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The Change from Red to White Meat: The Role of Technology

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Since 1950, the composition of the U.S. meat diet has shifted markedly from red meats to poultry. For example, from 1970 to 1984, on a percapita basis, beef consumption has declined by 6.4 percent, while chicken and turkey consumptions have increased by 37.9, and 42.5 percent respectively (U.S. Department of Agriculture, 1985). The numerous studies of this phenomenon from the demand side (Chavas, 1983; Braschler, 1983; Nyankori and Miller, 1982; Moschini and Meilke, 1984; Wohlgenant, 1985, Thurman, 1987; Chalfant and Alston, 1988) have failed to achieve a consensus as to whether a change in taste contributed to this shift. One reason for the lack of consensus is that the very large price and quantity changes make it difficult to establish whether consumers are on a new indifference map. But there have been no comparable studies of the nature and causes of the technological change that has made these large consumption and price changes possible. A decrease in the relative price of poultry with respect to red meat is in any case a major explanation of recent shifts in meat consumption patterns. The main reason for such a decrease appears to be a higher rate of technical progress in the poultry industry than in the red meat industry. Substantial productivity gains in both the production and marketing of poultry over the last two decades appears to have been translated into lower retail prices for poultry. Although some productivity gains have taken place in the red meat industry, they have not matched the cost reductions in the poultry industry (Chavas, 1987). Thus, a consumption shift from beef to poultry could possibly be interpreted as a response to changing relative prices, the structural change having occurred in the meat industry. This would imply that, if the beef industry desires to maintain or expand its market, it should seek a decrease in the production and marketing costs of beef.

Recently, a study by Eales and Unnevehr warns of the effects on demand studies of ignoring the supply side of the market. Most quantity-dependent meat demand studies ignore potential simultaneity in meat prices and quantities. They point out that a gradual structural change in supply also could appear as a demand shift. For example, increased broiler feed efficiency and higher carcass dressed weights probably have shifted supply curves for these meats steadily outward, and may have contributed to an appearance of demand growth unrelated to prices and expenditures. A study by Ball and Chambers has analyzed the characteristics of the technology in the meat processing industry including cost reductions through technological advances. The study, by focusing on the processing industry and considering all meats as one aggregate output does not provide information about the changes in output mix at the producer level over the past four decades. This change consisted mainly of a remarkable growth in poultry production, as shown in table 1. Poultry production increased four fold from 1950 to 1987; beef production double and pork production was stagnant for this period. As a result the poultry share of livestock production increased substantially, from 8 percent in 1950 to 13 percent in 1987. One possible explanation for the rapid restructuring of output is that, with favorable relative prices due to shifts in the structure of meat demand, poultry production grew faster than red meat production with the production possibility frontier remaining unchanged or shifting in a parallel fashion. However this demand side-oriented explanation is clearly incomplete, since, as observed in table 1, the price of white meat was unfavorable relative to red meats during most of the last four decades.

Therefore, this paper hypothesizes that technological change has been biased toward white meat production. That is, productivity of the white meat industry has been higher than productivity in the red meat industry. The major objective of this study is to test this hypothesis by empirically investigating the structure of U.S. meat production. One contribution of this study is the empirical measurement of the output bias caused by technological change in meat production. Although many studies have employed multiproduct cost and profit functions, only a few have explicitly treated output biases in technological change. Another contribution is the use of an input requirement function for productivity analysis. There are only a few studies using multiproduct transformation functions (Christensen, Jorgenson and Lau, 1973; Conrad and Jorgenson, 1977, Berndt and Christensen, 1973, 1974; Burgess, 1974) and even though production functions have been widely used in productivity analysis, their counterpart, input requirement functions, are not so common. As a first attempt to looking at the industry and given that the objective of this study is to measure technical change and output biases in this industry, the framework of a multiproduct input requirement function is utilized to capture the production relationship among outputs. This function is estimated for the period 1950-1987 using aggregate farm data.

