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TECHNOLOGICAL CHANGE AND ECONOMIES OF SCALE IN U.S. POULTRY PROCESSING

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This article uses a unique data set provided by the Census Bureau and a translog cost function to empirically examine technological change in the U.S. poultry industry. Results reveal substantial scale economies that show no evidence of diminishing with plant size and that are much greater than those realized in cattle and hog slaughter. Findings suggest that consolidation is likely to continue, particularly if demand growth diminishes, and that controlling for plant product mix is critical to accurate cost estimates.

Key words: chicken slaughter, consolidation, cost analyses, scale economies, structural change, turkey slaughter.

Over the past thirty years poultry processing changed from an industry of numerous small plants producing generic whole birds to one consisting of much larger plants producing deboned poultry, traypacks, and further processed products. The innovations that drove structural change had diverse impacts on costs: new processed products raised production costs, while new production technologies reduced production costs by increasing line speeds, improving yields, and realizing scale economies. In this article, we analyze the drivers of the industry's structural change by identifying the importance and extent of production scale economies, describing the degree to which plants have expanded to realize those economies, and measuring the impact of product and process innovations on costs and on measured scale economies.

Morrison-Paul (1999a) presents a modeling framework that captures multiple dimensions of the relationship between technological change and industry costs, and she has applied it to detail how several kinds of knowledge capital affected costs in food processing industries (Morrison-Paul, 1999b). Those studies yielded important insights from the use of publicly available industry-level data underlying her capital measures. However, the use of industry aggregates also limits examination of some other important elements driving industry structure and costs. We focus, instead, on plant-level scale economies and product mix by using data on individual chicken and turkey slaughter plants observed over the 1967–92 period. The data are drawn from the Longitudinal Research Database (LRD) at the Bureau of the Census, and consist of plant-level responses to Census of Manufactures survey forms.[1] We use the data to develop a modeling strategy aimed at identifying the separate impacts of several technological developments on plant costs and industry structure.

The article differs from related papers in two important ways. First, because we use data on individual plants observed over a twenty-five-year period, we can provide a more precise analysis of the effects of scale economies and product mix on plant level costs than can be obtained from studies of aggregated industry time series, such as Morrison-Paul (1999a, 1999b), Melton and Huffman, or Ball and Chambers. Second, while much related research focuses on the cost structure of red meat industries, we analyze costs and structural

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[1] Researchers can access microdata at the Center for Economic Studies (CES) of the Census Bureau at a cost of $4,000 per month at facilities located in Washington, DC and data centers at various universities. CES subjects project proposals to a lengthy review period that can take more than a year and approves only projects that it deems to have economic merit that can benefit the Census Bureau's own data collection efforts. Researchers cannot remove microdata but can take out summary data and regression analyses that have been reviewed by the Census Bureau.

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Table 1. Structural Change in Poultry Processing

	1967	1972	1977	1982	1987	1992
			Number of plants			
Chickens	140	194	179	134	125	144
Turkeys	75	59	50	36	31	30
			Animal slaughter (millions)			
Chickens	2,489	3,122	3,256	4,270	5,170	6,602
Turkeys	114	121	128	160	231	281
			Share of shipments from plants with over 400 employees			
Chickens	29	34	45	65	76	88
Turkeys	16	15	29	35	64	83
			Share of shipments from the largest four firms			
Chickens	23	18	22	32	42	41
Turkeys	28	41	41	40	38	35

Source: Slaughter data are from USDA (1997). Other data are drawn from Longitudinal Research Database, U.S. Bureau of the Census.

change in poultry industries, which have had distinctly different patterns of demand growth and product innovation.

Our results suggest that product innovations led to higher costs while process innovations, by allowing for larger plant sizes and greater commodity specialization, lowered plant costs. Our findings mirror those in the MacDonald et al. study of consolidation in cattle and hog slaughter, in that they suggest that extensive economies of scale in slaughter drove industry consolidation. However, we find that poultry scale economies are larger than those in cattle and hog slaughter, so that consolidation into large plants had a bigger impact on costs, and we find that even the largest plants have not exhausted all production scale economies.

Structural Change

A striking pattern of consolidation, coinciding with sharp industry growth, illustrates the remarkable structural changes in poultry industries during the twenty-five-year period of our study (table 1). Powered by rapid consumption growth, chicken slaughter grew by 4% per year between 1967 and 1992 while turkey slaughter grew 3.7% annually. Nevertheless, the number of turkey plants fell by 60%, while there were only a few more chicken plants in 1992 than there were in 1967. For that to happen, plants had to get much bigger: mean plant size in turkey slaughter increased more than sixfold, while the mean size of chicken plants almost tripled. If we define large plants as those with more than 400 employees (chosen to meet Census Bureau confidentiality requirements), then large plants also steadily expanded their share of chicken slaughter, from 29% in 1967 to 88% in 1992 while the large-plant share of turkey slaughter exploded along with consumption after 1982, increasing from 35% of output to 83% by 1992. Due to the industry's dramatic output growth, the impact of larger plants on industry concentration was limited, rising only to 42% in chickens and stabilizing after 1972 in turkeys (table 1).

Poultry firms also developed a host of new products ranging from chicken nuggets to deboned breasts and poultry luncheon meats. Most production of raw, semiprocessed branded, and unbranded products takes place in slaughter plants, along with substantial production of poultry ham and other further processed products (table 2). By adding cut-up and processing lines to the end of existing slaughter lines, poultry plants were able to increase net revenues by selling a variety of products in segmented markets. For example, a chicken plant might ship legs to Russia and retain chicken breasts for the United States.

The rise in turkey consumption over 1967–92 was accompanied by a transformation from a seasonal market, with sharp production expansions prior to the holiday season, to one in which turkey consumption became more of a year-round habit. Table 3 illustrates the change, showing a decided smoothing of intrayear production worker employment levels in turkey plants over time.

