Technological Change in Meat and Poultry-Packing and Processing

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Abstract

Nonparametric procedures are used to compare technological change in SIC 2011, meatpacking, and SIC 2015, poultry slaughter and processing. There has been a greater increase in total factor productivity in poultry than in the red meats. Evidence also suggests recent differences in the bias of this technological change, with production changes being labor using in poultry and biased towards greater efficiency in the use of live animal inputs in meatpacking.

Keywords: red meat, poultry, meatpacking, technological change, nonparametric analysis

Introduction

The slaughter, packing and processing of red meats and poultry products is a significant component of the U.S. agribusiness industry. The changing structure of these two industries has received considerable attention. Both Purcell and Ward have provided summary analyses of changes in red meat slaughter and packing. Both authors addressed the impacts of increasing concentration, especially in the beef sector, on industry performance. Marion and Kim have recently provided additional evidence of increasing firm concentration in poultry processing. The primary concern associated with these structural changes has been the potential for noncompetitive pricing practices in both the factor and output markets for the industries (Azzam and Pagoulatos; Azzam; Schroeter and Azzam).

The purpose of the present research is to estimate and compare the nature and the rates of changes in total factor productivity in meatpacking (SIC 2011) and poultry slaughter and processing (SIC 2015). Little work has been done quantifying productivity changes in the meat products industries on an aggregate level. Adelaja has recently found evidence of productivity growth of material inputs in New Jersey's meat products industry arising from increases in relative prices of the these inputs. Heien calculated Tornquist-Theil indices of total factor productivity growth in the entire U.S. food processing and distribution sector, but did not report results for individual subsectors. Ball and Chambers' analysis of productivity growth in the meat products industry between 1954 and 1976 found significant economies associated with increasing size. Some of these scale economies were associated with factor-saving biases with respect to labor. These authors warn that a declining cost industry might lead to increasing concentration, a finding recently substantiated by Marion and Kim's analysis of acquisitions and mergers in various food processing industries.

Most studies of technological change rely upon dual parametric models. However, there has recently been much interest in the nonparametric approach pioneered by Farrell. Farrell's insights spawned two branches of inquiry - the data envelopment approach (DEA) of Charnes, Cooper and Rhodes, and the nonparametric analyses of

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Afriat, Hanoch and Rothschild, and Varian. After an initial divergence, the two branches seem to be converging somewhat. One can see many similarities between the work of Fare, for example, with its roots in DEA models, and Chavas and Cox, whose work is largely based on Varian's nonparametric production techniques.

This study uses the approach of Chavas and Cox to estimate technological change in meatpacking and in poultry slaughter and processing. Modifications to past applications involve restricting technological change to be nonregressive. The addition of an error term to the calculation of the effective output of the industries allows for year-to-year deviations in total factor productivity presumably arising from exogenous factors unrelated to technological change. The model is further modified to allow distortions in both output and input markets arising from the exercise of market power by the two industries. Incorporation of these distortion terms is consistent with the finding of many authors of imperfect competition in the meat industries (Koontz et al.; Stiegert et al.).

Nonparametric Analysis of Production and Technological Change

Consider an industry composed of firms combining inputs $\mathbf{x} = \{x_1, ..., x_n\}$, purchased at price $\mathbf{r} = \{r_1, ..., r_n\}$, to produce single output y, which can be sold at price p. Profit maximization requires that, at any period of time t, input and output levels are chosen so that profits cannot be increased by any other feasible choice set. For example, input and output choices in year t would reflect optimal adjustment to prices in year t, and the input and output set chosen in year t-1 will have changed to reflect the changes in relative prices. Thus, $p_t y_t - \mathbf{r}_t'\mathbf{x}_t \geq p_t y_{t-1} - \mathbf{r}_t'\mathbf{x}_{t-1}$, or profits have been improved by changing the set (y, $\mathbf{x}$) to correspond to the new set of prices.

This assumption concerning optimal adjustments to changing economic factors results in the straightforward nonparametric test for profit maximization. Given observations on prices, inputs, and outputs for $t = 1 ,..., T$ periods, behavior consistent with profit maximization would find the relationship $p_t y_t - \mathbf{r}_t'\mathbf{x}_t \geq p_t y_s - \mathbf{r}_t'\mathbf{x}_s$ true for all periods t and s, $t,s = 1 ,..., T$.

This condition, however, is rarely satisfied in practice. Confounding the relationship are random events, such as weather or other environmental factors that affect input and output levels. Planned input and output levels might satisfy the condition for profit maximization, but observed levels may not. Another major factor, especially when $t > s$, is the influence of technological change on the production function. Consider a simple case of Hicks neutral change, in which outputs increase with no change in the input levels used, or $y_t > y_{t-1}$ with unchanged input levels, or $\mathbf{x}_t = \mathbf{x}_{t-1}$. The profit maximization criterion would deem production in year t-1 as nonoptimal in this comparison, even though the technology resulting in y_t may not have been available the previous year.

