Technological Performance in Meat Processing and Implications for Policy

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The meat processing industry is, partly because of its size, the most heavily watched in U.S. food manufacturing. At $102.1 billion in 1996 shipment value, it is the largest of the nine food sectors. It is also the final link of a production chain comprising a substantial part of U.S. agriculture: grain farming, feed manufacturing, and cattle raising and feeding. Yet most scholarly attention to this industry stems instead from worries it is becoming too concentrated. Signs of departure from price-taking behavior are often detected, but the general evidence seems to be that market power is weak (Azzam and Pagoulatos; Schroeter and Azzam; Azzam and Schroeter).

If processors indeed exert little influence on price, industry performance depends upon such other issues as the rate of new product development and of technical change permitting lower production costs. To our knowledge, only Ball and Chambers and Melton and Huffman have concentrated on this latter question, both studies restricted to red meat packing and Melton and Huffman's emphasizing unionization. In the present work, we analyze technical change in the red and white meat processing sub-sectors during the past two decades, focusing on changes in productivity growth, size economies, and factor use. Included are red meat slaughter and packing (SIC 2011), red meat further-processing (SIC 2013), poultry slaughter and dressing (SIC 2016), and poultry further-processing (SIC 2017). We find that, although productivity has risen consistently in these industries since the early 1970s, productivity growth rates have fallen dramatically. Global size economies have weakened as well. However, in the vicinity of the average establishment, size economies are constant or rising, implying that inducements to further industry concentration remain unabated.

Approach

To examine technology change in these sectors, we specify a firm's minimized cost as

$$(1) \qquad C \;=\; G(Y,\, W_l,\, W_m,\, K,\, A,\, t) \;+\; W_k K$$

where Y is output, K is capital quantity, W_l is labor wage, W_m is price of materials, W_k is rental price of capital, A is pollution abatement expenditure, and t is the technology change proxy. Materials M consist primarily, in red meat packing (SIC 2011), of live cattle and hogs, and in poultry dressing (SIC 2016) of live poultry. These two industries in turn provide the principal raw products for the further-processing sub-sectors, 2013 and 2017.

We will refer both to the dual measure of multi-factor productivity growth $\varepsilon_{ct} = -(\partial \ln C / \partial t)$ and to the primal measure $\varepsilon_{yt} = (\partial \ln Y / \partial t)$, respectively the proportionate cost saving and proportionate output growth achieved from disembodied technical change. The dual measure reflects any savings in the conventional input expenditures needed to produce a given output quantity. By the chain rule, $\varepsilon_{yt} = \varepsilon_{ct} / \varepsilon_{cy}$, where $\varepsilon_{cy} = \partial \ln C / \partial \ln Y$ is the cost elasticity (Ohta). Because size economies are so important in their own right, we employ an intuitive measure of a local size economy, ε_s^{loc}. Expression

$$(2) \qquad \varepsilon_s^{loc} \;=\; -\,\varepsilon_{cy}^{-1} \;+\; 1$$

is useful for this purpose, inasmuch as it is negative if returns to size are locally increasing, zero if constant, and positive if decreasing.

To represent global size economies ε_s^{glob} we use the percentage change in unit cost induced by a unit percentage increase in establishment size, taken as an average over the domain of establishment sizes. That is,

$$(3) \qquad \varepsilon_s^{glob} = \frac{(UC_{sm} - UC_{la})/UC_{sm}}{(Y_{sm} - Y_{la})/Y_{sm}}$$

where UC_{sm} and UC_{la} are unit cost at the smallest and largest establishment size, respectively, and Y_{sm}, Y_{la} are the corresponding output quantities. In our application, capital is permitted to adjust optimally to the given factor prices and output, so (3) is a long-run measure. To compute it, exogenous variables W_l, W_m, W_k, *A*, and *t* are held fixed. Unit costs *UC* = *C*/*Y* are then generated at alternative outputs *Y* and associated optimal inputs *L**, *M**, and *K**.

The nature of an industry's technical change is much revealed by the factor share adjustments accompanying it. Percentage changes in factor cost shares induced by technological growth are computed for the j^{th} factor as

$$(4) \qquad \beta_j = \frac{\partial \ln S_j}{\partial t} - \left(\frac{\partial \ln S_j}{\partial \ln Y}\right)\left(\frac{\varepsilon_{ct}}{\varepsilon_{cy}}\right), \; j = L, M, K,$$

where $S_j = W_j X_j / C$ is the j^{th} factor's cost share. Biases β_j, $j = L, M, K$, together characterize the degree to which technical change shifts the factor expansion paths, altering the cost shares. In non-homothetic technologies, any scale change $\partial \ln Y$ itself induces a cost share change. The second right-hand term in (4) corrects for such scale effects, leaving only share changes induced by expansion path shifts (Antle and Capalbo, pp. 36 – 42). Again, capital is permitted to adjust optimally with *t* and *Y*, so the bias estimates are long-run ones.

Functional Form and Estimation

We use Morrison's form of the Generalized Leontief (GL) variable cost function *G*:

$$
\begin{aligned}
(5) \qquad G \;=\; & Y\,[\left(\alpha_{ll}W_l + 2\alpha_{lm}W_l^{0.5}W_m^{\;0.5} + \alpha_{mm}W_m\right) \\
&+ \left(\beta_{ly}W_lY^{0.5} + \beta_{lt}W_l\,t^{0.5} + \beta_{la}W_lA^{0.5} + \beta_{my}W_mY^{0.5} + \beta_{mt}W_m\,t^{0.5} + \beta_{ma}W_mA^{0.5}\right) \\
&+ \left(\delta_{yy}Y + 2\delta_{yt}Y^{0.5}t^{0.5} + 2\delta_{ya}Y^{0.5}A^{0.5} + \gamma_{tt}\,t + 2\delta_{ta}\,t^{0.5}A^{0.5} + \delta_{aa}A\right)(W_l + W_m)] \\
&+ Y^{0.5}K^{0.5}[\left(\beta_{lk}W_l + \beta_{mk}W_m\right) + \left(\delta_{yk}Y^{0.5} + \delta_{tk}\,t^{0.5} + \delta_{ak}A^{0.5}\right)(W_l + W_m)\,] \\
&+ \delta_{kk}K(W_l + W_m)
\end{aligned}
$$

(Morrison 1988, 1997; Park and Kwon). Linear homogeneity in input prices and symmetry of the input-price hessian matrix are enforced in this specification. Monotonicity in *Y*, W_l, W_m, *K*, and *A*; convexity in *K* (i.e., $\partial^2 G/\partial K^2 > 0$); and concavity in factor prices are not. Pollution abatement expenditures are included in the cost specification to test the argument that pollution regulations have impaired efficiency and productivity growth (Jaffe, et al.; Smith and Sims).

