earlier years compared with 1992. Because all variables were standardized on their means before estimation, first-order coefficients can be read directly as estimated elasticities at the sample mean. Table 6-4 repeats the 1992 first-order coefficients and coefficients for the quadratic and interaction terms, showing how estimated elasticities vary as one moves away from sample means.

Consider factor price effects. First-order coefficients in table 6-3 can be interpreted as factor shares at sample mean data values. Animal and meat inputs (in this sample, almost all animal) account for over 83 percent of plant costs in 1992, while labor (PLAB) and other materials (PMAT—primarily packaging) are each less than 10 percent. The animal input share fell over time,

[19] As is common with analyses of Longitudinal Research Data (LRD) files, we deleted observations on very small plants that did not report all data, and some other observations with clear reporting errors.

**Table 6-1—Cattle slaughter cost function models, by goodness of fit**

| Model | Description | G-J statistic | Parameters estimated |
|---|---|---|---|
| I | Translog, factor prices and output only | 8324 | 15 |
| II | Adds product and input mix to I | 8252 | 28 |
| III | Adds first order time shifts to II | 7827 | 70 |
| IV | Adds single-establishment dummy to III | 7799 | 77 |
| IVa | Drops input mix variables from IV | 7855 | 58 |
| IVb | Imposes homotheticity on IV | 7820 | 74 |

Source: Authors' estimates, based on models and data described in text.

**Table 6-2—Tests of model selection, cattle slaughter cost function**

| | Test statistics[1] | | |
|---|---|---|---|
| Comparison | d.f. | Critical value@ 99 | Chi-square |
| II vs. I | 13 | 27.69 | 72 |
| III vs. II | 42 | 66.18 | 425 |
| IV vs. III | 7 | 18.48 | 28 |
| IV vs. IVA | 19 | 36.19 | 56 |
| IV vs. IVB | 3 | 11.34 | 21 |

[1] Chi-square statistics are the difference in G-J statistics in models reported in table 6-1. Degrees of freedom (d.f) are the differences in the number of estimated parameters.

Source: Authors' estimates, based on models and data described in text.

from just over 86 percent in 1977, while capital's (PCAP) grew substantially from a small base. Labor and material shares showed hardly any change.

Because factor shares must sum to one, we left capital out of the estimating equation, and recovered its value as 1 minus the sum of the other three factors. Using that approach, capital's share (PCAP) is less than 1 percent in 1963 and over 3 percent in 1992.[20] Estimated capital shares are consistent with Melton and Huffman (1995), who find a mean 1963-88 capital share of 15.6 percent of beef value added, which would equate to a 2.65-percent share of total costs (assuming our mean estimate that cattle purchase costs were 83 percent of total costs).

Many interactions on factor prices (table 6-4) are highly significant, and the coefficients can be used to make inferences about substitution among inputs (table 6-5). In particular, the own-price elasticity of demand for animal and meat inputs, 0.0001, is about as close to zero as one can get in these measures. Given meat output, demand for animal and meat inputs does not change at all as animal prices change. In short, one can feasibly estimate "value added" cost functions on the assumption of separability between animals and other inputs: that is, animal input demand is unresponsive to changes in other factor prices.

The labor demand elasticity is estimated to be -0.294 in 1992, close to the estimate (-0.373) reported by Melton and Huffman (1995) for the mean of their 1963-88 data based on aggregate time series. It is also close to the estimated elasticity of demand for other materials (-0.274), while that for capital is substantially larger (-1.028). Capital and labor appear to be substitutes in production, while substitution and cross-price elasticities between other input pairs is quite low. Table 6-5 also reports factor shares used in the estimation of 1992 elasticities. They are calculated at mean 1992 sample values for other variables, and are therefore different from factor shares in table 6-3, which are calculated at mean sample-wide values for other variables.

The factor share distribution identified here is a distinctive feature of slaughter industries. Rarely does a material input (in this case, cattle) account for such a large share of costs. The large share accorded to cattle inputs suggests that there are some important limits to the effect of slaughter scale economies on costs. The processes that drive scale economies are limited to the cooperating inputs of labor, capital, and other materials, which together make up only a fifth to a tenth of total slaughter costs.[21]

[20] The skewed distribution of factor shares gives rise to some violations of monotonicity conditions. Specifically, predicted factor shares for capital are negative in 9 percent of observations, and "other materials" factor shares are negative for 12 percent of observations. The violations occur primarily among the smallest plants, and early in the period.