The Model

The most general functional representation of multiple output production processes is based on the transformation function:

$$F(y,x) \ = \ 0 \tag{1}$$

This function implicitly defines the firm's production possibilities in terms of its vectors of outputs *y* and its vector of inputs *x*. It is assumed that the function *F (x,y)* is well behaved[1] and differentiable. Under input-output separability the transformation function can be specialized to

$$F^1(y) - F^2(x) \ = \ 0, \tag{2}$$

and in this case both aggregate output and an aggregate input index exist. Under separability, the production function concept that has extensively been used in the productivity literature could be defined as

$$F(x) \ = \ \max\{y:(x,y) \in T\}, \tag{3}$$

where ***y*** is an output index and *T* is the technology set[2]. The production function has proven to be a very useful tool when focusing on the characteristics of the input mix but does not provide information about the technological relation among outputs. When a technology is separable in inputs an input index *m(x)* and a set *T'* exist such that if *(x,y)* is a producible set, then $(m(x), y) \in T'$. Input separability is particularly advantageous for representing *T* in terms of a single-input, multioutput technology. When *T* is separable in inputs, the producible set *Y(x)* becomes

$$Y(x) \ = \ \{y: \ (x,y) \in T\} \ = \ \{y: \ (m(x),y) \in T'\} \ = \ Y(m). \tag{4}$$

Under these circumstances, we define the input requirement function as

$$F(y) \ = \ \min\{x\colon \ (x,y)\in T'\},$$

where x is an input index (for notational convenience x is used for $m(x)$).

The input requirement function approach was chosen in this study for the following reasons. First, industry characteristics and government regulation make marginal cost pricing questionable, and in this case, dual approaches would not be appropriate. Second, this methodology allows measurement output relationships for given input levels. If technical change is defined as the increase in output not accounted for input changes, the input requirement function would permit isolation of output changes due to technical change in production. Third, it captures the production relationships among outputs when inputs could not be assigned to different outputs. A disadvantage of this approach is that it implies that input allocation decisions are separable and independent of output allocation decisions[3].

Assume the following production specification: $x = F(\mathbf{y},t)$, where x is an input index, $\mathbf{y} = (y_1,...,y_m)$ is an output vector, and trend variable t proxies disembodied technological change. Assuming the function is continuous and twice differentiable, its translog approximation is

$$nx \ = \ \alpha_0 \ + \sum_{i=1}^{m} \ \alpha_i \ \ln y_i \ + \ \alpha_t \ t \ + \ 1/2 \sum_{i=1}^{m}\sum_{j=1}^{m} \beta_{ij} \ \ln y_i \ \ln y_j \ + \ 1/2 \ \beta_{tt} \ t^2 \ + \sum_{i=1}^{m} \ \beta_{it} \ \ln y_i \ t \qquad \textbf{(6)}$$

In principle, equation (6) is sufficient to describe the technology. In practice though, it is advantageous to include information provided by the following marginal input requirement conditions:

$$\frac{\partial \ln x}{\partial \ln y_i} = \alpha_i + \sum_{j=1}^{m} \beta_j \ln y_i + \beta_{it}\, t, \qquad i = 1, \ldots m. \tag{7}$$

Assuming efficiency in production and linear homogeneity of the input requirement function in outputs the marginal conditions (7) also represent the ith output share s_i. Multi factor productivity growth rate is

$$s_t = -\frac{\partial lnx}{\partial t} = -\{\alpha_t + \beta_{tt}\, t + \sum_{i=1}^{m} \beta_{it} \ln y_i\}. \tag{8}$$