Extensions to the nonparametric test to account for technological advance were developed by Varian, and have been extensively tested on U.S. agricultural data (Cox and Chavas, Chavas and Cox). Consider the production frontier faced by the representative firm within the industry,

$$Y = f(\mathbf{X}), \qquad (1)$$

where $Y = Y(y,A)$ is "effective output," or observed output y augmented by a measure A that may represent technological change (among other possibly random elements). Effective inputs are similarly defined as $\mathbf{X} = \mathbf{X}(\boldsymbol{x},\boldsymbol{B})$, where $\boldsymbol{B}$ might measure biased technological change affecting the marginal rates of input substitution over time. Under the translating hypothesis (Chavas and Cox), technological change is represented by an additive transformation of observed input and output levels, or $Y = y - A$ and $\mathbf{X} = \mathbf{x} + \boldsymbol{B}$. In the example above where output y increases with no corresponding increase in input levels, the profit maximization criterion would be altered to account for technological change by substituting the observed levels of outputs and inputs with effective levels, or,

$$p_t(y_t - A_t) - \mathbf{r}_t'(\mathbf{x}_t + \boldsymbol{B}_t) \geq$$

$$p_t(y_{t-1} - A_{t-1}) - \mathbf{r}_t'(\mathbf{x}_{t-1} + \boldsymbol{B}_{t-1}) \qquad (2)$$

A sufficient condition for profit maximization in both periods, in which the inequality in (2) is satisfied, is $A_t > 0$, and A_{t-1}, $\boldsymbol{B}_t$, and $\boldsymbol{B}_{t-1}$ all equal 0. A general formulation results by substituting s for t-1 in expression (2).

The profit maximization criterion in (2) is conditional upon competitive input and output markets. When these markets are not competitive, firms may consider the impact changing levels of y and **x** will have on both output and factor prices. Varian has modified the profit maximization criterion under monopoly. In this case, profit maximization implies the firm has chosen (y_t, $\mathbf{x}_t$) such that profits are greater than at any other feasible set, assuming the monopolist expects price p^e_{ts} in period t to occur if output were y_s. Formally,

$$p_t(y_t - A_t) \; - \; \mathbf{r}_t'(\mathbf{x}_t + \boldsymbol{B}_t) \; \geq$$

$$p^e_{ts}(y_s - A_s) \; - \; \mathbf{r}_t'(\mathbf{x}_s + \boldsymbol{B}_s) \qquad (3)$$

Several authors (Koontz et al.; Conner) have also found support for noncompetitive behavior in the market for the live animal input into meat packing. If we designate the noncompetitive factors x_t and let factors z_t be purchased competitively at prices w_t, (3) can be modified,

$$p_t(y_t - A_t) \; - \; \boldsymbol{r}_t'(\mathbf{x}_t + \boldsymbol{B}_t) \; - \; \mathbf{w}_t'(\mathbf{z}_t + \boldsymbol{B}_{zt}) \; \geq$$

$$p^e_{ts}\,(y_s - A_s) \; - \; r^e_{ts}(\mathbf{x}_s + \boldsymbol{B}_{xs}) \; - \; \mathbf{w}_t'(\mathbf{z}_s + \boldsymbol{B}_{zs}) \qquad (4)$$

Noting that all variables Θ_s can be expressed as $\Theta_s = \Theta_t + \Delta\Theta_t$, (4) can be rewritten

$$p^e_{ts}(y_t + \Delta y_t - A_s) \; - \; p_t(y_t - A_t) \; \leq$$

$$r^e_{ts}(\mathbf{x}_t + \Delta\mathbf{x}_t + \boldsymbol{B}_{xs}) \; + \; \mathbf{w}_t'(\mathbf{z}_t + \Delta\mathbf{z}_t + \boldsymbol{B}_{zs})$$

$$- \; \mathbf{r}_t'(\mathbf{x}_t + \boldsymbol{B}_t) \; - \; \mathbf{w}_t'(\mathbf{z}_t + \boldsymbol{B}_{zt}), \qquad (5)$$

or

$$(y_t - A_t)(p^e_{ts} - p_t) \; + \; p^e_{ts}\,(\Delta y_t - \Delta A_t) \; \leq$$

$$(\mathbf{x}_t + \boldsymbol{B}_{xt})(r^e_{ts} - \mathbf{r}_t) \; + \; r^e_{ts}\,(\Delta\mathbf{x}_t - \Delta\boldsymbol{B}_{xt})$$

$$+ \; \mathbf{w}_t'(\Delta\mathbf{z}_t - \Delta\boldsymbol{B}_{zt}) \qquad (6)$$

Expression (6) allows the introduction of indices of monopoly/monopsony power derived by Bresnahan (1982) with respect to monopolies. In the case of continuous cost and revenue functions, Bresnahan notes that profits will be

$$\pi_t \; = \; p_t y_t \; - \; r_t x_t \; - \; w_t z_t, \qquad (7)$$

where markets for both y and x may be noncompetitive. Determining first order conditions for profit maximization,

$$\frac{\partial\pi}{\partial x} = p\frac{\partial y}{\partial x} + y\frac{\partial p}{\partial y}\frac{\partial y}{\partial x} - r - x\frac{\partial r}{\partial x} - w\frac{\partial z}{\partial x} = 0 \qquad (8)$$

Noting that $\partial y/\partial x$ may be represented as a constant k in the meat processing industries, at least in the short run, (8) can be rewritten

$$k\left(p + y\,\frac{\partial p}{\partial y}\right) = \left(r + x\,\frac{\partial r}{\partial x}\right) + w\frac{\partial z}{\partial x} \qquad (9)$$