Organizationally, most poultry slaughter firms adopted an integrated structure in which the integrator, such as Tyson Foods or Perdue, owns the slaughter plant, feed mill, and further processing plants and contracts with a number of poultry growers. The integrator provides the grower with chicks or poults,

Table 2. Processed Poultry, Including Chicken Traypacks and Turkey Parts, Become a Major Component of Slaughter Plant Output

Year	Chicken			Turkey	
	Traypacks	Lunch Meat, Sausage, etc.	Parts[a]	Lunch Meat, Sausage, etc.	Parts[a]
	Share of industry shipments				
1963	n.a.	n.a.	12.5	n.a.	3.3
1972	11.0	2.6	28.4	8.5	15.7
1982	15.4	3.1	47.6	13.1	29.1
1992	18.9	3.1	78.5	16.8	55.1

[a]ERS, U.S. Egg and Poultry Statistical Series, 1960–90 (1991) for 1963–87 and ERS estimates for 1992.
Source: Longitudinal Research Database, U.S. Census Bureau and other sources as noted; n.a. is defined as not available.

Table 3. Seasonality of Production in Slaughter Industries

Ratio of first to fourth quarter employment				
Year	Cattle	Hogs	Chicken	Turkeys
1963	0.98	1.00	0.94	0.38
1967	0.99	1.00	0.97	0.50
1972	0.97	0.98	0.92	0.50
1977	0.97	0.98	0.96	0.53
1982	1.02	1.01	1.00	0.79
1987	0.92	0.96	0.96	0.92
1992	0.96	0.94	0.90	0.97

Table units are ratio of production workers in the first quarter (Jan.–March) to those in the last quarter (Oct.–Dec.).
Source: Longitudinal Research Database: U.S. Census Bureau.

feed, veterinary services, and other inputs. The grower contributes housing and labor services for raising birds to finished size. Growers frequently maintain long-term relationships with processors—Perry, Banker, and Morehart report that their sample of growers had been with the same processor for nine years, on average. Grower compensation is frequently based on performance relative to peers, with contracts structured to provide higher payments to growers that realize lower mortality rates and more efficient conversion of feed to meat than comparison groups (Knoeber). Such contracts also insulate growers against price risks as well as area-wide disease and weather risks.

A Model of Slaughter Plant Costs

We seek to identify the separate effects of increased plant sizes and changes in product mix on plant costs, while controlling for other key elements, such as changes in the seasonality of production. Our goal is to tie changes in plant technology to changes in costs and industry structure. To do so, we model production costs in the following general framework,

$$(1) \qquad C = f(Q, P_i, Z, \tau)$$

where C is total costs, Q is output, P_i are factor prices, Z is designed to capture firm-level variables, and τ is a vector of innovation measures (cost-lowering process innovations and cost-raising product innovations).

We assume competitive factor markets and take a well-accepted approach to modeling plant costs.[2] Ignoring technology for now, we specify a translog cost function with output, factor prices, and firm variables (Z) as

[2] We assume that processors are price takers in markets for live poultry. That assumption is controversial in the highly concentrated cattle industry, although empirical evidence to date has consistently found evidence of little to no monopsony power (see, e.g., Azzam, Schroeter, or Morrison-Paul [2001]). Our assumption of poultry price-taking behavior draws on the industry's distinctive industrial organization, where processors do not buy poultry but produce poultry by combining feed, chicks, growers' services, and other factors. Feed and chick expenses account for about 60% of poultry input costs (Perry, Banker, and Morehart), and it is unlikely that a plant's output decisions affect market prices for those inputs, which are in turn composed of items (grain, genetics, skilled technicians, etc.) traded in very large regional and global markets. We also think it unlikely that processors maintain local monopsony power in markets for growers' service because growers have many options. They can apply their labor and capital to alternative agricultural pursuits; they have abundant off-farm labor opportunities (we estimate, using USDA data, that contract broiler producers derive nearly 80% of their household income from off-farm sources); they are generally located in regions with several poultry processors who, in the period of our analysis, were aggressively aiming to expand production; and many growers are themselves geographically mobile.

arguments and all continuous variables (C, Q, and the P_i) transformed to natural logarithms:

$$(2)\quad \ln C = \alpha_0 + \sum_i \beta_i \ln P_i + \frac{1}{2}\sum_i\sum_j \beta_{ij} \ln P_i * \ln P_j + \gamma_Q \ln Q_Q + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \delta_z Z + \sum_i \gamma_{Qi} \ln Q * \ln P_i + \sum_i \delta_{Zi} Z * \ln P_i + \delta_{ZQ} Z * \ln Q + \xi.$$

As poultry plants expanded between 1967 and 1992, they reorganized production by adopting cost-lowering process innovations, such as automated dressing equipment and larger chill baths. Larger and more uniform birds permitted increased line speeds and meat yields, which increased production with little change in labor and capital inputs. Specialization led to the near disappearance of multispecies plants. Finally, changes in production scheduling enabled plants to avoid the costly start-ups and shutdowns associated with seasonal poultry demand, such as the holiday season for turkey slaughter.

But the more striking development was a series of product innovations that provided consumers with higher-value products. Table 2 shows the trends: chicken parts and deboned chicken, 28% of output in 1972, accounted for 78% by 1992, while turkey parts and deboned turkey rose from 16% to 55% of output. Those items were sometimes packaged or further processed within the plant into branded or private label products, but most went to export markets, domestic further processors, and domestic retailers and wholesalers for packaging or further processing. Because the new products require more in-plant processing, poultry product innovations will be cost-raising, factor-biased (the bird meat share of total costs will fall), and may be scale biased if larger slaughter plants do more processing (Ollinger, MacDonald, and Madison).