Under linear homogeneity in outputs, $p_x x = \sum_i p_i y_i$ and $\sum_i s_i = 1$, where p_x and p_i represent input and output prices.[4] The assumptions above require the following constraints on parameters of (6)

$$\sum_{i=1}^{m} \alpha_i = 1,$$

$$\sum_{j=1}^{m} \beta_{ij} = 0, \tag{9}$$

$$\sum_{i=1}^{m} \beta_{it} = 0.$$

In a multiple-product production process, technological change can affect output production and the marginal input requirement conditions differentially. The original definitions of neutral and bias technological change are due to Hicks (1963), who defined them in input space in terms of the marginal rate of technical substitution. Blackorby, Lovell, and Thursby point out several different interpretations of Hicks' definition arguing that Hicks intended neutrality to be defined as the invariance of the expansion path to technological change[5]. Following Antle and Capalbo, we extend the definition of the primal measure of technological change bias to output space defining it to be:

$$B_{ij} \equiv \frac{\partial \ln(\frac{F_i}{F_j})}{\partial t}, \qquad i \neq j \tag{10}$$

where F_i represents the first derivative of the input requirement function with respect to the ith output. Essentially, B_{ij} measures the rotation of the production possibility curve at a point in output space due to technological change. Figure 1 illustrates this concept in two output space. Suppose the initial expansion path is $e(t_1)$ and the firm is producing at A. Technological change leads to a new expansion path $e(t_2)$. The new production possibility curve $X_2(t_2)$ passes through point A. B_{ij} measures the change in slope of the production possibility curve at point A in output space. Equivalently it measures the change in slope of the isorevenue line R_1 tangent to X_1 to the slope of the isorevenue line R_2 tangent to X_2 at A. Technological change is Hicks neutral only if the expansion path is unchanged by technological change, then $B_{ij} = 0$. It is commodity i-producing relative to commodity j if $B_{ij} < 0$, indicating that the cost of additional units of y_i in terms of y_j has decreased as a result of technological change. In general,

$$B_{ij} = \frac{\partial F_i}{\partial t} - \frac{\partial F_j}{\partial t} \begin{cases} > 0, \textit{ biased toward output } j \\ = 0, \textit{ neutral} \\ < 0, \textit{ biased toward output } i. \end{cases} \tag{11}$$

For the multiproduct translog input requirement function used in this study, the pairwise output biases are obtained as follows

$$B_{ij} = \frac{\beta_{it}}{s_i} - \frac{\beta_{jt}}{s_j}. \tag{12}$$

One difficulty with the Hicks' definition of bias as pointed out by Antle and Capalbo is that it requires pairwise comparisons; it is thus not clear whether technological change is net output expanding or contracting in each output. They introduce an overall bias measure in input space for each factor. Extending the definition to output space, the net bias measure is

$$B_i \equiv \sum_{j=1}^{m} s_j \, B_{ij} \ . \tag{13}$$

Since the pairwise bias measures the rotation of the production possibility curve at the given point in output space, the net bias B_i can be interpreted as the change in the *ith* output share that would occur if output prices changed so that the firm's original revenue maximizing bundle remained on the expansion path. The overall bias measure is useful because it tells us if on average the cost of additional units of the *ith* output is increasing relative to all other outputs. Therefore if $B_i > 0$, technological change increases the cost of the *ith* product relative to all others and it is *i* contracting. $B_i = 0$ indicates a neutral change and $B_i < 0$ indicates *i* expanding technological change.

Another important characteristic of the technology that reveals information about the changes in production shares of red and white meat is the degree of substitutability of outputs in production. This is measured by the elasticity of transformation. In the multiple-output case there are several alternative definitions. The extension of Allen's partial elasticity of substitution to output space is

$$\tau_{ij} = \frac{\sum_{i=1}^{m} y_i F_i}{y_i y_j} \frac{|\bar{F}_{ij}|}{|\bar{F}|} \tag{14}$$

where τ_{ij} is the transformation elasticity, $|F|$ is the determinant of the bordered Hessian F, and $|F_{ij}|$ is the cofactor of F_{ij} in F. If $\tau_{ij} > 0$ outputs are complements and if $\tau_{ij} < 0$ they are substitutes in production. Since $F(y)$ is convex, $|F_{ii}| / |F| > 0$ and given that we have assumed $F_i > 0$, then $\tau_{ii} > 0$. From here, at least one τ_{ij} must be negative. In words, an output cannot be a complement to all other outputs in terms of the Allen measure. Using Mundlak's terminology the Allen elasticity of transformation is a one-output, one price elasticity of transformation (OOET); it is proportional to the percentage change in the ith output quantity when the price of the *jth* output changes if inputs and all other output prices are held fixed but all quantities are allowed to adjust to a new equilibrium position. It is therefore related to the input compensated supply elasticity in the following way