Labor and material demands are obtained by differentiating (5) with respect to the corresponding factor price. They were estimated jointly with (5) and with output demand function $P = \alpha_0 + \alpha_1 Y + \alpha_2 I + \alpha_3 t$ (where *P* is output price and *I* is disposable personal income) and with the firm's offer function $\partial G/\partial Y = P[1 + \theta/\varepsilon_{YP}]$, in which $\varepsilon_{YP} \approx P/a_1 Y$ is the output demand flexibility and θ a market power parameter (Park and Kwon). Pricing approaches the competitive norm as θ approaches zero. The system was estimated with 3SLS, using SAS procedure SYSLIN. Data from all four meat processing industries were included, giving four observations for each of the 22 years from 1973 through 1994.[i]

A virtue of the GL form is that it permits solving explicitly for long-run equilibrium capital quantity K^*, namely where market price W_K equals shadow price $Z_k = -\partial G/\partial K$. This allows use of the envelope property to find long-run cost function $C^* = G(Y, W_l, W_m, K^*, t, A) + W_k K^*$ and hence long-run dual productivity growth rate ε_{ct}^{lr}, long-run cost elasticity ε_{cy}^{lr}, and long-run factor demand elasticities. For example, since $W_k = Z_k$ in equilibrium, long-run marginal cost is

$$(6) \qquad \left.\frac{\partial C}{\partial Y}\right|_{K^* adjusting} = \left.\frac{\partial G}{\partial Y}\right|_{K^* adjusting} + W_k \frac{\partial K^*}{\partial Y}$$

$$= \left.\frac{\partial G}{\partial Y}\right|_{K^0=K^*} + \frac{\partial G}{\partial K^*}\frac{\partial K^*}{\partial Y} + W_k \frac{\partial K^*}{\partial Y} = \left.\frac{\partial G}{\partial Y}\right|_{K^0=K^*}$$

so that obtaining it econometrically is simply a matter of evaluating, at equilibrium capital quantity K^*, the derivative of (5) with respect to Y. The effect of technology change on long-run cost, and long-run labor and material demands $L^* = (\partial G/\partial W_l)|_{K^0=K^*}$, $M^* = (\partial G/\partial W_m)|_{K^0=K^*}$, are found similarly.

We use the SIC 4-digit manufacturing data prepared by the Bureau of Census and National Bureau of Economic Research (Bartelsman, Becker, and Gray). Prices were converted to a 1994 basis by dividing by the U.S. producer price index. NBER 4-digit data employ the 1972 SIC 4-digit industry classifications rather than the 1987 definitions. They include capital quantity K_t (weighted by base-year capital acquisition price $q_{k,0}$) and capital acquisition price index $q_{k,}/q_{k,0}$ but exclude capital rental price. The Bureau of Labor Statistics does report rental expenditures $W_{k,t}K_t$ at the SIC 2-digit (food and kindred products) level. The latter were allocated to each 4-digit industry according to that industry's proportionate share in the 2-digit-level capital stock. Dividing by reported capital quantity $q_{k,0}K_t$ gives rental price expressed as a percentage of base-year acquisition price. This assumes rental prices are, up to a multiplicative constant, the same in each 4-digit food industry.

Results

By way of background to the econometric results, it is useful to note that real output prices in all four industries fell dramatically during the 22-year sample period: by 40% in the two red meat sectors (2011 and 2013) and by 55% in the two white meat sectors (2016 and 2017). In red meats, real wage rates fell also (for example in red meat packing from $13.39/hour in 1973 to $9.89/hour in 1994), reflecting the decline in labor skills in modern packing plants. Real wages in the white meat industries fell during the stagflation of the 1970s but rose gradually thereafter. Real material prices in all four sectors have fallen, by about 33% in red meats and 40% in white meats. Only capital rental prices have trended upward, in fact have nearly doubled since 1973.

Parameter estimates (table 1**)** suggest our model fits the data well. Only five of the twenty-one parameter estimates are nonsignificant at the 5% level. Most of the latter are associated with pollution abatement costs, and in general we found little evidence that abatement costs affect factor demands or productivity growth. Remarkably, every regularity condition was satisfied in table 1 at each observation, implying that factor allocations predicted in this model are approximately cost-minimizing and that aggregation bias may be modest. Estimated market power parameters θ ranged from 0.070 in red meat packing to 0.003 in poultry further-processing, suggesting virtually price-taking behavior in every sub-sector. Below, we emphasize long-run results because they provide a good notion of the central tendencies in processor behavior and because they permit us to observe the effects of capital changes on industry performance.

Productivity Growth

Dual productivity growth rates, cost elasticities, and the primal productivity rates computed from Ohta's identity above, are shown in table 2 for each sample year between 1973 and 1994. All cost elasticities are below unity, implying locally increasing returns to scale. In the red meat sector these elasticities have been relatively constant, hovering between 0.88 and 0.92 in packing and between 0.93 and 0.96 in further-processing. In white meats, cost elasticities have declined somewhat, suggesting modest increases in local size economies. Because cost elasticity changes have been small, graphs of dual productivity growth rates over time are little more than mirror images of primal productivity graphs. The latter are pictured in figure 1, but we will refer frequently to both primal and dual rates.

Through both recessions and recoveries, primal productivity growth has been positive every year in every industry. Growth has been stronger in the further-processing than in the packing sub-sectors. Our finding of continually rising productivity stands in sharp contrast to Ball and Chambers' (p. 706, table 7) and Melton and Huffman's (p. 481) studies of red meat packing. The former authors reported negative productivity growth rates during the early 1970s and the latter authors during the mid-1980s. In particular, Ball and Chambers argued that technical change boosted costs 3.6% per year from 1973 through 1976.[ii] During that same four-year interval, we find instead that technology change was reducing red meat packing costs by an average 0.77 % per year.

Ball and Chambers, and Melton and Huffman after them, wondered whether the implausible finding of technical regress arose from a clockwise rotation (steepening) of the unit cost curve around a central point, combined with packers' failure to expand into the down-twisted portion of the curve. Although plant sizes did not indeed grow rapidly until the early 1980s, we suspect the observed negative growth came instead from a failure to account for capital's quasi-fixity. During each of the periods in which they said productivity fell, that is from 1973 to 1976 and again in the 1980s, capacity utilization in meat processing plants dropped significantly, idling resources that hitherto had been productive. Accounting for this capital overdeployment would have allowed distinguishing between input fixity and long-run technical change.

Consistent with Melton and Huffman, we do find that productivity growth has trended strongly downward. In red meat packing (2011), primal growth fell from near 1.00 in 1973 to 0.22 in 1994; in poultry dressing (2016), it fell from 1.22 in 1973 to 0.46 in 1994. Melton and Huffman ascribe the decline in beef packing productivity to the industry's transition to boxed beef – equivalently a quality improvement – in the 1960s and 1970s. Conceivably also, meat processors have paid less attention to research and development as firm concentration has risen. Perhaps, however, the dramatic breakthroughs in mechanization and floor layout in the 1960s and 1970s have not yet been matched by innovations in information processing. Nevertheless, one would not be surprised if new computer technology, particularly material quality sensing and inventory control, soon restores meat productivity growth to 1970s and 1980s rates.