The presence of cost-reducing process innovations and cost-raising product innovations requires a cost function that accounts for each. Process innovations could be captured with a vector of time shift dummy variables (T_k), imposing the view that technological change causes a drop in input usage (and hence total costs), given factor prices and levels of output (Stevenson).[3] However, in the presence of (cost-raising) product innovations, a simple time shift specification could merely comingle the separate cost effects of process and product innovations. We aim to separate the two by incorporating explicit measures of product and process innovations embodied in plant characteristics (c_j), along with T_k, into equation (2) to yield equation (3):

$$(3)\quad \ln C = \alpha_0 + \sum_i \beta_i \ln P_i + \frac{1}{2}\sum_i\sum_j \beta_{ij} \ln P_i * \ln P_j + \gamma_Q \ln Q_Q + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \sum_i \gamma_{Qi} \ln Q * \ln P_i + \delta_z Z + \sum_i \delta_{Zi} Z * \ln P_i + \delta_{ZQ} Z * \ln Q + \sum_k \alpha_{1k} T_k + \sum_j \delta_{1j} \ln c_j + \delta_{Zj} Z * \ln c_j + \frac{1}{2}\sum_j\sum_l \delta_{1jl} \ln c_j * \ln c_l + \sum_i\sum_j \delta_{1ij} \ln P_i * \ln c_j + \sum_j \delta_{3Qj} \ln Q * \ln c_j + \sum_i\sum_k \alpha_{1ik} \ln P_i * T_k + \sum_k \alpha_{3QK} \ln Q * T_k + \sum_j\sum_k \alpha_{4jk} \ln c_j * T_k + \sum_k \delta_{zk} Z * T_k$$

where T_k is a time shift variable that represents different Census periods and captures implicit

[3] Analyses that use aggregated industry time series data often assume a constant trend rate of change due to a limited sample size. However, since the LRD has many plants observed at intervals between the 1960s and 1990s, one can specify time shift dummy variables that allow rates of technological change to vary between time intervals (MacDonald and Ollinger).

technological change, and c_j is a vector representing specific types of product and process innovations. They include measures of the seasonality of production (C_{SEASON}); bird input specialization, measured as the share of chickens in all poultry inputs (C_{BIRD}); and two product mix variables, the share of bulk-packed products (C_{BULK}) and the share of chicken parts (C_{PARTS}) in output (for turkeys, we replace C_{PARTS} with the share of whole birds in output [C_{WHOLE}]). Precise definitions are provided in Appendix.

We expect costs to fall as C_{BULK} increases because plants that ship higher proportions of bulk-packed products do less processing. Given C_{BULK}, plant costs can vary because parts and deboned products require more processing than whole birds. Hence, increases in C_{PARTS} should increase processing costs. Greater species specialization (C_{BIRD}) should reduce costs because plants that specialize in one species should have faster, smoother production systems. We are uncertain as to the sign on C_{SEASON}. Seasonal plants run at full capacity only part of the year, suggesting excess capacity and higher costs, but they also produce a simpler product mix, and that could be associated with lower costs.

The major cost-reducing technological drivers in the period may have occurred through the realization of scale economies. We measure scale economies at the plant level by estimating the elasticity of total cost with respect to changes in output—the derivative of the cost function with respect to output (equation [4]):

$$(4)\qquad \varepsilon_{CQ} = \frac{\partial \ln C}{\partial \ln Q} = \gamma_Q + \gamma_{QQ}\ln Q + \sum_i \gamma_{Qi} * P_i + \delta_{Qz} Z + \sum_k \alpha_{3Qk} T_k + \sum_j \delta_{3Qj} * \ln c_j.$$

A value of ε_{CQ} of less than 1 provides evidence of economies of scale—costs increasing less than proportionately to changes in output—while values in excess of 1 indicate diseconomies of scale.[4] The coefficient for the first-order output term, γ_Q, gives the cost elasticity at the sample mean, and the coefficient on the second-order output term, γ_{QQ}, indicates how scale economies vary with plant size. Other terms show how estimated scale economies change with changes in factor prices, firm effects, product innovations, and time.

Data

We use the records of individual establishments reported in the Census of Manufactures' LRD for each five-year census from 1972 to 1992 for chicken and 1967 to 1992 for turkey. Our starting points reflect two facts: state-inspected poultry plants did not have to meet the more rigorous federal food-safety standards until 1967, and the Census did not collect chicken traypack data until 1972.

The LRD covers all plants with more than 20 employees and a sample of those with less than 20. We use the 694 chicken and 308 turkey plants that report product mix data and derive more than half of their total value of shipments from poultry slaughter products. The LRD notes each plant's ownership and location, and provides detailed information on employment, wages and benefits, building and machinery asset values, new capital expenditures, energy use and costs, the physical quantities and dollar sales of seven-digit SIC code products, and the physical quantities and dollar expenses of detailed materials purchases. Because the file contains data on individual plants over several Censuses, researchers can make comparisons for different plants during the same year, and can also trace changes in product and input mixes, costs, and concentration over time. See Appendix for complete sources and variable definitions.

Estimation and Model Selection

We followed standard practice in estimation. First, we imposed symmetry and homogeneity of degree 1 on the model. Second, we achieved efficiency gains by estimating the factor demand (cost share) equations, which are

[4] Poultry plants produce many products, and there are two general ways to handle multiple products in a cost function (Berndt). Ideally, we could use a multi-output cost function and then isolate the output bias of technological change. This is an approach taken by Morrison (1998), whose data were better suited for this type of analysis. However, since all poultry plants do not produce all products, we cannot use this method (because some outputs would have zero quantities, whose logarithms are undefined). Rather, we specified a single common output, pounds of meat, modified by a vector of product characteristics that could all be specified as nonzero shares. Allen and Liu provide one example of this approach, and Berndt notes others.

Table 4. Model Selection Tests for Poultry Slaughter Cost Functions

Chicken			Turkey			
Maintained Hypothesis	Test Hypothesis	Chi-Square	Maintained Hypothesis	Test Hypothesis	Chi-Square	d.f.
		Model selection with innovation variables				
P and Q	P, Q, BULK, BIRD (PQBB)	90*	P and Q	P, Q, BULK, SEASON (PQBS)	96**	13
PQBB	PQBB and PARTS (PQBBP)	40**	PQBS	PQBS and WHOLE (PQBSW)	16**	5
PQBBP	PQ, BULK, and PARTS	−96**	PQBSW	P, Q, and SEASON	−45**	12
PQBBP	PQ, BIRD, and PARTS	−61	PQBSW	P, Q, and BULK	−38	12
PQBBP	PQBBP and SEASON	−50**	PQBSW	PQBSW and BIRD	−10	8
PQBB	PQBB, TIME (PQBBT)[1]	51**	PQBSW	PQBS and TIME (PQBST)	52**	25
		Model selection with firm-level variables and homotheticity				
PQBBP	PQBBP and SINGLE	−9	PQBS	PQBS and SINGLE	9	5
PQBBP	Homothetic PQBBP	−19**	PQBSW	Homothetic PQBSW	−33**	3

**Significant at 99% level; *significant at 95% level.
Notes: Chi-square equals the Gallant-Jorgenson statistic of maintained minus test hypotheses.
There are 694 observations over 1972–92 for chicken and 308 over 1967–92 for turkey slaughter.

the derivatives of the cost function with respect to each factor price, together with the cost function in a seemingly unrelated regression (SUR) technique (dropping one factor demand equation, in this case capital, because its coefficients are implied by the other three and the requirement that cost shares sum to one). Finally, we normalized all variables by their sample means, so the first-order factor price coefficients (β_i) can be interpreted as cost shares at sample means.