$$\epsilon_{ij} = s_j \, \tau_{ij} \tag{15}$$

where ϵ_{ij} is the elasticity of $y_i(\boldsymbol{p},x)$ with respect to p_j, and s_j is the *jth* output share.

The Morishima elasticity of transformation is a two-output, one price elasticity of transformation (TOET), and can be written as

$$\tau_{ij}^{M} = \frac{F_i \, |\bar{F}_{ij}|}{y_i \, |\bar{F}|} - \frac{F_j \, |\bar{F}_{ij}|}{y_j \, |\bar{F}|}. \tag{16}$$

Following Chambers, (16) can be rewritten as

$$\tau_{ij}^{M} = s_j(\tau_{ij} - \tau_{jj}) = \epsilon_{ij} - \epsilon_{jj} \,, \tag{17}$$

and it represents the change in the relative quantity of the *ith* and *jth* outputs as a result of a change in the *jth* output price.

The shadow elasticity of transformation (McFadden) is a two-output, two-price elasticity of transformation (TTET) and following Mundlak it can be expressed in terms of the Allen elasticities as

$$\tau^{s}_{ij} = \frac{s_i s_j}{s_i + s_j}(2\tau_{ij} - \tau_{ii} - \tau_{jj}). \qquad \textbf{(18)}$$

Note that (14) and (18) are symmetric while (16) is not. Further, suppose that $\tau_{ij} > 0$, but that $|\tau_{jj}| > |\tau_{ij}|$. Since the convexity of the input function implies that $\tau_{jj} > 0$, it follows that $\tau^{M}_{ij} < 0$. Thus there are instances where outputs are substitutes according to Morishima but complements according to Allen. As shown in input space by Blackorby and Rusell, the Morishima and shadow elasticities are a measure of ease of substitution or curvature of the production possibility curve while the Allen elasticity is not. They also show that these elasticities are the logarithmic derivative of a quantity ratio with respect to the marginal rate of transformation which makes them the natural extension to the n-dimensional space of the original Hicksian concept. For comparison purposes we present all three calculations.

Substituting the three-output translog bordered Hessian in (14) yields

$$\tau_{ij} = \frac{|G_{ij}|}{|G|} \qquad \textbf{(19)}$$

where $|G|$ is the determinant of

$$G = \begin{bmatrix} 0 & s_1 & s_2 & s_3 \\ s_1 & \beta_{11} + s_1^2 - s_1 & \beta_{12} + s_1 s_2 & \beta_{13} + s_1 \\ s_2 & \beta_{12} + s_1 s_2 & \beta_{22} + s_2^2 - s_2 & \beta_{23} + s_2 \\ s_3 & \beta_{13} + s_1 s_3 & \beta_{23} + s_2 s_3 & \beta_{33} + s_3 \end{bmatrix} \qquad \textbf{(20)}$$

and $|G_{ij}|$ is the cofactor G_{ij} in G. Given this measure of Allen elasticities, Morishima and shadow elasticities can be calculated from (17) and (18).

Data and Estimation

The empirical analysis assumes the existence of a well-behaved, aggregate input requirement function for the U.S. livestock sector,

$$x = F(B, P, C, t) , \tag{21}$$

where *B, P, C* refer to beef, pork, and poultry. Time is indicated by *t* and reflects disembodied technical change. This function is represented by the translog specification in equation (6) where symmetry has been assumed, i.e. $\beta_{ij} = \beta_{ji}$. For estimation purposes the share equations (7) are incorporated along with the equality restriction and the restrictions in (9). The system of input requirement function (6) and share equations (7) are jointly estimated for the 1950-1987 period after addition of disturbance terms. Due to singularity of the covariance matrix the pork share equation is dropped and its coefficients obtained by using the parametric restrictions imposed on the system.

