TECHNICAL CHANGE AND RESEARCH AND DEVELOPMENT IN FOOD PROCESSING

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INTRODUCTION

Productivity change (Nadiri) is both the cause and the consequence of the evolution of dynamic forces operative in an economy (technical progress, accumulation of human and physical capital, and enterprise and institutional improvements). The two major determinants of factor productivity are the technical characteristics of the production process and the movement of the relative factor prices. The often mentioned technical characteristics (Nadiri) include: (1) efficiency of the production process, (2) biased technical change, (3) elasticity of factor substitution, (4) economies of scale and (5) homotheticity of the production process.

Improved efficiency of the production process including organizational and managerial efficiency, could involve a reduction in unit cost of all factors of production equally (neutral technological progress) or greater saving in one input over the others (factor biased technical change). Neutral economies (diseconomies) of scale (a homothetic process) distributes the returns to scale evenly among all factors of production. A non-homothetic production process increases one factor requirement proportionately more than other factor requirements as output expands. The elasticity of substitution between factors influences the ability of the firm or industry to capture the benefits of embodied technical change. The effectiveness of changes in factor prices on factor productivity also depends on the elasticity of substitution.

Previous authors modeled technical change using the production function (Gollop and Jorgenson; Jorgenson, Gollop and Fraumeni; Terleckyj; Grilliches; Jones and Williams; Mairesse and Hall; Bartelsman and Dhrymes; Adelaja) and the cost function (Binswanger; Mohr; Koltz, Madoo and Hansen; Slade; Jang and Norsworthy; Clark and Youngblood; Lambert and Shonkwiler; Mohnen et al.; Gopinath and Roe; Morrison). The theory of production suggests that the physical volume of goods produced is the appropriate concept of output since output depends on physical inputs of raw materials, labor and capital. Modeling cost requires few a priori restrictions on the structure of production unlike empirical estimation of production or value-added functions. A priori restrictions of homogeneity of inputs or separability may distort the scale economies or marginal cost of inputs associated with the production technology (Brown et al.). The cost function is homogeneous in factor prices irrespective of the homogeneity of inputs because doubling of all prices will double cost.

The cost function must satisfy the following conditions: (1) Linear homogeneity in prices: when all factor prices double, the total cost has to double; (2) Monotonicity: the function must be an increasing function of input prices; (3) Concavity in input prices, which implies that the matrix of second derivatives (equivalently the matrix of partial elasticities of substitution) must be negative semidefinite within the range of input prices; (4) Non-decreasing in output; and (5) Non-negativity in prices and output.

Although several alternative functional forms exist, the translog cost function is the most commonly used (Binswanger; Slade; Jang and Norsworthy; Clark and Youngblood; Lambert and Shonkwiler). The translog cost function is a logarithmic Taylor series expansion to the second term around input prices of an arbitrary twice differentiable cost function (Binswanger). With the proper set of constraints on its parameters, it can be used to approximate any one of the known cost and production functions. The translog flexible form allows for testing of linear homogeneity or homotheticity rather than a priori imposition of the above restrictions. Use of the translog cost function also facilitates easy computation of the Allen elasticities of substitution and factor demand elasticities.

Guilkey et al., conducted Monte Carlo studies on the performance of the three flexible functional forms (the translog, extended generalized Cobb Douglas, and the Generalized Leontief cost functions) and concluded that the translog form provides a dependable approximation to reality and demonstrates robustness. Functional forms other than logarithmic transforms may result in nonlinear state-space models when the augmentation parameters evolve over time (Lambert and Shonkwiler). Even under an assumption of normally distributed disturbances, an optimal filter for nonlinear models cannot, in general, be derived (Harvey).

The food and kindred products manufacturing (SIC code 20) sector (a.k.a. food processing) accounts for about 14 percent of total value of output in manufacturing and two percent of gross domestic product (GDP) of the United States. Compared to research on agricultural productivity, there is relatively little research on measuring technological change in the food processing industry. The available studies focus on labor and total factor productivity and on structural changes in the food processing sector.

There are several questions that need to be answered with respect to technical change in food processing. These include: (1) What type of technological change (embodied, disembodied) occurs in the food and kindred products sector? (2) What are the effects of these changes in technology on factor demands? (3) What is the contribution of the productivity of each factor of production to total factor productivity? (4) Is there evidence against the hypothesis of constant returns to scale? (5) What is the magnitude of the returns to industry research and development expenditures in food processing? (6) If agricultural raw materials constitute the largest share of input cost to food processing, what is the effect of the technological spillovers between crop agriculture, animal agriculture and food processing (if any) on unit variable costs and factor demands? (7) What is the state economic development impact of increased factor productivity in food processing? This dissertation addresses the above questions in three parts.

Part I: Modeling Technological Spillover Effects between Agriculture and Food Processing

Part I addresses questions 1, 2, 3, 6 and 7 for the two-digit SIC food processing sector. The following specific objectives pertain to the food processing sector: (1) determine the behavior and contribution of productivity indices for four classes of food-processing inputs (production labor, non-production labor, equipment capital, and material inputs) to total factor productivity; (2) determine the contribution of technical change to factor bias; and (3) determine empirical research and development spillovers from crop and animal agriculture to food processing.

Part II: Returns to Research and Development in Food Processing

Part II addresses questions 4 and 5 above. Specific objectives are: (1) measure returns to research and development spending in food processing; (2) determine the existence of non-constant returns to scale in food processing; and (3) determine empirical research and development spillover from the aggregated agriculture sector to food processing.

Part III: State Economic Development Impact of Increased Factor Productivity in Food Processing for Oklahoma

Part III answers question 7 in a general equilibrium setting. The specific objective of Part III is to analyze the impact of increased efficiency in food processing on output, employment, real wage, household welfare and gross state product.

Paper I

MODELING TECHNOLOGICAL SPILLOVER EFFECTS BETWEEN AGRICULTURE AND FOOD PROCESSING

INTRODUCTION

Adelaja analyzed changes in total factor productivity as well as productivity indexes for four classes of food processing inputs: production labor, non-production labor, capital and materials using the state of New Jersey as a case study. The author argues that in food processing material inputs account for over 60 percent of production cost and gains in material efficiency are likely to have greater effect on total factor productivity growth than do gains in labor efficiency. In spite of limited material productivity growth (21 percent), material productivity's growth alone contributed 45 percent of the 28 percent growth in total factor productivity growth over the 1964-84 period. About 70 percent of materials used in food processing are farm products (Adelaja (a)) and hence material productivity indices should reflect the dynamics of the efficiency of use of farm products in food processing (Adelaja (b)).

Gopinath, Roe and Shane (1996) concluded that the rate of growth in food processing GDP averaged 1.04 percent annually during the period 1959 - 91. Material inputs alone account for almost all of the growth in food processing GDP. However, the contribution from other inputs to growth in the sector's output is offset by a 0.83 percent decline in the real price for the sector's output. Total factor productivity (TFP), often referred as the "residual" or the index of "technical progress", in food processing is relatively low, at 0.41

percent. This estimate compares to the TFP growth rate of 0.47 for the economy as a whole and 2.31 percent per annum for primary agriculture.

Shonkwiler and Stranahan (1987) modeled technical change in the Florida frozen concentrated orange juice processing industry using a translog cost function including research and development expenditure. They concluded that investment in research and development generated a material saving and labor using technology.

Morrison considered the impacts of capital quasi-fixity on variable capital and non-capital input decisions made in the United States food and kindred products industry from 1965 to 1991. Morrison used a generalized Leontief cost function where technology was represented by office and information capital and time trend variables. She concluded that the impact of capital and its fixities on productivity growth was fairly low, due to its small cost share and rapid adjustment to capital demand. Impact of capital fixitiy on value-added productivity, however, was large (increases in capital have more than compensated for declines in labor use in this industry). The division of capital stock into three components (office and information technology equipment, other equipment, and structures) and the separation of energy input from non-energy material inputs made Morrison's study rich in information. However, technical change was inadequately represented.

The food and kindred products manufacturing (SIC code 20) sector accounts for about 14 percent of total value of output in manufacturing and two percent of gross domestic product (GDP) of the United States. Compared to research on agricultural productivity, there is relatively little research on measuring technological change in the food processing industry. The available studies focus on labor and total factor productivity and on structural changes in the food-processing sector.

Most studies used a time trend in a translog production function to represent technological change (Jorgenson, Gollop and Fraumeni; Adelaja; Gopinath, Roe and Shane). The major criticisms of these studies are the absence of an explanatory variable representing the latent variable (technological change) other than time trend and the emphasis on only labor productivity (the exception is Adelaja who also emphasized material productivity).

Several authors based their results on the duality model (Binswanger; Lopez; Fulginiti and Perrin; Morrison; Shumway and Alexander) using a deterministic time trend to measure technical change. A major limitation of the duality models used in these studies is a failure to incorporate recent theoretical developments in time series analysis. Regression of one integrated process on another independent integrated process leads to non-normal coefficient estimates, a non-X^2 test statistic, Durbin-Watson statistics biased toward zero, and a coefficient of determination that has a non-degenerate, limiting distribution (Durlauf and Phillips). Regression of one random walk on another, with time included to account for trend, is strongly subject to spurious regression phenomenon (Nelson and Kang). The presence of unit roots in factor shares and price series has implications on the nature of technological change and, hence, the use of time as a proxy is inappropriate (Clark and Youngblood; Lambert and Shonkwiler).

Clark and Youngblood have argued that modeling technical change as a deterministic time trend is a restrictive representation that may be inconsistent with the type of nonstationarity of other model variables. Clark and Youngblood used a time series approach to estimate a cost function for central Canadian agriculture and found that factor shares, prices, and output were cointegrated, implying that technical change is neutral. When Clark and Youngblood estimated the share equations with a time trend as a technical change measure, technical change was found to be biased. They concluded that time series properties of all system variables are of critical importance to proper estimation of duality model parameters and technical change. If these properties are not accounted for and the traditional practice of using a deterministic trend as a proxy for technical change is followed, inconsistent estimates as well as spurious correlation could result.

Lambert and Shonkwiler employed a time series procedure to determine the influence of technological change in inducing factor bias in U.S. agricultural production. Lambert and Shonkwiler have also found unit roots in share and price series and thus rejected the use of time as a proxy for technological change in econometric analysis of the series due to the estimation problems. They used a dynamic measurement error model to link research expenditures to the unobserved technological change variable and found that technological change was biased, with technical change being labor saving and material using over the period.

Slade modeled the state of technology in the U.S. primary metals industry as a stochastic trend and estimates of total factor productivity were corrected for measurement error that induces a pro-cyclical bias. Slade stated that a calculated total factor productivity index increases over time as technology improves and will be pro-cyclical. The trend component represents the true rate of technical change, whereas the cyclical component is a systematic bias due to measurement error. Total factor productivity indices calculated from market prices overestimate technical change in good times and underestimate it when times are bad. Through the use of state-space estimation techniques, significant cost changes are uncovered that fail to be detected when more traditional methods are employed.

The objectives of this paper are to: (1) determine the behavior and contribution of productivity indices for four classes of food processing inputs (production labor, non-production labor, equipment capital, and material inputs) to total factor productivity; (2) determine the contribution of technical change to factor bias; and (3) determine empirical research and development (R & D) spillovers from crop and animal agriculture to food processing.

THE MODEL

The technology of the representative firm in the two-digit food processing industry is given by a production function relating one output, (Q), to four variable inputs (X) (equipment capital (X_k), production labor (X_p), non-production labor (X_n), and material inputs (X_m)) and one fixed capital input (structure capital (X_s)). Dual to the production function is the firm's total cost function. A commonly used functional form is the translog (Christensen, Jorgenson, and Lau; Clark and Youngblood; Slade; Lambert and Shonkwiler; Harvey and Marshall). The translog cost function for the s[th] sector (1, 2, and 3) in terms of the augmented factor prices (R_{sit}), output (Q_{st}), and a quasi-fixed input (F_{st}) is represented as:

$$\begin{aligned} \ln C_{st} &= \alpha_{s0} + \sum_i \alpha_{si} \ln R_{sit} + \tfrac{1}{2} \sum_i \sum_j \alpha_{sij} \ln R_{sit} \ln R_{sjt} + \alpha_{sq} \ln Q_{sq} \\ &+ \sum_i \alpha_{siq} \ln Q_{sq} \ln R_{sit} + \alpha_{sqq} (\ln Q_{qq})^2 + \alpha_{sf} \ln F_{st} \\ &+ \sum_i \alpha_{sif} \ln F_{st} \ln R_{sit} + \alpha_{sff} (\ln F_{st})^2 \end{aligned} \qquad \textbf{(1)}$$

where the various α's are parameters and R_{it} are augmented input prices. Real estate in agriculture and non-residential structure capital in food processing are the quasi fixed inputs.

Following previous authors (Binswanger; Harvey; Lambert and Shonkwiler), factor prices and input levels are augmented for quality changes. Augmentation transforms the inputs from physical to efficient units (Harvey) and prices from observed to effective prices (Lambert and Shonkwiler). Let z and s index sectors. The observed input levels (X_{it}) and prices (P_{it}) are related to augmented values as

$$R_{sit} = \frac{P_{sit}}{\prod_{z=1}^{3} A_{zit}} \qquad (2)$$
$$X^{*}_{sit} = \prod_{z=1}^{3} A_{zit} X_{sit}$$

where A_{zit} are the augmentation parameters for factor i in sector z (z = 1,2,3). The augmentation parameters for factor i due to spillover effect are represented by A_{zit} where z≠s. Let the overall augmentation parameter for factor i at time t be represented by

$$A_{it} = \prod_{z=1}^{3} A_{zit}. \qquad (3)$$

Substituting (2) into (1) and differentiating with respect to the logarithm of augmented prices and adding a random disturbance term gives the share equations:

$$S_{sit} = \alpha_{si} + \sum_{j} \alpha_{sij} \ln(P_{sjt} / A_{jt}) + \alpha_{siq} \ln Q_{t} + \alpha_{sif} \ln F_{st} + \varepsilon_{sit} \qquad (4)$$

where

$$S_{sit} = R_{sit} X^{*}_{sit} / C_{st}.$$

Assume that the augmentation parameters have the form

$$A_{sit} = \mu_{st}^{\gamma_{si}} \qquad (5)$$
$$A_{it} = \prod_{s=1}^{3} \mu_{st}^{\gamma_{si}}$$

where μ_{st} are the state of technology in sector s at time t; γ_{si} are deviations in the quality of factor i from the overall state of technology in sector s. Lambert and Shonkwiler assumed a similar form for the augmentation parameters in the agriculture sector. They postulated a dynamic measurement error model to account for the temporal properties of the agricultural research expenditure series. This paper extends the model to account for R&D spillover effects among crop agriculture, animal agriculture and food processing. Previous studies considered only one sector.

The system of share equations with a random disturbance term included would become

$$S_{sit} = \alpha_{si} + \sum_j \alpha_{sij}(\ln P_{sjt} - \sum_s \gamma_{sj} \ln \mu_{st}) + \alpha_{siq} \ln Q_{sq} + \alpha_{sif} \ln F_{st} + \varepsilon_{sit} \quad \textbf{(6a)}$$

$$S_{sit} = \alpha_{si} + \sum_j \alpha_{sij} \ln P_{sjt} - \sum_j \alpha_{sij} \sum_s \gamma_{sj} \ln \mu_{st} + \alpha_{siq} \ln Q_{sq} + \alpha_{sif} \ln F_{st} + \varepsilon_{sit} \quad \textbf{(6b)}$$

$$S_{sit} = \ln \beta_{it} + \sum_j \alpha_{sij} \ln P_{sjt} + \alpha_{siq} \ln Q_{sq} + \alpha_{sif} \ln F_{st} + \varepsilon_{sit} \quad \textbf{(6c)}$$

where

$$\ln \beta_{it} = \alpha_{si} - \sum_j \alpha_{sij} \sum_s \gamma_{sj} \ln \mu_{st}.$$

To identify the γ_{sj}'s , the following restrictions are necessary:

$$\begin{aligned} &\sum_s \sum_j \gamma_{sj} = 0 \\ &\sum_j \gamma_{sj} = 0. \end{aligned} \quad \textbf{(7)}$$

For adding up property to hold, two additional restrictions are required. The first restriction states that the sum of changes in cost shares for factors in sector due to change in the state of technology in the same sector should be zero. The second restriction states that the sum of changes in cost shares for all factors due to change in the state of technology in other sectors should be zero.

$$\sum_i \frac{\partial S_{sit}}{\partial \mu_{st}} = 0 \qquad \text{for } s = 1,2,3 \text{ and}$$

$$\sum_i \frac{\partial S_{sit}}{\partial \mu_{zt}} = 0 \qquad \text{for } s \neq z,\ s, z = 1,2,3. \qquad \textbf{(8)}$$

The derivative of each factor share with respect to the state of technology in sector s indicates bias in technical change:

$$\frac{\partial S_{sit}}{\partial \mu_{st}} = -\sum_j \alpha_{sij}\gamma_{sj}/\mu_{st} \qquad \text{for } s = 1, 2, 3 \text{ and}$$

$$\frac{\partial S_{sit}}{\partial \mu_{zt}} = -\sum_j \alpha_{sij}\gamma_{zj}/\mu_{zt} \qquad \text{for } s \neq z,\ z = 1, 2, 3. \qquad \textbf{(9)}$$

Research and development (R&D) expenditure is used as an imperfect indicator of the unobserved technical change. The R&D spillover effects between agriculture and food processing in terms of unit cost reduction and increased factor demand would be modeled in a three-sector stochastic trend model. Due to limitation of R&D spending data in food processing, the analysis is at the aggregated level for the United States. The deflated research and development expenditure in sector s, RD_{st}, is related to the unobserved level of technology in that sector, μ_{st}, in a stochastic trend model of the form.

$$\ln RD_{st} = \ln \mu_{st} + \omega_{st} \qquad \text{for } s = 1, 2, 3$$

$$\ln \mu_{st} = \ln \mu_{s,(t-1)} + \eta_{st} \qquad \text{for } s = 1, 2,3. \qquad \textbf{(10)}$$

where ω_{st} and η_{st} are random elements.

The state of technology is related to the share equations via Equation 6(b). The restriction of homogeneity, symmetry, and adding up are directly imposed on the parameters in the estimation equations. Estimation was made only for food-processing sector. The complete specification for the four-factor share equations model is:

$$
\begin{aligned}
S_{s1t} &= \ln\beta_{1t} + \alpha_{s11}\ln P_{s1t} + \alpha_{s12}\ln P_{s2t} + \alpha_{s13}\ln P_{s3t} - (\alpha_{s11}+\alpha_{s12}+\alpha_{s13})\ln P_{s4t} + \alpha_{s1q}\ln Q_{sQ} + \alpha_{s1f}\ln X_{st} + \varepsilon_{s1t} \\
S_{s2t} &= \ln\beta_{2t} + \alpha_{s12}\ln P_{s1t} + \alpha_{s22}\ln P_{s2t} + \alpha_{s23}\ln P_{s3t} - (\alpha_{s12}+\alpha_{s22}+\alpha_{s23})\ln P_{s4t} + \alpha_{s2q}\ln Q_{sq} + \alpha_{s2f}\ln X_{st} + \varepsilon_{s2t} \\
S_{s3t} &= \ln\beta_{3t} + \alpha_{s13}\ln P_{s1t} + \alpha_{s23}\ln P_{s2t} + \alpha_{s33}\ln P_{s3t} - (\alpha_{s13}+\alpha_{s23}+\alpha_{s33})\ln P_{s4t} + \alpha_{s3q}\ln Q_{sq} + \alpha_{s3f}\ln X_{st} + \varepsilon_{s3t}
\end{aligned}
\tag{11}
$$

$$
\begin{aligned}
\ln\beta_{1t} &= \alpha_{s1t} + b_{11}\ln\mu_{1t} + b_{12}\ln\mu_{2t} + b_{13}\ln\mu_{3t} \\
\ln\beta_{2t} &= \alpha_{s2t} + b_{21}\ln\mu_{1t} + b_{22}\ln\mu_{2t} + b_{23}\ln\mu_{3t} \\
\ln\beta_{3t} &= \alpha_{s3t} + b_{31}\ln\mu_{1t} + b_{32}\ln\mu_{2t} + b_{33}\ln\mu
\end{aligned}
\tag{12}
$$

$$
\begin{aligned}
\ln RD_{1t} &= \ln\mu_{1t} + \varpi_{1t} \\
\ln RD_{2t} &= \ln\mu_{2t} + \varpi_{2t} \\
\ln RD_{3t} &= \ln\mu_{3t} + \varpi_{3t}
\end{aligned}
\tag{13}
$$

$$
\begin{aligned}
\ln\mu_{1t} &= \ln\mu_{1,(t-1)} + \eta_{1t} \\
\ln\mu_{2t} &= \ln\mu_{2,(t-1)} + \eta_{2t} \\
\ln\mu_{3t} &= \ln\mu_{3,(t-1)} + \eta_{3t}
\end{aligned}
\tag{14}
$$

The random elements, ε_{st}, ω_{st} and η_{st} , are assumed to be normally distributed with zero means and covariance matrices $\Omega_{\varepsilon st}$, $\Omega_{\omega st}$ and $\Omega_{\eta st}$.