Some authors have suggested productivity growth is cyclical. Heien, for instance, observed a correlation between turning points in unemployment and those in the total factor productivity of food processing. Morrison (1997) argued that, in the presence of size economies, productivity should decline during recessions because shrinking output reduces cost elasticity and hence the absolute value of ε_{ct} *via* Ohta's identity. Alternatively, however, one might expect productivity growth to *rise* during slumps. Sagging profits induce firms to retire inputs. Because of such fixities as union contracts, longevity-based salary conventions, investment transactions costs, and difficulties in observing material and labor quality, factors of higher-than-average quality often are valued at market prices proportionately lower than their marginal productivity. Thus, firms in recession lay off their lowest-quality inputs first, pushing productivity upward. Reasoning from induced-innovation theory, capital prices may also affect productivity growth because of the importance of capital investment in technical change.

These hypotheses were tested for the two red meat industries (2011 and 2013) by regressing the detrended ε_{ct} observations against: (i) the most recent annual change in the U.S. unemployment rate divided by the average of such changes in the preceding three years, and (ii) the average annual change in the capital rental price during the preceding two years. In both industries, rising unemployment has increased dual productivity growth, although only in red meat packing has the effect been statistically significant (t = 2.51). Rising capital rental prices have reduced productivity growth significantly (t = -5.14 in SIC 2011 and t = -7.11 in SIC 2013). Nevertheless, elasticities computed from the regression coefficients are small. For example, a one-percent capital rental price increase depressed productivity growth in red meat packing by only 0.05%. Most of the historical changes in productivity growth have come from secular rather than cyclical causes.

It is interesting to observe in connection with the role of capital that γ_{tk} in table 1 is negative and strongly statistically significant. Because $\partial(\partial G/\partial t)/\partial K$ has the same sign as γ_{tk}, the negative sign says that additions to capital stock increase the rate at which technology change reduces labor and material costs at given output. And since $\partial(\partial G/\partial K)/\partial t = -\partial Z_k/\partial t$, technology change since the early 1970s has enhanced the shadow value of capital. We conclude that the quality of capital in meat processing has been rising relative to that of labor and materials. This conclusion is consistent with rapid breakthroughs in machinery and computing design and with the evident decline in average worker skills in the meats sector.

Size Economies

Long-run unit cost curves, computed as explained under equation (3), are depicted in figure 2 for each of the four meat processing sub-sectors and for each of several sample years. Output volumes range, for the most part, two standard deviations above and below the output sample mean and are expressed in figure 2 on a per-establishment basis.[iii] Input prices are held at 1973 - 1994 constant-dollar sample means. The square dot on each curve signifies the mean establishment size that year.

With the exception of the 1970s' and 1980s' red meat packing industry, productivity growth has shifted unit cost curves downward rather than rotated them around a central axis. Where rotation did occur, it was counter-clockwise rather than clockwise. Indeed, contrary to Ball and Chambers' (and later Melton and Huffman's) suggestion that unit cost curves might be getting steeper, they have become flatter, and the flattening is particularly evident in 1970s' and 1980s' red meat packing. The concave-downward shapes, at low plant sizes, of some of the figure 2 unit cost curves implies an exceptionally strong incentive for small plants to increase size. At higher sizes, the curves assume the normal convex shape.

Comparing global with local size economies provides important clues about firm and plant expansion and hence about future changes in industry concentration. In table 3, elasticities of global size economy computed from equation (3) and figure 2 are compared with plant numbers and mean plant sizes, and with local economies computed from equation (2). Global size economies have fallen in every industry, especially in red meat packing. The declines are due primarily to the flattening of the unit cost curves but are dampened somewhat by the curves' downward shifts, since as cost curves fall, a given unit cost reduction represents a larger percentage change from its base point.

In the classically shaped unit cost curve, local size elasticity declines (cost elasticity rises) with increasing establishment size. The slope on the curve, in other words, declines proportionately more quickly than does the ratio of unit cost to establishment size. The fact that local size elasticities in table 3 have, in red meat packing, been stable and in the other industries have risen over time despite growing plant size is due entirely to productivity-induced downshifts in unit costs. Technical change, that is, explains why plant size growth in these industries has not exhausted local size economies evaluated at the mean plant. Inasmuch as, in the neighborhood of the mean plant, a local size economy is the principal inducement to continued aggregate plant growth, productivity change is enhancing incentives for further industry concentration.

Technical Change Biases

Long-run biases of technical change, depicted in figure 3, show that technological innovations in meat processing have been strongly capital-using, shifting expansion paths strongly in the direction of the capital axis. Between 1993 and 1994, for example, capital's expenditure share in the red meat industries rose by about 3%, and in the white meat industries by about 2.5%, on account of technical change alone, holding factor prices constant and adjusting for any output scale effects. Since, for instance, capital's expenditure share in poultry dressing was 12% in 1993, the 2.5% capital-use bias shown in figure 3 implies a technology-induced increase that year of about 0.36 percentage points in capital's expenditure share. Cumulated over the 22 years of our sample, such effects are quite significant. In particular, the capital expenditure share in red meat packing predicted on the basis of long-run optimal capital use rose from an average 6 % in the mid-1970s to 10 % in 1994 despite dramatic increases in relative capital prices over the two decades.

In all four meat processing industries, technical change has been material-saving; and the rate at which materials are being saved has increased in recent years. Plant re-configurations have substituted capital for materials; new equipment is more effective than the old in extracting usable product from a given carcass. This finding contrasts with Morrison (1997), who argues that technical change in the aggregate food processing sector has been material-using. Despite the material-saving bias we find in meat processing, long-run material expenditure shares in the red meat sub-sectors have been roughly constant, and in the white meats have been increasing, because of declines in real material prices and consequent price-induced substitution into materials. Figure 3 demonstrates that technical change in the flagship industry, red meat packing, has been strongly and increasingly labor-using, a remarkable result given our predisposition to think of modernization as worker-displacing. In the other three industries, however, technology has been approximately labor-neutral in recent years and labor expenditure shares show little sign of rising.

Selected long-run expansion paths in the red meat packing and poultry dressing industries (figure 4) demonstrate these same technical change biases as well as the generally nonhomothetic structure of meat processing technology. Between 1974 and 1994, technical change in both sub-sectors shifted capital-material expansion paths significantly in the direction of the capital axis. In red meat packing, labor-material expansion paths shifted toward the labor axis as well, implying technical change was substituting labor as well as capital for materials. However, labor-material expansion paths in poultry dressing have shifted toward the material axis instead. In 1974, 200 labor units could process 6,750 units of live poultry; in 1994, they could process 10,000 units. Perhaps most striking are the negatively sloped labor-material expansion paths in red meat packing: until the 1990s, increasing plant output at fixed factor prices meant reducing labor inputs. Most likely, the low-output plants were the antiquated ones still operating with labor-intensive technologies. By the 1990s, these plants had been retired and the normally positive relation between output and labor had been restored.