[21] Potential scale economies in slaughter plants arise from opportunities to achieve specialization of labor, and from opportunities to apply capital equipment in larger plants. But even if these strategies result in substantial reductions in slaughter and fabrication costs, those costs are small fractions of total plant costs, swamped by animal purchase costs.

**Table 6-3—Cattle slaughter cost function parameters: first-order terms and year shifts**[1]

| Variables | First-order 1992 | Changes from 1992 1963 | 1967 | 1972 | 1977 | 1982 | 1987 |
|---|---|---|---|---|---|---|---|
| | *Coefficients (standard errors)* | | | | | | |
| Intercept | -.2857 | -.0016 | -.0181 | .0224 | .0601 | .0154 | .0487 |
| | (.0288) | (.0324) | (.0318) | (.0325) | (.0321) | (.0333) | (.0350) |
| PLAB | .0816 | -.0054 | .0014 | .0044 | -.0011 | -.0014 | -.0017 |
| | (.0052) | (.0055) | (.0056) | (.0057) | (.0058) | (.0061) | (.0064) |
| PMEAT | .8371 | .0233 | .0125 | .0144 | .0258 | .0148 | .0031 |
| | (.0081) | (.0088) | (.0088) | (.0091) | (.0091) | (.0098) | (.0102) |
| PMAT | .0510 | .0050 | .0087 | .0088 | -.0024 | -.0026 | -.0022 |
| | (.0032) | (.0088) | (.0034) | (.0035) | (.0036) | (.0038) | (.0040) |
| PCAP | .0303 | -.0228 | -.0226 | -.0189 | -.0223 | -.0108 | .0008 |
| | (.0083) | (.0089) | (.0089) | (.0092) | (.0093) | (.0099) | (.0103) |
| Q (lbs) | .9322 | .0370 | .0382 | .0179 | .0109 | .0088 | .0075 |
| | (.0140) | (.0158) | (.0156) | (.0159) | (.0164) | (.0169) | (.0173) |
| PMIX | .0409 | -.0131 | -.0103 | - .0058 | .0114 | - .0086 | .0129 |
| | (.0114) | (.0106) | (.0104) | (.0104) | (.0104) | (.0112) | (.0113) |
| IMIX | .1534 | -.0916 | -.0869 | -.0658 | .0071 | -.0014 | -.2593 |
| | (.1647) | (.1636) | (.1636) | (.1646) | (.1729) | (.1674) | (.1997) |

[1] Results of estimation of translog cost function for cattle slaughter plants, 1963-1992. Since all variables are standardized at their means, first-order coefficients can be interpreted as elasticities at the sample means, while year shifts capture shifts in those elasticities over time.

## Economies of Scale

Equation 5-4 shows how to use estimated coefficients to calculate an elasticity of total cost with respect to output—our measure of scale economies. Recall that it is:

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

Variation in the Z variables (plant characteristics) is too small, when combined with the estimated coefficients (the $\delta_{1k}$), to have any appreciable impact on calculated values for $\in_{CQ}$. Similarly, temporal variation in factor prices has no appreciable effect (the $\gamma_{1i}$ coefficients essentially cancel one another out). As a result, the important coefficents in equation 5-4 are the first-order term, $\gamma_1$, the second-order coefficients on Q ($\gamma_2$), and the time shift coefficients ($\alpha_{1n}$).

In table 6-3, the first-order coefficient for Q is 0.9322 (at the sample mean, a 1-percent increase in output—holding constant factor prices, product mix, and input mix—is associated with a 0.9322-percent increase in total costs). The result implies modest but statistically significant 1992 scale economies; that is, the coefficient is significantly less than 1. The coefficient rises, by increasing and statistically significant amounts, as we move back toward 1963 (table 6-3, row 6), when the cost elasticity was 0.97. Estimated scale economies in cattle slaughter became more important, modestly but steadily, through time.

In table 6-4, the first-order coefficient on Q is repeated in the first column. The coefficient on the interaction of Q with itself (Q squared) is positive and statistically significant: the cost elasticity gets closer to 1 as output gets bigger, but never reaches 1. The largest value for Q is just over 3, in 1992 (recall that we're dividing all variables by their means, and then taking logs). With a 1992 value of the first-order coefficient of 0.93 (table 6-3), the largest 1992 plants generate elasticities of just over 0.96, closer to constant returns than average sized plants, but still within the range of increasing returns to scale. Note that, in 1967 technology, the largest 1992 plants would have exhausted economies of scale, with an estimated value of $\in_{CQ}$ slightly in excess of 1.0 (.9322 + .0382 + [3 *.0105]).