Biases in technical progress are estimated using a discrete approximation suggested by Harvey and Marshall to the definition of Binswanger. This is defined as

$$\beta_{it} = 100(\overline{\mu}_{it}/T - \overline{\mu}_{1,(t-1)}/T)/S_{it} \tag{15}$$

where B_{it} is the bias of input i at time t, and $\overline{\mu}_{it}/T$ is the smoothed estimate of μ_{it}. In other words, bias in input i is defined as observed changes in shares less the effects of changes in factor prices and output. The factor-specific quality augmentation estimates of A_{it} are derived from equation (7). Allen partial elasticity of substitution, σ_{ij}, and the price elasticity of demand, e_{ij} , are estimated from the parameters in the model:

$$\sigma_{ij} = (\alpha_{ij} + S_i S_j)/S_i S_j \qquad \text{If } i \neq j$$
$$\sigma_{ii} = \left(\frac{1}{S_i S_i}\right)(\alpha_{ii} + S_i^2 - S_i) \qquad \text{If } i = j \tag{16}$$
$$e_{ij} = \sigma_{ij} S_j$$

Because μ_{it} and β_{it} are not observed, maximum likelihood estimation is preceded by Kalman filtering and fixed-interval smoothing algorithms. To facilitate the operation of these algorithms, the observed dependent variables are expressed as linear combinations of observed explanatory variables and unobserved or state vector. The state vector summarizes all the information from the present and past values of the time series relevant to the prediction of future values of the series. For each sector, the $\mathbf{S}_t$ matrix includes share variables and research and development expenditures of the three sectors whereas the θ_t matrix includes ln β_{it} and ln μ_{it} for i=1,2,3. The kx1 vector $\mathbf{S}_t$, is related to an mx1 vector, θ^*_t, known as the state vector, via the measurement equation

$$\mathbf{S}_t = \mathbf{H}^*_t \theta^*_t + \mathbf{X}_t \delta_t + \varepsilon_t, \qquad t = 1, \ldots, T \tag{17}$$

where $\mathbf{H}^*_t$ is a kxm matrix, $\mathbf{X}_t$ is a kxp matrix of observed explanatory variables (factor prices and fixed capital stock variables), δ_t is a px1 vector of unobserved parameters, and ε_t is a kx1 vector of disturbances with zero mean and covariance matrix $\Omega_{\varepsilon t}$. The unobserved elements of θ^*_t are generated by the transition equation,

$$\theta^*_t = \mathbf{R}^*_t \theta^*_{t-1} + \mathbf{W}_t \delta_t + \mathbf{G}\eta_t \tag{18}$$

where $\mathbf{R}^*_t$ is an mxm matrix, $\mathbf{W}_t$ is an mxp matrix, $\mathbf{G}$ is a mxj matrix and η_t is a jx1 vector of disturbances with mean zero and covariance matrix $\Omega_{\eta t}$. Because θ^*_t and δ_t are not observable the above equations are rewritten in a concise form as:

$$\mathbf{S}_t = \mathbf{H}_t \theta_t + \varepsilon_t$$
$$\theta_t = \mathbf{R}_t \theta_{t-1} + \mathbf{G}\eta_t \tag{19}$$

where $\mathbf{H}_t = (\mathbf{H}^*_t\, \mathbf{X}_t)$, $\theta_t = (\theta^*_t\ \ \delta_t)'$ and $\mathbf{R}_t = (\mathbf{R}^*_t\ \ \mathbf{0}, \mathbf{0}\ \mathbf{I}_p)$. It is assumed that the initial state vector, θ_0, has a mean of $\mathbf{a}_0$ and a covariance matrix $\mathbf{V}_0$. State space models and the Kalman filter and smoothing are discussed in Harvey; Anderson and Moore; and Hamilton.

The Kalman filter is a recursive procedure for computing the optimal (in the mean squared error sense) estimator of the state vector, θ_t, and for updating the estimate when new observations become available. The purpose of filtering is to find the expected value of the state vector, conditional on the information available at time t, that is $\mathbf{a}_{t|t} = E[\theta_t | \mathbf{S}_t]$ where E is the expectation operator. The purpose of smoothing is to take into account information made available after time t. The mean of the distribution of θ_t, conditional on all the sample, $\mathbf{a}_{t|T} = E[\theta_t | \mathbf{S}_T]$ is known as a smoothed estimate. Because the smoother is based on more information than the filtered estimator, it will have a mean square error (MSE) which, in general, is smaller than that of the filtered estimator; it cannot be greater (Harvey). As with the filtered estimator ($\mathbf{a}_{t|t}$), $\mathbf{a}_{t|T}$ is the minimum mean square (MMSE) estimator of θ_t. If the normality assumption is dropped, $\mathbf{a}_{t|T}$ is the minimum mean square linear estimator (MMSLE) of θ_t.

The log-likelihood function for the S_t's and θ_t's are written as in Harvey:

$$\begin{aligned}\log L(\phi) = &-T/2 \log 2\pi - T/2 \log \Omega_\varepsilon^{-1} \sum_{t=1}^{T} (S_t - H_t'\theta_t)^2 - NT/2 \log 2\pi - T/2 \log|\ \Omega_\eta\ | \\ &- 1/2 \sum_{t=1}^{T} (\theta_t - R_t\theta_{t-1})'\Omega_\eta^{-1}(\theta_t - R_t\theta_{t-1}) - NT/2 \log 2\pi - N/2 \log 2\pi - 1/2 \log|\ V_0\ | \\ &- 1/2 (\theta_0 - a_0)' V_0^{-1} (\theta_0 - a_0)\end{aligned} \tag{20}$$

$$E\left[\frac{\partial \log L}{\partial \phi} | S_t\right] \tag{21}$$

where φ is a vector consisting of all unknown parameters, that is, θ_t and variances of the transition and the measurement equations. The log-likelihood function is maximized using the estimation and moments (EM) algorithm as discussed in Watson and Engle. The EM algorithm proceeds iteratively by evaluating conditional on the latest estimate (smoothed values) of φ. The smoothed values of the unobserved variables are combined with other variables for iterative three-stage least squares regression.

DATA

The National Bureau of Economic Research (NBER) Manufacturing Productivity (MP) database constructed by Bartelsman and Gray contains annual information on 450 manufacturing industries from 1958 to 1994. The industries are redefined in the 1987 Standard Industrial Classification, and cover the entire manufacturing sector. The data themselves come from various government data sources, with many of the variables taken directly from the Census Bureau's Annual Survey of Manufactures (ASM) and Census of Manufactures (CM). The advantages of using the MP database are that it gathers together several years of data, adjusts for changes in industry definitions over time, and links to additional key variables (i.e. price deflators and capital stock).

The basic information in the ASM is used for eleven of the eighteen variables in the current data set. These are number of workers, total payroll, number of production workers, number of production worker hours, total production worker wages, value of shipments, value added, end-of-year inventories, new capital investment, expenditure on energy, and expenditure on materials (including energy). All of these variables are deflated to millions of 1987 dollars, except for the labor-input variables that are in thousands of workers and millions of worker hours.

The following variables are not included directly in the ASM data, and their construction is described in the MP documentation. These are real total capital stock (equipment plus plant), real equipment capital stock, real structures capital stock (all three in millions of 1987 dollars), and price deflators (base 1987) for value of shipments, materials (energy plus non-energy materials), energy and new investments. The data source for price deflators include BEA, Bureau of Labor Statistics (BLS), and ASM.

Data series on R&D expenditure in the food and kindred products sector are available from the National Science Foundation (NSF) Research and Development in Industry (various issues). National Science Foundation has conducted a survey of industrial research and development annually since 1954. The share of the Federal Government in R&D in food processing is very small. The R&D expenditure data were deflated to 1987 dollars.

Research and development expenditure on agriculture data were obtained for the period 1958 to 1990 from Huffman and Evenson. It includes U.S. agricultural research expenditures (measured in real 1984 dollars) for public and private research. The data were redefined in terms of real 1987 dollars. For the period 1991 to 1994, R & D on agriculture were obtained from the U.S. Department of Agriculture's Inventory of Agricultural Research (various issues).

Research and development expenditures on agriculture exclude expenditures on programs such as natural resources, forest resources, people, communities and institutions, general resources / technology, and food science / human nutrition. According to the USDA's Inventory of Agricultural Research, about 34.8 percent of the agricultural R & D expenditures were spent on crops and 23.8 to 28 percent on animal research and development. Research and development expenditures were distributed to crop and animal agriculture sectors based on these benchmarks. The data set used in this study is presented in Appendix I.

RESULTS

Total and Partial Factor Productivity

Total factor productivity (TFP_t) and partial factor productivity (PFP_{it}) indices derived for the aggregate food processing sector appear in Table 1. TFP_t is the ratio of output (Q_t) to the quantity of aggregate input in the t^{th} year. It shows changes in aggregate input when output is held constant. PFP_{it} is the ratio of output (Q_t) to the quantity of i th input (X_t) in the t^{th} year. It shows changes in the input's quantity when output is held constant. Output has increased 2.3 percent annually from 1958 to 1994 whereas aggregate input increased 1.4 percent per year. Total and partial factor productivity indices were computed as:

$$\begin{aligned} TFP_t &= \ln Q_t - \ln Q_{t-1} - \sum_i S_{it} * [\ln X_{it} - \ln X_{i,(t-1)}] \\ PFP_{it} &= \ln Q_t - \ln Q_{t-1} - [\ln X_{it} - \ln X_{it}] \end{aligned} \qquad \textbf{(22)}$$

where S_{it} is cost share of factor i in time t.

Total factor productivity increased about 1 percent per annum from 1958 to 1994. The 35 percent growth in TFP in the aggregate sector is the result of a productivity growth of 84 percent in production labor, 11 percent in equipment capital, 22 percent in material, and 118 percent in non-production labor. Material productivity growth was low compared to production and non-production labor during the 1958 to 1994 period. This suggests greater constraints in increasing the productivity of materials compared to labor. This can

TABLE 1

ESTIMATED PRODUCTIVITY INDICES FOR U.S. AGGREGATE FOOD PROCESSING SECTOR (SIC 20) 1958-94.

				Partial Factor Productivity			
Year	Aggregate Input Growth Rate	Output Growth Rate	Total Factor Productivity	Production Labor	Variable Capital	Material	Non-Production Labor
1958			100%	100%	100%	100%	100%
1959	3.6%	7.3%	104%	105%	103%	102%	107%
1960	-0.3%	3.6%	108%	109%	112%	104%	110%
1961	1.3%	2.0%	108%	112%	113%	103%	112%
1962	4.1%	3.2%	107%	117%	100%	105%	116%
1963	-2.1%	-0.8%	109%	119%	101%	106%	119%
1964	5.3%	5.0%	108%	122%	95%	105%	123%
1965	0.1%	0.2%	108%	124%	92%	106%	124%
1966	3.0%	0.9%	106%	125%	83%	106%	126%
1967	3.3%	7.6%	111%	131%	91%	106%	135%
1968	-1.4%	2.3%	114%	135%	99%	107%	140%
1969	1.9%	1.8%	114%	135%	96%	109%	141%
1970	1.9%	1.4%	114%	139%	91%	109%	144%
1971	0.6%	3.1%	116%	145%	95%	108%	150%
1972	1.5%	5.0%	120%	149%	99%	111%	158%
1973	-2.7%	-9.0%	114%	141%	91%	106%	150%
1974	3.2%	4.1%	114%	146%	83%	110%	155%
1975	1.6%	3.2%	116%	152%	88%	109%	160%
1976	6.4%	9.0%	119%	160%	93%	109%	169%
1977	2.5%	0.9%	117%	160%	92%	106%	174%
1978	2.7%	3.9%	118%	162%	91%	108%	178%
1979	-3.5%	-0.2%	121%	161%	95%	112%	177%
1980	1.3%	2.0%	122%	164%	95%	113%	180%
1981	-0.6%	2.3%	125%	168%	101%	113%	183%
1982	3.0%	3.8%	126%	176%	99%	116%	186%
1983	-8.1%	-0.2%	134%	178%	116%	118%	189%
1984	3.6%	0.9%	131%	179%	108%	119%	191%
1985	5.4%	3.6%	130%	185%	104%	119%	195%
1986	-2.4%	0.8%	133%	186%	110%	119%	198%
1987	1.4%	4.8%	136%	186%	116%	120%	203%
1988	-0.8%	1.9%	139%	186%	118%	124%	204%
1989	4.5%	-1.3%	133%	184%	109%	121%	205%
1990	2.9%	2.1%	132%	183%	108%	120%	208%
1991	2.0%	1.2%	132%	184%	106%	120%	210%
1992	3.7%	4.5%	132%	184%	107%	121%	215%
1993	-2.7%	1.9%	137%	185%	115%	122%	217%
1994	2.6%	0.6%	135%	184%	111%	122%	218%
1958-94	1.4%	2.3%	35%	84%	11%	22%	118%

be attributed to a strong complementary relationship between material inputs and output and limited short-run substitution of other inputs for materials.

The limited capital productivity growth is due to a high annual growth rate of capital input. However, equipment capital's contribution to total factor productivity growth was significant. Equipment capital's true contribution to total factor productivity growth is the product of equipment capital's factor share and equipment capital's productivity growth, divided by total factor productivity growth in year t. Hence, capital productivity growth alone contributed 69 percent of the 35 percent growth in total factor productivity (24.2 percent TFP growth). Material and production labor productivity growth contributed 19 percent and 10 percent of the TFP growth, respectively.

The overall state of technology observations were generated from a system of share equations and research and development expenditure for the three sectors in a stochastic manner using Kalman filtering, fixed interval smoothing and estimation and moments (E-M) algorithms. These observations together with observed data were used in the iterative three-stage least squares.

The estimated coefficients and their standard errors are shown in Table 2. A one-percent increase in the price of production labor increases cost share of production labor by 0.53 percent[1]. The cost share of production labor declined by 0.45 percent and 0.24 percent

[1] The cost share elasticities are calculated as follows.

$$CE_{ij} = \frac{\partial S_i}{\partial p_j} * \frac{P_j}{S_i} = \frac{\partial S_i}{\partial \ln p_j} * \frac{\partial \ln P_j}{\partial P_j} * \frac{P_j}{S_i}$$

$$CE_{ij} = \frac{\alpha_{ij}}{P_j} * \frac{P_j}{S_i} = \frac{\alpha_{ij}}{S_i}.$$

TABLE 2

PARAMETER ESTIMATES IN SHARE EQUATION SYSTEMS.

Equation	Variable[1]	Parameter	Parameter Estimate	Standard Error	P-Value
Production Labor	Intercept	α_1	2.7308	0.1449	0.0001
	Ln μ_1	μ_{11}	0.0177	0.0124	0.1658
	Ln μ_2	μ_{21}	-0.1231	0.0604	0.0513
	Ln μ_3	μ_{31}	0.1061	0.0587	0.0820
	Ln P_1	α_{11}	0.0546	0.0059	0.0001
	Ln P_2	α_{12}	-0.0460	0.0049	0.0001
	Ln P_3	α_{13}	-0.0243	0.0055	0.0001
	Ln P_4	α_{14}	0.0156	0.0057	0.0108
	Ln Q	α_{1q}	0.0636	0.0142	0.0001
	Ln F	α_{1f}	-0.3029	0.0194	0.0001
Equipment Capital	Intercept	α_2	-3.6157	0.3098	0.0001
	Ln μ_1	μ_{12}	0.0498	0.0392	0.2146
	Ln μ_2	μ_{22}	1.0775	0.1191	0.0001
	Ln μ_3	μ_{32}	-1.1320	0.1112	0.0001
	Ln P_1	α_{12}	-0.0460	0.0049	0.0001
	Ln P_2	α_{22}	-0.0018	0.0075	0.8068
	Ln P_3	α_{23}	0.0677	0.0051	0.0001
	Ln P_4	α_{24}	-0.0199	0.0040	0.0001
	Ln Q	α_{2q}	0.3527	0.0365	0.0001
	Ln F	α_{2f}	-0.0962	0.0547	0.0897
Materials	Intercept	α_3	-0.5062	0.3899	0.2051
	Ln μ_1	μ_{13}	-0.0788	0.0448	0.0897
	Ln μ_2	μ_{23}	-0.9101	0.1625	0.0001
	Ln μ_3	μ_{33}	0.9924	0.1580	0.0001
	Ln P_1	α_{13}	-0.0243	0.0055	0.0001
	Ln P_2	α_{23}	0.0677	0.0051	0.0001
	Ln P_3	α_{33}	-0.0250	0.0072	0.0017
	Ln P_4	α_{34}	-0.0184	0.0042	0.0001
	Ln Q	α_{3q}	-0.4440	0.0457	0.0001
	Ln F	α_{3f}	0.6399	0.0749	0.0001

[1] μ_s is state of technology in sector s (s = 1, 2, 3); P_1 is price of production labor; P_2 is price of equipment capital; P_3 is price of material inputs; P_4 is price of non-production labor; Q is quantity of output in food processing sector; F is quasi-fixed structure capital in food processing sector.

for every one-percent increase in the price of equipment capital and materials, respectively. An increase in the price of non-production labor increases cost share of production labor. Output and capacity (fixed capital) have a positive and a negative effect, respectively, on the cost share of production labor. As output increased over time the share of materials increased. All of the above relationships were found to be statistically significant. A positive relationship between a factor price and a cost share implies factor substitution. But a negative relationship does not necessarily indicate complementary relationship. Capital and materials may have a weak substitution effect on production labor but a significant increase on total variable cost with a net effect of declining cost share of production labor.

The relationship between cost share of capital and price of equipment capital was not significant at the 5 percent level. There is a significant positive relationship between prices of materials and cost share of equipment capital.

The relationship of cost share of equipment capital with the prices of production and non-production labor was negative and significant. Output has a significant positive effect on cost share of equipment capital whereas the effect of capacity on cost share of equipment capital was significant at 10 percent.

Output, prices of production and non-production labor and prices of materials all have a significant negative relationship with the cost share of materials whereas capacity and price of equipment capital have a significant positive relationship with cost share of materials.