Factor Demand and Substitution

Meat processing plants have, like much of North American industry, become increasingly specialized. In the 1990s, therefore, one would expect to see less input substitutability and less elastic factor demands than in the 1970s. Our results confirm part of this expectation rather dramatically. In red meat packing, output-conditional own-price elasticities of labor demand fell from –1.35 to –0.25, and of material demand from –0.40 to –0.23, between 1973 and 1994. Capital demand elasticities, on the other hand, rose from –0.80 to –1.29.[iv]

Morishima substitution elasticities have fallen, implying that isoquants have become more convex than in earlier years. In red meat packing, for example, Morishima elasticity M_{lm} (percent change in the material-to-labor ratio induced by a one percent rise in the labor wage) has fallen from 1.6 to 0.4 since the early 1970s. In the other three industries, M_{lm} has approached zero. Labor rates, in short, have a weaker effect on live animal demands than they used to have.[v] Substitutability between capital and materials, however, has grown. Through the end of the 1970s, a one percent rise in capital price reduced the material-to-capital ratio in the red meat packing sector by about 1.0% (M_{km} = 1.00). In the early 1990s, it reduced it by about 1.5% (M_{km} = 1.50). Interest rates and other capital costs, that is, increasingly affect processor demands for cattle and hogs. Finally, red meat packing capital in recent years has become weakly complementary with labor ($M_{kl} < 0$), although labor remains a substitute for capital ($M_{lk} > 0$) and no complementarity was found in the other meat industries.

Conclusions

Productivity in all four meat processing sub-sectors has risen consistently since the early 1980s, contrasting with arguments in Ball and Chambers, Melton and Huffman, and Morrison (1997) that technical change has often been regressive. We do observe that productivity growth rates have declined substantially. Because economic recession and low capital prices appear to a modest extent to enhance productivity growth, recent prosperity and high capital prices may be partly to blame for the decline. Increased industry concentration may also be at fault, although the explanation for falling growth rates perhaps lies instead in the lags naturally encountered in the application of scientific breakthroughs. We see no evidence that pollution regulations have affected productive efficiency in any significant way.

Global size economies, expressed as percentage savings in unit cost as plant size expands, have declined in these industries, particularly in red meat packing. Nevertheless, size economies computed in the neighborhood of the mean plant have been static or increasing, as productivity-induced downshifts in unit cost curves counteract the transition to larger plant sizes. Because aggregate incentives to expand size depend largely on local size economies, expansion incentives appear to remain undiminished. Nevertheless, as in most other econometric studies, we find little evidence of market power in the meat sector, and no sign that marginal increases in plant size will exacerbate such power. Rather, size growth appears to be technology-driven in the sense of an effort to exploit the extant size economies.

Technical change in meat processing has been significantly capital-using and material-saving, likely because the relative quality of capital has improved. Technology-induced substitution between capital and materials is broadly consistent with our finding that these two inputs are rather strong price substitutes for one another, a substitutability that in some sub-sectors has grown, and in other sub-sectors has diminished only slightly, during the past several decades. Production models in which value-adding inputs combine in fixed proportions with raw products have, therefore, little relevance to the long run or to four-digit-aggregated industries. Rather, corroborating Wohlgenant's earlier work, substitution is quite pronounced between materials and the inputs that add value to them. For this reason, relative factor price changes will continue to have significant impacts on both factor use and technology change in the meat sector.

Table 1. System Parameter Estimates, Meat Processing Industries, 1973-1994

Parameter	Estimate	t-statistic [a]
α_{LL}	0.320	7.13
α_{LM}	0.001	0.57
α_{MM}	2.350	34.92
β_{LY}	-0.001	-5.70
β_{Lt}	-0.066	-7.22
β_{LA}	0.004	1.82
β_{MY}	-0.001	-8.45
β_{Mt}	-0.151	-15.15
β_{MA}	-0.003	-1.03
γ_{YY}	4.26E-07	8.80
γ_{Yt}	1.8E-05	4.08
γ_{YA}	-9E-06	-12.52
γ_{tt}	0.004	7.34
γ_{tA}	-6.4E-05	-0.55
γ_{AA}	5.99E-05	2.12
β_{LK}	0.168	4.90
β_{MK}	-0.616	-12.68
γ_{YK}	2E-04	6.35
γ_{tK}	-0.025	-8.36
γ_{AK}	0.001	1.65
γ_{KK}	0.050	3.84

a. Degrees of freedom for t-tests: 67.

Table 2. Productivity Growth Rates and Cost Elasticities in the Meat Processing Industries, 1974-1994

	Red Meat Packing (2011)			Red Meat Further-Processing (2013)		
Year	ε_{Ct}	ε_{Yt}	ε_{CY}	ε_{Ct}	ε_{Yt}	ε_{CY}
1973	-0.920	0.997	0.923	-1.226	1.271	0.964
1974	-0.831	0.914	0.909	-1.211	1.259	0.962
1975	-0.709	0.786	0.903	-1.019	1.064	0.958
1976	-0.636	0.722	0.881	-1.046	1.097	0.953
1977	-0.618	0.718	0.860	-1.006	1.061	0.948
1978	-0.735	0.824	0.893	-1.074	1.122	0.957
1979	-0.792	0.864	0.916	-1.092	1.141	0.957
1980	-0.719	0.801	0.898	-1.065	1.110	0.960
1981	-0.602	0.693	0.869	-0.974	1.021	0.954
1982	-0.562	0.586	0.960	-0.908	0.949	0.957
1983	-0.521	0.572	0.912	-0.838	0.897	0.934
1984	-0.490	0.554	0.885	-0.801	0.845	0.948
1985	-0.414	0.475	0.873	-0.740	0.789	0.937
1986	-0.426	0.487	0.875	-0.715	0.770	0.928
1987	-0.443	0.498	0.890	-0.659	0.711	0.927
1988	-0.409	0.457	0.895	-0.609	0.657	0.927
1989	-0.401	0.441	0.910	-0.579	0.614	0.943
1990	-0.405	0.441	0.920	-0.562	0.593	0.948
1991	-0.369	0.412	0.896	-0.526	0.578	0.909
1992	-0.292	0.323	0.904	-0.466	0.499	0.934
1993	-0.299	0.328	0.913	-0.473	0.505	0.936
1994	-0.193	0.216	0.892	-0.409	0.437	0.937
Mean	-0.536	0.596	0.899	-0.818	0.863	0.945

Table 2 (continued). Productivity Growth Rates and Cost Elasticities in the Meat Processing Industries, 1974-1994