The bracketed term on the left hand side equals marginal revenue. The right hand side equals marginal factor cost to the monopsonist, where z is purchased competitively. Bresnahan introduces an index to modify marginal revenue (which we generalize to include marginal factor costs as well) to indicate the appropriate marginal terms as perceived by firms operating in markets that might be intermediate between the perfectly competitive and the case of the single seller/buyer:

$$k\left(p + \beta_y\, y\,\frac{\partial p}{\partial y}\right) = \left(r + \beta_x\, x\,\frac{\partial r}{\partial x}\right) + w\frac{\partial z}{\partial x} \qquad (10)$$

If the industry is perfectly competitive in both factor and output markets, both terms equal zero, and price (adjusted by k) equals marginal costs. The monopolistic/monopsonistic solution is represented by (9), in which both β terms are 1. Intermediate values for β index the degree of distortion in factor and output markets.

The discrete counterpart to (10) has been employed by Ashenfelter and Sullivan in their nonparametric test of market structure in the U.S. cigarette industry. Rewriting (6):

$$(y_t - A_t)\Delta p^e_{ts} + p^e_{ts}(\Delta y_t - \Delta A_t) \leq \qquad (11)$$

$$(\mathbf{x}_t + \boldsymbol{B}_{xt})\Delta \boldsymbol{r}^e_{ts} + \boldsymbol{r}^e_{ts}\Delta(\mathbf{x}_t - \boldsymbol{B}_{xt}) + \mathbf{w}_t'\Delta(\mathbf{z}_t - \boldsymbol{B}_{zt})$$

yields, after some manipulation[1],

$$\frac{\Delta(y_t - A_t)}{\Delta(x_t - B_{xt})}\left(p^e_{ts} + y_t\frac{\Delta p^e_{ts}}{\Delta y_t}\right) \leq \left(\boldsymbol{r}^r_{ts} + \boldsymbol{x}_t\frac{\Delta \boldsymbol{r}^e_{ts}}{\Delta(\boldsymbol{x}_t - \boldsymbol{B}_{xt})}\right) + w_t\frac{\Delta(\boldsymbol{z}_t - \boldsymbol{B}_{zt})}{\Delta(\boldsymbol{x}_t - \boldsymbol{B}_{xt})} \qquad (12)$$

If the industry is perfectly competitive in both output and factor markets, then $p^e_{ts} = p_t$ and $r^e_{ts} = r_t$, and marginal value product equals marginal cost: On the other hand, the monopolist/monopsonist will satisfy (12) by equating perceived marginal value product with perceived marginal cost. Intermediate distortions from the perfectly competitive situation can be detected by measuring deviations from perceived market prices through Bresnhan's indexes:

$$\frac{\Delta(y_t - A_t)}{\Delta(\boldsymbol{x}_t - \boldsymbol{B}_{xt})}\left(p^e_{ts} + \beta_y\, y_t\frac{\Delta p^e_{ts}}{\Delta y_t}\right) \leq \left(\boldsymbol{r}^r_{ts} + b_x\,\boldsymbol{x}_t\frac{\Delta \boldsymbol{r}^e_{ts}}{\Delta(\boldsymbol{x}_t - \boldsymbol{B}_{xt})}\right) + \boldsymbol{w}_t\frac{\Delta(\boldsymbol{z}_t - \boldsymbol{B}_{zt})}{\Delta(\boldsymbol{x}_t - \boldsymbol{B}_{xt})} \qquad (13)$$

Analogous to the continuous case in (10), β_y will measure the perceived divergence of marginal revenue from output price with effective output level Y_s. β_x will measure the divergence of factor price and marginal cost corresponding to the production set (Y_s, $\mathbf{X}_s$, $\mathbf{Z}_s$).

Not all of the variation in observed input and output levels can be ascribed to technological change. For example, environmental factors may introduce a random component to A and B. A further restriction is thus imposed on the profit maximization criterion under technological change. Specifically, we impose the restriction of nonregressive technological change, such that $A_t \geq A_s$ if $t \geq s$. Program feasibility is maintained by allowing, for example, $Y_t < Y_s$ for $t > s$, by appending error terms to the expressions $Y_t = y_t - A_t - e_t$. The index of technological change, A_t, cannot be less than earlier index values, A_{t-i}, $i = 1, ..., T-t$. However, the observed level of output in period t may fall from an earlier period due to stochastic events. These decreases, unexplained by changes in input levels, would be measured by the scalar e_t.