Table 6-6 presents estimated cost elasticities for several representative plant sizes and for two different years.

**Table 6-4—Cattle slaughter cost function parameters: higher order terms[1]**

| Variables | First-order | Interactions with: PLAB | PMEAT | PMAT | PCAP | Q (lbs) | PMIX | IMIX | EST1 |
|---|---|---|---|---|---|---|---|---|---|
| | | *Coefficients (standard errors)* | | | | | | | |
| PLAB | .0817<br>(.0052) | .0380<br>(.0027) | -.0612<br>(.0026) | .0070<br>(.0009) | .0162<br>(.0017) | -.0214<br>( .0008) | .0053<br>(.0004) | -.0167<br>( .0018) | -.0145<br>( .0026) |
| PMEAT | .8371<br>(.0081) | | .1189<br>(.0037) | -.0435<br>( .0011) | -.0142<br>(.0027) | .0265<br>(.0011) | -.0051<br>( .0006) | -.0015<br>(.0028) | .0151<br>(.0041) |
| PMAT | .0510<br>(.0032) | | | .0369<br>(.0006) | -.0004<br>(.0010) | .0013<br>(.0005) | -.0007<br>(.0002) | -.0014<br>(.0011) | .0035<br>(.0016) |
| PCAP | .0303<br>(.0083) | | | | | -.0064<br>(.0012) | .0006<br>(.0006) | .0190<br>(.0024) | -.0041<br>(.0041) |
| Q (lbs) | .9322<br>(.0140) | | | | | .0105<br>(.0031) | -.0023<br>(.0014) | -.0040<br>( .0065) | -.0075<br>(.0077) |
| PMIX | .0409<br>(.0114) | | | | | | .0108<br>(.0017) | -.0001<br>(.0019) | -.0017<br>( .0046) |
| IMIX | .1535<br>(.1647) | | | | | | | .0136<br>(.0077) | .0030<br>( .0249) |
| EST1 | -.0284<br>( .0161) | | | | | | | | |

[1] Quadratic (on diagonal) and interaction terms from estimation of translog cost function. First-order terms from table 6-3 are repeated in first column.

The top row repeats information that can be gleaned from table 6-3, by presenting the estimated scale elasticities for a plant at the sample mean size, calculated for 1992 and 1963. But plants in 1992 were generally much larger, so we recalculate the 1992 cost elasticity for the mean size plant in 1992 and for a relatively large 1992 plant, one at the 95th percentile of the 1992 size distribution of plants reporting to GIPSA (that is, only 5 percent of plants produced more). We also calculate elasticities for the typically smaller plants of 1963, again using the mean and 95th percentile sizes, but this time from the 1963 size distribution.

The largest 1963 plants produced near constant returns (an estimated cost elasticity of 0.98—lower right corner of table 6-6) with 1963 technology. But in 1992 technology, the largest 1963 plants fell noticeably short of constant returns, with a cost elasticity of 0.944. Plants grew dramatically in the period; a large 1992 plant produced five times as much meat as a large 1963 plant (in fact, the large 1963 plant would be below the 1992 mean). Part of that growth probably reflected attempts to realize scale economies. But the large 1992 plant still falls short of constant returns, with a scale parameter of 0.961. That estimate suggests that further consolidation in slaughter is likely.

Indeed, GIPSA data after 1992 show a continuing sharp shift toward the largest slaughter plants. Plants that slaughtered over 1 million cattle accounted for 34 percent of cattle slaughter in 1992 and 63 percent in 1997.

Changes in labor markets reinforced the growing importance of scale economies. Recall that large slaughter plants paid higher wages in the first decade of our study period—as much as 23 percent above the industry average and 33 percent above smaller commercial plants (table 4-8). Given the factor share of labor, that size differential would translate into a large plant cost disadvantage of 1.5 to 3.8 percent, attenuating the advantages of scale. But between 1977 and 1992, the size differential in wages disappeared, adding to the growing advantages of scale.