The model outlined in equation (3) is quite general, so we used a Gallant-Jorgenson likelihood ratio test (a chi-square test) to choose the specific model best able to explain plant production costs from among a set of more restrictive models. Table 4 summarizes the test models, maintained hypotheses, and relevant statistical data for both chickens and turkeys. In general, our best-fitting models, in turkeys and chickens, were nonhomothetic and included several explicit c_j measures of product and process innovations.

In each industry, we began the selection process with the most restrictive version of equation (3) (termed *PQ*), containing only factor prices (*P*) and output (*Q*), and then performed a series of tests to identify the best-fitting model for capturing technological change.

Available data constrained our tests in an important way. The variable C_{PARTS} in chickens (in turkeys, C_{WHOLE}) was not available at the plant level in LRD files, and was available only at the industry level from USDA (see the variable definitions in Appendix). With variability in that measure limited to intercensal shifts, we could only introduce it as a first-order term (no squared term) and in interactions with factor price and output variables (no interactions with the other product mix variables). Moreover, C_{PARTS} (and C_{WHOLE}) was highly correlated with our time shift variables T_k, so we could not estimate a model that included both C_{PARTS} and T_k.

In chickens, we started with a test of PQ against a less restrictive PQBB model that adds the coefficients associated with C_{BULK} and C_{BIRD} (B & B) to *PQ*, and rejected the PQ model. We then rejected the PQBB model in favor of PQBBP, which added the six coefficients associated with C_{PARTS} (*P*) to PQBB.[5] We then successively dropped C_{BIRD} and then C_{BULK}, but these more restrictive models were rejected in favor of the PQBBP model that includes three innovation measures. We next added C_{SEASON} to the PQBBP model, but did not find an improved fit.

We then aimed to evaluate the effects of replacing C_{PARTS} with T_k. We found, first, that

[5] As noted above, the six coefficients are the first-order term and interactions with the four factor prices and output.

interactions of the time shifts with output (Q) and with the innovation measures C_{BIRD} and C_{BULK} were not jointly significant, a finding in stark contrast to our work in red meat (MacDonald et al.).[6] When we estimated a model with first-order T_k terms and interactions with factor prices (PQBBT), we found that that model actually provided a slightly better fit than PQBBP. However, the estimated first-order coefficients on T_k were negative, relative to the 1992 base, which suggests technical regress, so we opted to stay with the PQBBP model on the grounds that the results were more transparent. That is, costs rose through time as plants added more processing. We felt that the model that explicitly accounts for processing, through the C_{PARTS} variable, provides a better representation.

In two final tests, we rejected homotheticity restrictions imposed on model PQBBP, and found that adding single establishment firm (SINGLE) to PQBBP did not improve model fit.[7]

For turkeys, we first rejected the restrictive PQ model in favor of a model that added the variables associated with C_{BULK} (B) and C_{SEASON} (S) to create PQBS, and then rejected that model in favor of PQBSW, which added the variables stemming from C_{WHOLE} (W) to PQBS. Other model comparisons show that neither C_{BULK} nor C_{SEASON} could be rejected from PQBSW, but that adding C_{BIRD} did not improve the fit of our preferred PQBSW model.

Next, we compared models with T_k replacing C_{WHOLE} in the PQBSW model but came to the same conclusion as in our chicken models—while the model fit was slightly improved with T_k, the interpretation was more transparent with C_{WHOLE}, and collinearity between the two prevented their joint inclusion. As in the chicken analysis, we rejected homotheticity, and we found that adding SINGLE did not improve model fit.[8]

Analyzing Results from the Preferred Models

Our final estimating equation for chickens (PQBBP) included factor prices, output, and two innovation measures (C_{BIRD} and C_{BULK}) in a full translog specification with all interactions, and with one other innovation measure (C_{PARTS}) entered directly and in interactions with factor prices and output. The final turkey model (PQBSW) also included factor prices, output, and two innovation indicators (C_{BULK} and C_{SEASON}) in the full translog specification, with one innovation indicator (C_{WHOLE}) entered directly and in a limited interaction with factor prices and output. Appendix tables A1 and A2 report coefficients and t-statistics for each model.

Table 5 reports factor shares calculated at 1992 means: live poultry (P_{MEAT}) accounted for about 69% of total costs, while labor (P_{LAB}) and other materials (P_{MAT}—primarily packaging) each comprised 14%, and the capital share about 3%. Live poultry dominated other factor shares in turkey slaughter (66% of costs), while labor and materials shares came to 14% and 18%, respectively.[9]

Own-price factor demand elasticities indicate downward-sloping demand curves for labor, poultry, materials, and capital, with similar magnitudes in the two industries (table 5). Poultry demand is highly inelastic with respect to its own price (about −0.07 for each)—not surprising since the measure estimates the response to own-price changes while holding meat output constant, so that substitution would have to occur through changes in meat yields per animal.

A key focus of our analysis is the role of scale economies. The first-order coefficient on output (Q, measured in pounds of meat) is the cost elasticity at the sample mean—a direct measure of scale economies. The coefficient on

[6] In hogs and cattle, we found small but statistically significant reductions in cost elasticities over time, suggesting increasing technological scale economies. We found no evidence of temporal shifts in cost elasticities in our poultry models, which suggest that plants expanded to realize existing scale economies, rather than new scale economies.

[7] Our tests reject the assumption of homotheticity, or factor shares that are invariant to changes in output, and indicate that larger plants adopt more capital intensive production techniques.