Since the disturbances are assumed to be contemporaneously correlated and the right -hand side variables may be endogenously determined, the iterative three-stage least squares procedure was employed. The instrumental variables consisted of output prices, input prices, and expenditures on meat products.

Annual data for the period 1950-1987 are derived from figures reported in Eswaramoorthy. The input aggregate is a Tornquist index of operating capital, durable capital, grain feed, high protein feed, hay, hired labor, and breeding herd stocks. Operating capital includes expenditures on feeder livestock purchases, petroleum and fuel oils, electricity, and other production expenses. Indices of prices paid by producers for their livestock purchases, fuel oils, etc. and the expenditures on various operating capital items were used to construct the index. Durable capital is an index of the stock of durable farm machinery, equipments, buildings, and other structures attributable to livestock production. Grain feed is a composite index of corn, sorghum, barley, and oats used as feed in livestock production while protein feed is a composite index of oil seed meals, protein feed from animal source, wheat, and rye. Total hours of all labor employed (family and hired) in the livestock sector and the annual average wage rate for all hired laborers in the agricultural sector (crops as well as livestock) are used as the relevant input quantity and price respectively. Hay includes alfalfa, clover, timothy, wild hay, grain crops cut for hay, peanut vine, etc. The average price of hay received by farmers for all baled hay is the appropriate input price. Beef cows, diary cows, sows, chicken layers, turkey hens, and ewes and mohair goats are the livestock breeding herd stocks aggregated into an index using purchase prices as weights.

Beef, milk, sheep, and lambs produced (live weight) have been aggregated into an output Tornquist index. Commercial and other chicken produced, total production of eggs, and total production of turkeys constitute the second aggregate output category. Quantity of hogs produced (live weight) is the third output considered. In all three cases, the indexes used the average price received by farmers as weights.

The main sources for the data are USDA's *Agricultural Statistics*, *Livestock and*

Poultry Situation and Outlook, and *Economic Indicators of the Farm Sector*. A detailed description can be found in Eswaramoorthy. Procedures used to obtain the indexes are available from the author.

We estimate equations (6) and (7) by maximum likelihood methods using the IT3SLS option of the MODEL procedure in SAS (version 6.07). Cross equation symmetry and identity restrictions are imposed along with linear homogeneity in outputs. The system has three equations, with the dependent variables being the logarithm of an input aggregate and two output share equations. The stacked model has 114 observations and 10 estimated parameters.

Collinearity diagnostics developed by Belsley, Kuh, and Welsch (1980) indicate an absence of strong multicollinearity. Because time-series data are used, and due to the "dynamic" nature of livestock production, the presence of autocorrelation in the residuals is possible. Simple Durbin-Watson statistics for each of the equations in the system based on the iterative three stage least squares estimates are 0.475 for the input requirement function, 1.636 for the beef share equation, and 1.057 for the poultry share equation. After correcting for the appropriate number of degrees of freedom we reject the hypothesis of serially uncorrelated errors in the first equation while the DW statistics for the other two fall in the inconclusive range. We follow Berndt and Savin (1975) and test the hypothesis of no first order autocorrelation in the system using the likelihood ratio test[6]. The value of this statistic is 8.18 which indicates rejection of the null hypothesis of no autocorrelation (the critical value of the F distribution with 1 and 100 degrees of freedom is 6.90 at 1 percent significance level). Estimation proceeds under the assumption of serially correlated errors.

Table 2 presents the parameter estimates of the restricted model. The table contains a total of 14 parameters, four of which are significant at the 1 percent level, four at the 5 percent, and four at the 10 percent.