## Plant Characteristics

In table 6-4, the first-order coefficient on product mix (PMIX, the noncarcass share of plant shipments) is positive and significant, while that on its square is positive and highly significant. Holding output constant, increases in the noncarcass share of output are associated with cost increases. The result is logical since

**Table 6-5—Mean input shares and elasticities, 1992[1]**

| Item | PLAB | PMEAT | PMAT | PCAP |
|---|---|---|---|---|
| | Input price variables | | | |
| Input share | .0587 | .8622 | .0550 | .0301 |
| $\in_{ii}$ | -0.294 | 0.0001 | -0.274 | -1.028 |
| $\sigma_{ij}$ | | | | |
| PLAB | -5.01 | -0.209 | 3.167 | 10.170 |
| PMEAT | | 0.0001 | 0.083 | 0.453 |
| PMAT | | | -4.98 | 0.789 |
| PCAP | | | | -34.10 |

[1] All values are calculated using mean 1992 data values and parameters from tables 6-3 and 6-4. The own-price input demand elasticities ($\in_{ii}$) are calculated holding output and other factors constant, while the elasticities of substitution ($\sigma_{ij}$) are calculated using Allen's formula.

higher values of PMIX imply more fabrication, and therefore more labor, capital, and materials.

For product mix (PMIX), the interaction terms with factor prices are all highly significant (table 6-4, column 7). As the noncarcass share gets larger, the share of costs accounted for by labor gets larger while that accounted for by animals gets smaller, also logical given the value added in fabrication.

We can show the effects of likely changes in PMIX on average costs, with the approach taken above for scale economies. Estimated average costs rise by about 3.2 percent, for a large plant (at the 95th percentile of the size distribution), as the plant goes from minimal to extensive fabrication (from PMIX of 0.38 to 0.90).[22] Finally the negative and marginally significant sign on the interaction of PMIX and output (Q) gives evidence of scope economies—the scale parameter gets smaller (steeper, or further below 1) as PMIX gets larger. But the effect is small: a plant at the 75th percentile of the 1992 size distribution (about a third as large as a plant at the 95th percentile) would incur additional fabrication costs of 3.6 cents per pound in going from minimal to extensive fabrication, compared with 3.2 cents per pound for a plant at the 95th percentile.

Most of the individual coefficients involving input mix (IMIX, the share of animals in meat and animal inputs) are small and not significant, although the G-J tests in table 6-2 favor retaining the measure. There

[22] In turn, average processing costs (value added) would rise by slightly over 30 percent, if animal acquisition costs were 90 percent of the total at the minimal plant and were unchanged as one moves to the extensive plant.

**Table 6-6—Estimated cost elasticity coefficients, by plant size and year[1]**

| Plant size | Technology vintage 1992 | Technology vintage 1963 |
|---|---|---|
| Sample mean | 0.932 | 0.969 |
| 1992 mean | 0.946 | 0.983 |
| 1992 95th percentile | 0.961 | 0.998 |
| 1963 mean | 0.925 | 0.962 |
| 1963 95th percentile | 0.944 | 0.981 |

[1] The coefficients report the percentage change in total costs corresponding to a 1-percent change in output, for plants of differing sizes and technological vintages.

are three exceptions. The coefficient on IMIX squared is small but positive and statistically significant, suggesting that costs increase as the animal share increases above its mean, given output. The coefficient on the interaction term with the price of labor is negative, while that on capital is positive, with each highly significant. Labor shares are lower, and capital shares are higher, in plants that use higher ratios of animal to meat inputs.

Tables 6-3 and 6-4 also show that, all else equal, single-establishment firms have lower costs, as well as slightly different input shares (higher shares of animals and materials, and lower labor shares). Interpretation is difficult here—the coefficients could be picking up differences in accounting techniques; differences in product mix, input mix, or scale that our model does not capture; or real efficiency differences. Because these results are hard to interpret, we look at single-establishment variables as control measures, and other coefficients are not affected by their inclusion.

Finally, consider changes in the model's intercept over time, in table 6-3. None of the coefficients are significant, and they show no consistent sign pattern. By implication, there are no temporal changes in slaughter costs that are not picked up by movements in factor prices, scale, and product mix effects. This suggests that much of the cattle slaughter industry's productivity growth is accounted for by scale economies, either through changes in the estimated scale parameter or through increases in plant size to take advantage of scale economies.