[8] In our analysis, SINGLE was the only firm level variable (the Z) that we could test for. The estimated coefficients were small and not significant for variables involving SINGLE in both chicken and turkey models, leading us to conclude that, among plants included in our data, multi-plant firms had no evident production cost advantage over their single plant counterparts.

[9] Estimation with flexible functional forms, such as the translog, sometimes leads to violations of regularity conditions drawn from economic theory (Diewert and Wales) and can, as pointed out by an anonymous reviewer, affect the scale elasticity. In our case, while output regularity held (all observations had positive predicted marginal cost) the skewed distribution of factor shares led to several violations of input regularity in small plants in the earlier years. We had negative predicted factor shares in 11%, 5%, and 0.1% of chicken observations for capital, other materials, and labor inputs, respectively, and negative predicted other materials shares in 8% of turkey observations. Similarly, there were slightly larger proportions of positive predicted own price elasticities, again among smaller plants in early years. Researchers limit flexibility when they impose regularity on the data; since we judged the violations to be minor, and since we are primarily interested in issues of scale and technological change, we chose to retain the flexibility of the traditional translog.

Table 5. 1992 Input Demand Estimates

	Chicken				Turkey			
	Factor Price Variables				Factor Price Variables			
	PLAB	PMEAT	PMAT	PCAP	PLAB	PMEAT	PMAT	PCAP
Estimated factor shares	0.143	0.691	0.139	0.027	0.131	0.658	0.187	0.024
ε_{ij} (own factor price)	−0.305	−0.076	−0.271	−1.119	−0.028	−0.073	−0.289	−1.101
M_{ij} (Morishima)								
PLAB	–	0.329	0.405	0.778	–	0.237	0.286	0.397
PMEAT	0.193	–	0.220	0.915	0.075	–	0.140	0.077
PMAT	0.368	0.300	–	0.395	0.330	0.525	–	0.302
PCAP	0.208	1.152	1.143	–	1.933	1.127	1.113	–

Note: All values are evaluated at the sample mean. The own-price-factor demand elasticities (ε_{ii}) are calculated holding output and other factors constant. The Morishima elasticity equals cross price elasticity minus own price elasticity, that is, $M_{ij} = \varepsilon_{ij} - \varepsilon_{ii}$.

Table 6. How Costs Vary with Plant Size

Species	Output Millions of Pounds	Ratio Output to Sample Mean	Cost Elasticity	Cost Index
Chicken				
	37.4	0.50	0.925	1.056
Mean→	74.8	1.00	0.911	1.00
	149.6	2.00	0.897	0.931
	299.2	4.00	0.883	0.851
Turkeys				
	21.9	0.50	0.933	1.064
Mean→	43.7	1.00	0.892	1.000
	87.4	2.00	0.851	0.916
	174.8	4.00	0.808	0.814

the second-order output term shows how measured scale economies vary with output. The estimates, reported for chicken in Appendix table A1 and for turkey in Appendix table A2, reveal statistically significant and substantial economies of scale that become stronger as plant size grows. That is, the first-order coefficients on output are significantly less than 1, and the coefficients on the quadratic terms are negative and significantly different from zero. By contrast, MacDonald et al. found somewhat weaker economies of scale that diminished as plant size grew in red meats.

Table 6 evaluates the extent of estimated scale economies for poultry plants at one-half, one, two, and four times the sample mean size. For chickens, the sample mean is about 75 million pounds of output; the 1972 mean plant size is about half the sample mean, and the 1992 mean plant size is about twice the sample mean. For each size, we report the scale elasticity and an index of average costs.[10] The first-order coefficient for Q (0.911 in table A1) is the cost elasticity at the sample mean for chickens. The second column shows that cost elasticities decline from 0.925 to 0.883 as plant size rises from one-half to four times the sample mean.

The second panel of table 6 shows estimates for turkey plants at four sizes: the sample mean (about 44 million pounds) as well as one-half, two, and four times that size. Cost elasticities are more responsive to changes in plant size in turkeys, declining from 0.933 to 0.808. The average cost index drops by an increasing amount with each doubling of plant size and declines by more than 25% over the size range.

Expanding poultry plants reduced costs substantially during this period through the realization of scale economies. By 1992, wholesale chicken costs were 12% below what they would have been had plant sizes not changed between 1972 and 1992 (applying the change in mean plant sizes to the information in table 5). The effects in the turkey industry was greater—increasing average plant sizes from the 1967 level to the 1992 level reduced costs by 20%. Moreover, the large cost differentials

[10] These are calculated at sample mean values of all other independent variables.

between the largest and smallest plants coincides with the near disappearance of small plants and likely led to the sharp shift to large plants over 1967–92.

Why Aren't Poultry Plants Even Larger?

Cost elasticities below 1 suggest that unit slaughter and processing costs decline as plant size increases. Elasticities well below 1—0.883 in chickens and 0.808 in turkeys, for the *largest* plants in table 6—suggest very strong pressures to increase plant size even further. In general, we would expect that plants in competitive industries would grow to realize all available scale economies, but the poultry industries are subject to well-known external constraints on slaughter plant size.

Henry and Seagraves outlined the spatial economics of poultry processing many years ago. In their model, the scale economies present in slaughter and processing create strong pressure to expand output. But output expansion requires a concomitant increase in poultry production. If poultry production is expanded at the external margin by expanding the area of production, the integrator faces higher transportation costs for shipping feed, chicks, and medicines to farms, and for shipping mature poultry to the plant. Alternatively, the integrator could realize greater production by expanding the density of poultry within a local area, but that effort may face rising costs of poultry litter disposal. Hence the integrator's economic problem has been to trade off slaughter and processing cost reductions from increased production against additional transportation and environmental costs.

Transportation costs were a major constraint on expansion at the external margin in Henry and Seagraves' time and remain so today. Large plants buy millions of chickens from contract growers, forcing them to precisely manage the logistical and transportation necessities of raising the birds and getting them to the plant. Transportation distances exceeding twenty miles taxes the health of chicks and poults and finished birds, causing death and weight loss. As a result, plant catchment areas remain limited.