The test for profit maximization in imperfectly competitive markets under nonregressive technological change can be conducted by solution of the following nonlinear programming problem:

$$\text{Min}_{A, B, e} \quad c_a A + c_b B + c_e e \tag{14}$$

subject to

$$\beta_y (y_t - A_t - e_t)(p^e_{ts} - p_t)$$

$$+ p^e_{ts}(\Delta y_t - \Delta A_t - \Delta e_t) \leq \quad \text{for all } t, s = 1,...,T$$

$$\beta_x (\mathbf{x}_t + \boldsymbol{B}_{xt})(\mathbf{r}^e_{ts} - \mathbf{r}_t)' + r^e_{ts}{}' (\Delta \mathbf{x}_t - \Delta \boldsymbol{B}_{xt})$$

$$+ \mathbf{w}_t'(\Delta \mathbf{z}_t - \Delta \boldsymbol{B}_{zt})$$

$$A_t - A_s \leq 0 \quad \text{for } t < s$$

$$\beta_x \leq 1$$

$$\beta_y \leq 1$$

$$A, \beta_x, \beta_y \geq 0, \boldsymbol{B} \text{ and } e \text{ unrestricted}$$

Feasibility of the model signifies values can be found for both the technological change variables A and $\boldsymbol{B}$, the error terms, and the monopoly/monopsony indices. Optimality, and subsequent interpretation of the levels of these variables, depends upon the objective function coefficients. We follow Chavas and Cox by placing a high penalty on $\boldsymbol{B}$ such that values of A are biased towards Hicks neutrality. In addition, we place a high penalty on the error terms e, such that larger values for A will result consistent with the nonregressive assumption. In practice, we set c_a = 1, c_b = 10000 and c_e = 100. An additional assumption must be made concerning the subjective prices expected by the firm decision makers, p^e_{ts} and r^e_{ts}. Varian offers several suggestions. We adopt his suggestion that $p^e_{ts} = p_s$ and $\mathbf{r}^e_{ts} = r_s$, or that subjective prices equal actual prices observed when input and output levels corresponded to those in period s.

Two measures of "technological change" can be calculated. Following Chavas and Cox, who based their calculation on an earlier work of Diewert's, a total factor productivity index measuring the impact of technological change between period s and base year t can be measured as $((A_s - A_t)/y_t + 1)$. Consistency with Chavas and Cox's measure, in which technological regress is allowed, can be expressed by incorporating the random element for year s into the expression, $((A_s - e_s + A_t)/y_t + 1)$.

Data

Annual data were collected for SIC industries 2011, meatpacking, and 2015, poultry slaughtering and processing. A single measure of output quantity was used for each sector, the commercial production of red meats for 2011 and of poultry for 2015 (*Livestock and Meat Statistics*). Implicit output prices were calculated by dividing the value of shipments data for each industry by commercial production. In order to assess improved efficiency in the slaughter and processing of live animals, animal input quantities were the number of beef cattle, calves, hogs and sheep and lambs slaughtered (SIC 2011) and the number of broilers and turkeys slaughtered (for SIC 2015). Input animal prices were expressed on a per animal basis to account for changes in slaughter weights over the period. Both slaughter, weight and price data were found in *Agricultural Statistics*. Non-meat material inputs are reported for census years in the *Census of Manufacturers*. Linear interpolations were used to approximate non-meat material inputs in non-census years. These non-meat inputs were valued using the producer price index for intermediate materials (*Survey of Current Business*). Production labor quantities and wages and new capital expenditures were from *Annual Survey of Manufacturers*. The price of capital investment was set equal to the prime rate charged by banks on short term business loans, reported in the *Survey of Current Business*.

Capital asset measurement has posed a problem in earlier models of the meat and poultry sectors (Schroeter). New capital expenditures are reported annually in the *Census of Manufacturers*. End of year depreciable asset values have been reported for 22 of the 28 years included in the analysis. A simple interpolation to determine asset values for nonreported years was calculated by finding the depreciation rate δ for each sector that minimized the sum of squared errors between reported asset values and calculated values derived from the following capital adjustment formula:

$$d_t = d_{t-1} (1 - 1/\delta) + I_t \tag{15}$$

where d is end of year depreciable asset value and I is the reported new capital expenditures. $\delta = 25$ for poultry and $\delta = 18$ for meatpacking minimized the sum of squared errors. All capital values and input and output prices were deflated using the producer price index.

Results

Profit maximization without technological change was soundly rejected for both the red meat and poultry industries. Interestingly, the rejections were much more plentiful when $s > t$, or in comparing future production levels with a base year t. For red meat, rejections were 64 (16.9 percent of the 378 interyear comparisons) when $s < t$ and 283 (74.9 percent) when $s > t$. Comparable values were 4 (1.1 percent) and 374 (98.9 percent) for poultry. These results immediately suggest the strong possibility of technological change occurring in both industries.

Evidence did not support the existence of imperfectly competitive factor and output markets in the poultry sector. The problem was infeasible for the poultry sector under the imperfectly competitive criterion of formulation (14). However, feasibility was obtained when β_x and β_y were set to zero, and p^e_{ts} and r^e_{ts} were set to p_t and r_t, respectively. We conclude that the observed data cannot jointly rationalize profit maximization and imperfect competition for this sector.

Distortions from perfect competition were found in the meatpacking sector. The output market distortion that minimized the objective function in (14) was 0.39. The monopsony indices for the beef and hog animal inputs were both equal to the upper bound, 1.0.[2] These index values support earlier findings (Stiegert et al., Koontz et al., Schroeter and Azzam) of distortions in the meatpacking sector. It would not be advisable, of course, to emphasize the absolute levels of these indices since hypotheses regarding the extent of these distortions were not explicitly considered in the optimization problem.