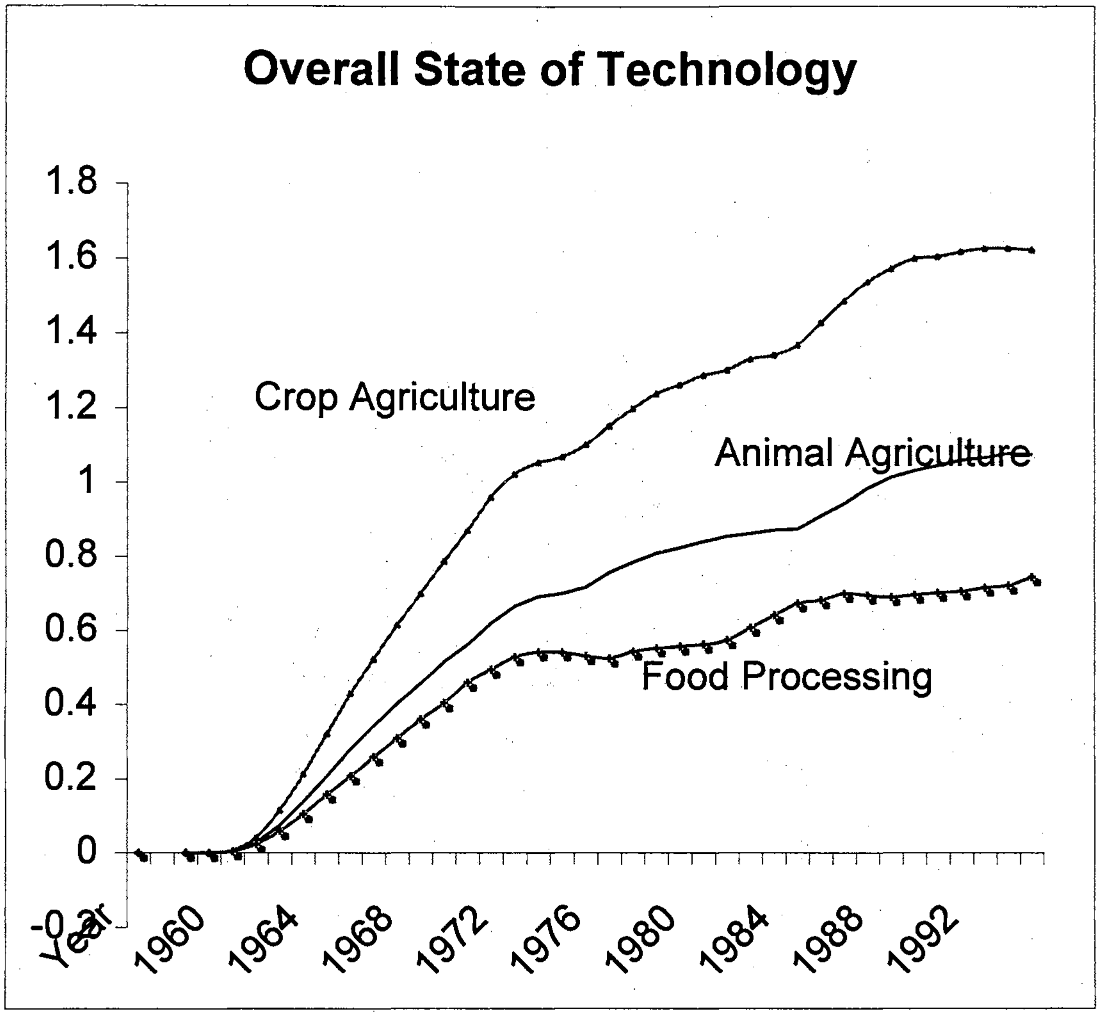

Figure 1: Overall State of Technology by sector, 1958 to 1994.

Estimates of Factor Bias

Conditional estimates of the state of technology, μ_{st}, for the three sectors are graphed in Figure 1. All have increased at a decreasing rate from 1958 to 1994 but the growth rate was the lowest for food processing followed by animal agriculture. The derivatives of the shares with respect to the state of technology in food processing, $\partial S_{si}/\partial \mu_{1t}$, resulting from Equation (9) are $0.0177/\mu_{1t}$ (labor), $0.0498/\mu_{1t}$ (capital) and $-0.0788/\mu_{1t}$ (materials). However, the estimates for labor and capital were not statistically different from zero at the 10 percent level. The estimate for materials was significant at the 10 percent level. These results suggest that technological change in U.S. food processing has been labor and capital neutral and material saving. The derivatives of the cost shares in food processing with respect to the state of technology in crop agriculture, μ_{2t}, are $-0.1231/\mu_{2t}$ (labor), $1.0775/\mu_{2t}$ (capital) and $-0.9101/\mu_{2t}$ (materials). These estimates indicate that labor and material saving and capital using technological spillovers from crop agriculture to food processing have occurred over time. Technological spillovers from animal agriculture to food processing have a neutralizing effect, i.e., labor ($0.1061/\mu_{3t}$) and material ($0.9924/\mu_{3t}$) using and capital saving ($-1.1320/\mu_{3t}$). The spillover results with respect to labor are statistically significant at 10 percent whereas other results are significant at 1 percent. This implies that technological spillovers from agriculture to food processing have a mild net effect on factor bias.

Technological spillovers from agriculture to food processing may have resulted in more uniform quality and less perishablility, as in the case of milk, fruits and vegetables. These developments allow food-processing firms to invest in the development of new value-added products such as breakfast cereals, bakery products, and frozen concentrated juice and/or to explore distant markets.

Distinguishing the changes in cost shares that have resulted from changing relative prices from those changes resulting from technological change is estimated in a manner similar to Binswanger (1974). Bias in input i is defined as $B_{it} = \partial S^*_{it} / S_{it}$ where S^*_{it} is the change in the share of factor i in the absence of price, output and capacity changes. This value is estimated as:

$$\partial S^*_{it} = \partial S_{it} - \left(\sum_j \hat{\alpha}_{ij} \partial \ln P_{jt} + \hat{\alpha}_{iq} \partial \ln Q_t + \hat{\alpha}_{ix} \partial \ln X_t \right) \tag{23}$$

where the effects of changes in factor prices ($\partial \ln P_{it}$), capacity ($\partial \ln X_t$), and output ($\partial \ln Q_t$) are subtracted from observed changes in shares. Accumulation of ∂S^*_{it} over time results in an estimate of factor shares that would have occurred in the absence of changing prices, output , and quasi-fixed input levels. These corrected factor shares are compared with actual factor shares in Tables 3.

The actual cost share of production labor fell from 19.5 percent in 1958 to 3.4 percent in 1994. The cumulative effects of the changes in production labor's share of costs in the absence of changes in factor prices, quasi-fixed input level, and output ($\sum_{t=1958}^{1994} \partial S^*_{it}$) would have resulted in production labor's share falling to 19.1 percent in 1994. Thus technological bias was responsible for only 2.4 percent [(0.1949-0.1911)/(0.1949-0.0344)]of the total fall of 16.1 percentage points in production labor's cost share. Changes in capacity and factor prices were responsible for 74.4 percent and 56.3 percent, respectively, of the total fall whereas changes in output offset 33.1 percent of the fall in production labor's cost share.

The actual cost share of equipment capital increased from 20.4 percent in 1958 to 47.9 percent in 1994. In the absence of changes in factor prices, quasi-fixed input level, and output the share of equipment capital would have fallen to 15.2 percent in 1994. Change in output was responsible for 107 percent of the total increase of 27.5 percentage points in equipment capital's cost share. Changes in relative prices contributed 25.3 percent. Changes

TABLE 3

CORRECTED AND ACTUAL FACTOR SHARES, FIVE YEAR AVERAGES FROM 1958-94

Year	Observed Shares (a)	Observed Changes In Cost Shares (b)	Changes in Cost shares due to Changes in Factor Prices: Total changes due to Prices (d)	Changes due to Output (e)	Changes due to Capacity (f)	Total Changes (d + e + f)	Changes in Cost Share due to Technology (g)	Factor Bias	Corrected Factor Shares (a + g)
Production Labor									
1958	0.1949								0.1949
1958-62	0.1894	-0.0055	0.0047	0.0103	-0.0191	-0.0042	-0.0074	-0.0380	0.1879
1963-67	0.1752	-0.0142	0.0007	0.0082	-0.0296	-0.0207	0.0031	0.0163	0.1910
1968-72	0.1457	-0.0295	-0.0113	0.0088	-0.0338	-0.0364	0.0024	0.0096	0.1960
1973-77	0.0946	-0.0511	-0.0262	0.0052	-0.0178	-0.0388	-0.0093	-0.0900	0.1864
1978-82	0.0609	-0.0337	-0.0392	0.0075	-0.0134	-0.0451	0.0099	0.1402	0.1904
1983-87	0.0448	-0.0161	-0.0041	0.0063	0.0004	0.0027	-0.0084	-0.1854	0.1887
1988-94	0.0364	-0.0084	-0.0150	0.0070	-0.0062	-0.0143	0.0059	0.1391	0.1906
1994	0.0344	-0.0020	-0.0017	0.0004	-0.0002	-0.0016	0.0008	0.0220	0.1911
1958-94	0.1029	-0.1605	-0.0904	0.0532	-0.1195	-0.1567	-0.0038	-0.0082	0.1904
Equipment Capital									
1958	0.2043								0.2043
1958-62	0.2168	0.0125	-0.0049	0.0569	-0.0061	0.0460	-0.0260	-0.1224	0.1858
1963-67	0.2399	0.0231	-0.0012	0.0452	-0.0094	0.0346	-0.0058	-0.0207	0.1818
1968-72	0.2869	0.0470	0.0098	0.0485	-0.0107	0.0476	-0.0063	-0.0125	0.1840
1973-77	0.3105	0.0236	0.0247	0.0288	-0.0056	0.0479	-0.0065	-0.0247	0.1605
1978-82	0.3815	0.0709	0.0269	0.0416	-0.0043	0.0643	0.0338	0.0855	0.1638
1983-87	0.4469	0.0655	-0.0001	0.0352	0.0001	0.0352	-0.0096	-0.0173	0.1920
1988-94	0.4685	0.0216	0.0142	0.0386	-0.0020	0.0508	-0.0316	-0.0631	0.1630
1994	0.4789	0.0104	0.0009	0.0021	-0.0001	0.0029	0.0061	0.0130	0.1524
1958-94	0.3430	0.2745	0.0695	0.2949	-0.0380	0.3264	-0.0519	-0.1751	0.1757
Materials									
1958	0.4691								0.4691
1958-62	0.4624	-0.0067	-0.0028	-0.0717	0.0404	-0.0341	0.0290	0.0627	0.4923
1963-67	0.4665	0.0041	0.0001	-0.0569	0.0624	0.0056	0.0017	0.0030	0.4899
1968-72	0.4745	0.0080	0.0079	-0.0611	0.0715	0.0183	0.0033	0.0063	0.4798
1973-77	0.5377	0.0633	0.0159	-0.0363	0.0375	0.0171	0.0219	0.0399	0.5192
1978-82	0.5226	-0.0151	0.0328	-0.0524	0.0283	0.0087	-0.0517	-0.0975	0.5092
1983-87	0.4812	-0.0414	0.0049	-0.0443	-0.0008	-0.0401	0.0232	0.0517	0.4825
1988-94	0.4739	-0.0073	0.0076	-0.0486	0.0132	-0.0279	0.0235	0.0541	0.5096
1994	0.4676	-0.0063	0.0017	-0.0027	0.0005	-0.0005	-0.0070	-0.0147	0.5199
1958-94	0.4876	-0.0015	0.0665	-0.3713	0.2524	-0.0523	0.0508	0.1203	0.4975

in capacity and technological bias were responsible for offsetting the increase in cost share by 13.8 percent and 18.9 percent, respectively.

The actual cost share of materials marginally fell from 46.9 percent in 1958 to 46.8 in 1994. In the absence of changes in relative prices, changes in output and quasi-fixed capital input, the cost share of materials would have increased to 52 percent in 1994. Changes in output and technological change encouraged the use of materials over the period. However, the impact of changes in relative prices and changes in capacity level on material's cost share had more than offsetting effects and hence cost share of materials marginally declined over the period of 1958 to 1994.

Elasticity of Substitution and Price Elasticity of Factor Demand

Tables 4 and 5 present the Allen partial elasticity of substitution at means and the price elasticity of demand for factors. The price elasticity of factor demand measures the impact in the j^{th} factor price on the demand for the i^{th} factor holding output and other factor prices constant. Own-price elasticities of factor demands calculated from the results in Table 2 at the means of the data are –0.3662 (production labor), -0.6623 (equipment capital), -0.5636 (materials) and –0.5163 (non-production labor).

The Allen elasticity of substitution between factors i and j measures the impact of a change in the price of the j^{th} factor on the quantity demanded of the i^{th} factor when output is fixed but quantities of other factors are allowed to vary. The Allen elasticity of substitution and price elasticity of factor demand give important information on the relationship between factor inputs. The elasticities of substitution may affect the factor substitution possibilities of the producer and hence influence factor bias over time. All of the own price factor

TABLE 4

ALLEN PARTIAL ELASTICITY OF SUBSTITUTION (AT MEANS)

	Production Labor	Equipment Capital	Materials	Non-Production Labor
Production Labor	-3.5577			
	(0.5542)			
Equipment Capital	-0.3018	-1.9308		
	(0.1400)	(0.0634)		
Materials	0.5156	1.4048	-1.1558	
	(0.1091)	(0.0306)	(0.0301)	
Non-Production labor	3.2860	0.1264	0.4308	-7.7717
Labor	(0.8347)	(0.1758)	(0.1287)	(1.8411)

TABLE 5

PRICE ELASTICITY OF DEMAND FOR FACTORS (AT MEANS)*

	Production Labor	Equipment Capital	Materials	Non-Production Labor
Prod Labor	-0.3662	-0.1035	0.2514	0.2183
	(0.0570)	(0.0480)	(0.0532)	(0.0555)
Capital	-0.0311	-0.6623	0.6850	0.0084
	(0.0144)	(0.0218)	(0.0149)	(0.0117)
Materials	0.0531	0.4819	-0.5636	0.0286
	(0.0112)	(0.0105)	(0.0147)	(0.0086)
NonProd labor	0.3382	0.0434	0.2101	-0.5163
	(0.0859)	(0.0603)	(0.0628)	(0.1224)

* Estimated factor price elasticities measures the effect of a change in theprice of the input in the jth column on the quantity demanded of the input in ith row.

** Figures in brackets are standard errors of the respective elasticities.

demand and substitution elasticities have the correct negative sign. The own partial elasticities of substitution have little economic meaning. The own price factor demand elasticities for all factors are significant and less than one in absolute value. This result suggests that the factor demands for all factors are inelastic.

The positive values of the off-diagonal elements in Tables 4 and 5 suggest that the factors are substitutes. Conversely, negative values indicate complementarity among factors. The substitution between factors is best evaluated by utilizing the Allen elasticity of substitution rather than the price elasticity of factor demand. This occurs because the factor demand elasticity reflects the relative importance of the factor's share in total cost whereas those of the Allen elasticity do not (Binswanger).

Allen partial elasticity of substitution calculated at the means of the data indicates that there is a limited complementary relationship between production labor and equipment capital (-0.3018). However, it is associated with a large standard error and thus the result is tenuous. The elasticity of substitution between equipment capital and non-production labor is not significant. The estimated substitutability between materials and equipment capital is statistically significant. This relationship reflects the sector's trend towards more capital-intensive production processes.

The estimated Allen elasticities of substitution associated with production labor and materials is significant and suggests that these factors are substitutes. A highly significant substitutability is found between production labor and non-production labor as well as between materials and non-production labor.

SUMMARY AND CONCLUSIONS

The food and kindred products manufacturing (SIC code 20) sector accounts for about 14 percent of total value of output in manufacturing and two percent of gross domestic product (GDP) of the United States. Compared to research on agricultural productivity, there is relatively little research on measuring technological change in the food processing industry. The available studies focus on labor and total factor productivity and on structural changes in the food-processing sector.

Previous authors have shown that modeling technical change as a deterministic time trend is a restrictive representation that may be inconsistent with the type of non-stationarity of other model variables. Total factor productivity indices calculated from market prices overestimate technical change in good times and underestimate it when times are bad. Through the use of state-space estimation techniques, time series properties of all system variables that are of critical importance to proper estimation of duality model parameters and technical change could be accounted for.

The objectives of this paper were to: (1) determine the behavior and contribution of productivity indices for four classes of food-processing inputs (production labor, non-production labor, equipment capital, and material inputs) to total factor productivity; (2) determine the contribution of technical change to factor bias; and (3) determine empirical research and development spillovers from crop and animal agriculture to food processing.

Research and development (R&D) expenditure was used as an imperfect indicator of the unobserved technical change. The R&D spillover effects between agriculture and food processing in terms of unit cost reduction and increased factor demand were modeled in a three-sector stochastic trend model. Due to limitation of R&D spending data in food processing, the analysis is at the aggregated level for the United States.

The National Bureau of Economic Research (NBER) Manufacturing Productivity (MP) database contains annual information on 450 manufacturing industries from 1958 to 1994. The industries are redefined in the 1987 Standard Industrial Classification, and cover the entire manufacturing sector. Data series on research and development expenditure in the food and kindred products sector were available from National Science Foundation (NSF) Research and Development in Industry (various issues). Research and development expenditures on agriculture were obtained for the period 1958 to 1990 from Huffman and Evenson. For the period 1991 to 1994, R & D on agriculture were obtained from the U.S. Department of Agriculture's Inventory of Agricultural Research (various issues).

Total factor productivity of aggregated food processing sector grew by 35 percent from 1958 to 1994 (about 1 percent per annum). Equipment capital productivity growth alone contributed 69 percent of the 35 percent growth in total factor productivity. Material and production labor productivity growth contributed 19 percent and 10 percent of the TFP growth, respectively.

The overall state of technology observations were generated from a system of share equations and research and development spending of the three sectors in a stochastic manner using Kalman filtering, fixed interval smoothing and estimation and moments (E-M) algorithms. These observations together with observed data were used in the iterative three-stage least squares.

Technological change in U.S. food processing has been labor and capital neutral and material saving. Labor and material saving and capital using technological spillovers from crop agriculture to food processing have occurred over time. Technological spillovers from animal agriculture to food processing have a neutralizing effect, i.e., labor and material using and capital saving. This implies that technological spillovers from agriculture to food processing have a mild net effect on factor bias.

The actual cost share of production labor decreased from 19.5 percent in 1958 to 3.4 percent in 1994. Technological bias was responsible for only 2.4 percent of the total decrease of 16.1 percentage points in production labor's cost share. Changes in capacity and factor prices were responsible for 74.4 percent and 56.3 percent, respectively, of the total decrease whereas changes in output offset 33.1 percent of the decrease in production labor's cost share. The actual cost share of equipment capital increased from 20.4 percent in 1958 to 47.9 percent in 1994. In the absence of changes in factor prices, quasi-fixed input level, and output the share of equipment capital would have decreased to 15.2 percent in 1994. Change in output was responsible for 107 percent of the total increase of 27.5 percentage points in equipment capital's cost share. Changes in relative prices contributed 25.3 percent. Changes in capacity and technological bias were responsible for offsetting the increase in cost share by 13.8 percent and 18.9 percent, respectively. Changes in output and technological change encouraged the use of materials over the period. However, the impact of changes in relative prices and changes in capacity level on material's cost share had more than an offsetting effect and hence cost share of materials marginally declined over the period of 1958 to 1994.

The Allen partial elasticities of substitution indicate that there is a significant substitutability between materials and equipment capital; between production labor and materials; between materials and non-production labor; and between production labor and non-production labor. The elasticity of substitution between equipment capital and production labor was not conclusive.

References

Adelaja, A. O. "Material Productivity in Food Manufacturing." *Amer. J. Agr. Econ.* 74(January, 1992):177-185

Adelaja, A. O. "Productivity Growth and Input Mix Changes in Food Processing." *Northeastern Journal Of Agricultural and Resource Economics.* 74(April, 1992): 21-29.

Anderson, B. D. O. and J. B. Moore. *Optimal Filtering.* New Jersey: Prentice-Hall, Englewood Cliffs. 1979.

Bartelsman, E. J., and Phoebus J. Dhrymes. *Productivity Dynamics: U.S. Manufacturing Plants, 1972-1986.* Finance and Economics Discussion Series (January, 1994). Division of Research & Statistics and Monetary Affairs, Federal Reserve Board, Washington, D.C.

Bartelsman, E., and W. Gray. Manufacturing productivity Database. National Bureau of Economic Research (electronic form), Cambridge MA, 1997.