	Poultry Dressing (2016)			Poultry Further-Processing (2017)		
Year	ε_{Ct}	ε_{Yt}	ε_{CY}	ε_{Ct}	ε_{Yt}	ε_{CY}
1973	-1.201	1.220	0.984	-1.313	1.320	0.995
1974	-1.164	1.188	0.980	-1.272	1.280	0.994
1975	-0.922	0.947	0.974	-1.009	1.019	0.991
1976	-0.974	1.003	0.971	-1.080	1.090	0.991
1977	-0.961	0.989	0.971	-1.083	1.093	0.990
1978	-0.996	1.028	0.969	-1.152	1.163	0.991
1979	-0.998	1.034	0.965	-1.148	1.159	0.990
1980	-0.964	1.003	0.960	-1.137	1.148	0.990
1981	-0.867	0.911	0.951	-1.019	1.033	0.987
1982	-0.798	0.839	0.951	-0.953	0.969	0.984
1983	-0.786	0.827	0.950	-0.940	0.956	0.983
1984	-0.777	0.814	0.955	-0.907	0.921	0.985
1985	-0.712	0.753	0.945	-0.864	0.880	0.982
1986	-0.716	0.760	0.942	-0.870	0.887	0.981
1987	-0.616	0.669	0.921	-0.768	0.790	0.972
1988	-0.605	0.658	0.919	-0.751	0.772	0.973
1989	-0.582	0.634	0.918	-0.704	0.729	0.965
1990	-0.517	0.569	0.908	-0.638	0.664	0.961
1991	-0.481	0.537	0.896	-0.612	0.640	0.957
1992	-0.437	0.493	0.887	-0.580	0.609	0.953
1993	-0.452	0.507	0.890	-0.596	0.624	0.955
1994	-0.411	0.462	0.891	-0.551	0.577	0.955
Mean	-0.770	0.811	0.941	-0.907	0.924	0.978

Table 3. Global and Local Size Economies in the Meat Processing Industries, 1974-1994

	Red Meat Packing (2011)				Red Meat Further-Processing (2013)			
Year	Global Size Elasticity (ε_s^{glob})	Number of Plants (N)	Mean Plant Size (Y/N)	Local Size Elasticity (ε_s^{loc})	Global Size Elasticity (ε_s^{glob})	Number of Plants (N)	Mean Plant Size (Y/N)	Local Size Elasticity (ε_s^{loc})
1974	-0.077	2520	19.17	-0.101	-0.030	1325	7.38	-0.040
1979	-0.058	2266	21.68	-0.091	-0.026	1331	8.93	-0.045
1984	-0.035	1642	29.85	-0.130	-0.022	1324	10.26	-0.055
1989	-0.029	1415	32.23	-0.099	-0.017	1311	14.34	-0.061
1994	-0.016	1368	36.87	-0.121	-0.013	1232	16.44	-0.068
Mean	-0.043	1842	27.96	-0.108	-0.022	1305	11.47	-0.053

	Poultry Dressing (2016)				Poultry Further-Processing (2017)			
Year	Global Size Elasticity (ε_s^{glob})	Number of Plants (N)	Mean Plant Size (Y/N)	Local Size Elasticity (ε_s^{loc})	Global Size Elasticity (ε_s^{glob})	Number of Plants (N)	Mean Plant Size (Y/N)	Local Size Elasticity (ε_s^{loc})
1974	-0.008	492	12.1926	-0.020	-0.008	139	7.41	-0.006
1979	-0.007	418	19.2599	-0.036	-0.007	155	9.17	-0.010
1984	-0.007	358	27.8373	-0.047	-0.007	146	13.44	-0.015
1989	-0.006	370	40.6881	-0.090	-0.006	144	30.62	-0.036
1994	-0.006	463	45.7996	-0.123	-0.005	179	34.69	-0.047
Mean	-0.007	420	29.1555	-0.063	-0.007	153	19.07	-0.023