Models for both industries were infeasible when Hicks neutrality was imposed ($\boldsymbol{B}_t = 0$ for all t). The results in table 1 indicate that, at the objective function values used, biased technological change did occur. A trend in labor-using bias is seen in the poultry sector. Technological change was labor saving, though at a decreasing rate, over the first half of the study period. Increased mechanization in the sector and larger scale of plants within the industry may have resulted in early labor savings. However, the bias has been towards increased labor usage since 1980. Paralleling this labor using tendency in the poultry industry has been the greater degree of cut-up, further processed, and boneless product available from processors. For example, over 87 percent of broilers were sold as whole birds in 1962. This percentage had dropped to 18 percent in 1989 (Perez, Duewer and Weimar). The data may be reflecting an increase in labor intensity in poultry processing.

There is no evidence of bias in labor, capital, or non-meat material inputs in the meatpacking sector. However, the model supports the existence of biased technological change with respect to live cattle, calf, and sheep and lamb inputs. The recent factor saving biases in the live animal inputs may reflect increases in live animal weights and improvements in animal handling practices. Increases have been significant in both liveweights of slaughter animals, as well as commercial production per animal in both sectors (Table 3). The factor-saving bias in live cattle, calves, and sheep may reflect the increased production of 13.42 percent, 30.06 percent, and 30.29 percent, respectively, for the three classes. Commercial production per hog slaughtered has also increased over the period, but at a more modest 8.42 percent. There has been some factor-saving technological change in the poultry sector in several of the years, especially with respect to turkeys. However, the trend is not as evident as in the meatpacking sector. Average slaughter weights of both broilers and turkeys have increased over the period. More than a quarter fewer broilers needed to be slaughtered in 1990 to produce a pound of chicken on a wholesale weight basis than in 1963. Commercial production per turkey increased 15 percent over the period. However, efficiency gains in the sector were more neutral overall, with the exception of labor, than in SIC 2011, reflecting approximately proportional increases in the efficiency of all inputs (except labor) in SIC 2015.

Table 1. Input augmentations for SIC 2011, meatpacking and SIC 2015, poultry slaughtering and processing

		SIC 2011			SIC 2015	
Year	Calves	Sheep	Beef	Labor	Broilers	Turkeys
1963	-0.232	3.196	9.583	469.234		7.042
1964	1.830	-0.164	8.013	458.467		
1965			3.741	436.634		0.352
1966	-0.950			366.601		61.112
1967	-0.603	-1.152	-0.202	328.604		
1968		-0.514	-1.517	265.095		-33.710
1969	-1.016	-4.981	-3.865	269.268		-15.632
1970	-1.359	3.976	-3.408	270.061		30.839
1971	-3.689	6.152		287.339		
1972	-3.053		-8.440	247.870		
1973			-14.146	204.565		115.725
1974	-2.879		-7.563	267.152		-19.478
1975		-4.126	-9.707	293.292	292.120	
1976	0.520	-3.925	-8.419	266.963		
1977	7.381		-5.945	246.186		62.255
1978		-5.369	-7.985	21.865		125.099
1979	-2.824		-6.449	72.472		
1980	-0.088		-0.986	1.315		29.266
1981	2.406	5.991	1.015	-63.801		
1982	10.160	1.843	-2.922	-134.281		23.141
1983	9.009	5.879	1.378	-123.369		
1984	13.618	3.992	0.220	-127.127		11.405
1985	6.926		5.698	-124.186		51.778
1986	8.394	1.403	3.513	-181.879		
1987	3.662	-1.487	0.972	-253.000		-191.632
1988	2.166		3.043	-266.649		-144.942
1989	2.571	7.965	5.484	-286.500		-261.280
1990	1.173	25.696		-312.158	-329.861	-282.450

Total factor productivity increased substantially over the 1963-1990 period for poultry (figure 1 and table 2). The error term affected total factor productivity in 12 of these years. Interestingly, the error affected TFP positively in 8 of the years, indicating that some factor had a positive influence on TFP in 1974, for example, but the increase was unsustainable. The trend in TFP is consistent over the study period, increasing from about 0.48 to 1.0 in 1990. TFP has increased at an annual rate of 2.63 percent between 1963 and 1990 in the sector.

The situation is much more erratic in the red meat packing sector (figure 1 and table 2). There were minor improvements in TFP between 1963 and 1970. Subsequent changes in the effective output Y could not be explained by monotonic changes in the efficiency of production. Changes instead reflected small and erratic year-to-year fluctuations in effective output. These changes may have resulted from the patterns observed in commercial red meat production over the period. There was a large increase in production through the 1960s, during which red meat production increased from 31,590 million pounds in 1963 to 38,610 million pounds in 1971 (USDA). Production has fluctuated around this level ever since, with a low of 34,959 in 1973 and a high of 39,763 million pounds in 1988. The erratic pattern of total factor productivity may possibly reflect differences in capacity utilization over this period, an explanation offered by Purcell for the smaller than expected returns to equity observed in meatpacking. Ball and Chambers reached a similar conclusion in light of the regressive technical change they observed in the early 1970's in their analysis of the meatpacking industry. They ascribed the drop in efficiency to overexpansion in plant size and capital utilization that unfortunately occurred simultaneously with decreases in consumer demand for meat products. Ball and Chambers offer the interesting insight that the industry failed to "grow" into its new technology. Reductions in the error portion of the