Binswanger, H. P. "The Measurement of Technical Change Biases with Many Factors of Production." *American Economic Review.* 64(1974)65-78.

Brown, R., D. Caves, and L. Christensen. "Modeling the Structure of Cost and Production for Multiproduct Firms." *Southern Economic Journal.* 46(1979):265-272.

Christensen, L. R., D. W. Jorgenson, and L. J. Lau. "Conjugate Duality and the Transcedental Logarithmic Production Function." *Econometrica* 39(1971)255-256.

Clark, J. S. , and C. E. Youngblood. "Estimating Duality Models with Biased Technical Change: A Time Series Approach. " *Amer. J. Agr. Econ.* 74(May, 1992):353-60.

Durlauf, S. N., and P. C. B. Phillips. "Trends versus Random Walks in Time Series Analysis." *Econometrica* 56(November, 1988):1333-54.

Fulginiti, L. E., and R. K. Perrin. "Argentine Agricultural Policy in a Multiple-Input, Multiple-Output Framework." *Amer. J. Agr. Econ.* 72(1990):279-88.

Gollop, F., and Dale W. Jorgensen. "U.S. Productivity Growth by Industry, 1947-73." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Gopinath, M. and T. L. Roe. *R&D Spillovers: Evidence from U.S. Food Processing, Farm Machinery and Agriculture.* Economic Development Center, Bulletin

96-2(October, 1996). Department of Economics, Minneapolis and Department of Applied Economics, St. Paul, University of Minnesota.

Gopinath, M., T. Roe, and M. D. Shane. "Competitiveness of U.S. Food Processing: Benefits from Primary Agriculture." *Amer. J. Agr. Econ.* 78(1996):1044-11055.

Griliches, Zvi. "Returns to Research and Development Expenditures in the Private Sector." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Guilkey, D., C. A. K. Lovell, and R. C. Sickles. "A Comparison of the Performance of Three Flexible Functional Forms." *International Economic Review* 24(October, 1983): 591-616.

Hamilton, J. D. *Time Series Analysis*. New Jersey: Princeton University Press. 1994.

Harvey, A. C. *Forecasting, Structural Time Series Models and the Kalman Filter.* New York: Cambridge University Press, 1989.

Harvey, A. C., and P. Marshall. "Inter-fuel Substitution, Technical Change and the Demand for Energy in the UK Economy." *Applied Economics* 23(June, 1991):1077-86.

Huffman, W. E., and R. Evenson. *Science for Agriculture*. Ames, IA: Iowa State University Press, 1993.

Jang, S. L., and J. R. Norsworthy. "Measurement Methods for Technological Change Embodied in Inputs." *Economic Letters* 32(April, 1990):325-30.

Jones, C.I., and J.C. Williams. *Measuring the Social Return to R&D.* Finance and Economics Discussion Series (January, 1997). Division of Research & Statistics and Monetary Affairs, Federal Reserve Board, Washington, D.C.

Jorgensen, D. W., F. Gollop, and B. Fraumeni. *Productivity and U.S. Economic Growth.* Cambridge MA: Harvard University Press, 1987.

Klotz, B., R. Madoo, and R. Hanson. "A Study of High and Low "Labor Productivity" Establishments in U.S. Manufacturing." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Lambert, D. K., and J. S. Shonkwiler. "Factor Bias Under Stochastic Technical Change." *Amer. J. Agr. Econ.* 77(August, 1995):578-590.

Lopez, Ramon E. "The Structure of Production and the Derived Demand for Inputs in Canadian Agriculture." *Amer. J. Agr. Econ.* 62(February, 1980):38-45.

Mairesse, Jacques and Bronwyn H. Hall. *Estimating the Productivity of Research and Development: An Exploration of GMM Methods Using the Data on French and United States Manufacturing Firms*. National Bureau of Economic Research, Inc. Working Paper 5501 (March, 1996). Cambridge, MA.

Mohr, M. F. "The Long-Term Structure of Production, Factor Demand, and Factor Productivity in U.S. Manufacturing Industries." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Morrison, Catherine J. "Structural Change, Capital Investment and Productivity in the Food Processing Industry." *Amer. J. Agr. Econ.* 79(1997):110-125.

Nadiri, I. "Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey." *Journal of Economic Literature*, 8(1970):1137-1177.

National Science Foundation. Various years. *Research and Development Expenditures in Industry*. Washington, DC: U.S. Government Printing Office.

Nelson, C. R. , and C. H. Kang. "Pitfalls in the Use of Time as an Explanatory Variable in Regression." *J. Bus. and Economic Statistics.* 2(January, 1984):73-82.

Shonkwiler, J. S., and H. A. Stranahan. *Modeling Technical Change in the Frozen Concentrated Orange Juice Processing Industry*. Agricultural Experiment Station, Bulletin 863. Institute of Food and Agricultural Sciences, University of Florida, Gainesville. 1987.

Shumway, R. C., and W. P. Alexander. "Agricultural Product Supplies and Input Demands: Regional Comparisons." *Amer. J. Agr. Econ.* 70(1988):153-61.

Slade, M. "Modeling Stochastic and Cyclical Components of Technical Change: An Application of the Kalman Filter." *Journal of Econometrics* 41(July, 1989):363-83.

Terleckyj, N. E. "Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

U.S. Department of Agriculture. 1991–1994. *Inventory of Agricultural Research.* U.S. Department of Agriculture, Cooperative States Research Service.

Paper II

RETURNS TO RESEARCH AND DEVELOPMENT IN FOOD PROCESSING

INTRODUCTION

Various studies have shown that definitive relationships exist between research and development (R&D) and the amount of innovative activity originating from an industry (Kamian and Schwartz) or between R&D and productivity increase (Mansfield). Many factors in addition to R&D are associated with technical change and productivity growth. Increase in capital intensity, advancement in human capital, urbanization and the learning process are found to interact and complement advances in technology (Nelson).

Growth in factor productivity is closely linked to the level of investment in research and development. The R&D investment by a firm reduces its own production cost and, as a result of spillovers, costs of other firms are also reduced. However, firms undertaking R&D investment are unable to completely appropriate all of the benefits from their own R&D investments. The degree to which firms can appropriate the returns to their R&D capital influences both the causes and consequences of R&D investment. Federal funding for direct R&D in food processing has been minimal. The main source of funding for R&D in food processing has been the private sector. Spillovers could lead to a higher productivity growth and factor bias in vertically integrated sectors.

Griliches (1980) used a productivity index approach to estimate the relationship between technological development and research investments. Shonkwiler and Stranahan (1987) modeled technical change in the Florida frozen concentrated orange juice processing industry using a translog cost function including expenditures for research and development. They concluded that investment in R&D generated a material saving and labor using technology. Bernstein and Nadiri (1988) used a truncated translog cost function to investigate the effects of inter-industry R&D spillovers in five high-tech industries where each industry is treated as a separate spillovers source.

The direct economic benefits of research are measured by examining how the improved technology reduces the cost of output. Reductions in the cost of output generally result in some combination of higher returns to producers, lower prices, and more consumption. A frequently used measure of research effectiveness is the rate of return earned by research investments. Compared to the agriculture sector, there is relatively little research on measuring the returns to R&D capital and the extent to which factor productivity in food processing is affected by spillovers from sectors that are vertically integrated with food processing. The papers by Gopinath and Roe and Morrison and Siegel indicate that researchers have started to devote time and resources to the problem.

Gopinath and Roe analyzed the extent of R&D spillovers in agriculture, food processing, and farm machinery and equipment. They concluded that unit variable costs are reduced by R&D capital spillovers with evidence of factor biases associated with the spillovers in all three sectors. The private rates of return to R&D capital range from an average of 10.2 percent for food processing to 22.3 percent for farm machinery and equipment. The direct rates of return to agricultural public R&D averaged 37.3 percent. They also found that spillovers appear to occur between primary agriculture and food processing which yields a social rate of return to investment in agricultural R&D averaging 46.2 percent and an average rate of 15.1 percent in food processing. The main limitation of this study is the lack of quasi-fixed physical capital in the model, i.e., the model captures only the relative inflexibility of R&D capital compared to other factors of production.

Morrison and Siegel emphasized the importance of short-run fixities and the resulting differential between apparent short- and long run scale economies. They argued that adding a quasi-fixed private capital input and investment in capital (adjustment cost), and external scale factors such as human capital, research and development and high-tech capital to the cost function causes the observed cost-output relationship to represent the short-run instead of the long-run. Morrison and Siegel concluded that scale economies allow 10 percent proportionate cost savings in food processing. Among three-digit food processing sectors, the Bakery Products industry appears to be characterized by more extensive scale economies and Meat Products and Preserved Fruits and Vegetables are characterized by less extensive scale economies. Diminishing returns to private capital (capital deepening) was strong for food processing industries particularly for Bakery Products. They concluded that across three-digit industries, Dairy Products and Preserved Fruits and Vegetables benefited the least from R&D expenditures and Sugar and Confectionery Products achieved the largest cost-saving impact from R&D. Dairy Products and Sugar Products experienced the greatest returns to (cost savings from) high-tech capital investment, and Grain Milling and Sugar Products benefited the most from educational investments. For the two-digit food-processing sector, the cost elasticity with respect to R&D was –0.127 for the 1959-89 period.

In Part I of this dissertation, the empirical research and development spillovers from crop agriculture and animal agriculture to food processing were determined by first generating state of technology variables using Kalman filtering, fixed interval smoothing and estimation and moments (E-M) algorithms. These observations together with observed price and quantity data were used in an iterative three-stage least squares procedure. Estimates of the elasticities of the cost shares with respect to the state of technology indicate that labor and material saving and capital using technological spillovers from crop agriculture to food processing occurred over time. Technological spillovers from animal agriculture to food processing have a neutralizing effect, i.e., labor and material using and capital saving. This implies that technological spillovers from agriculture to food processing have a mild net effect on factor bias. Even though the method used in Part I is very comprehensive in terms of associating R&D expenditures to the state of technology, it does not allow the computation of returns to research and development expenditures.

The purpose of this paper is to complement Part I by computing returns to research and development and to determine the effect of R&D spillovers from the aggregated agriculture sector to food processing. The specific objectives are: (1) measure returns to research and development spending in the food processing sector; (2) determine the existence of non-constant returns to scale in food processing; and (3) determine empirical research and development spillovers from the aggregated agriculture sector to food processing.

DATA AND METHODS

The technology of the representative firm in food processing is given by a production function relating one output (Q) to five input categories: materials (X1), equipment capital (X2), labor (X3), physical capital stock of structures (X), and the firm's own stock of R&D knowledge (R) resulting from accumulations of past R&D expenditures. The model allows for R&D spillovers from agriculture to food processing (RA) since they are vertically integrated and food processing benefits from stock of R&D knowledge in agriculture.

Materials, equipment capital and labor are treated as variable inputs and structures and stock of research and development knowledge are considered to be quasi-fixed inputs. The R&D capital is assumed to be a quasi-fixed factor because of the development costs that generate lags in the completion of R&D projects.

The cost function duality approach was used to evaluate the effects of own R&D stock and spillovers from agriculture. Behavioral patterns and their underlying determinants are not accommodated in the primal framework, thus output and input choices cannot be directly modeled and measured (Morrison and Siegel). A commonly used functional form is the translog (Christensen, Jorgenson, and Lau; Clark and Youngblood; Slade; Lambert and Shonkwiler; Harvey and Marshall). A translog variable cost function with external factors included is defined by:

$$\begin{aligned} \ln C_t = {} & \alpha_0 + \sum_i \alpha_i \ln P_{it} + \frac{1}{2} \sum_i \sum_j \alpha_{ij} \ln P_{it} \ln P_{jt} + \alpha_q \ln Q_t + \sum_i \alpha_{iq} \ln Q_t \ln P_{it} + \\ & \alpha_x \ln X_t + \sum_i \alpha_{ix} \ln X_t \ln P_{it} + \alpha_r \ln R_t + \alpha_{ir} \ln P_{it} \ln R_t + \alpha_{qx} \ln Q_t \ln X_t + \\ & \alpha_{qr} \ln Q_t \ln R_t + \alpha_{xr} \ln X_t \ln R_t + \alpha_a \ln RA_t + \alpha_{ira} \ln P_{it} \ln RA_t + \\ & \alpha_{qa} \ln Q_t \ln RA_t + \alpha_{ra} \ln R_t \ln RA_t + \omega_t . \end{aligned} \tag{1}$$

The various α's are parameters and the P_{it} are implicit factor prices. The following restrictions were imposed on the parameters in the estimation equations: (a) symmetry: $\alpha_{ij} = \alpha_{ji}$ (i,j = 1,2,3), (b) adding up: $\sum S_i = 1$ where S_i is cost share of factor i; and (c) homogeneity: $\sum \alpha_i = 1$; $\sum \alpha_{ij} = \sum \alpha_{ij} = 0$; $\sum \alpha_{iq} = 0$; $\sum \alpha_{ir} = 0$; $\sum \alpha_{ix} = 0$; $\sum \alpha_{ira} = 0$; for all i and j.

In addition to the above restrictions, the regularity conditions require the cost function to be non-decreasing in output and input prices at each observation. The translog cost function will be non-decreasing in output and input prices if both the derivative of the logarithm of cost with respect to the logarithm of output and predicted shares are greater than zero at each observation. The cost function will be concave in factor prices provided the Hessian matrix of second order price derivatives is negative semi-definite at each data point. This requirement is satisfied by the translog formulation if the matrix of estimated substitution elasticities is negative semi-definite at all data points.

By Shephard's Lemma, the share equations for the variable inputs X_i (i=1,2,3) are:

$$S_{it} = \alpha_i + \sum_j \alpha_{ij} \ln P_{jt} + \alpha_{iq} \ln Q_t + \alpha_{ix} \ln X_t + \alpha_{ir} \ln R_t + \alpha_{ira} \ln RA_t + \varepsilon_{it} \tag{2}$$

$$S_{1t} = \alpha_1 + \alpha_{11} \ln P_{1t} + \alpha_{12} \ln P_{2t} - (\alpha_{11} + \alpha_{12}) \ln P_{3t} + \alpha_{1q} \ln Q_t + \alpha_{1x} \ln X_t + \alpha_{1r} \ln R_t + \alpha_{1ra} \ln RA_t + \varepsilon_{1t} \tag{3}$$

$$S_{2t} = \alpha_2 + \alpha_{12} \ln P_{1t} + \alpha_{22} \ln P_{2t} - (\alpha_{12} + \alpha_{22}) \ln P_{3t} + \alpha_{2q} \ln Q_t + \alpha_{2x} \ln X_t + \alpha_{2r} \ln R_t + \alpha_{2ra} \ln RA_t + \varepsilon_{2t} \tag{4}$$

The random elements, ε_{it}, and ω_t, are assumed to be normally distributed with zero means and covariance matrices $\Omega_{\varepsilon t}$, and $\Omega_{\omega t}$.

The National Bureau of Economic Research (NBER) Manufacturing Productivity (MP) database constructed by Bartelsman and Gray contains annual information on 450 manufacturing industries from 1958 to 1994. The industries are redefined in the 1987 Standard Industrial Classification and cover the entire manufacturing sector. The data themselves come from various government data sources, with many of the variables taken directly from the Census Bureau's Annual Survey of Manufactures (ASM) and Census of Manufactures (CM). The advantages of using the MP database are that it gathers together many years of data, adjusts for changes in industry definitions over time, and links to additional key variables (i.e. price deflators and capital stock).

The basic information in the ASM is used for eleven of the eighteen variables in the current data set. These are number of workers, total payroll, number of production workers, number of production worker hours, total production worker wages, value of shipments, value added, end-of-year inventories, new capital investment, expenditure on energy, and expenditure on materials (including energy). All of these variables are deflated to millions of 1987 dollars, except for the labor-input variables that are in thousands of workers and millions of worker hours.

The following variables are not included directly in the ASM data, and their construction is described in the MP documentation. These are real total capital stock (equipment plus plant), real equipment capital stock, real structures capital stock (all three in millions of 1987 dollars), and price deflators (base 1987) for value of shipments, materials (energy plus non-energy materials), energy and new investments. The data source for price deflators include BEA, Bureau of Labor Statistics (BLS), and ASM.

Data series on research and development (R & D) expenditure in the food and kindred products sector are available from National Science Foundation' (NSF') Research and Development in Industry (various issues). National Science Foundation has conducted an annual survey of industrial research and development expenditures since 1954. The share of the Federal Government in R & D in food processing is very small. The R & D expenditure data were deflated to 1987 dollars. Research and development price deflators for food processing for the period 1969-88 were taken from Jankowski and recomputed to 1987 base period. Price deflators for the period 1958-68 were computed based on the average growth rate for the period 1969 to 1979. Similarly, the R&D price deflators for the period 1989 to 1994 were computed based on the average growth rate for the period 1980 to 1988.

Agricultural research and development expenditure data were obtained for the period 1958 to 1990 from Huffman and Evenson. It includes U.S. agricultural research expenditures (measured in real 1984 dollars) for public and private research. The data were redefined in terms of real 1987 dollars. For the period 1991 to 1994, R&D on agriculture were obtained from the U.S. Department of Agriculture's Inventory of Agricultural Research. The agricultural research price deflator for the 1993-94 period was estimated based on the average growth rate for the period 1960-92.

Research and development funds on agriculture include expenditures on programs other than crop and animal agriculture such as natural resources, forest resources, people, communities and institutions, general resources / technology, and food science / human nutrition. According to USDA's Inventory of Agricultural Research, about 58 percent of the agricultural R&D expenditures were spent on crop and on animal research and development.

The total stock of R&D capital in a given year is equal to the sum of contributions from past R&D investments. It changes from year to year to reflect new gross investments net of efficiency losses. The stocks of R&D capital are derived using the perpetual inventory method. The relationship between the economic efficiency of an asset and its age is very complex and depends on the particular type of asset as well as on a host of other factors such as the level of economic activity, relative input prices, interest rates, and technological developments. Besides, it is difficult to directly measure quantity of capital services. The standard practice is to use an efficiency function that is proportional to the rental income, in constant prices, which the good is capable of producing.

An efficiency function is a schedule that indicates the quantity of services provided by an asset of a given age relative to a new asset of the same type. The age / efficiency relationship is given by a hyperbolic function $E_t = (L-t)/(L-\beta t)$ where E_t is the relative efficiency of a t-year-old asset, L is the service life, t is the age of the asset and β is the parameter allowing the shape of the curve to vary (U.S. Department of Labor, Bureau of Labor Statistics). A value of β equal to zero corresponds to a straight-line efficiency pattern, while a value of β less than one is consistent with the concave efficiency pattern.

The Bureau of Labor Statistics uses a concave efficiency form (β=0.5 for equipment and β=0.75 for structures) in their measure of the productive stock of capital by asset type. The decision to use a concave efficiency form instead of a convex form implies that equipment tends to depreciate slowly in earlier years. The average life used is that estimated by the Bureau of Economic Analysis (BEA). This study used β=0.5 and a service life of 16 years in both food processing and agriculture, which is a service life of special industry machinery or that of agricultural machinery except tractors. In order to measure the first year's stock, it is necessary to collect historical investment data extending back as long as the life of the asset. Real R&D in food processing for 1943-1957 period was estimated based on the average growth rate of real R&D for the period 1958 to 1968 (3 percent per year). Similarly, private agricultural R&D data for the 1943-55 period was estimated based on average growth rate for the period 1956 to 1966 of 5.03 percent per year. Real public agricultural R&D data for the 1943-57 period was obtained from Huffman and Evenson (1991). The data set used in this study is presented in Appendix I.

RESULTS

The variable cost function and the share equations for materials and equipment capital (Equations (1), (3) and (4)) were estimated in three-stage least squares. The estimates are based on the following instrumental variables: (1) a constant term; (2) the capital-output ratio; (3) the R&D capital stock to output ratio; (4) the growth rate of output; (5) the growth rate of stock of R&D capital in food processing; (6) the growth rate of stock of R&D in agriculture; (7) the growth rate of the implicit prices of equipment capital and materials; (8) the growth rate of stock of structure capital; (9) the derivatives of the dependent variables (ln C, S_1 and S_2) with respect to α_{ij} (i,j = 1,2); and (10) exogenous variables (implicit factor prices).