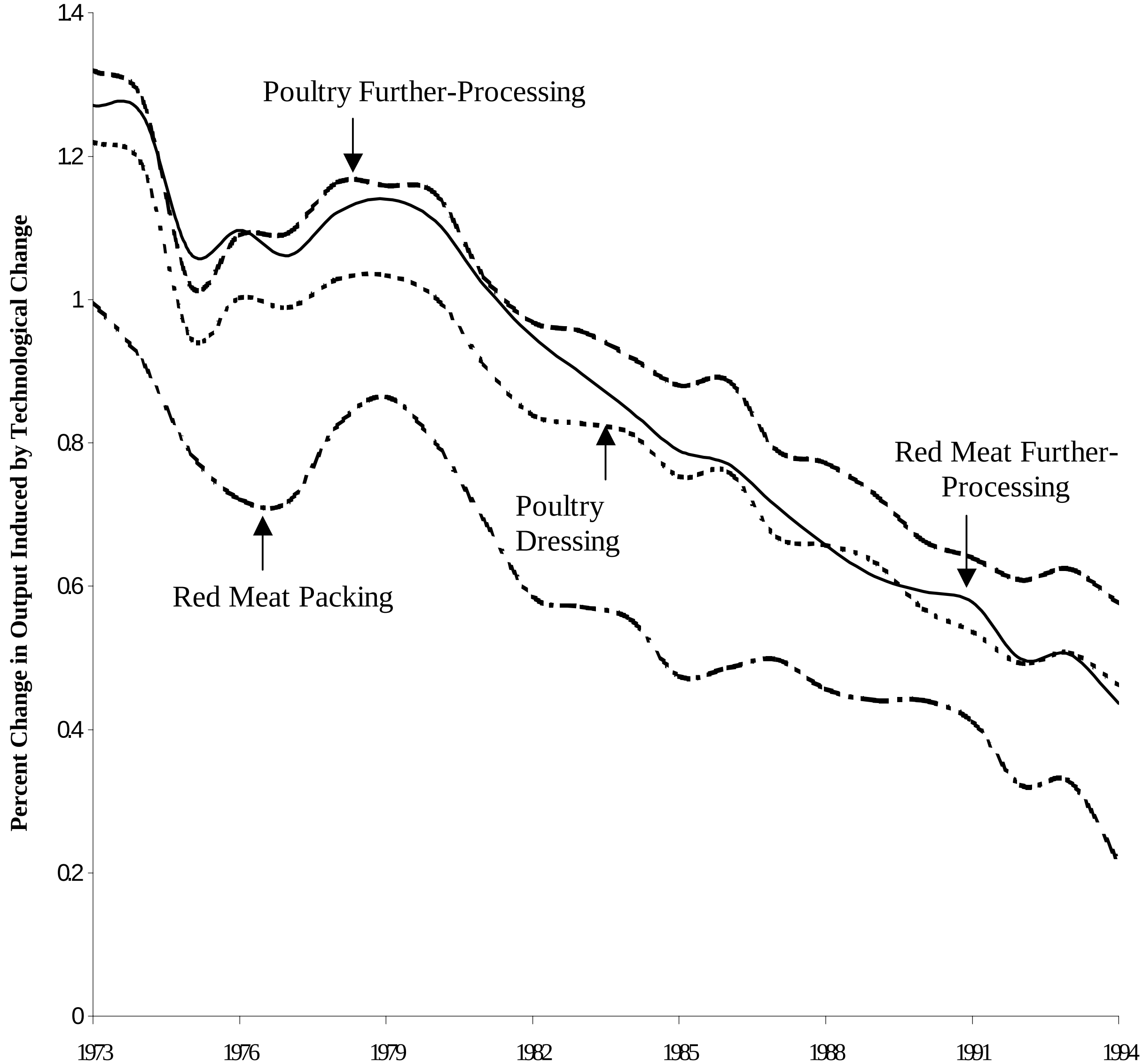
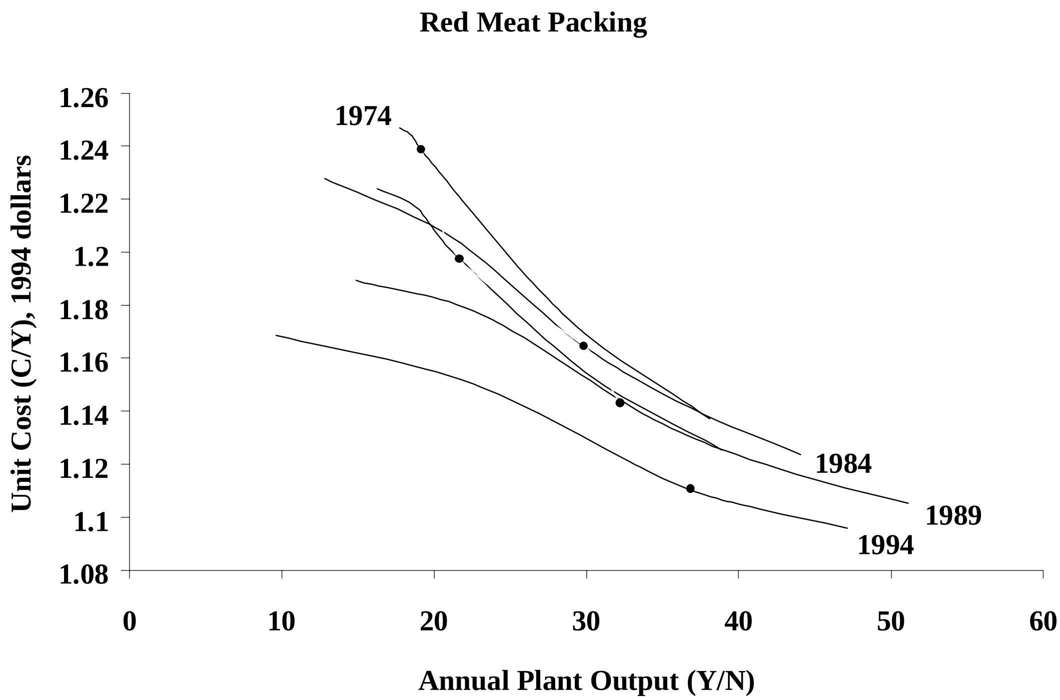


Figure 1. Long-Run Primal Productivity Growth Rates in the Meat Processing Industries, 1973-1994



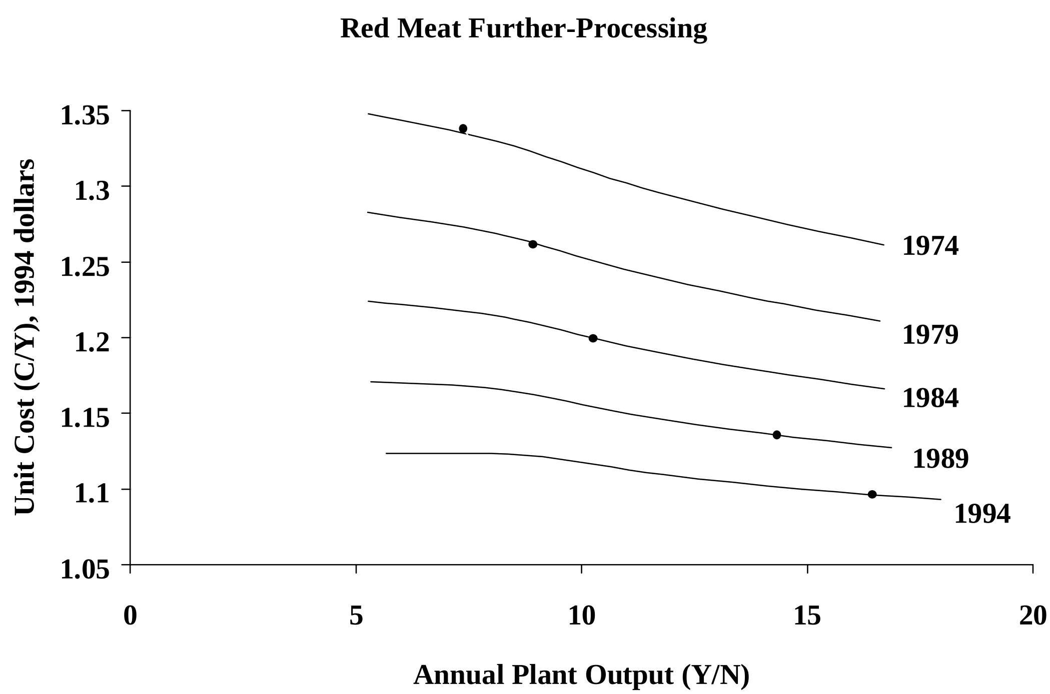
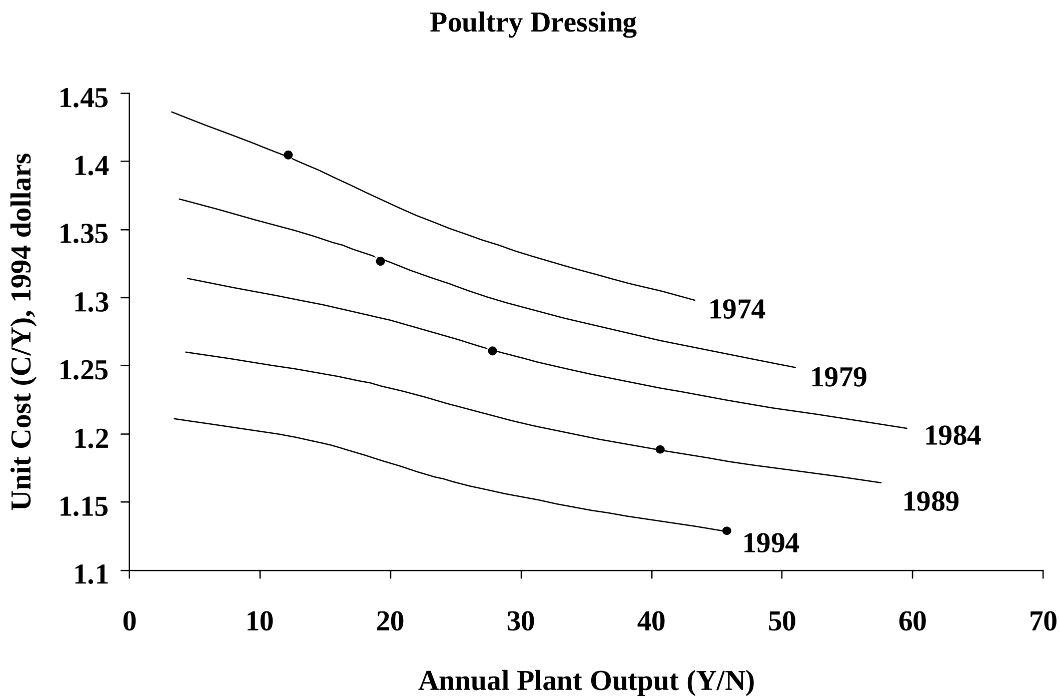