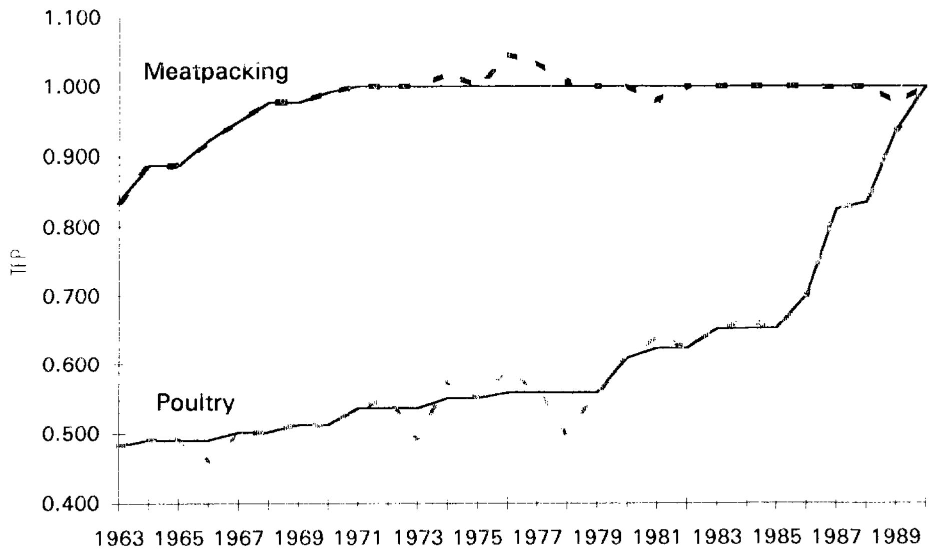
Table 2. Output augmentation, output error,and total factor productivity with and without error for SIC 2011 and 2015

	SIC 2011			SIC 2015		
Year	*A* Level	TFP	TFP+Err	*A* Level	TFP	TFP+Err
1963	0	0.837	0.837	0	0.482	0.482
1964	1938.021	0.887	0.887	197.555	0.490	0.490
1965	1938.021	0.887	0.887	197.555	0.490	0.494
1966	3336.583	0.923	0.923	197.555	0.490	0.460
1967	4393.779	0.951	0.951	451.101	0.501	0.501
1968	5429.117	0.977	0.977	471.102	0.502	0.502
1969	5429.117	0.977	0.977	702.358	0.512	0.513
1970	5978.484	0.992	0.992	702.358	0.512	0.512
1971	6302.314	1	1.001	1281.063	0.536	0.536
1972	6302.314	1	1	1281.063	0.536	0.550
1973	6302.314	1	1	1281.063	0.536	0.493
1974	6302.314	1	1.019	1603.445	0.550	0.575
1975	6302.314	1	1	1603.445	0.550	0.550
1976	6302.314	1	1.046	1807.342	0.558	0.592
1977	6302.314	1	1.035	1807.342	0.558	0.560
1978	6302.314	1	1.006	1807.342	0.558	0.500
1979	6302.314	1	1	1807.342	0.558	0.558
1980	6302.314	1	1	3004.898	0.609	0.609
1981	6302.314	1	0.979	3336.241	0.623	0.640
1982	6302.314	1	1	3336.241	0.623	0.623
1983	6302.314	1	1	3989.319	0.651	0.651
1984	6302.314	1	1	4016.624	0.652	0.663
1985	6302.314	1	1	4016.624	0.652	0.652
1986	6302.314	1	1	5147.876	0.700	0.700
1987	6302.314	1	0.998	8116.723	0.825	0.825
1988	6302.314	1	1	8354.169	0.835	0.835
1989	6302.314	1	0.977	10755.956	0.937	0.937
1990	6302.314	1	1	12243.850	1	1

Table 3. Liveweight and commercial production by type, 1963 and 1990

	Liveweight per Animal			Commercial Production per Animal			Commercial/Liveweight Proportion		
	1963	1990	Percent Change	1963	1990	Percent Change	1963	1990	Percent Change
Broilers	3.46	4.43	28.03 %	2.51	3.18	26.69 %	72.54 %	71.78 %	-1.05 %
Turkeys	17.93	21.43	19.52 %	14.35	16.55	15.33 %	80.03 %	77.23 %	-3.51 %
Cattle	1024	1136	10.94 %	603.26	684.19	13.42 %	58.91 %	60.23 %	2.23 %
Hogs	238	249	4.62 %	166.35	180.35	8.42 %	69.89 %	72.43 %	3.63 %
Calves	220	283	28.64 %	135.81	176.64	30.06 %	61.73 %	62.42 %	1.12 %
Sheep	98	125	27.55 %	48.60	63.32	30.29 %	49.59 %	50.66 %	2.16 %

Figure 1. Total Factor Productivity and TFP plus Error in Meatpacking and in Poultry Slaughter and Processing, 1963-1990



TFP measure during the 1980's may reflect gradual adjustment within the industry to a reduced supply of animals.

Conclusions

Many authors have considered the pricing behavior of firms in meatpacking and, to a lesser extent, in poultry slaughtering and processing. However, little attention has been paid to quantifying the production effects of the changing structure . This research has considered changes in total factor productivity for SIC 2011 and 2015 from 1963 to 1990.