The estimated coefficients and their standard errors are shown in Table 1. Output and price of labor have a significant negative relationship with the cost share of materials whereas capacity and prices of equipment capital and materials have a significant positive relationship with cost share of materials. A one percent increase in the price of materials increases cost share of materials by 0.03 percent[2]. The cost share of materials increased by 0.13 percent and decreased by 0.17 percent for every one percent increase in the price of equipment capital and labor, respectively. These relationships were significant at the one percent level.

2 The cost share elasticities are calculated as follows.

$$CE_{ij} = \frac{\partial S_i}{\partial p_j} * \frac{P_j}{S_i} = \frac{\partial S_i}{\partial \ln p_j} * \frac{\partial \ln P_j}{\partial P_j} * \frac{P_j}{S_i}$$

$$CE_{ij} = \frac{\alpha_{ij}}{P_j} * \frac{P_j}{S_i} = \frac{\alpha_{ij}}{S_i}.$$

TABLE 1

PARAMETER ESTIMATES IN SHARE EQUATION SYSTEMS.

Variable	Parameter	Estimate	Parameter Error	Standard P-Value
Intercept	α_0	30.1420	18.379	0.1131
ln P_1	α_1	-0.6014	0.1764	0.0020
lnP_2	α_2	-0.4099	0.1188	0.0018
lnP_3	α_3	2.0113	0.1584	0.0001
(lnP_1)^2	α_{11}	0.0164	0.0054	0.0051
lnP_1lnP_2	α_{12}	0.0652	0.0053	0.0001
lnP_1lnP_3	α_{13}	-0.0816	0.0070	0.0001
(lnP_2)^2	α_{22}	-0.0088	0.0067	0.1996
lnP_2lnP_3	α_{23}	-0.0564	0.0046	0.0001
(lnP_3)^2	α_{33}	0.1381	0.0071	0.0001
lnQ	α_q	-9.5469	3.8808	0.0201
lnP_1lnQ	α_{1q}	-0.1480	0.0492	0.0055
lnP_2lnQ	α_{2q}	0.0539	0.0382	0.1683
lnP_3lnQ	α_{3q}	0.0941	0.0351	0.0120
lnQ_lnR	α_{qr}	0.0512	0.5691	0.9251
lnQ_lnRA	α_{qa}	-1.6321	0.5829	0.0091
lnQ_lnX	α_{qx}	4.0084	1.3870	0.0074
lnX	α_x	-11.1745	5.4931	0.0527
ln$P_l$lnX	α_{1x}	0.6404	0.0539	0.0001
lnP_2lnX	α_{2x}	0.0179	0.0381	0.6437
lnP_3 lnX	α_{3x}	-0.6583	0.0376	0.0001
lnX lnR	α_{xr}	-8.2551	1.1513	0.0001
lnR	α_r	21.3909	3.9394	0.0001
lnP_1 lnR	α_{1r}	-0.1039	0.0224	0.0001
lnP_2 lnR	α_{2r}	0.0918	0.0184	0.0001
lnP_3 lnR	α_{3r}	0.0121	0.0184	0.5173
lnR lnRA	α_{ra}	3.3381	0.5499	0.0001
lnRA	α_a	4.2059	2.3366	0.0827
lnP_1 lnRA	α_{1ra}	-0.1628	0.0475	0.0019
lnP_2 lnRA	α_{2ra}	0.0671	0.0326	0.0483
lnP_3 lnRA	α_{3ra}	0.0957	0.0460	0.0465

P_{ij} = Implicit factor prices (P_1 = materials, P_2= Equipment Capital, P_3 = Labor)
Q = Output, X= Physical stock of structure capital, R = Stock of R&D capital in food processing, RA = Stock of R&D capital in agriculture.

The relationship between cost share of equipment capital and price of equipment capital was not significant at the five percent level. There is a significant negative relationship between prices of materials and cost share of equipment capital. The relationship of cost share of equipment capital with the price of labor was negative and significant. An increase in the price of labor increases cost share of labor. The relationship between cost share of labor with the prices of equipment capital and materials was negative and significant.

Output has a significant negative effect on cost share of materials and a positive effect on the share of labor. A one percent increase in output decreases cost share of materials by 0.3 percent and increases the cost share of labor by 0.56 percent. The effect of output on the cost share of equipment capital was not significant. The effect of capacity on cost share of equipment capital was not significant at the 10 percent. Capacity (quasi-fixed capital) has a significant positive and negative effect on materials and labor, respectively. As capacity increased over time the share of labor decreased.

The Allen elasticity of substitution and price elasticity of factor demand give important information on the relationships between factor inputs. Allen partial elasticity of substitution, σ_{ij}, and the price elasticity of demand, e_{ij}, were estimated from the parameters in the model as

$$\sigma_{ij} = (\alpha_{ij} + S_i S_j)/S_i S_j \qquad \text{If } i \neq j$$
$$\sigma_{ii} = \frac{1}{S_i^2}(\alpha_{ii} + S_i^2 - S_i) \qquad \text{If } i = j \tag{5}$$

$$e_{ij} = \sigma_{ij} S_j \tag{6}$$

where S_j is cost share of factor j (j=1,2,3). Table 2 presents the Allen partial elasticity of substitution at mean values. The Allen elasticity of substitution between factors i and j where S_j is cost share of factor j (j=1,2,3). Table 2 presents the Allen partial elasticity of substitution at mean values. The Allen elasticity of substitution between factors i and j measures the impact of a change in the price of the j^{th} factor on the quantity demanded of the i^{th} factor when output is fixed but quantities of other factors are allowed to vary. The elasticities of substitution may affect the factor substitution possibilities of the producer and hence influence bias over time. All of the own price factor demand and substitution elasticities have the correct negative sign. The own partial elasticities of substitution have little economic meaning.

The price elasticity of factor demand measures the impact in the j^{th} factor price on the demand for the i^{th} factor holding output and other factor prices constant. The price elasticities of demand for factors are shown in Table 3. Own-price elasticities of factor demand calculated from the results in Table 1 at the means of the data are –0.4787 (materials), -0.6826 (equipment capital), and -0.0156 (labor). The own price factor demand elasticities for materials and equipment capital are statistically significant and less than one in absolute value. This result suggests that the factor demands for materials and equipment capital are inelastic. Since both materials and equipment capital have a significant cost share in food processing, this is not an unlikely result. The own price factor demand elasticity for labor was not significant at the five percent level.

The positive values of the off-diagonal elements in Tables 2 and 3 suggest that the factors are substitutes. Conversely, negative values would have indicated complementarity among factors. The substitution between factors is best evaluated by utilizing the Allen elasticity of substitution rather than the price elasticity of factor demand. This occurs

TABLE 2

ALLEN PARTIAL ELASTICITY OF SUBSTITUTION (AT MEANS)[1]

	MATERIALS	EQUIP CAPITAL	LABOR
MATERIALS	-0.9817 (0.0227)		
EQUIP. CAPITAL	1.3898 (0.0320)	-1.9900 (0.0569)	
LABOR	0.0117 (0.0921)	0.0289 (0.0792)	-0.0923 (0.2474)

[1] Figures in brackets are standard errors of the respective elasticities.

TABLE 3

PRICE ELASTICITY OF DEMAND FOR FACTORS (AT MEANS)[2]

	Materials	Equipment Capital	Labor
Materials	-0.4787 (0.0111)	0.4767[a] (0.0110)	0.0057 (0.0156)
Equip. Capital	0.6777 (0.0156)	-0.6826 (0.0195)	0.0049 (0.0134)
Labor	0.0057 (0.0449)	0.0099 (0.0272)	-0.0156 (0.0419)

[2] Figures in brackets are standard errors of the respective elasticities.
[a] Estimated price elasticity measures the effect of a change in the price of the input in the j^{th} column on the quantity demanded of the input in i^{th} row

because the factor demand elasticity reflects the relative importance of the factor's share in total cost whereas those of the Allen elasticity does not (Binswanger).

Allen partial elasticity of substitution calculated at the means of the data indicates that there is a statistically significant substitutability between materials and equipment capital. This relationship reflects the sector's trend towards more capital-intensive production processes. The estimated Allen elasticities of substitution between labor and materials and between labor and equipment capital are not significant.

Returns to Research and Development

The elasticity of the shares with respect to the own stock of R&D capital, α_{ir}/S_{it}, resulting from Equations (3) and (4) are –0.2131 (materials), 0.2676 (equipment capital), and 0.0714 (labor). The estimates for materials and equipment capital were statistically different from zero at the one percent level whereas the estimate for labor was not significant. A one-percent increase in own stock of R&D capital decreases cost share of materials by 0.21 percent and increases cost share of equipment capital by 0.26 percent. This implies that technological change in U.S. food processing has been capital using and material saving.

The productivity effect associated with own stock of research & development capital is given by

$$\partial \ln C_t / \partial \ln R_t = \alpha_r + \sum_i \alpha_{ir} \ln P_{it} + \alpha_{qr} \ln Q_t + \alpha_{xr} \ln X_t + \alpha_{ra} \ln RA_t . \qquad (7)$$

A one percent increase in own stock of R&D capital caused variable cost in food processing to decline by 0.14 percent from 1958 to 1994. This decline came from material saving technologies.

The private rate of return is defined by the real value of variable cost reduction due to an increase in an industry's own R&D, that is, the rate of return is measured by its shadow price. This is given by

$$\gamma_t = -\frac{\partial C_t / \partial R_t}{\Pr_t} = -\frac{(C_t / R_t)(\partial \ln C_t / \partial \ln R_t)}{\Pr_t} \quad \textbf{(8)}$$

where γ_t is the gross private rate of return and Pr_t is the price of R&D capital at time t. The private rate of return to R&D capital in food processing was 11.6 percent over the sample period. This rate of return is consistent with the estimate by Gopinath and Roe of 10.2 percent.

The effect of the agricultural R&D spillovers on productivity of food processing is given by

$$\partial \ln C_t / \partial \ln RA_t = \alpha_{ra} + \sum_i \alpha_{ira} \ln P_{it} + \alpha_{qra} \ln Q_t + \alpha_{ra} \ln R_t . \quad \textbf{(9)}$$

A one percent increase in the spillovers caused variable cost in food processing to decline by 0.11 percent. The factor biases associated with the stock of spillovers capital are determined by α_{ira} in Table 1. If the sign of these parameters is positive (negative), then the effect is factor using (reducing). Estimates of the elasticity of the shares with respect to the stock of spillovers capital indicate that material saving, capital and labor using technological spillovers from agriculture to food processing have occurred over the sample period.

The model also allows a straight forward computation of short-run cost-output (scale) elasticities ($\varepsilon_{cq} = \partial \ln C_t / \partial \ln Q_t$). The average cost-output elasticity over the sample period was 0.9142. This estimate of the short-run cost-output elasticity is not too different from those reported elsewhere for this industry. Morrison and Siegel obtained a cost-output elasticity of 0.902 over the period 1958-89 using a Generalized Leontief variable cost function with external factors. This implies that the food processing sector enjoyed a 9 percent cost savings from scale economies over the 1958 to 1994 period. The dual measure of returns to scale is given by $1/\varepsilon_{cq} = 1/0.9142 = 1.094$. This can be interpreted as a one percent increase in variable cost increases output by 1.094 percent which is a characteristic of increasing returns to scale. However, the hypothesis of constant returns to scale was not rejected at the five percent level.

The estimated cost-capacity elasticity $((\varepsilon_{cx} = \partial \ln C_t / \partial \ln X_t)$ was –0.0457. This estimate was larger in absolute value than the estimate by Morrison and Siegel (-0.013). The negative sign suggests that additional cost savings are obtained as capacity expands. This may explain why the industry became more capital intensive over the sample period. The coefficient for the interaction term between capacity and stock of R&D capital was negative and significant which implies that increasing both capacity and R&D capital increases cost saving.

SUMMARY AND CONCLUSION

Growth in factor productivity is closely linked to the level of investment in research and development. The R&D investment by a firm reduces its own production cost and, as a result of spillovers, costs of other firms. However, firms undertaking R&D investment are unable to completely appropriate all of the benefits from their R&D investments.

The main source of funding for R&D in food processing has been the private sector. Spillovers could lead to a higher productivity growth and factor bias in vertically integrated sectors. The direct economic benefits of research are measured by examining how the improved technology reduces the cost of output. A frequently used measure of research effectiveness is the rate of return earned by research investments. Compared to the agriculture sector, there is relatively little research on measuring the returns to R&D capital and the extent to which factor productivity in food processing is affected by spillovers from sectors that are vertically integrated with food processing.

The purpose of this paper was to complement Part I by computing returns to research and development and determine the effect of R&D spillovers from the aggregated agriculture sector to food processing. The specific objectives were to: (1) measure returns to research and development spending in food processing; (2) determine the existence of non-constant returns to scale in food processing; and (3) determine empirical research and development spillovers from the aggregated agriculture sector to food processing.

The cost function method was used to evaluate the effects of own R&D stock and spillovers from agriculture on factor substitution and returns to scale. A translog variable cost function with external factors and factor share equations were estimated using iterative three-stage least squares. The National Bureau of Economic Research (NBER) Manufacturing Productivity (MP) database was used for the period from 1958 to 1994. The industries are redefined in the 1987 Standard Industrial Classification, and cover the entire manufacturing sector. Data series on research and development expenditure in the food and kindred products sector were available from National Science Foundation' (NSF') Research and Development in Industry. Research and development expenditures on agriculture were obtained for the period 1958 to 1990 from Huffman and Evenson. For the period 1991 to 1994, R & D on agriculture were obtained from the U.S. Department of Agriculture's Inventory of Agricultural Research. The R & D expenditure data were deflated to 1987 dollars. Research and development price deflators for food processing for the period 1969-88 were taken from Jankowski and recomputed to 1987 base period. Price deflators for the period 1958-68 were computed based on the average growth rate for the period 1969 to 1979. Similarly, the R&D price deflators for the period 1989 to 1994 were computed based on the average growth rate for the period 1980 to 1988. The stocks of R&D capital were derived using the perpetual inventory method.

A statistically significant substitutability between materials and equipment capital was found over the sample period. The estimated Allen elasticities of substitution between labor and materials and between labor and equipment capital were not significant. Technological change in U.S. food processing has been capital using, labor neutral and material saving. Material saving and labor and capital using technological spillovers from agriculture to food processing have occurred over time.

A one percent increase in own stock of R&D capital caused variable cost in food processing to decline by 0.14 percent from 1958 to 1994 period. This decline came from material saving technologies. The private rate of return to R&D capital in food processing was 11.6 percent over the sample period. A one percent increase in the spillovers caused variable cost in food processing to decline by 0.11 percent. There has been a 9 percent cost savings from scale economies over the 1958 to 1994 period. However, there was insufficient evidence to reject the null hypothesis of constant returns to scale at the five percent level.

References

Bartelsman, E., and W. Gray. Manufacturing Productivity Database. National Bureau of Economic Research (electronic form), Cambridge MA, 1997.

Bernstein, J. I. and M. I. Nadiri. "Interindustry R&D Spillovers, Rates of Return and Production in High-Tech Industries." *Amer. J. Agr. Econ.* 78(May, 1988):429-434.

Binswanger, H. P. "The Measurement of Technical Change Biases with Many Factors of Production." *American Economic Review.* 64(1974)65-78.

Christensen, L. R., D. W. Jorgenson, and L.J. Lau. "Conjugate Duality and the Transcedental Logarithmic Production Function." *Econometrica* 39(1971)255-256.

Clark, J. S. , and C. E. Youngblood. "Estimating Duality Models with Biased Technical Change: A Time Series Approach." *Amer. J. Agr. Econ.* 74(May, 1992):353-60.

Gopinath, M. and T. L. Roe. *R&D Spillovers: Evidence from U.S. Food Processing, Farm Machinery and Agriculture.* Economic Development Center, Bulletin 96-2 (October, 1996). Department of Economics, Minneapolis and Department of Applied Economics, St. Paul, University of Minnesota.

Griliches, Zvi. "Returns to Research and Development Expenditures in the Private Sector." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Harvey, A. C., and P. Marshall. "Inter-fuel Substitution, Technical Change and the Demand for Energy in the UK Economy." *Applied Economics* 23(June, 1991):1077-86.

Huffman, W. E., and R. Evenson. *Science for Agriculture.* Ames, IA: Iowa State University Press, 1993.

Jankowski, J. E. (Jr). "Do We Need a Index for Industrial R&D?" *Research Policy* 22(1993): 195-205.

Kamin, M. I., and N. L. Schwartz. "Market Structure and Innovation: A Survey." *Journal of Economic Literature* 13(1975): 242-263.

Lambert, D. K., and J. S. Shonkwiler. "Factor Bias Under Stochastic Technical Change. " *Amer. J. Agr. Econ.* 77(August, 1995):578-590.

Mansfield, E. "Contribution of R&D to Economic Growth in the U.S." *Science* 19(1972): 477-486.

Morrison, C. J. and D. Siegel. "Knowledge Capital and Cost Structure in the U.S. Food and Fiber Industries." *Amer. J. Agr. Econ.* 80(1998):30-45.

National Science Foundation. Various years. *Research and Development Expenditures in Industry.* Washington, DC: U.S. Government Printing Office.

Nelson, R. R. "Research on Productivity, Growth and Productivity Differences: Dead Ends and New Departurres." *Journal of Economic Literature* 19(1981): 1029-1064.

Shonkwiler, J. S., and H. A. Stranahan. *Modeling Technical Change in the Frozen Concentrated Orange Juice Processing Industry.* Agricultural Experiment Station, Bulletin 863. Institute of Food and Agricultural Sciences, University of Florida, Gainesville. 1987.

Slade, M. "Modeling Stochastic and Cyclical Components of Technical Change: An Application of the Kalman Filter." *Journal of Econometrics* 41(July, 1989):363-83.

U.S. Department of Agriculture. 1991–1994. *Inventory of Agricultural Research.* U.S. Department of Agriculture, Cooperative States Research Service.

U.S. Department of Labor, Bureau of Labor Statistics. *Trends in Multifactor Productivity, 1948–81.* Bulletin 2178. Washington, Government Printing Office, September, 1983.

Paper III

ECONOMIC DEVELOPMENT IMPACTS FROM INCREASED EFFICIENCY IN THE FOOD AND KINDRED PRODUCTS SECTOR FOR OKLAHOMA

INTRODUCTION

Economic development results in the increase in the well-being of people and households. Major issues of concern arise in what constitutes an increase in the well-being of people, how it is measured, and what methods are used to measure change (Schreiner et al.). State-wide task forces have independently concluded that value-added food and agricultural products processing should be expanded as an area for economic development in Oklahoma (Tilley and Gilliland). Oklahoma has invested in a Food and Agricultural Products Research and Technology (FAPRT) Center for purposes of expanding the potential development of this sector. Yet few empirical estimates are available to quantitatively show the potential impacts of this Center on measures of economic development in the state.

This paper demonstrates the potential of the Center by showing the state economic impact of increased efficiency in the aggregate for the food and kindred products sector. The food and kindred products sector accounts for about 10 percent of value added and 8.5 percent of wage payments for total manufacturing in Oklahoma. There are currently more than 400 firms with a total of 14,000 plus employees and this industry accounts for about $863 million gross state product (value added). The objective of this paper is to evaluate the state economic development impacts of increased efficiency in the food processing industries. Previous methods were restricted to fixed-price multiplier analysis with biased results (Koh et al.). The current method allows commodity and factor markets to endogenously determine prices, quantities, and incomes (Schreiner et al.).

DATA AND METHODS

The procedure of analysis included the following: (1) a social accounting matrix (SAM) was estimated for the impact region using the IMPLAN Database and other data sources; (2) a regional computable general equilibrium (CGE) model was specified and calibrated; and (3) a ten percent increase in the efficiency of food processing was simulated.