Figure 2. Long-Run Unit Cost Curves In the Meat Processing Industries, 1974-1994 [a]



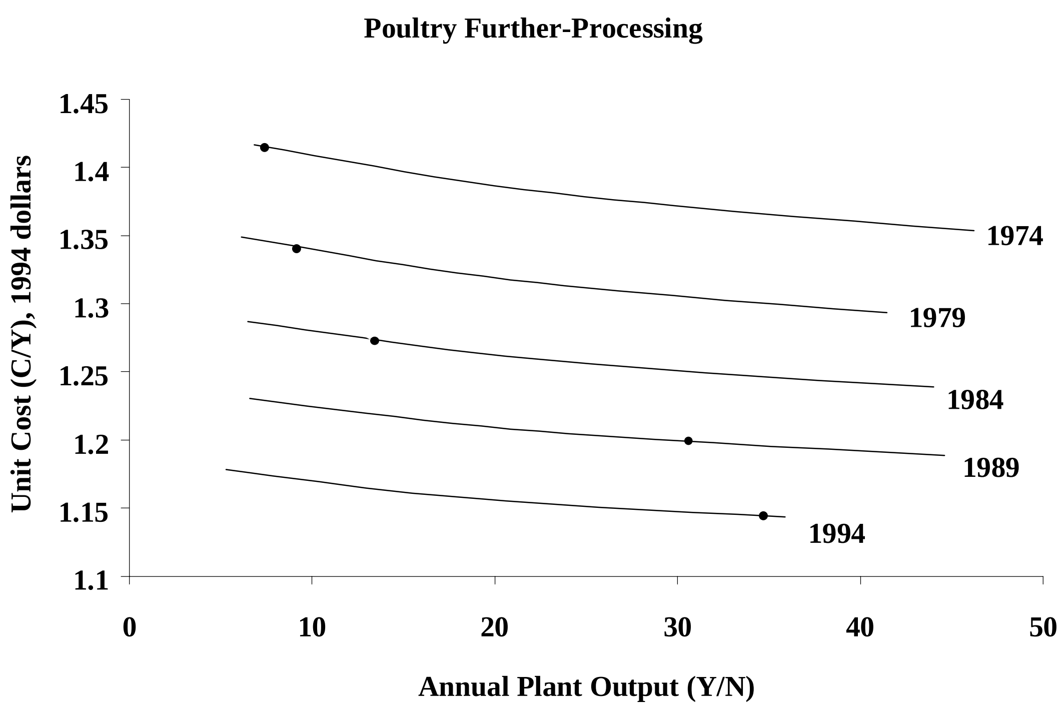


Figure 2 (continued). Long-Run Unit Cost Curves in the Meat Processing Industries, 1974-1994 [a]

a. Dots indicate mean establishment output in respective year.