A nonparametric model for the measurement of technological change under profit maximization was modified to allow noncompetitive markets. The observed data for the poultry sector could not rationalize the joint hypotheses of profit maximization and imperfect markets. However, parameters associated with market distortions were found to be nonzero for SIC 2011, supporting the considerable evidence that has been amassed concerning the pricing effects resulting from increased firm concentration in meatpacking.

In the absence of technological regress, TFP has steadily increased in the poultry sector over the last 28 years. Relaxing the no regress assumption had little effect on the measurement of TFP, indicating that technological change has, in fact, been fairly monotonic in the poultry slaughter and processing industry.

There has been considerably less change in TFP in the meatpacking sector over the period, with long periods of little or no improvement. There was some increase in TFP in the first few years of the period. Fluctuations in TFP since 1971 have all resulted from an error term imposed to maintain an assumption of no technological regress. Although there has been some biased technological change in the sector, due perhaps to increased animal slaughter weights and improved handling practices, these improvements are not measurable in the index procedure suggested by Chavas and Cox and used in this study. Possible explanations for the lack of measurable improvements in TFP include excess capacity in the 1970's as the steady increase in commercial red meat production that occurred in the 1960's leveled off.

The distribution of welfare gains from technological change in the two sectors cannot be directly extracted from the results. However, figures 2-4 illustrate price and quantity changes that have occurred in the two sectors. Value of shipments, in real terms, have increased 11.6 percent in SIC 2011 and 153.8 percent in SIC

2015. The value of shipments has been positively influenced by increases in commercial production, with redmeat and poultry production increasing 22.2 percent and 281.9 percent, respectively, over the period. The increased production has been accompanied by a drop in real price of 8.7 percent for redmeat and 33.6 percent for poultry. It would appear that the consumer has benefitted from technological change resulting in a lowering of the marginal cost curve facing the poultry industry. Gains have also occurred to consumers of redmeat, but the gains are lower than those in poultry. The model cannot distinguish the relative effects of minimal technological change in the industry, imperfectly competitive markets possibly distorting the transfer of gains to consumers, and shifts in demand resulting from changing preferences and/or changes in the price of poultry.

It is also difficult to derive gains to producers within each sector over the period resulting from technological change. One indication of sector performance, reported in figure 5, is the ratio of value added, net of production labor costs, to the value of shipments. This ratio has been fairly constant at about 10 percent in SIC 2011 over the period. The ratio has, however, almost doubled between 1963 and 1990 in SIC 2015. Attributing these changes solely to technological change ignores many of the other market forces that have shaped factor and output markets over the period. However, it is likely that at least some of the increase in the poultry sector performance indicator arises from the input and output augments resulting from technological change.

This research has presented a comparative analysis of the extent and, to a certain degree, the nature of technical change in meatpacking and in poultry slaughter and processing. Additional work is necessary to identify the factors that underlie the observed differences between the two industries.

Figure 2. Value of Shipments, SIC 2011 (Redmeat) and SIC 2015 (Poultry) (Constant 1990 Dollars)

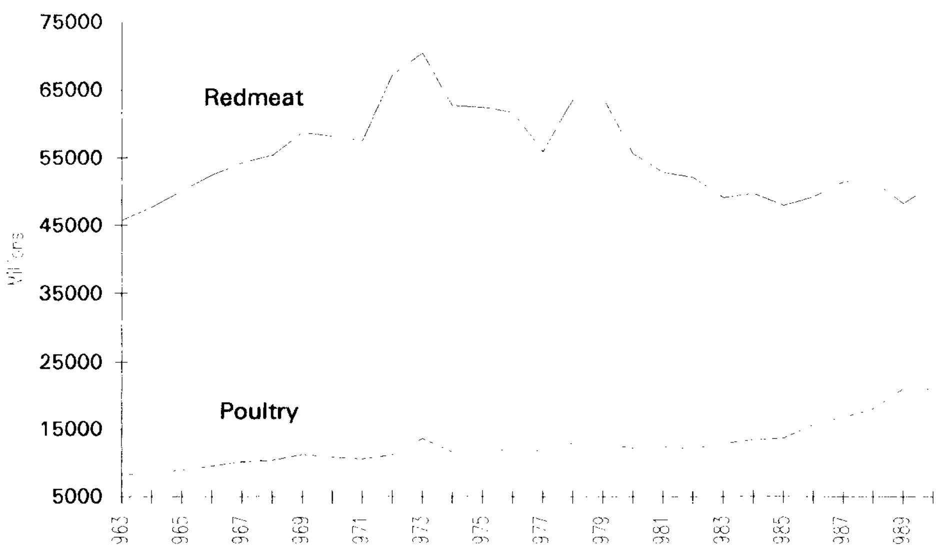


Figure 3. Price per Pound of Commercial Redmeat and Poultry Production (Constant 1990 Dollars)