In addition to the imposed properties, monotonicity and convexity in outputs are additional properties of the technology that cannot be satisfied globally by the translog function. However, they may hold at the specific data points used in estimating the function. For the estimates in Table 2, monotonicity is satisfied for all predicted shares at the mean of the data and at each individual data point. Furthermore we find that the bordered Hessian calculated from the estimates are positive definite at the mean (no calculation has been done at each data point yet).

Output jointness in production is another property of the technology that is useful to test. A likelihood ratio test, conditional on the maintained hypothesis of symmetry, identity, linear homogeneity in outputs under an autoregressive error structure rejects the null hypothesis of nonjointness for the input requirement function.

Hicks neutrality of technological change can also be tested. In the single-input, multiple-output case the following null hypothesis is tested conditional on the above stated restrictions: $\beta_{it} = 0, \forall$ i (i = B, C, P). The computed F was 8.00 with 2 and 100 degrees of freedom, and is decisively rejected since the critical F's values are 3.09 and 4.82 at the 5 percent and 1 percent levels, respectively. This result implies that there are biases in technological change in output space.

To examine the rapid growth of white meats production during the last four decades, a pairwise and a net bias of technological change towards white meat production was hypothesized, that is,

$$B_{cj} = \frac{\partial F_c}{\partial t} - \frac{\partial F_j}{\partial t} < 0 \ , \qquad j = B,P,$$

$$B_c = \sum_{j=B,P} s_j \ B_{cj} < 0. \tag{22}$$

To test this hypothesis, the pairwise bias and the overall output bias were computed on an annual basis as well as for the entire period 1950-1987 using equations (12) and (13). The overall bias estimates are provided in Table 3.

The first three columns in Table 3 use equation (12) with predicted shares evaluated at the mean value of variables to calculate the estimated pairwise output biases. They indicate that technological change has been biased in favor of chicken and turkey production relative to beef and pork. This output bias of technological change is clearly captured by a diagrammatic interpretation. By changing the horizontal and vertical axes in figure 1 from y_i to C and from y_j to B, the shift in the production possibility frontier from $X_1(t_1)$ to $X_2(t_2)$ corresponds to technological change biased toward poultry production (C). This implies a decrease in the marginal rate of transformation from R_1 to R_2 indicating that the cost of additional units of C in terms of B has decreased. The estimated B_{CB} (< 0) in table 3 is consistent with this shift.

The net bias, calculated using equation (13) at the mean value of the variables is presented in the last column in Table 3. It shows that overall technological change bias was chicken producing, slightly favorable to pork and beef reducing. In other words, the marginal cost of white meat has decreased relative to all other outputs.

Another interesting result is obtained by evaluating equation (8), the multifactor productivity growth rate, s_t. Table 4 shows this index and its evolution for a subset of years[7]. The average rate of technical progress has been positive indicating an average productivity rate for this industry of 1.79 percent.. The table shows a consistent upward trend. This result could be attributed to both genetic improvements in livestock as well as changes in the feeding industry. For example, there have been significant changes in the average slaughter weight per head for beef, hogs have become much leaner, broilers have increased their feed efficiency and the percentage of grain-finished cattle relative to all cattle slaughter has increased from 40 percent in the mid-1950s to 80 percent in the 1970s.

Estimated elasticities of transformation with predicted shares evaluated at the mean values of the variables are reported in tables (5)-(7). Standard errors for these elasticities are not reported given the complexity in calculating them and the preliminary nature of these results. The interpretation of these elasticities will proceed even though some of them might not be significant.