This analysis is based on the 1993 IMPLAN Database. The IMPLAN 528 sectors were aggregated into 30 industries corresponding to the 1987 Standard Industrial Classification (SIC) code and following Regional Input-Output Modeling Systems (RIMS) II (USDC). Eight of the thirty sectors were the three-digit food and kindred products sectors.

Social Accounting Matrix (SAM)

A social accounting matrix (SAM) was developed using the information from IMPLAN and the Bureau of Economic Analysis (BEA) for the state of Oklahoma for the year 1993. In this study, employee compensation, proprietary income and other property income were distributed to factors of labor, capital and land and indirect business taxes. Following Koh, Lee and Budiyanti, factor shares for agriculture were estimated at 23.94 percent for labor, 33.94 percent for capital and 42.12 percent for land. For the nonagricultural sectors, all of employee compensation and 31.41 percent of proprietary income were allocated to labor, and 68.59 percent of proprietary income and all of other property income were allocated to capital.

Procedures for estimating sources of income are Budiyanti and Lee. A factor tax rate of 13.4 percent was imposed on labor, 13.39 percent on capital and 15.98 percent on land. About 72.91 percent of capital income (84.18 percent of enterprise income) is reserved as retained earnings. The aggregated SAM for Oklahoma is presented in Table 1 (the disaggregated SAM is in Appendix II). Total commodity output was $109,740 million of which total exports account for about 31 percent ($33,859 million). Total commodity demand in the region was $151,524 million of which $41,784 million (27.6 percent) was fulfilled by imports. Intermediate inputs used and produced in the region account for about 59 percent ($31,848 million) of total intermediate inputs used. Shares of factor income were 65.1 percent for labor, 33.6 percent for capital, and 1.2 percent for land.

Specification of State CGE Model

General equilibrium models have four essential ingredients: endowments of consumers (households), production technology, demand functions, and the conditions for equilibrium (Ballard et al.). In our model, consumers possess endowments of labor, land and capital. The model is built based on the assumptions of competitive markets with full information, and profit or utility maximizing behavior of producers and consumers. A sector is an aggregation of many producers but the sector is treated as a single firm in the model. Households are an aggregation of many similar households within each income group but each income group is treated as a single household.

Under the Walrasian general equilibrium framework, relative prices are assumed to be the only force that determines the flow of commodities and factors. Therefore, all Table 1 prices are expressed in terms of relative value with respect to a base price of one.

TABLE 1

SOCIAL ACCOUNTING MATRIX FOR THE STATE OF OKLAHOMA.

1993 (MILLION DOLLARS).

		Factor Income				Enterprise	Household Income			Government Income					
	Commodity	Labor	Capital	Land	Total	Income	Low	Med	High	St & Local	Federal	Total	Capital	Exports	Total
Commodity	31848						7072	16899	11148	3802	775	38695	5338	33859	109740
Factor Income															
Labor	30401						16	48	42	3679	3303	7089			37490
Capital	19352														19352
Land	709														709
Total	50462						16	48	42	3679	3303	7089			57551
Enterprise Income			12511		12511										12511
Household Income															
Low		2301	942	35	3278	131				818	4944	5893		95	9265
Medium		14718	3906	259	18883	705				1656	2828	5189		362	24433
High		14344	3000	390	17734	899				477	768	2143		305	20182
Total		31363	7848	683	39894	1734				2950	3540	13225		761	53880
Government															
State & Local	4303	747	586	26	1359	254	134	780	924	3562	1971	7623		473	13758
Federal	965	5380	-1593		3787	1446	205	2140	2794		2945	9531		3902	18185
Total	5268	6127	-1007	26	5146	1700	339	2920	3718	3562	4916	17154		4375	31943
Capital						9077.1	-1258.0	-2887.9	276.5			5208		2790	7997
Imports	22161						3096	7454	4997	766	651	16964	2659		41784
Total	109740	37490	19352	709	57551	12511	9265	24433	20182	13758	18185	98334	7997	41784	315406

The regional market price of the composite good is a weighted average of the imported and domestic good prices. Import prices are exogenous to the region whereas regional prices are endogenous.

Production functions are characterized at two (nested) levels. At the first level, each of n production sectors produces only one homogeneous commodity using intermediate and primary inputs. Technology assumes no substitution between composite intermediate inputs and composite primary factors nor between intermediate inputs produced by different sectors. This is the Leontief input-output production function technology. At the second level, substitution among primary factors of labor, capital and land is represented by a constant returns to scale Cobb-Douglas (C-D) production function. It is assumed that there exists only one type of each factor.

Economic efficiency in food processing may be explained as a reduced cost to process a given amount of output or to increase the amount of product (output) for the same amount of inputs used. The latter, in its most simple form, may be expressed as a Cobb-Douglass production function utilizing inputs of capital and labor (Ferguson). Value-added of the food and kindred products sector may be expressed as:

$$VA_i = \omega_i A_i L_i^{\alpha_L^i} K_i^{\alpha_L^i}$$

where VA is a physical index of value-added of the sector, K is a measure of physical capital, L is a measure of physical labor, and A, α_L and α_K are parameters of the production function. The parameters α_L and α_K are production elasticities and explain how value-added (VA) changes with percentage changes in capital and labor, respectively. A is an efficiency parameter and represents how K and L are technically transformed into a level of value-added output, VA. The parameter ω is used in the CGE model to simulate a percent change in the efficiency of a specific sector. During calibration ω equals one. Technology in this case is fixed, the only variable inputs are capital and labor. An alternative specification of efficiency is through a technology variable, T, and expressed in the production function as:

$$VA_i = A_i L^{\alpha_L^i} K^{\alpha_K^i} e^{rT}$$

where T is a measure of technology, and r is a parameter. If time is used as a surrogate for technology, then the parameter r is a measure of technical change over time. Our interest currently, however, is not to measure the rate of technological change over time but to propose that the impact of the FAPRT Center is to change technology and thus to increase efficiency of the food and kindred products sector through increases in output. Technology is thus a discrete variable and is hypothetically measured before and after establishment of the FAPRT Center.

Demand for the composite and individual intermediate inputs is derived from the Leontief input-output production relationship whereas primary factor demand is determined from the C-D production relationship by profit maximizing for each sector. The first order conditions for profit maximization are included in the CGE model. The model assumes that full employment is always attained by adjustment of the wage rate and the rates of return to land and capital for a given time period. Land is used only in agriculture and is assumed fixed in supply. Capital is assumed fixed in supply by sector in the short run. Both intersectoral and interregional mobility of capital are allowed in the long run analysis. Labor supply from regional households is part of the household expenditure system and is derived from the labor-leisure choice. Labor migration is defined as a function of the ratio of regional and out-of-region wage rate and an assumed labor migration elasticity.

Intermediate inputs are treated as a mix of regional and imported products. Quantity of the intermediate input demanded is described by a constant elasticity of substitution (CES) function between regional and imported components. The elasticity of substitution parameters are exogenously specified. The regional intermediate input demand is obtained from first order conditions of cost minimization subject to a given level of composite intermediate input defined by the CES function. Relative prices of regionally produced and imported inputs and the elasticity of substitution parameter determine regional intermediate input demand.

Similarly, each sector transforms its output for export or a product used by the region. A constant elasticity of transformation (CET) function describes this transformation process. The regional supply function is derived from the first order conditions for maximizing revenue subject to a given output level with the CET function. Relative prices of regional goods to exported goods and the constant elasticity of transformation parameter determine regional supply and export supply for market goods.

Three household annual income groups are considered in this study: low income (<$20,000 income), medium income ($20,000 to $40,000), and high income (>$40,00). The level of ownership of the primary factors (labor, land, and capital), factor prices, and government transfers determine income for each household group. Government transfers are assumed fixed in this analysis. It is assumed that resource ownership structure remains unchanged. Quantity of labor supplied by households is endogenous and determined by wage rate and the labor-leisure choice. Consumer demand functions are derived from maximization of utility. The Stone-Geary utility function is used which results in a linear expenditure system (LES) and satisfies the assumption of a diminishing marginal rate of substitution.

The demand system derived from this utility function satisfies the general properties required; homogeneity of degree zero in all prices and income, symmetry of cross-substitution effects, adding up condition, and negativity of direct substitution effects. Household consumption is modeled at two levels. The first level determines consumption of the composite goods and the demand for leisure (or supply of labor) derived from maximizing utility subject to prices and full income. The average budget shares are calculated from the SAM data. Income elasticity of demand for goods and services, income elasticity of labor supply, and a Frisch parameter are exogenously assigned to allow calibration of the minimum subsistence consumption parameters. A backward bending labor supply curve is assumed and hence the income elasticity of labor supply is greater in absolute value for high income than for low income household groups.

The second level determines the optimal combination of imported and regionally produced goods. The optimal combination is the result of first order conditions for cost minimization subject to the level of composite commodity obtained from the first level and the CES function of imported and regionally produced components. Relative prices and the elasticity of substitution determine the optimal combination.

Federal and state and local government revenues include indirect business taxes, factor taxes, intergovernmental transfers, and household and corporate income taxes. Their expenditures include commodity consumption, transfers to households and governments, and payment to labor. Quantity of commodity consumption is held constant but as regional prices change total government expenditure changes. The proportion of regional relative to imported commodities is also specified by a CES function.

Total saving is composed of household savings, retained earnings for enterprises, and net transfers (saving) from rest-of-world. Capital expenditures are for investment demand and include regionally produced and imported components as specified through a CES function. Capital expenditures are the result of a fixed quantity (exogenous) and a regionally determined composite price. Gross regional product is estimated by before tax factor income plus indirect business taxes. Welfare changes measured by compensating variation (CV) were computed outside of the model for each household income group. The total CGE model is presented in Amera and Schreiner.

SIMULATION RESULTS

Commodity Markets

Short run and long run changes in commodity markets of the impact region from an assumed 10 percent increase in the efficiency of food processing sector are presented in Tables 2 and 3. The changes are expressed in terms of indices with the base value equal to one. Most food processing regional prices in the short run analysis decreased because of an increased output and regional supply. The exception is vegetable and animal oil. Regional prices of most non-food sectors in the short run increased. The exceptions are agricultural services, textile and chemical petroleum. As efficiency in the food processing sectors increases, the demand for material inputs increases which result in a higher regional price of material inputs. Material inputs account for about 60 to 70 percent of the cost of production in food processing. Agricultural raw materials and energy are the most important material inputs in food processing and hence the increases in regional prices of animal agriculture, crop agriculture and utility sectors are expected.

Composite prices of most food processing sectors increased in the short run analyses except bakery products. Composite prices of non-food sectors show mixed results. This is because composite prices are a net result of changes in regional prices and changes in quantities of regional supply and imports. The long run composite prices of food processing sectors are higher than the short run levels (except bakery products and vegetable and animal oil). This is due to the mobility of capital in the long run. For non-food sectors, the short run and the long run composite prices show mixed results. The food processing regional prices are less than the composite prices in the short run for each sector except bakery products. This is because of the fixed nature of external prices and the effect of increased efficiency on regional prices. The exception for bakery products may be due to shifting of resources out of bakery products into other sectors. Regional prices are the same or higher than the composite prices in the short run for each non-food sector except for animal agriculture, crop agriculture, wood and paper products, and business services.

The food processing regional prices are less than the composite prices in the long run for each sector except bakery products, milling products and vegetable and animal oil. In general, non-food regional prices are greater than the composite prices in the long run. The long run regional prices of food processing sectors are higher than the short run levels except for prepared meat, vegetable and animal oil, and beverages. For non-food sectors, the short run regional prices are in general less than the long run regional prices.

TABLE 2

IMPACTS OF INCREASED EFFICIENCY (10%) OF FOOD PROCESSING

ON COMMODITY PRICES, 1993 (INDICES).

Commodities	Base	Regional Prices		Composite Prices	
		Short Run	Long Run	Short` Run	Long Run
Animal Agriculture	1.0000	1.0063	1.0320	1.0306	0.9712
Crop Agriculture	1.0000	1.0018	0.9403	1.0050	1.1243
Agricultural Services	1.0000	0.9993	0.9870	0.9965	0.9021
Mining	1.0000	1.0023	0.9852	0.9889	0.9666
Construction	1.0000	1.0019	1.0031	0.9990	0.9818
Prepared Meats	1.0000	0.9976	0.9841	1.0035	1.0800
Dairy	1.0000	0.9851	1.0032	1.0280	1.0883
Fruits and Vegetables	1.0000	0.9731	0.9983	1.0163	1.1787
Milling Products	1.0000	0.9941	1.1918	1.0393	1.1044
Bakery Products	1.0000	0.9532	0.9702	0.9063	0.8796
Misc. Food Products	1.0000	0.9700	0.9995	1.0280	1.0980
Vegetable and Animal Oil	1.0000	1.0153	1.0053	1.0746	0.8437
Beverages	1.0000	0.9726	0.9353	1.0085	1.0415
Textile	1.0000	0.9999	0.9942	0.9936	0.9673
Wood and Paper Products	1.0000	1.0044	1.0252	1.0199	1.0383
Printing and Publishing	1.000	1.0045	1.0368	0.9965	1.0592
Chemical Petroleum	1.0000	0.9980	0.9913	0.9956	1.0003
Other Manufacturing	1.0000	1.0011	1.0016	0.9981	0.9927
Transportation	1.0000	1.0029	1.0080	0.9971	1.0173
Communications	1.0000	1.0028	0.9961	0.9938	0.9807
Energy	1.0000	1.0042	0.9932	0.9989	0.9852
Wholesale Trade	1.0000	1.0039	1.0063	1.0002	1.0308
Retail Trade	1.0000	1.0045	1.0049	1.0000	0.9877
Hotels	1.0000	1.0042	1.0135	0.9972	0.9882
Finance	1.0000	1.0026	1.0033	0.9972	0.9845
Insurance	1.0000	1.0011	1.0056	0.9950	1.0032
Real Estate	1.0000	1.0049	1.0023	1.0037	0.9890
Business Services	1.0000	1.0038	1.0068	1.0088	1.0208
Health Services	1.0000	1.0033	1.0048	0.9998	0.9886
Misc. Services	1.0000	1.0023	1.0047	1.0023	0.9873

TABLE 3

IMPACTS OF INCREASED EFFICIENCY (10%) OF FOOD PROCESSING

ON OUTPUT AND EXPORTS, 1993 (INDICES).

Commodities	Base	Sectoral Output		Exports	
		Short Run	Long Run	Short` Run	Long Run
Animal Agriculture	1.0000	0.9893	0.8757	0.9806	0.8364
Crop Agriculture	1.0000	0.9995	0.9358	0.9960	1.0467
Agricultural Services	1.0000	0.9986	0.9996	0.9997	1.0210
Mining	1.0000	0.9997	1.0621	0.9983	1.0716
Construction	1.0000	1.0007	1.0083	0.9952	0.9994
Prepared Meats	1.0000	1.0087	0.9711	1.0155	1.0154
Dairy	1.0000	1.0073	0.9665	1.0500	0.9580
Fruits and Vegetables	1.0000	1.1650	0.9286	1.1719	0.9290
Milling Products	1.0000	1.0322	0.4490	1.0335	0.4249
Bakery Products	1.0000	1.0824	1.1008	1.2414	1.2004
Misc. Food Products	1.0000	1.0717	0.9570	1.1678	0.9583
Vegetable and Animal Oil	1.0000	0.9844	0.7406	0.9628	0.7350
Beverages	1.0000	1.1767	1.4503	1.1876	1.4810
Textile	1.0000	1.0086	1.0415	1.0089	1.0580
Wood and Paper Products	1.0000	0.9889	0.9042	0.9843	0.8804
Printing and Publishing	1.000	0.9915	0.8888	0.9864	0.8513
Chemical Petroleum	1.0000	1.0067	1.0087	1.0114	1.0296
Other Manufacturing	1.0000	0.9978	1.0000	0.9970	0.9988
Transportation	1.0000	1.0021	0.9876	1.0009	0.9845
Communications	1.0000	1.0032	1.0170	1.0019	1.0189
Energy	1.0000	1.0035	1.0134	1.0016	1.0166
Wholesale Trade	1.0000	1.0028	0.9897	1.0003	0.9859
Retail Trade	1.0000	1.0052	1.0184	1.0022	1.0150
Hotels	1.0000	1.0051	1.0106	1.0021	1.0011
Finance	1.0000	1.0032	1.0106	1.0016	1.0086
Insurance	1.0000	1.0044	1.0000	1.0039	0.9975
Real Estate	1.0000	1.0002	1.0145	0.9971	1.0131
Business Services	1.0000	1.0021	1.0015	0.9996	0.9970
Health Services	1.0000	1.0050	1.0171	1.0027	1.0137
Misc. Services	1.0000	1.0022	1.0102	1.0011	1.0078
Total	1.0000	1.0032	1.0014	1.0021	0.9938

Changes in output by sector are net results of changes in regional and composite prices, changes in factor prices, substitutions between factor inputs, elasticity of substitution between regionally produced and imported intermediate goods, and elasticity of transformation between regional supply and export. In both the short run and long run analysis, the overall output level increased. The overall increase for non-food sectors is less than the percentage increase for food processing sectors that are directly affected by an increase in efficiency. The changes in output by sector show mixed results. In the short run analyses, output decreased in animal agriculture, crop agriculture, agricultural services, mining, vegetable and animal oil, wood and paper products, printing and publishing, and other manufacturing. Output increased in all other sectors. This means labor resources were generally shifting from the output decreasing sectors to the output increasing sectors. In the long run analysis, output decreased in all food processing sectors except bakery products and beverages. Output increased in all non-food sectors except agricultural sectors, wood and paper products, printing and publishing, transport, and wholesale trade.

The overall export level increased in the short run and decreased in the long run. The level of exports in the short run increased for all food processing sectors except vegetable and animal oil. This increase in exports is expected because increased efficiency increases output and lowers regional prices relative to out-of-region prices and induces export demand. The level of export demand in the short run has concentrated increases more in bakery products, beverages, fruits and vegetables, and miscellaneous food products which is consistent with the increases in sector output. The changes in exports for non-food sectors show mixed results. The level of exports in the long run decreased for food processing sectors except prepared meats, bakery products, and beverages. The decline in export levels is the highest for milling products (58 percent). The increase in export levels is the highest for beverages (48 percent) followed by bakery products (20 percent). Among non-food sectors, exports in animal agriculture declined the highest (16 percent).

Factor Markets

It is the factor market where distinction occurs between the short run and the long run. In the short run, capital is fixed by sector but labor is mobile between sectors and between regions. In the long run, both labor and capital are mobile between sectors and regions. Land is fixed in both short and long run.

Wage rate increased in both short run and long run (Table 4). Long run wage rate is higher than short run. Wage rate increased by 0.28 percent and 0.83 percent in the long run, respectively. Equilibrium wage rate is determined by supply and demand for labor. Total labor demand increased both in the short run and long run. The increase in labor demand is higher in the long run than in the short run. For non-food sectors, labor demand increased in sectors where output increased except agricultural services in the long run. Labor demand decreased in most food processing sectors despite an increase in output. The exceptions are fruits and vegetables and beverages in the short run and bakery products and beverages in the long run. The decline in labor demand is the highest for the bakery products (59 percent) in the long run and vegetable and animal oil (17 percent) in the short run. The increase in labor demand is the highest for beverages both in the short run (14 percent) and the long run (32 percent).

Higher wage rate relative to out-of-region wage rate encourages in-migration. Migration of labor depends on the assumed labor migration elasticity (0.92 in this study). Labor in-migrated to Oklahoma by 0.26 percent and 0.47 percent of the initial labor supply in the short run and long run, respectively. This is equivalent to a gain of 4488 and 8090 jobs, respectively.

In all scenarios, the change in total labor use is less than the change in the wage rate. This result is consistent with results of Budiyanti and Amera and Schreiner. Budiyanti attributed this result to at least three factors: (1) a slight inelasticity of labor migration which means that the change in overall wage rate leads to a smaller than proportional change in labor supply, (2) a negative income elasticity of labor supply, which means that with a lower wage rate (and subsequent income) households supply more labor, and (3) a lower wage rate increases industry demand for labor in the region.