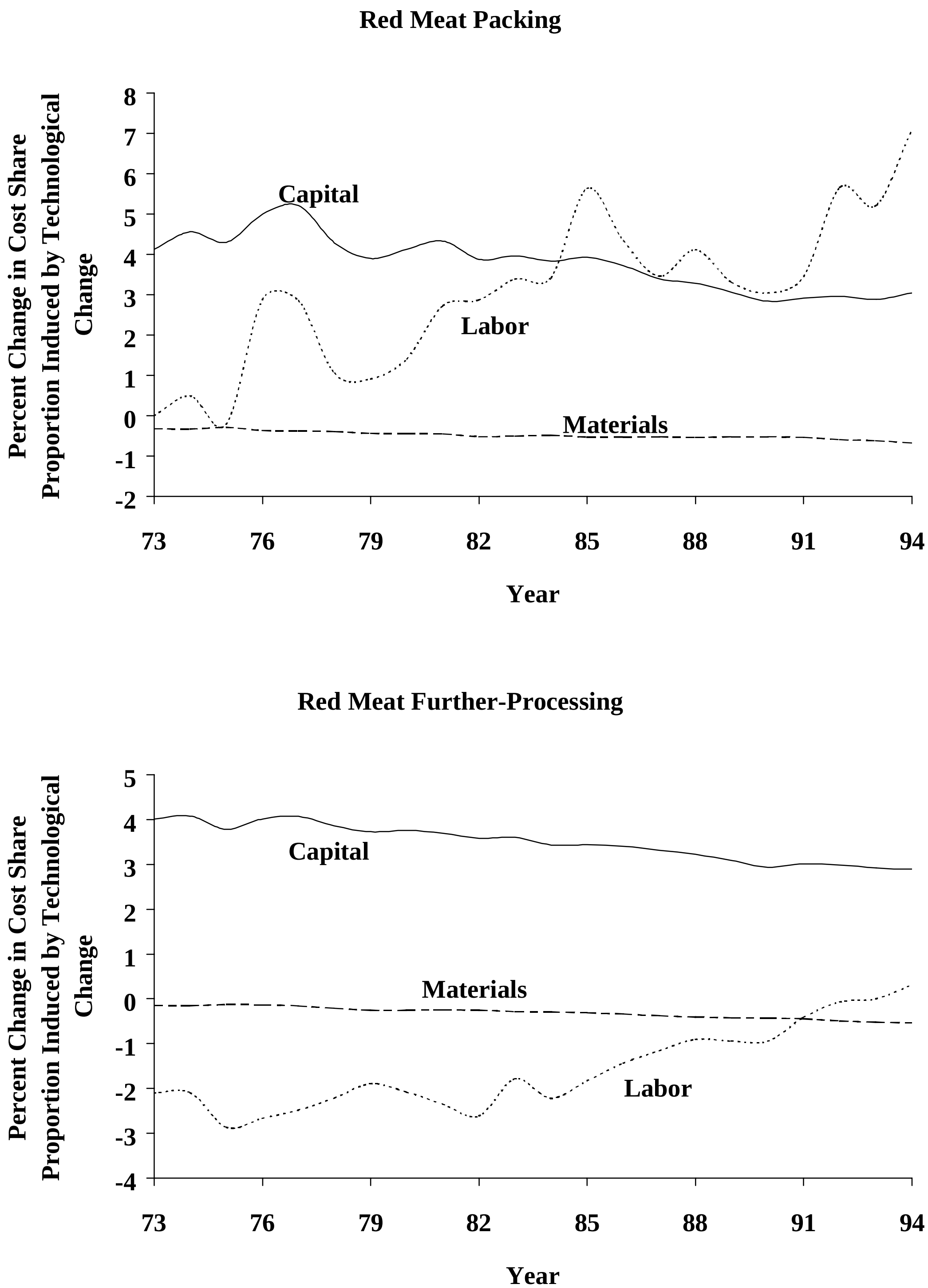


Figure 3. Long-Run Biases of Technological Change in the Meat Processing Industries, 1973-1994

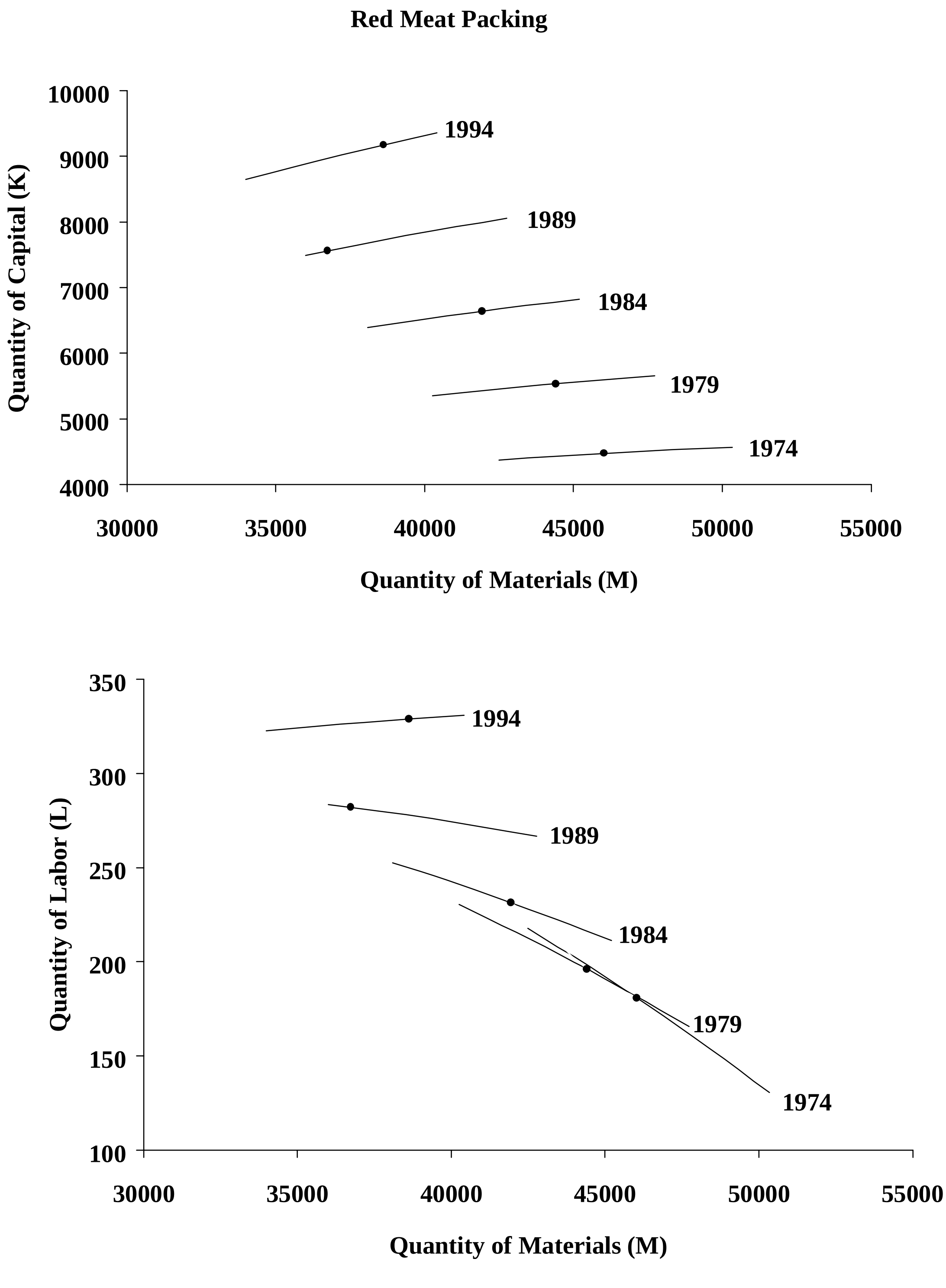


Figure 4. Long-Run Expansion Paths in the Red Meat Packing Industry, 1974-1994 [a]

a. Output (Y) varies two standard deviations above and below the 1973-1994 sample mean. Dots indicate input quantities required to produce the output quantities observed in the stated years. Input prices are held fixed at 1973-1994 means.

Endnotes

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1. Parameters α_1 were restricted so that, at sample means, output demand elasticities would approximate those reported in Tomek and Robinson. The elasticities were, for SIC 2011 and 2013, -0.66 and, for SIC 2016 and 2017, -0.55. Estimates of the remaining parameters were insensitive to α_1 restrictions.
2. Some authors, Ball and Chambers among them, quote productivity growth rates in decimal rather than percentage form. Thus, 0.036 refers to a 3.6 % change. Following Morrison and others, growth rates in the present paper are expressed in percentage form by multiplying the decimals by 100.
3. Data on establishment numbers are collected at four-year intervals; those in non-report years were estimated here by linear interpolation. Several establishments may be identified at a given plant or location if each is considered a separable activity (Bureau of Census). In this paper, we use the terms "establishment" and "plant" interchangeably.
4. Goodwin and Brester conclude that, between their 1972-1980 and 1980-1990 regimes, the demand elasticity of labor in aggregate U.S. food manufacturing fell from –0.77 to –0.47. The demand elasticity of material rose and of capital remained constant.
5. Morishima elasticity M_{ij} is defined as $\partial \ln(X_j/X_i)/\partial \ln(W_i/W_j)$. In this expression, W_j effectively is held constant, so it is meaningful to think of only the j^{th} price as varying. Morishima elasticities are not symmetric; for example, $M_{ml} \neq M_{lm}$ and material prices have a different effect on relative labor demand than labor wages have on relative material demand.

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