When Henry and Seagraves published their model, they argued that the additional environmental costs from increased production density were quite minor, compared to the gains from slaughter and processing scale economies. They predicted a substantial increase in slaughter plant size and the density of local agricultural production, particularly in the Southeast. Subsequent events bore out their prediction. Today, however, environmental concerns may limit further expansions in plant sizes, according to interviews with Bill Roenigk of the National Chicken Council (25 March 1999) and with Alice Johnson of the National Turkey Federation (10 May 1999). For example, data from the Census of Agriculture show that broiler production on the Delmarva Peninsula (parts of Maryland, Delaware, and Virginia on the eastern shore of the Chesapeake Bay) remained essentially stable after 1987, even as nationwide broiler sales expanded sharply. Manure disposal is particularly problematic there, and stringent regulations appear to have discouraged expansion.[11]

As production stabilized in the Delmarva, it expanded sharply just to the west, in Virginia and West Virginia around the Shenandoah Valley, more than doubling in the ten years between 1987 and 1997. Today, available poultry litter increasingly exceeds the capacity of the fields to absorb it. The spatial transportation and environmental constraints identified by Henry and Seagraves continue to limit the realization of processing scale economies.[12]

The Role of Product Mix in Our Models

Modern plants produce many products, ranging from whole birds, which require the least processing, to parts, deboned products, and further processed products, which undergo the most. Costs should increase as plant product mixes shift to more highly processed products.

Recall our variables that measure characteristics of the plant's product mix. C_{BULK} captures the nature of shipments—the share of shipments that are packed in bulk. C_{PARTS} reflects the plant output share comprising cut-up parts (the residual is whole carcasses). Each strongly affects costs. Evaluating all other variables at sample mean values, chicken plant costs rise 5.5% as C_{BULK} falls to half the sample

[11] In 1997, water run-off was linked to hundreds of thousands of dead fish on the Delmarva. Maryland regulators then imposed restrictions on manure application by Delmarva farmers. Tyson's, a major processor in Maryland, has since begun to shift production to other plants.

[12] Food safety factors may also limit poultry plant size. Federal meat inspectors cap linespeeds, limiting plant capacity, to allow for more accurate inspection. Some plants have also had to reduce production because their plants required more water for carcass washes, which is needed to control *Salmonella* contamination, than local water authorities could provide.

mean value and increases about 3% as C_{PARTS} rises by half from the sample mean. More dramatically, turkey costs rise 15% as C_{BULK} falls by half from the sample mean, and drops by about 8% as C_{WHOLE} rises by 50%.

Over time, product differentiation in chicken processing raised plant costs by 6.3%, if we use the 1972–92 shift in mean values of C_{BULK} and C_{PARTS} to gauge the change, while increased product differentiation in turkeys raised costs by 18.6%, using the 1967–92 shift in mean values of C_{BULK} and C_{WHOLE} as the measure of increased differentiation.

Species specialization (C_{BIRD}) appears to reduce costs in chicken production, but it had no significant effect on costs in turkey plants. Chickens must be of uniform size to permit efficient processing in the high-speed automated processes characterizing chicken slaughter, suggesting that species specialization is very important. Turkey processing, on the other hand, requires much more manual effort because turkeys have more random sizes, and, as a result, species specialization is less important.

We controlled for seasonality (C_{SEASON}) in our turkey model because of the large change in the seasonality of production over time. The coefficient was negative and significant—plants with highly seasonal production schedules had *lower* total costs, given output (table A2). We attribute this finding to differences in product mix between seasonal and full-time plants—seasonal plants tended to do less processing than other plants. While we have useful measures of product mix, neither C_{BULK} nor C_{WHOLE} can fully account for the costs of producing whole birds (or parts) at the plant level. However, this is not to say that seasonal plants were more profitable than year-round plants. If seasonal plants were more profitable, then one would expect seasonal production to grow. Yet, table 3 shows that the near disappearance of plants with heavily skewed production schedules and other Census data show the near disappearance of plants with more than two-thirds of their production occurring in the second half of the year.

The Importance of Controlling for Product Mix in Slaughter Industries

Poultry plants grew dramatically over 1967–92 as small plants left the industry and production shifted to much larger operations, which could realize lower costs through realization of production scale economies. But plants also added cut-up and other further processing lines to the end of their slaughter lines, aiming to satisfy consumer demands for processed products. By 1992, parts and deboned poultry accounted for more than one-half of all turkey and more than three-quarters of all chicken production. These more processed products were cost-raising innovations in that they required more inputs, particularly labor.

Because larger plants often do more processing, and plants grew larger over time while adding more products, we believe that it is critically important to separate the effects of increased output from the effects of changing product mix. Table 7 shows how controlling for product mix affects measures of scale economies, providing estimated cost elasticities with and without controls for product mix for two plant sizes—those at the sample mean and at four times the sample mean output. We compare results for chicken and turkey slaughter cost models to findings for cattle and hog models (whose controls are described in MacDonald et al.).

The first two rows compare estimates for mean plant sizes with and without controls

Table 7. How Controls for Product Mix Affect Estimates of Scale Economies

Plant Size[a]	Controls for Product and Input Mix?[b]	Elasticity of Cost with Respect to Output			
		Chicken	Turkeys	Cattle[c]	Hogs[c]
Mean	No	0.945	0.989	0.959	0.980
Mean	Yes	0.911	0.892	0.932	0.926
Large	No	0.953	0.985	0.971	1.00
Large	Yes	0.883	0.808	0.947	0.946

[a] Plant sizes: "Mean" is sample mean for each industry. "Large" is four times sample mean.

[b] Product mix controls include bulk and parts shares for chickens and turkeys and noncarcass output shares for cattle and hogs. Input mix is liveweight animal inputs of primary species as share of all meat inputs (e.g., cattle weight divided by all meat inputs to cattle slaughter plants). Input mix not included in turkey model (not significant), but seasonality is.