## What Do Other Studies Find?

Our findings for scale economies conflict with Ball and Chambers (1982) and with Melton and Huffman

**Table 6-7—Comparing size-cost estimates in cattle slaughter**

| Head/year | Cost/head, including cattle acquisition W&S[1] | D&N | Census | Cost/head, slaughter & fabrication only W&S | D&N | Census |
|---|---|---|---|---|---|---|
| | | | *Index* | | | |
| 175,000 | 102.3 | 101.4 | 104.3 | 116.9 | 111.2 | 130.7 |
| 300,000 | 101.2 | 100.6 | 101.5 | 109.3 | 104.3 | 110.7 |
| 425,000 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 850,000 | 98.7 | 98.4 | 97.9 | 90.4 | 87.1 | 85.0 |
| 1,100,000 | 97.7 | 98.0 | 97.3 | 82.6 | 84.4 | 80.7 |
| 1,350,000 | 97.5 | 98.0 | 97.0 | 81.3 | 84.4 | 78.6 |

[1] "W&S" refers to estimates of Ward (1993), derived from Sersland; "D&N" refers to estimates derived from Duewer and Nelson (1991); "Census" refers to estimates derived from tables 6-3 and 6-4. In order to protect the confidentiality of Census data, the data are presented as index numbers, with 425,000 set to 100.

(1995). Each reports cost elasticities that range substantially above and below 1, with large economies of scale in some years and diseconomies in others. Ball and Chambers estimate a value-added cost function using annual data for the entire meat products sector (SIC 201). They report cost elasticities for the early 1970's, and find scale economies that are substantially larger than those reported here. Moreover, their estimates vary, as they report substantial diseconomies of scale for 1971. Melton and Huffman estimate a value-added cost function using aggregated annual data for beef and pork slaughter separately. They report economies of scale for 1975, and very large diseconomies of scale for the 1980's.

Each study used highly aggregated data that afforded limited opportunities to distinguish among capacity utilization, technological change, and the realization of scale economies, and neither attempted to control for changes in product and input mix over the period. Since large plants led the move to greater fabrication in beef (table 4-1), those plants would have begun to incur higher average costs per head than smaller slaughter-only plants, and analyses that fail to control for product mix would likely report evidence of diseconomies.

Kambhampaty et al. (1996) and Morrison (1998) estimate shortrun variable cost functions, and those data sets are poorly suited to estimation of longrun scale economies. Each finds important shortrun increasing returns to scale, in that average costs decline as output increases at plants within the year. In that respect, they support the assertions of Ball and Chambers (1982) and Ward (1990)—that capacity utilization is an important element in average costs at cattle slaughter plants.

Our findings on economies of scale are quite similar to the estimates reported for the simulation models of Duewer and Nelson (1991) and of Ward (1993), who reports the work of his student, Sersland (1985). The simulation models differ from our econometric model in one major respect: while our econometric estimates are based on the statistical estimation of cost functions using operating data from many plants, simulation models rely on idealized operations across a few standardized plant types. Sersland obtained her data from a mail survey of managers, who provided her with cost estimates for several specified plant types, while Duewer and Nelson constructed an engineering-economic model of costs at specified plant types, by building up from specified activities, input quantities, and input prices.

In table 6-7, we calculate indexes of average cost (per head), based on the data in Ward and in Duewer and Nelson, and compare them to calculations based on the models and data underlying this report. We separately report indexes for slaughter cost, which excludes purchase expenses for animals, and total cost, which includes animal expenses. All estimates were converted to index numbers to preserve Census confidentiality. Index numbers reveal no actual cost estimates, but show how estimated average costs change as plant size varies.[23]

[23] We can use our model to estimate costs per head for a hypothetical plant. We first estimate the 1992 animal share of total costs for a large plant (1.1 million head annually, or 300 head per hour in a two-shift-per-day plant operated 40 hours per week). Then, using our census data for the mean 1992 animal factor price, we calculate total cost per pound and subtract the animal cost from that to get slaughter/fabrication cost per pound. We then multiply by the 1992 average meat yield (701 pounds) to estimate a cost per head. The resulting estimate, $59 per head, compares with D&N's estimate of $60 dollars per head at a similarly sized plant and Sersland's estimate of $55 (Ward, 1993). Our analysis is based on

We began with Ward, who derives a set of annual slaughter volumes from typical combinations of hourly slaughter speeds and daily shifts (the three smaller plants are assumed to operate single shifts, with correspondingly smaller investments in storage capacity, while the three larger plants are designed to operate two daily shifts). Each simulated plant performs slaughter and fabrication functions. For each simulated plant, we took Ward's slaughter/fabrication cost estimates, and then converted them to index numbers with his midpoint plant (425,000 head per year) set to 100.[24] To convert Ward's slaughter cost indexes to total cost indexes, we then made two assumptions about cattle prices: that cattle costs account for 86 percent of total costs at Ward's midpoint plant (consistent with the 1992 Census mean) and that all plants pay the same cattle prices. With those assumptions, we can derive an estimated cattle price from Ward's data, and then simply add that price to average slaughter fabrication costs to get average total costs.