The estimated Allen elasticities, calculated according to equation (19), suggest that pork is a substitute in production for all other outputs and beef is a complement to poultry. The implied own price elasticities are 0.44 for beef, 1.22 for poultry, and 0.51 for pork when evaluated at the mean. Even though the Allen elasticities measure output responsiveness to output price changes, the concept is somewhat limited since it only measures how one product adjusts to a change in one product price. It yields little information on relative output adjustments to a product price change. The Morishima elasticity measures relative product adjustment to output price changes. To illustrate the difference between the two measures, consider the effects of rises in the poultry price and the beef price. The Allen measure indicates that as the poultry price decreases, beef production decreases. On the other hand, the Morishima elasticity (table 6) indicates that as the poultry price decreases, the beef-poultry output ratio increases; poultry production decreases more percentage-wise than beef production in response to a poultry price decline. By the Allen measure, a rise in the beef price implies an increase in the production of poultry. The Morishima elasticity, however, indicates that as the beef price increases the poultry-beef ratio rises; percentage-wise, the beef price rise caused a smaller increase in beef production than in poultry production. Thus, the Morishima elasticities highlight a fundamental asymmetry in the responsiveness of the beef-poultry ratio to different output price changes which, because it ignores relative percentage output adjustments, the Allen measure does not.

The shadow elasticity of transformation shows the percentage adjustment in output ratios to changes in product price ratios. Using this measure, table 7 indicates that when changes in price ratios, as opposed to single price changes, are considered, all outputs act as if they were substitutes.

The Morishima and shadow elasticities provide less evidence of complementary behavior than the Allen measure. Their use depends on the purpose at hand. The results indicate that the Morishima and shadow elasticities contain information ignored by the Allen elasticity.

The finding that technical change was nonneutral implies that the rate of technical progress is significantly affected by changes in the level of outputs. These effects are illustrated in table 8 where the elasticity of s_t with respect to the different outputs and time are reported. Higher beef production leads to a lower productivity growth rate in the industry. The rate of technological change increases with poultry production. The time coefficient indicates that technological change has been increasing at an increasing rate.

Finally, these inferences must be regarded as tentative for several reasons. First, contrary to the assumptions in this simple model, it is unlikely that crop and livestock production are nonjoint. A model that accounts for this relationship is on the workings but insufficient data has precluded it in this draft. Second, the results are based on a technology assumed to be input-output separable. This maintained hypothesis allows the use of an input index and the input requirement function as presented in this paper. A non-separable multioutput technology would be desirable. Third, the aggregation of outputs were not based on prior separability tests. This might be particularly important for red meats (beef and pork). Fourth, due to highly collinear results in estimating the input requirement function alone, it was necessary to include the shares in the estimation. The use of shares rests on assumptions of optimizing behavior and a technology that is linear homogeneous in outputs. It would be desirable to test this assumptions rather than impose them. Fifth, no attempt has been made in this version to model the dynamics of livestock production. Breeding stocks have been simply considered in this study to be an input in the production of marketable animals.

There are two other points related to the technological change proxy used in this study that seem important. This paper uses a time trend to capture technological change. Understanding could be enhanced with hedonic measures of quality changes in inputs and outputs. Other proxies for t could be useful, such as research and development per commodity, feed efficiency and reproductive efficiency. In addition the multifactor productivity growth rate in this study has been derived from the parameter estimates of the system, some of which only appear in the input requirement function. An alternative would be to follow Jorgenson and Fraumeni and include the multifactor productivity growth rate equation as part of the estimated system using a Tornquist index as dependent variable.

Conclusions and Implications

This study has attempted to model the supply side in the meat industry in order to shed light on the role of technological change on the large changes in this market during the last four decades. Using an input requirement function, it focused on changes in the output mix and on the characteristics of the technological change process.

The major findings of the empirical analysis are as follows. Technological change has been non-neutral and has been biased towards poultry. This largely explains the rapid growth in white meat production relative to red meat during the last four decades.

The classification of outputs as substitutes or complements depends critically on which elasticity measure is utilized. The relative absence of complementary relationships using the Morishima or shadow definitions suggests that Allen elasticities "overstate" the degree of complementarity among outputs. In fact, all outputs are substitutes when output price ratios change.

Although caution should be exercised when interpreting this results, they seem to provide useful information about the large quantity and price changes experienced in the meat market. Structural changes on the supply side help understand the large price movements inducing consumers' change in diet from red to white meat.