[c] Cattle and hog results are based on MacDonald et al. (2000).

for product and input mix. Note that estimated elasticities are closer to 1 (constant returns to scale) in each industry when product mix controls are omitted. The effects are quite large for turkeys and hogs. Now compare the estimates for large plants. Without product mix controls, three of the four scale elasticities are quite close to 1. With controls, elasticities drop sharply, suggesting substantial economies of scale in chickens and turkeys and much smaller, though still important, scale economies in hogs and cattle. Moreover, once one controls for product and input mix, cost elasticities for chicken and turkey plants imply very substantial unexploited scale economies in large plants that are greater than those for smaller plants. These very potent scale economies in poultry slaughter are easily reconciled with data showing the near disappearance of plants with fewer than 100 employees, the large plant dominance of the market, and the four-fold increase in plant size over 1967–72. Such a reconciliation cannot be made, however, for these data and a model that fails to control for product mix.

Here and in our work on red meat industries (MacDonald and Ollinger; MacDonald et al.), we find that slaughter cost model fits are significantly improved when we add controls for product and input mix. Of perhaps more importance, we also find that the controls alter one's view of the importance of scale economies. Once one controls for the more costly product mixes of large plants, scale economies appear far more important, and they provide a ready explanation for the sharp changes in plant sizes observed in each industry.

Conclusion

We find large and extensive scale economies in poultry slaughter. Average costs at the largest plants were about 8% lower than costs at plants that were half that size, and about 20% lower than costs at plants one-eighth that size. Cost advantages of these magnitudes help explain the near disappearance of small plants and the dramatic shift of production to large plants, whose share of output rose from less than 30% in 1967 to over 80% in 1992.

Nevertheless, poultry slaughter plants do not realize all potential scale economies, and firms could reduce processing costs further if they could build and fully utilize even larger plants. Two external cost factors limit plant sizes: transportation costs associated with expanding a catchment area for poultry production, and environmental costs associated with more intensive local production. The tension among these three factors implies that, given the constraints imposed by transportation costs, large potential processing scale economies help to drive the geographic concentration of poultry production into very large production units located in limited geographic areas, as long as environmental restriction do not absolutely limit growth.

Our analysis focuses on the period 1967–92, an era in which livestock and poultry processing were dramatically transformed. We find that slaughter scale economies played an important role in each transformation, but that potential and realized poultry scale economies were much larger than those found in red meat industries (MacDonald et al.). One result is that industry consolidation into larger plants reduced poultry costs more than red meat costs, even while the introduction of a wider variety of poultry products has further stimulated demand.

Even though we find larger scale economies in poultry slaughter, industry concentration rose much more in cattle and in hog slaughter. In part, the difference reflects the constraints that keep poultry plants from growing to completely realize all economies of scale (as well as the apparent lack of multi-plant economies). But demand patterns have also played a major role—rapidly growing poultry demand allowed many poultry processors to grow larger without concentration, while stagnant U.S. beef demand meant that increasing plant sizes could only be realized though increased concentration.

Our analysis ends in 1992. But we found that a rather simple representation of technology provided the best fit to our poultry data, and that model provides continuing insights. That is, we found that product innovations raise costs, and that we could represent those innovations with direct measures of their importance in output. In contrast to our analyses of red meats, we did not find substantive temporal shifts in poultry processing technology (in the sense of parameter shifts). Rather, we found that output shifts and changes in factor prices were driving factors in temporal changes in cost. In turn those output shifts consisted of increases in plant size to realize scale economies and continuing changes in product mix toward more highly processed products (the cost effects of which were captured in our product mix measures).

The forces that we have identified remain in place. After 1992, chicken plant product mixes continued to shift toward more extensive in-plant processing (e.g., the share of whole birds in output fell from 15% to 9% between 1992 and 2000, according to the National Chicken Council, an industry trade group). Demand continued to grow sharply—total slaughter volume grew by over one third between 1992 and 2003 (USDA). Our model would predict a modest continuing increase in plant costs due to the more complex product mix, but it would also predict that demand growth would be met with expanded plant sizes, not with more plants. Indeed, USDA inspection data reveal that the number of chicken plants has remained unchanged since 1992, despite continuing strong demand growth.

In contrast, turkey slaughter actually declined by about 6% between 1992 and 2003 (the birds got larger, so meat output actually grew slightly). With declining demand set against unrealized scale economies turkey processing shows signs of consolidation. USDA inspection data show a 12% decline in plant numbers after 1992, and we expect to see increased concentration.

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Appendix

Variable Specifications

All variables except those for capital rental prices and one product mix variable are derived from the Longitudinal Research Database (LRD) maintained at the Center for Economic Studies of the U.S. Census Bureau. Total cost (COST) is the sum of labor, meat, material, and capital input expenses. The price of labor (PLAB) is total employee wages and benefits divided by total employees. The meat input price (PMEAT) is the cost of live poultry and unprocessed poultry meat divided by pounds of live poultry and unprocessed poultry meat. It includes all payments to growers as well as feed, transportation, and veterinary services expenses borne by integrators. The price of nonmeat materials (PMAT) is the cost of energy, packaging, and other materials divided by pounds of live poultry and unprocessed poultry meat. The price of capital (PCAP) follows Allen and Liu and has two components. The first is the weighted sum of machinery and structures rental values, where the weights are their respective book values. Annual capital rental prices are calculated by the Bureau of Labor Statistics separately for buildings and for machinery in the two-digit Food and Kindred Products Industry Group. They use methods described in chapter 10 of the BLS *Handbook of Methods*, Bulletin 2490, and on the Multifactor Productivity Website (stats.bls.gov/mprhome.htm). The measures include components for depreciation, changes in asset prices, and taxes. Since the weights (book values of structures and equipment) differ across plants, capital prices are plant-specific. The second component adds the ratio of new investment to beginning-of-year assets as a way to capture the costs of adjustment.