Duewer and Nelson's size categories do not match up exactly to Ward's. For comparison, we interpolated average costs between Duewer and Nelson's output levels to get to costs for Ward's output levels.[25] We added in the estimated cattle price to get to total costs, and converted Duewer and Nelson's estimates to index numbers, with average costs at an output of 425,000 head set to the base of 100.

We next calculated a total cost index for our model, first converting our output measure (pounds of meat) to cattle numbers with the Census mean meat yield of 701 pounds per animal. We estimated total and average costs for a plant with output corresponding to 425,000 head per year, and set its index to 100. Finally, we used our estimated cost function to project how total and average costs would vary with output, holding other variables constant at 1992 means.

Average total costs fall with plant size in each model, but the declines are very modest (table 6-7). In particular, as we move to the largest plant from the midpoint plant, average total costs per head fall by 3.0 percent in the Census model, 2.5 percent in Ward, and 2.0 percent in Duewer and Nelson. Average total costs rise more sharply in the Census model as we move toward smaller plants from the midpoint plant (a 4.3-percent rise vs. 2.3 percent in Ward and 1.4 percent in D&N), suggesting more severe diseconomies of small scale.[26]

Average costs for slaughter/fabrication alone fall by around 20 percent from midpoint to largest plant (Census reports a 22.4-percent decline, compared with 18.7 percent for W&S and 15.6 percent for D&N). This comparison also points up one area of difference—the Census model reports continuing scale economies among the very largest plants, while D&N report constant returns among the largest plants.

Given the uncertainties involved in comparing econometric and simulation models, the two approaches still tell a common story regarding economies of scale in cattle slaughter. There are large scale economies in the slaughter and fabrication functions, the economies extend across a wide range of plant sizes, and they translate into modest but significant economies of scale when considering total costs (including animal procurement costs).

We can use table 6-7 to gauge the relative importance of technological and pecuniary scale effects. The table shows technological scale economies: given 1992 factor prices, total costs per head fall by 2 to 3 percent as we move from average sized to very large plants. Pecuniary diseconomies at larger 1970's plants (in the form of higher wages) increased large plant costs by 1.5 to 3.8 percent, compared with smaller plants. Pecuniary diseconomies were close in magnitude to technological economies, and their disappearance in

1992 factor prices and technology, while D&N's analysis is for 1988 and Sersland's for 1985. As noted above, our incremental cost of adding fabrication lines in a plant appears to be low, compared with the simulation studies. Nevertheless, our estimated costs are quite close, and provide further confidence for the econometric estimates.

24 The largest plant listed in table 6-7 matches the largest plants operating today, while plants that slaughter more than a million head accounted for just over half of all steer and heifer slaughter in 1996 (table 3-3). Plants slaughtering less than a half million accounted for nearly two thirds of 1982 slaughter and less than one fifth of 1996 slaughter.

25 We selected Duewer and Nelson's estimates corresponding to slaughter/fabrication operations, 40-hour work weeks, single shifts for smaller plants, and double shifts for larger plants.

26 Capacity utilization may play a role here. Ward (1990) and 1992 GIPSA data suggest that larger plants have systematically higher levels of capacity utilization, which would show up as part of scale economies in our econometric cost functions. Our cost estimates for Ward and D&N plants assume no differences in capacity utilization across plants. If we alternatively assume that small plants operate 32 instead of 40 hours per week, then the D&N index at the smallest plant size rises to 102.9, closing half the gap with the Census indexes.

the 1980's reinforced the effects of growing technological scale economies in providing cost advantages to large plants.

## Conclusion

The estimated cost function finds small but important scale economies. They became more important through time, and extend throughout the range of plant sizes in the 1990's, suggesting that the largest plants continue to have cost advantages over smaller commercial operations. Wage-based pecuniary diseconomies limited the realization of technological scale economies in the 1970's, and their disappearance in the 1980's reinforced growing large-plant cost advantages. Changes in product mix, toward greater fabrication, have small positive effects on costs, and add slightly less to unit costs in larger plants. The results suggest that slaughter plants shifted to greater fabrication because they could do so at lower costs than carcass buyers (meat wholesalers and retailers) could, and that larger plants had greater fabrication advantages than smaller plants.