Labor supply, which is determined by labor-leisure choice, decreased for each household income group. The largest percentage decrease was for the high income group because income elasticity of labor supply was assumed to be larger in absolute value for high income than for low income households. The decrease in labor supply is higher in the long run than in the short run due to higher wages in the long run. The decline in labor supply by the initial households is more than offset by in-migrating labor both in the short run and the long run. Thus total labor supply after the shock is higher by 0.17 percent in the short run and by 0.29 percent in the long run.

In the short run, capital is fixed by sector and hence the total capital demand remains unchanged. In the long run, capital demand increased by 0.64 percent. The overall capital rent increased by 0.45 percent in the short run and by 0.70 percent in the long run. The increase in capital rent was higher in the long run than in the short run despite the effects of in-migrating capital (0.64 percent of the initial capital stock) on capital rent. The capital rents by industry in the short run show mixed results. Capital rents decreased for all food processing sectors except fruits and vegetables (13 percent) and beverages (14.5 percent).

TABLE 4

IMPACTS OF INCREASED EFFICIENCY (10%) OF FOOD PROCESSING ON FACTOR MARKETS, 1993

Items	Base	Short Run	Long Run
Labor			
Labor Demand (index)	1.0000	1.0021	1.0036
Wage Rate (index)	1.0000	1.0028	1.0083
Migration (No. of Jobs)	0	4488	8090
Industry Demand (index)			
Animal Agriculture	1.0000	0.9562	0.7959
Crop Agriculture	1.0000	0.9981	0.8943
Agriculture Services	1.0000	0.9947	1.0004
Mining	1.0000	0.9990	1.0635
Construction	1.0000	1.0012	1.0090
Prepared Meats	1.0000	0.8872	0.8833
Dairy	1.0000	0.8455	0.8795
Fruits and Vegetables	1.0000	1.1313	0.8450
Milling Products	1.0000	0.9091	0.4084
Bakery Products	1.0000	0.9661	1.0018
Misc. Food Products	1.0000	0.9456	0.8709
Vegetable and Animal Oil	1.0000	0.8257	0.6738
Beverages	1.0000	1.1416	1.3197
Textile	1.0000	1.0119	1.0421
Wood and Paper Products	1.0000	0.9780	0.9051
Printing and Publishing	1.0000	0.9870	0.8894
Chemical Petroleum	1.0000	1.0120	1.0095
Other Manufacturing	1.0000	0.9969	1.0005
Transportation	1.0000	1.0028	0.9881
Communication	1.0000	1.0057	1.0179
Energy	1.0000	1.0089	1.0145
Wholesale Trade	1.0000	1.0035	0.9901
Retail Trade	1.0000	1.0068	1.0189
Hotels	1.0000	1.0064	1.0110
Finance	1.0000	1.0044	1.0111
Insurance	1.0000	1.0063	1.0006
Real Estate	1.0000	1.0038	1.0163
Business Services	1.0000	1.0032	1.0021
Health Services	1.0000	1.0062	1.0174
Misc. Services	1.0000	1.0028	1.0106
Capital			
Capital Demand (index)	1.0000	1.0000	1.0064
Capital Rent (index)	1.0000	1.0045	1.0070
Capital Migration			
Rents ($)	NA	0.0	-124484
Flows ($)	NA	0.0	123619

TABLE 4 (Continued)

Items	Base	Short Run	Long Run
Industry Rents (index			
Animal Agriculture	1.0000	0.9589	1.0070
Crop Agriculture	1.0000	1.0009	1.0070
Agricultural Services	1.0000	0.9975	1.0070
Mining	1.0000	1.0018	1.0070
Construction	1.0000	1.0040	1.0070
Prepared Meats	1.0000	0.8897	1.0070
Dairy	1.0000	0.8478	1.0070
Fruits and Vegetables	1.0000	1.1345	1.0070
Milling Products	1.0000	0.9116	1.0070
Bakery Products	1.0000	0.9688	1.0070
Misc. Food Products	1.0000	0.9483	1.0070
Vegetable and Animal Oil	1.0000	0.8280	1.0070
Beverages	1.0000	1.1448	1.0070
Textile	1.0000	1.0148	1.0070
Wood and Paper Products	1.0000	0.9808	1.0070
Printing and Publishing	1.0000	0.9898	1.0070
Chemical Petroleum	1.0000	1.0148	1.0070
Other Manufacturing	1.0000	0.9997	1.0070
Transportation	1.0000	1.0056	1.0070
Communications	1.0000	1.0086	1.0070
Energy	1.0000	1.0117	1.0070
Wholesale Trade	1.0000	1.0063	1.0070
Retail Trade	1.0000	1.0097	1.0070
Hotels	1.0000	1.0092	1.0070
Finance	1.0000	1.0072	1.0070
Insurance	1.0000	1.0091	1.0070
Real Estate	1.0000	1.0066	1.0070
Business Services	1.0000	1.0060	1.0070
Health Services	1.0000	1.0090	1.0070
Misc. Services	1.0000	1.0056	1.0070
Land			
Land Demand (index)	1.0000	1.0000	1.0000
Land Rents (index)			
Animal Agriculture	1.0000	0.9589	0.7999
Crop Agriculture	1.0000	1.0009	0.8989
Agricultural Services	1.0000	0.9975	1.0055

Capital rent in the vegetable and animal oil sector decreased by the highest percentage (17 percent). Capital rents increased for all non-food sectors except animal agriculture, agricultural services, wood and paper products, printing and publishing, and other manufacturing. Land demand was assumed fixed for all scenarios. Rental price of land for animal agriculture decreased both in the short run and long run. The decrease in land rent is higher in the long run than in the short run. Rental price of land for crop agriculture increased in the short run and decreased in the long run.

Welfare Impacts of Increased Efficiency in Food Processing

Impacts of increased efficiency in food processing sectors are discussed in terms of how it affects the welfare of the impact region and of the original households remaining in the region.

Region. Gross state product (GSP), which is the sum of factor income and indirect business taxes, increased by $259,776,000 in the short run and by $399,551,000 in the long run (Table 5). The increase in GSP is higher in the long run than in the short run due to the higher wage rate, plus labor and capital in-migration in the long run. In the short run, value-added by industry increased for all food processing sectors except vegetable and animal oil. In the long run, however, value-added by industry decreased for all food processing sectors except beverages and bakery products. Aggregate value-added increased both in the short run and long run.

Households. Compensating variation for households is computed to assess the impact of simultaneous changes in prices and incomes on household welfare. Households staying in the region had a welfare gain equal to $179,443,000 and $470,948,000 for the short run and long run, respectively. The medium income household group had the largest gain both in the short run and long run followed by the high income group.

In the short run, each household group in the region showed an increase in household income with the medium income class showing the largest increase in absolute value both in the short run ($94,038,000) and long run ($168,441,000) followed by the high income class. These results include wage income of in-migrating labor. However, the result remains unchanged when the income of in-migrating labor is excluded. The initial households gained a total of $120,664,000 in the short run and $201,894,000 in the long run.

Comparison of income and welfare gains for each household income group at different scenarios gave different results. In the short run, the income gain is greater than the welfare gain for all household income groups. This implies that the income effect is greater than the price effect for all household groups in the short run. In the long run, however the welfare gain is greater than the income gain for all household income groups. This implies that the price effect is greater than the income effect for all household income groups.

SUMMARY AND CONCLUSION

Economic impacts of a 10 percent increase in the efficiency of food processing industries would result in short (land and capital fixed by sector and for the state and labor mobile by sector and for the state) and long run (land fixed and capital and labor mobile) effects. Short run impacts include the following. Wage rate increase of 0.28 percent and labor in-migration. Returns to capital increase of 0.45 percent. Quantity output of food processing increase of 5.6 percent and overall quantity output increase of 0.32 percent. Gross state product, employment and household income increases of 0.41 percent, 0.17 percent and 0.37 percent, respectively.

TABLE 5

WELFARE IMPACTS OF INCREASED EFFICIENCY (10%), 1993.

	Base	Short Run	Long Run
Impact Region			
Gross Regional Product			
Index	1.0000	1.0041	1.0064
Change ($1000)	NA	259776	399551
Industry Value-Added (index)			
Animal Agriculture	1.0000	0.9893	0.8757
Crop Agriculture	1.0000	0.9985	0.9358
Agricultural Services	1.0000	0.9985	0.9996
Mining	1.0000	0.9997	1.0621
Construction	1.0000	1.0007	1.0083
Prepared Meats	1.0000	1.0087	0.9711
Dairy	1.0000	1.0073	0.9665
Fruits and vegetables	1.0000	1.1650	0.9286
Milling Products	1.0000	1.0322	0.4490
Bakery Products	1.0000	1.0824	1.1008
Misc. Food Products	1.0000	1.0717	0.9570
Vegetable and Animal Oil	1.0000	0.9844	0.7406
Beverages	1.0000	1.1767	1.4503
Textile	1.0000	1.0086	1.0415
Wood and Paper Products	1.0000	0.9889	0.9042
Printing and Publishing	1.0000	0.9915	0.8888
Chemical Petroleum	1.0000	1.0067	1.0087
Other Manufacturing	1.0000	0.9978	1.0000
Transportation	1.0000	1.0021	0.9876
Communications	1.0000	1.0032	1.0170
Energy	1.0000	1.0035	1.0134
Wholesale Trade	1.0000	1.0028	0.9897
Retail Trade	1.0000	1.0052	1.0184
Hotels	1.0000	1.0051	1.0106
Finance	1.0000	1.0032	1.0106
Insurance	1.0000	1.0044	1.0000
Real Estate	1.0000	1.0002	1.0145
Business Services	1.0000	1.0021	1.0015
Health Services	1.0000	1.0050	1.0171
Misc. Services	1.0000	1.0022	1.0102
Total	1.0000	1.0029	1.0061
Households			
Change in Welfare ($1000)			
Low Income	0	27009	69610
Medium Income	0	89749	236929
High Income	0	62685	164409
Total	0	179443	470948
Change in Household Income			
Total ($1000)			
Low Income	0	29458	55264
Medium Income	0	94038	168441
High Inocme	0	78378	124922
Total	0	201874	348627
Per household (index)			
Low Income	1.0000	1.0032	1.0060
Medium Income	1.0000	1.0038	1.0069
High Income	1.0000	1.0039	1.0062
Total	1.0000	1.0037	1.0065

Long run results include the following. Wage rate increase of 0.83 percent and more labor in-migration. Returns to all capital increase of 0.70 percent and capital in-migration. Food processing quantity output decrease of 5.8 percent. Overall quantity output increase of 0.31 percent. Gross state product and employment increases of 0.64 percent and 0.29 percent, respectively. Household income increase of 0.65 percent with low income households showing the lowest percent increase and middle income households showing the highest percent increase. Household welfare increase of $470,948,000 with low income households showing the lowest increase and middle income households showing the highest increase in absolute value.

The target group for this research is the FAPRT Center staff and state policy makers responsible for investments in food processing research and development. FAPRT staff may identify which of the food processing sub-industries has the greatest potential for increased efficiency and which has the greatest potential for contributing to the state economic development objectives. The food processing industry and ultimately the state of Oklahoma will benefit from development of this sector. The ultimate impacts are the changes in all factor and product markets with increases in the efficiency of food processing in Oklahoma. Owners of resources (labor and capital) used in the food processing and associated industries will benefit the greatest.

REFERENCES

Amera, Aleligne and Dean F. Schreiner. *Regional General Equilibrium Analysis of Reduced Trip Demand at Lake Texoma.* Research Bulletin B-811. Agricultural Experiment Station, Division of Agricultural Sciences and Natural Resources, Oklahoma State University, Stillwater, Oklahoma. 1998.

Ballard, C. L., D. Fullerton, J. B. Shoven and J. Whalley. A General Equilibrium Model for Tax Policy Evaluation. University of Chicago Press for the National Bureau of Economic Research, Chicago. 1966.

Budiyanti, Rini. *Application of General Equilibrium Modeling for Measuring Regional Economic and Welfare Impacts of Quality Changes in Sport Fishing in Oklahoma.* Unpublished Ph.D. Dissertation, Oklahoma State University, Stillwater, Oklahoma. 1996.

Ferguson, C. F. *Microeocnomic Theory.* Richard D. Irwin, Inc., Homewood, Illinois. 1966.

Koh, Y. K. *Analysis of Oklahoma's Boom and Bust Economy by Means of a CGE Model.* Unpublished Ph.D. Dissertation, Oklahoma State University, Stillwater, Oklahoma. 1991.

Koh, Young-Kon, Dean F. Schreiner, and Huijune Shin. "Comparisons of Regional Fixed Price and General Equilibrium Models." *Regional Science Perspectives*, Vol. 23, No. 1(1993):33-80.

Lee, H. S. *Welfare Measures of Rural Development: Regional General Equilibrium Analysis Including Non-Market Goods.* Unpublished Ph.D. Dissertation, Oklahoma State University.

Schreiner, D. F., H. S. Lee, Y. K. Koh, and R. Budiyanti. "Rural Development: Towards an Integrative Policy Framework." *The Journal of Regional Analysis and Policy*, vol. 26, No. 2(1996):53-72.

Tilley, D. S. and S. E. Gilliland. *Business Plan for the Food and Agricultural Products Research and Technology Center at Oklahoma State University.* Division of Agricultural Sciences and Natural Resources, Oklahoma State University, Stillwater, Oklahoma. 1996.

U.S. Department of Commerce. *Regional Multipliers: A User Handbook for the Regional Input-Output Modeling System (RIMS II).* Second Edition. U.S. Department of Commerce, Washington, D.C. 1992.

Chapter VI

OVERALL SUMMARY AND CONCLUSIONS

OVERALL SUMMARY AND CONCLUSIONS

The food and kindred products manufacturing (SIC code 20) sector (aka food processing) accounts for about 14 percent of total value of output in manufacturing and two percent of gross domestic product (GDP) of the United States. Compared to research on agricultural productivity, there is relatively little research on measuring technological change in the food processing industry. The available studies focus on labor and total factor productivity and on structural changes in the food-processing sector.

In Paper I of this dissertation, a time series approach was followed in understanding technological change in U.S. food processing during the 1958-94 period. The model allows for factor bias over the sample period by modifying the augmentation procedures recently employed by Lambert and Shonkwiler to assess the contribution of research and development expenditures of food processing and spillovers from crop and animal agriculture sectors to changes in factor quality.

Previous authors have shown that modeling technical change as a deterministic time trend is a restrictive representation that may be inconsistent with the type of non-stationarity of other model variables. Total factor productivity indices calculated from market prices overestimate technical change in good times and underestimate it when times are bad. A state-space estimation technique was used to generate the unobserved state of technology variables. Research and development (R&D) expenditure is used as an imperfect indicator of the unobserved technical change. The R&D spillover effects from agriculture to food processing were modeled in a three-sector stochastic trend model.

The objectives of Paper I were to: (1) determine the behavior and contribution of productivity indices for four classes of food-processing inputs (production labor, non-production labor, equipment capital, and material inputs) to total factor productivity; (2) determine the contribution of technical change to factor bias; and (3) determine empirical research and development spillovers from crop and animal agriculture to food processing.

In Paper II, the cost function method was used to evaluate the effects of own R&D stock and spillovers from agriculture on factor substitution and returns to scale. The purpose of this paper was to complement Paper I by computing returns to research and development and determine the effect of R&D spillovers from the aggregated agriculture sector to food processing. The specific objectives of Paper II were to: (1) measure returns to research and development spending in food processing; (2) determine the existence of non-constant returns to scale in food processing; and (3) determine empirical research and development spillovers from the aggregated agriculture sector to food processing.

The results of the two studies were consistent despite some differences in methods used. These differences were:

(1) Adjustment for factor quality differences over time was made in Paper I through factor augmentation hypothesis but not in Paper II.

(2) In Paper II, stocks of research and development capital in food processing and agriculture were directly used as explanatory variables to facilitate computation of returns to R&D. In Paper I, R&D expenditures were used in a stochastic model to generate the unobserved state of technology variables.

(3) Paper I was a four-factor variable cost function model in which labor was disaggregated into production and non-production labor. Paper II was a three-factor variable cost function model (labor was aggregated).

(4) Paper I considered R&D spillovers from crop and animal agriculture to food processing whereas Paper II considered spillovers from the aggregated agriculture to food processing.

Oklahoma has invested in a Food and Agricultural Products Research and Technology (FAPRT) Center for purposes of expanding the potential development of this sector. The food and kindred products sector accounts for about 10 percent of value added and 8.5 percent of wage payments for total manufacturing in Oklahoma. The objective of Paper III was to evaluate the state economic development impacts of increased efficiency in the food processing industries. The procedure of analysis included the following: (1) a social accounting matrix (SAM) was estimated for the impact region using the IMPLAN Database and other data sources; (2) a regional computable general equilibrium (CGE) model was specified and calibrated; and (3) a ten percent increase in the efficiency of food processing was simulated. The method allowed commodity and factor markets to endogenously determine prices, quantities, and incomes and provided empirical estimates to quantitatively show the potential impacts of the FAPRT Center on measures of economic development in the state.

The National Bureau of Economic Research (NBER) Manufacturing Productivity (MP) database contains annual information on 450 manufacturing industries from 1958 to 1994. The industries are redefined in the 1987 Standard Industrial Classification, and cover the entire manufacturing sector. Data series on research and development expenditure in the food and kindred products sector were available from National Science Foundation' (NSF') Research and Development in Industry (various issues). Research and development expenditures on agriculture were obtained for the period 1958 to 1990 from Huffman and Evenson (1991). For the period 1991 to 1994, R & D on agriculture were obtained from the U.S. Department of Agriculture's Inventory of Agricultural Research (various issues). The stocks of R&D capital for food processing and the aggregated agriculture sectors were derived using the perpetual inventory method.

The state development impact analysis was based on the 1993 IMPLAN Database. The IMPLAN 528 sectors were aggregated into 30 industries corresponding to the 1987 Standard Industrial Classification (SIC) code and following Regional Input-Output Modeling Systems (RIMS) II (USDC, 1992). Eight of the thirty sectors were the three-digit food and kindred products sectors.

Major conclusions of the study may be stated as the following:

(1) Total factor productivity of aggregated food processing sector grew by 35 percent from 1958 to 1994 period (about 1 percent per annum). Equipment capital productivity growth alone contributed 69 percent of the 35 percent growth in total factor productivity. Material and production labor productivity growth contributed 19 percent and 10 percent of the TFP growth, respectively.

(2) Technological change in U.S. food processing has been labor and capital neutral and material saving. Labor and material saving and capital using technological spillovers from crop agriculture to food processing have occurred over time. Technological spillovers from animal agriculture to food processing

have a neutralizing effect, i.e., labor and material using and capital saving. Spillovers from the aggregated agriculture to food processing have been labor and capital using and material saving.

(3) The Allen partial elasticities of substitution indicate that there is a significant substitutability between materials and equipment capital; between production labor and materials; between materials and non-production labor; and between production labor and non-production labor. The elasticity of substitution between equipment capital and production labor was not conclusive.

(4) A one percent increase in own stock of R&D capital caused variable cost in food processing to decline by 0.14 percent from 1958 to 1994. This decline came from material saving technologies.

(5) The private rate of return to R&D capital in food processing was 11.6 percent over the sample period. A one percent increase in the spillovers caused variable cost in food processing to decline by 0.11 percent.

(6) There was a 9 percent cost savings from scale economies over the 1958 to 1994 period. However, there is insufficient evidence to reject the null hypothesis of constant returns to scale at the five percent level.