Table 1. Production and price indexes of red and white meat 1950-87, selected years

	Beef		Poultry[a]		Pork		Others[b]	
Year	Prod.	Price	Prod.	Price	Prod.	Price	Prod.	Price
1950	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1960	1.33	0.76	1.71	0.55	0.95	0.73	1.06	0.87
1970	1.86	0.84	2.86	0.37	1.05	0.92	1.02	0.94
1980	1.90	0.82	4.00	0.31	1.15	0.64	1.08	0.81
1987	1.90	0.70	5.57	0.26	1.00	0.76	1.19	0.68

[a]Includes chicken and turkey
[b]Includes milk, eggs, mutton, wool and mohair

Table 2. IT3SLS parameter estimates of the translog function coefficients

	Explanatory Variables				
	First Order Coefficients	Second Order Coefficients			
		Beef	Poultry	Pork	Time
Beef	1.11 (0.12)	-0.25 (0.06)	0.03 (0.04)	0.22 (0.03)	0.03 (0.01)
Poultry	0.15 (0.09)		0.03 (0.05)	-0.06 (0.03)	-0.03 (0.01)
Pork	-0.15 (0.20)			-0.15 (0.03)	-0.0004 (0.01)
Time	1.11 (0.46)				-0.41 (0.15)

NOTE: Standard errors in parentheses

ρ = 0.56
(0.04)

Intercept = 1.62
(0.67)

Table 3. Output biases due to technological change

$i \backslash j$	B_{ij} Beef	Poultry	Pork	B_i
Beef	-----	0.24 (0.08)	0.05 (0.09)	0.05 (0.008)
Poultry	-0.24 (0.08)	-----	-0.19 (0.09)	-0.19 (0.011)
Pork	-0.05 (0.09)	0.19 (0.09)	-----	-0.003 (0.006)

Note: Standard errors in parentheses

Table 4. Multifactor productivity growth rates

Year	s_t
1950	0.24
1960	1.61
1970	1.98
1980	2.21
1987	2.33
1950-1987	1.79

Table 5. Allen partial elasticities of transformation

Item	Beef	Poultry	Pork
Beef	0.67	1.16	-0.08
Poultry		7.20	-2.70
Pork			3.02

Table 6. Morishima elasticities of transformation

i \ j	Beef	Poultry	Pork
Beef	0	-1.026	-0.527
Poultry	0.323	0	-0.972
Pork	-0.495	-1.683	0

Table 7. Shadow elasticities of transformation

Item	Beef	Poultry	Pork
Beef	0	-0.75	-0.343
Poultry		0	-1.33
Pork			0

Table 8. Responsiveness of the rate of technical progress to outputs and to time

	s_t
Beef	-0.0329 (0.017)
Poultry	0.0325 (0.018)
Pork	0.0004 (0.013)
Time	0.4152 (0.158)

Note: Standard errors in parentheses

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Endnotes

1. The production possibilities set T(x,y) is a nonempty, closed, bounded and convex set. Free disposability and weak essentiality are also assumed.

2. If T is separable in outputs, the input requirement set generalizes the single-output case:

$$V(y) = \{x:\ (x,y)\in T\} = \{x:\ (x,F(y))\in T\} = v(F).$$

3. This is a first attempt at modelling the sector. It would be desirable to use a nonseparable multi-output, multi-input transformation function. It is also a static model while some type of dynamics seem in order, i.e. breeding herd stocks might be treated as a quasifixed input).

4. The linear homogeneity in outputs and competitive behavior assumptions simplify estimation but impose strong restrictions on the characterization of the technology of the livestock sector.

5. If the technology is homothetic, neutrality can be defined equivalently in terms of either the marginal rate of technical substitution at a point, optimal output factor proportions, or the expansion path.

6. The autocovariance matrix is assumed to be diagonal. In the translog case, as stated in Berndt and Savin (1975), the diagonal elements must be equal. This assumption is not rejected by the likelihood ratio test (the value of the statistic is 1.40 with 2 and 98 degrees of freedom).

7. This number is comparable to a state average of that obtained by Huffman for the U.S. livestock sector. The state productivity indexes are of the Tornquist type.