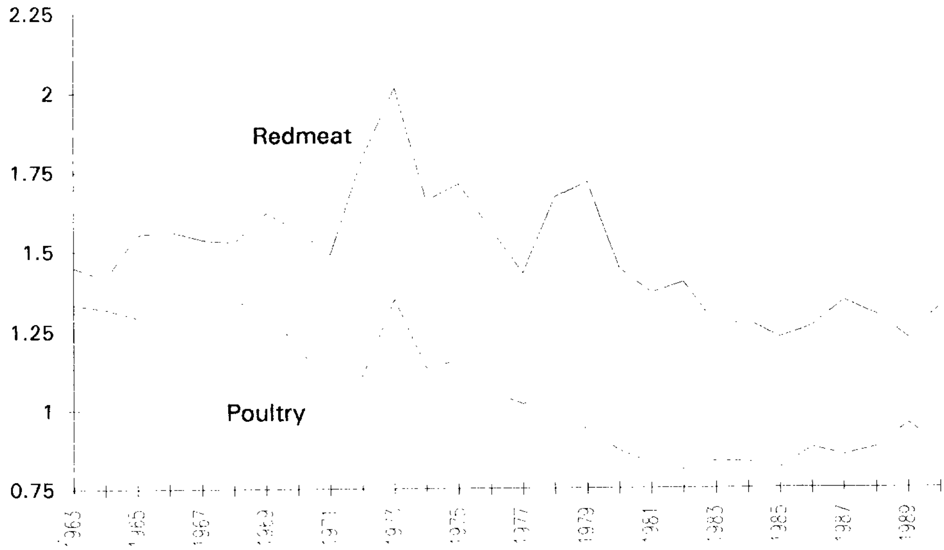


Figure 4. Commercial Redmeat and Poultry Production (Millions of Pounds)

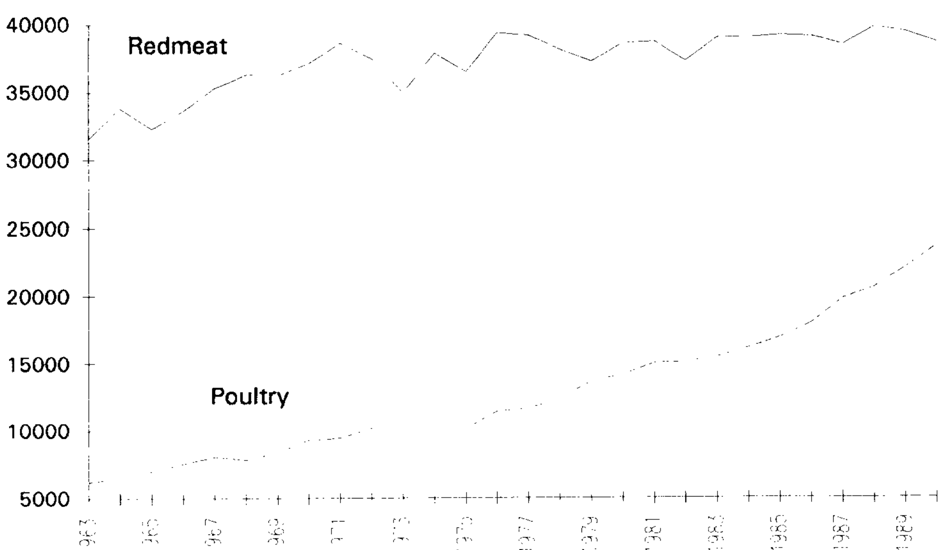
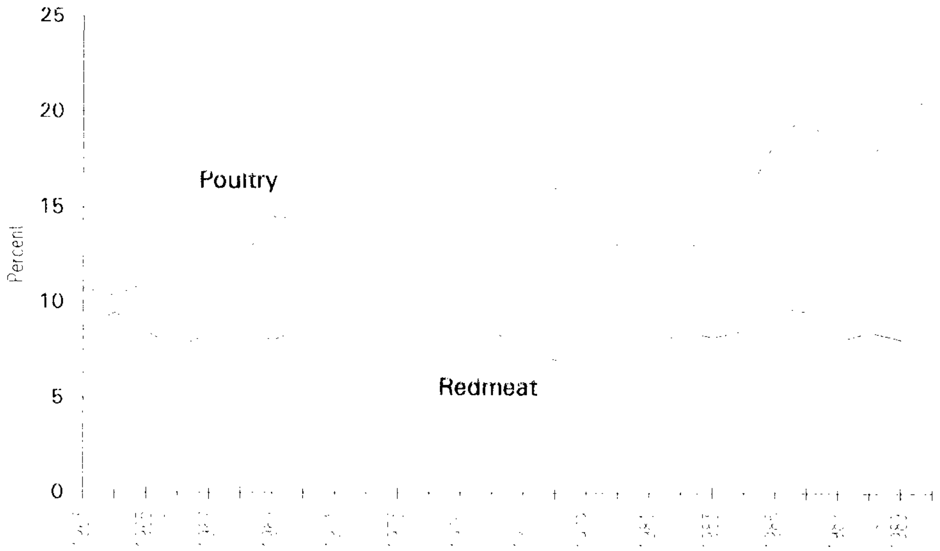


Figure 5. Value Added (Net of Production Labor Costs) As a Proportion of Value of Shipments



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Endnotes

1. Multiply the left hand side by $\frac{\Delta(y_t - A_t)}{\Delta(y_t - A_t)}$ and divide both sides by $\Delta(\mathbf{x}_t - \mathbf{B}_{xt})$.

2. To minimize the number of variables in this large nonlinear programming problem, β_x was fixed at zero for the calf and sheep input markets. These factors were chosen because of the much smaller size of these factor markets relative to those for hogs and beef.