Output (Q) is defined as pounds of meat products (all categories in SIC 2015). The technological change variables are defined as follows. BULK equals 1 minus chicken traypacks and further processed products as a share of total output for chicken and 1 minus further processed products as a share of output for turkey. The residual in each case equals the share of industry shipments accounted for by whole birds, poultry parts, and deboned poultry packed in bulk containers. Bird species specialization (BIRD) is defined as live chickens (by weight) as a percentage of all poultry inputs and live turkeys as a percentage of all poultry inputs. Since seasonal production should be reflected in changing levels of production worker employment over the course of the year, we define seasonality (SEASON) as the share of annual employment occurring in the second half of the year. Second-half

Table A1. Cost Function Parameter Estimates for Chicken Plants

Variable	Coefficient	t-Statistic	Variable	Coefficient	t-Statistic
Intercept	−0.039	3.90	$P_{LAB} * C_{BIRD}$	−0.102	6.01
P_{LAB}	0.143	71.50	$P_{LAB} * C_{PARTS}$	−0.0003	0.51
P_{MEAT}	0.691	230.33	$P_{MEAT} * P_{MAT}$	−0.076	25.33
P_{MAT}	0.139	69.52	$P_{MEAT} * P_{CAP}$	−0.004	1.33
P_{CAP}	0.027	27.11	$P_{MEAT} * Q$	0.022	11.07
Q	0.911	70.08	$P_{MEAT} * C_{BULK}$	0.004	3.08
C_{BULK}	−0.090	5.63	$P_{MEAT} * C_{BIRD}$	0.073	3.65
C_{BIRD}	−0.178	1.38	$P_{MEAT} * C_{PARTS}$	−0.038	4.75
C_{PARTS}	0.068	2.43	$P_{MAT} * P_{CAP}$	−0.0004	0.56
$P_{LAB} * P_{LAB}$	0.079	15.80	$P_{MAT} * Q$	0.002	1.00
$P_{MEAT} * P_{MEAT}$	0.161	26.83	$P_{MAT} * C_{BULK}$	−0.0001	0.16
$P_{MAT} * P_{MAT}$	0.082	41.07	$P_{MAT} * C_{BIRD}$	0.300	2.31
$P_{CAP} * P_{CAP}$	0.005	a	$P_{MAT} * C_{PARTS}$	−0.001	0.18
$Q * Q$	−0.020	1.82	$P_{CAP} * Q$	−0.004	4.07
$C_{BULK} * C_{BULK}$	−0.018	4.54	$P_{CAP} * C_{BULK}$	−0.0004	0.80
$C_{BIRD} * C_{BIRD}$	−0.395	1.60	$P_{CAP} * C_{BIRD}$	−0.001	0.07
$P_{LAB} * P_{MEAT}$	−0.082	16.47	$P_{CAP} * C_{PARTS}$	0.039	9.75
$P_{LAB} * P_{MAT}$	−0.006	2.95	$Q * C_{BULK}$	0.002	0.67
$P_{LAB} * P_{CAP}$	0.009	3.03	$Q * C_{BIRD}$	0.020	0.41
$P_{LAB} * Q$	−0.020	9.94	$Q * C_{PARTS}$	0.042	1.56
$P_{LAB} * C_{BULK}$	−0.004	4.38	$C_{BULK} * C_{BIRD}$	−0.026	0.65

Notes: Translog cost function estimated for chicken slaughter plants, 1972–92.
694 observations.
a—Standard error could not be estimated.

Table A2. Cost Function Parameter Estimates for Turkey Plants

Variable	Coefficient	*t*-Statistic	Variable	Coefficient	*t*-Statistic
Intercept	−0.227	15.13	$P_{LAB} * C_{SEASON}$	−0.024	11.98
P_{LAB}	0.131	21.83	$P_{LAB} * C_{WHOLE}$	0.047	2.47
P_{MEAT}	0.658	82.25	$P_{MEAT} * P_{MAT}$	−0.079	13.17
P_{MAT}	0.187	46.75	$P_{MEAT} * P_{CAP}$	−0.013	2.17
P_{CAP}	0.024	8.01	$P_{MEAT} * Q$	0.017	2.13
Q	0.892	28.77	$P_{MEAT} * C_{BULK}$	0.063	5.25
C_{BULK}	−0.329	4.16	$P_{MEAT} * C_{SEASON}$	0.022	7.33
C_{SEASON}	−0.279	3.32	$P_{MEAT} * C_{WHOLE}$	−0.012	0.23
C_{WHOLE}	−0.121	4.48	$P_{MAT} * P_{CAP}$	−0.002	0.67
$P_{LAB} * P_{LAB}$	0.084	6.46	$P_{MAT} * Q$	0.002	0.50
$P_{MEAT} * P_{MEAT}$	0.177	11.80	$P_{MAT} * C_{BULK}$	−0.033	5.50
$P_{MAT} * P_{MAT}$	0.098	24.46	$P_{MAT} * C_{SEASON}$	0.001	0.06
$P_{CAP} * P_{CAP}$	−0.003	a	$P_{MAT} * C_{WHOLE}$	−0.005	0.42
$Q * Q$	−0.060	2.00	$P_{CAP} * Q$	−0.005	0.61
$C_{BULK} * C_{BULK}$	−0.192	4.47	$P_{CAP} * C_{BULK}$	−0.007	1.38
$C_{SEASON} * C_{SEASON}$	0.388	0.49	$P_{CAP} * C_{SEASON}$	0.002	2.02
$P_{LAB} * P_{MEAT}$	−0.085	7.08	$P_{CAP} * C_{WHOLE}$	−0.030	2.98
$P_{LAB} * P_{MAT}$	−0.017	4.25	$Q * C_{BULK}$	0.039	1.63
$P_{LAB} * P_{CAP}$	0.018	3.02	$Q * C_{SEASON}$	−0.157	1.51
$P_{LAB} * Q$	−0.014	2.33	$Q * C_{WHOLE}$	−0.053	0.87
$P_{LAB} * C_{BULK}$	−0.023	2.56	$C_{BULK} * C_{SEASON}$	−0.519	1.52

Notes: Translog cost function estimated for turkey slaughter plants, 1967–92.
308 observations.
a—Standard error could not be estimated.

employment equals plant employment recorded in the LRD on August 12 plus employment on November 12. Total employment is second half employment plus employment reported on March 12 and May 12.

Data for PARTS were not contained in the LRD but were available from USDA at the industry levels. It equals chicken parts and deboned chicken as share of total production for chickens and WHOLE is whole birds divided by total production for turkeys. Total production is the sum of parts, deboned poultry, and whole birds. Further processing is assumed to occur in a later step.

Finally, we also control for single establishment firms (Z = SINGLE) defined as one for firms owning only one plant and zero otherwise.