(7) Economic impacts of a 10 percent increase in the efficiency of food processing industries would result in short (land and capital fixed by sector and for the state and labor mobile by sector and for the state) and long run (land fixed and capital and labor mobile) effects. Short run impacts include the following. Wage rate increase of 0.28 percent and labor in-migration. Returns to capital increase of 0.45 percent. Quantity output of food processing increase of 5.6

percent and overall quantity output increase of 0.32 percent. Gross state product, employment and household income increases of 0.41 percent, 0.17 percent and 0.37 percent, respectively.

(8) Long run results include the following. Wage rate increase of 0.83 percent and more labor in-migration. Returns to all capital increase of 0.70 percent and capital in-migration. Food processing quantity output decrease of 5.8 percent. Overall quantity output increase of 0.31 percent. Gross state product and employment increases of 0.64 percent and 0.29 percent, respectively. Household income increase of 0.65 percent with low income households showing the lowest percent increase and middle income households showing the highest percent increase. Household welfare increase of $470,948,000 with low income households showing the lowest increase and middle income households showing the highest increase in absolute value.

(9) The target group for this research is the FAPRT Center staff and state policy makers responsible for investments in food processing research and development. FAPRT staff may identify which of the food processing sub-industries has the greatest potential for increased efficiency and which has the greatest potential for contributing to the state economic development objectives. The food processing industry and ultimately the state of Oklahoma will benefit from development of this sector. The ultimate impacts are the changes in all factor and product markets with increases in the efficiency of food processing in Oklahoma. Owners of resources (labor and capital) used in the food processing and associated industries will benefit the greatest.

Limitations of the Study

Like any economic study at the national level, this study also suffers the criticism of too much aggregation. Productivity studies are best presented at the firm level. However, research and development expenditure data are not readily available even at the three-digit SIC Code.

In Paper I of this dissertation, the procedure of factor augmentation was extended to capture the impacts of spillovers on factor quality changes. The augmented values were assumed to have Cobb-Douglas type of functional form. This functional form was chosen solely on the merits of computational ease.

In determining the impact of spillovers on factor bias, it would have been better to estimate share equations of all sectors involved simultaneously. However, the number of parameters would be too many to be estimated from the available annual data.

The CGE model was based on the assumption that no substitution between composite intermediate inputs and composite primary factors or between intermediate inputs produced by different sectors. Papers I and II rejected this assumption. However, at this point in time we do not have substitution elasticities between composite intermediate inputs and primary factors by sector and region.

References

Adelaja, A. O. "Material Productivity in Food Manufacturing." *Amer. J. Agr. Econ.* 74(January, 1992):177-185

Adelaja, A. O. "Productivity Growth and Input Mix Changes in Food Processing." *Northeastern Journal Of Agricultural and Resource Economics.* 74(April, 1992):21-29.

Amera, Aleligne and Dean F. Schreiner. *Regional General Equilibrium Analysis of Reduced Trip Demand at Lake Texoma.* Research Bulletin B-811. Agricultural Experiment Station, Division of Agricultural Sciences and Natural Resources, Oklahoma State University, Stillwater, Oklahoma. 1998.

Anderson, B. D. O. and J. B. Moore. *Optimal Filtering.* New Jersey: Prentice-Hall, Englewood Cliffs. 1979.

Ballard, C. L., D. Fullerton, J. B. Shoven and J. Whalley. *A General Equilibrium Model for Tax Policy Evaluation.* University of Chicago Press for the National Bureau of Economic Research, Chicago. 1966.

Bartelsman, E. J., and Phoebus J. Dhrymes. *Productivity Dynamics: U.S. Manufacturing Plants, 1972-1986.* Finance and Economics Discussion Series (January, 1994). Division of Research & Statistics and Monetary Affairs, Federal Reserve Board, Washington, D.C.

Bartelsman, E., and W. Gray. Manufacturing productivity Database. National Bureau of Economic Research (electronic form), Cambridge MA, 1997.

Bernstein, J. I. and M. I. Nadiri. "Interindustry R&D Spillovers, Rates of Return and Production in High-Tech Industries." *Amer. J. Agr. Econ.* 78(May, 1988):429-434.

Binswanger, H. P. "The Measurement of Technical Change Biases with Many Factors of Production." *American Economic Review.* 64(1974)65-78.

Brown, R., D. Caves, and L. Christensen. "Modeling the Structure of Cost and Production for Multiproduct Firms." *Southern Economic Journal.* 46(1979):265-272.

Budiyanti, Rini. *Application of General Equilibrium Modeling for Measuring Regional Economic and Welfare Impacts of Quality Changes in Sport Fishing in Oklahoma.* Unpublished Ph.D. Dissertation, Oklahoma State University, Stillwater, Oklahoma. 1996.

Christensen, L. R., D. W. Jorgenson, and L. J. Lau. "Conjugate Duality and the Transcedental Logarithmic Production Function." *Econometrica* 39(1971)255-256.

Clark, J. S. , and C. E. Youngblood. "Estimating Duality Models with Biased Technical Change: A Time Series Approach." *Amer. J. Agr. Econ.* 74(May, 1992):353-60.

Durlauf, S. N., and P. C. B. Phillips. "Trends versus Random Walks in Time Series Analysis." *Econometrica* 56(November, 1988):1333-54.

Ferguson, C. F. *Microeocnomic Theory*. Richard D. Irwin, Inc., Homewood, Illinois. 1966.

Fulginiti, L. E., and R. K. Perrin. "Argentine Agricultural Policy in a Multiple-Input, Multiple-Output Framework." *Amer. J. Agr. Econ.* 72(1990):279-88.

Gollop, F., and Dale W. Jorgensen. "U.S. Productivity Growth by Industry, 1947-73." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Gopinath, M. and T. L. Roe. *R&D Spillovers: Evidence from U.S. Food Processing, Farm Machinery and Agriculture*. Economic Development Center, Bulletin 96-2 (October, 1996). Department of Economics, Minneapolis and Department of Applied Economics, St. Paul, University of Minnesota.

Gopinath, M., T. Roe, and M. D. Shane. "Competitiveness of U.S. Food Processing: Benefits from Primary Agriculture." *Amer. J. Agr. Econ.* 78(1996):1044-11055.

Griliches, Zvi. "Returns to Research and Development Expenditures in the Private Sector." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Guilkey, D., C. A. K. Lovell, and R. C. Sickles. "A Comparison of the Performance of Three Flexible Functional Forms." *International Economic Review* 24(October, 1983):591-616.

Hamilton, J. D. *Time Series Analysis*. New Jersey: Princeton University Press. 1994.

Harvey, A. C. *Forecasting, Structural Time Series Models and the Kalman Filter.* New York: Cambridge University Press, 1989.

Harvey, A. C., and P. Marshall. "Inter-fuel Substitution, Technical Change and the demand for Energy in the UK Economy." *Applied Economics* 23(June, 1991):1077-86.

Huffman, W. E., and R. Evenson. *Science for Agriculture*. Ames, IA: Iowa State University Press, 1993.

Jang, S. L., and J. R. Norsworthy. "Measurement Methods for Technological Change Embodied in Inputs." *Economic Letters* 32(April, 1990):325-30.

Jankowski, J. E. (Jr). "Do We Need a Index for Industrial R&D?" *Research Policy* 22(1993): 195-205.

Jones, C. I., and J. C. Williams. *Measuring the Social Return to R&D.* Finance and Economics Discussion Series (January, 1997). Division of Research & Statistics and Monetary Affairs, Federal Reserve Board, Washington, D.C.

Jorgensen, D. W., F. Gollop, and B. Fraumeni. *Productivity and U.S. Economic Growth.* Cambridge MA: Harvard University Press, 1987.

Kamin, M. I., and N. L. Schwartz. "Market Structure and Innovation: A Survey." *Journal of Economic Literature* 13(1975): 242-263.

Klotz, B., R. Madoo, and R. Hanson. "A Study of High and Low " Labor Productivity" Establishments in U.S. Manufacturing." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Koh, Y. K. *Analysis of Oklahoma's Boom and Bust Economy by Means of a CGE Model.* Unpublished Ph.D. Dissertation, Oklahoma State University, Stillwater, Oklahoma. 1991.

Koh, Young-Kon, Dean F. Schreiner, and Huijune Shin. "Comparisons of Regional Fixed Price and General Equilibrium Models." *Regional Science Perspectives*, Vol. 23, No. 1(1993):33-80.

Lambert, D. K., and J. S. Shonkwiler. "Factor Bias Under Stochastic Technical Change." *Amer. J. Agr. Econ.* 77(August, 1995):578-590.

Lee, H. S. *Welfare Measures of Rural Development: Regional General Equilibrium Analysis Including Non-Market Goods.* Unpublished Ph.D. Dissertation, Oklahoma State University.

Lopez, Ramon E. "The Structure of Production and the Derived Demand for Inputs in Canadian Agriculture." *Amer. J. Agr. Econ.* 62(February, 1980):38-45.

Mairesse, Jacques and Bronwyn H. Hall. *Estimating the Productivity of Research and Development: An Exploration of GMM Methods Using the Data on French and United States Manufacturing Firms.* National Bureau of Economic Research, Inc. Working Paper 5501 (March, 1996). Cambridge, MA.

Mansfield, E. "Contribution of R&D to Economic Growth in the U.S." *Science* 19(1972): 477-486.

Mohr, M. F. "The Long-Term Structure of Production, Factor Demand, and Factor Productivity in U.S. Manufacturing Industries." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Morrison, Catherine J. "Structural Change, Capital Investment and Productivity in the Food Processing Industry." *Amer. J. Agr. Econ.* 79(1997):110-125.

Morrison, C. J. and D. Siegel. "Knowledge Capital and Cost Structure in the U.S. Food and Fiber Industries." *Amer. J. Agr. Econ.* 80(1998):30-45.

Nadiri, I. "Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey." *Journal of Economic Literature*, 8(1970):1137-1177.

National Science Foundation. Various years. *Research and Development Expenditures in Industry.* Washington, DC: U.S. Government Printing Office.

Nelson, C. R. , and C. H. Kang. "Pitfalls in the Use of Time as an Explanatory Variable in Regression." *J. Bus. and Economic Statistics.* 2(January, 1984):73-82.

Schreiner, D. F., H. S. Lee, Y. K. Koh, and R. Budiyanti. "Rural Development: Towards an Integrative Policy Framework." *The Journal of Regional Analysis and Policy*, vol. 26, No. 2(1996):53-72.

Shonkwiler, J. S., and H. A. Stranahan. *Modeling Technical Change in the Frozen Concentrated Orange Juice Processing Industry.* Agricultural Experiment Stations, Bulletin 863. Institute of Food and Agricultural Sciences, University of Florida, Gainesville. 1987.

Shumway, R. C., and W. P. Alexander. "Agricultural Product Supplies and Input Demands: Regional Comparisons." *Amer. J. Agr. Econ.* 70(1988):153-61.

Slade, M. "Modeling Stochastic and Cyclical Components of Technical Change: An Application of the Kalman Filter." *Journal of Econometrics* 41(July, 1989):363-83.

Terleckyj, N. E. "Direct and Indirect Effects of Industrial Research and Development on the Productivity Growth of Industries." *New Developments in Productivity Measurement and Analysis.* Kendric and Vaccara (eds.). National Bureau of Economic Research. 1980.

Tilley, D. S. and S. E. Gilliland. *Business Plan for the Food and Agricultural Products Research and Technology Center at Oklahoma State University.* Division of Agricultural Sciences and Natural Resources, Oklahoma State University, Stillwater, Oklahoma. 1996.

U.S. Department of Agriculture. 1991–1994. *Inventory of Agricultural Research.* U.S. Department of Agriculture, Cooperative States Research Service.

U.S. Department of Commerce. *Regional Multipliers: A User Handbook for the Regional Input-Output Modeling System (RIMS II).* Second Edition. U.S. Department of Commerce, Washington, D.C. 1992.

U.S. Department of Labor, Bureau of Labor Statistics. *Trends in Multifactor Productivity, 1948–81.* Bulletin 2178. Washington, Government Printing Office, September, 1983.

APPENDIX

APPENDIX I

APPENDIX I

TIME SERIES DATA

Variable Descriptions and Comments

The following data set is primarily from NBER Manufacturing Productivity Database translated to 1987 SIC (Statndard Industrial Classification) code and aggregated over subsectors.

EMP - number of employees (in 1,000s). This includes both production and non-production workers.

PAY - total payroll (millions of dollars). This does not include social security or other legally mandated payments, or employer payments for some fringe benefits.

PRODE - number of production workers (in 1,000s). This excludes supervisors above the line-supervisor level, clerical, sales, office, professional, and technical workers.

PRODH - number of production worker hours (in millions of hours). This includes all hours worked or paid for, including actual overtime hours, but excluding vacation, holidays, or sick leave.

PRODW - production worker wages (millions of dollars).

MATCOST - cost of materials (millions of dollars). This includes the total delivered cost of raw materials, parts, and supplies put into production or used for repair and maintenance, along with purchased electric energy and fuels consumed for heat and power, and contract work done by others for the plant. This excludes the costs of services used, overhead costs, or expenditures related to plant expansion. Because MATCOST includes energy spending, to calculate spending on non-energy materials one must use (MAT - ENERGY).

ENERGY - expenditures on purchased fuels and electrical energy (millions of dollars).

VSHIP - value of industry shipments (millions of dollars). These are based on net selling values, f.o.b. plant, after discounts and allowances. This includes receipts for contract work and miscellaneous services provided by the plant to others.

CAP - real capital stock (millions of 1987 dollars). This equals (EQUIP + PLANT).

EQUIP - real equipment capital stock (millions of 1987 dollars).

PLANT - real structures capital stock (millions of 1987 dollars).

PISHIP - price deflator for value of shipments (equals one in 1987).

PIMAT - price deflator for materials (equals one in 1987).

MATCOST, this is a deflator for all materials, including energy.

PIINV - price deflator for new investment (one in 1987). This combines separate deflators for structures and equipment, based on the distribution of each type of asset in the industry.

PILAB - price deflator for labor (one in 1987).

R&D Expenditures for food processing, crop and animal agriculture are in millions of 1987 dollars.

Rental price of capital in 1987 dollars.

YEAR	EMP	PAY	PRODE	PRODH	PRODW	MATCOST	ENERGY
58	1717	7620	1152	2315	4547	42160	516
59	1729	8074	1161	2361	4739	43362	536
60	1733	8296	1163	2365	4897	44156	554
61	1716	8452	1148	2336	4980	45805	575
62	1697	8683	1128	2302	5108	47456	595
63	1644	8637	1098	2228	5169	46785	593
64	1646	9028	1095	2270	5367	48675	626
65	1641	9162	1096	2233	5446	50805	661
66	1639	9528	1097	2237	5669	55000	696
67	1652	10077	1121	2259	6061	57500	732
68	1632	10497	1114	2233	6390	59307	768
69	1652	11135	1132	2265	6782	63608	806
70	1619	11698	1105	2216	7095	66456	845
71	1574	12180	1073	2145	7438	69777	885
72	1569	12922	1085	2167	8008	79800	968
73	1560	13670	1081	2158	8470	97430	1091
74	1550	14764	1074	2125	9190	118225	1448
75	1524	15842	1055	2068	9838	123726	1858
76	1534	17269	1066	2103	10802	128565	2160
77	1520	18544	1072	2112	11731	136976	2541
78	1547	20308	1097	2158	12864	153965	2870
79	1552	21678	1102	2178	13838	167981	3201
80	1539	23249	1091	2155	14814	181394	3880
81	1511	24696	1069	2115	15707	191595	4421
82	1494	26139	1048	2034	16436	192217	5030
83	1446	26603	1013	1991	16638	193904	5219
84	1438	27350	1010	1977	17061	202075	5392
85	1422	28077	994	1941	17428	197274	5229
86	1409	28567	989	1932	17789	196443	4883
87	1448	30245	1029	2019	18897	208722	4671
88	1465	31420	1046	2061	19622	223674	4750
89	1459	32108	1049	2079	20128	232986	4863
90	1470	33470	1061	2139	21013	243692	4938
91	1475	34578	1070	2155	21764	242481	5013
92	1505	36777	1101	2245	23362	250248	5290
93	1520	37707	1118	2277	24079	257258	5502
94	1512	38492	1111	2299	24694	259262	5591

YEAR	VSHIP	CAP	EQUIP	R & D PLANT	R & D Food Proc.	R & D Crop Agr.
58	59737	58088	25950	32138	445	1033
59	62382	60689	28001	32688	462	995
60	64244	62307	29367	32941	543	1035
61	66431	63677	30520	33156	569	1040
62	68947	66188	31955	34232	535	1067
63	68467	67075	32543	34532	532	1112
64	71594	69503	34063	35440	562	1157
65	74248	71817	35691	36126	554	1230
66	79659	74545	37671	36874	574	1266
67	83960	77152	39412	37740	603	1298
68	87327	79512	40866	38646	581	1195
69	93380	81922	42235	39686	589	1292
70	98533	84647	43756	40890	662	1337
71	103631	86957	45321	41637	638	1386
72	115060	89227	47028	42199	654	1465
73	135583	91328	48809	42518	624	1511
74	161882	93962	50821	43141	643	1501
75	172039	96348	52881	43466	664	1528
76	180824	98967	54832	44135	665	1708
77	192912	101544	56798	44746	736	1770
78	215989	104052	58785	45267	766	1854
79	235975	106182	60549	45633	789	1860
80	256188	108282	62130	46153	833	1984
81	272140	109762	63353	46409	797	2007
82	280530	111641	64874	46767	912	2045
83	287158	112087	65333	46754	926	2017
84	300012	112927	66175	46752	1170	2037
85	301562	114230	67452	46778	1205	2101
86	308523	114996	68331	46665	1321	2147
87	329587	116669	69957	46711	1206	2189
88	351515	118149	71395	46754	1148	2335
89	364403	120077	73091	46985	1162	2302
90	384009	122040	74829	47211	1111	2356
91	387601	124075	76647	47428	1085	2399
92	407157	126331	78699	47631	1123	2444
93	422220	127779	80135	47644	1039	2491
94	430994	129543	81863	47681	1088	2538

YEAR	R & D Animal Agr.	PIMAT	PISHIP	PINV	PILAB	Rental Price of Capital	R&D Deflator (Food Proc.)
58	665	0.3414	0.3749	0.2500	0.2596	0.7077	0.1867
59	639	0.3336	0.3639	0.2535	0.2623	0.7221	0.1971
60	666	0.3337	0.3614	0.2576	0.2666	0.7178	0.2080
61	667	0.3361	0.3662	0.2574	0.2687	0.7240	0.2195
62	685	0.3439	0.3681	0.2601	0.2724	0.7181	0.2317
63	714	0.3438	0.3686	0.2648	0.2755	0.7182	0.2445
64	745	0.3397	0.3668	0.2695	0.2793	0.7206	0.2581
65	795	0.3560	0.3798	0.2738	0.2843	0.7251	0.2724
66	820	0.3808	0.4038	0.2828	0.2906	0.7595	0.2875
67	842	0.3708	0.3944	0.2951	0.2999	0.7840	0.3034
68	774	0.3779	0.4008	0.3082	0.3124	0.8284	0.3203
69	836	0.4031	0.4209	0.3232	0.3289	0.9060	0.3380
70	857	0.4154	0.4377	0.3408	0.3465	0.9466	0.3568
71	883	0.4220	0.4461	0.3604	0.3634	0.9711	0.3762
72	937	0.4696	0.4710	0.3739	0.3754	1.0140	0.3963
73	967	0.5988	0.6070	0.3867	0.3979	1.0741	0.4311
74	963	0.7283	0.6959	0.4299	0.4405	1.2539	0.4632
75	980	0.7305	0.7164	0.4965	0.4852	1.3410	0.5047
76	1101	0.6908	0.6883	0.5305	0.5106	1.4225	0.5335
77	1145	0.7068	0.7277	0.5768	0.5448	1.5228	0.5636
78	1199	0.7825	0.7838	0.6248	0.5831	1.6620	0.6158
79	1206	0.8865	0.8582	0.6844	0.6503	1.8475	0.6693
80	1287	0.9478	0.9130	0.7576	0.7387	2.1212	0.7443
81	1303	0.9826	0.9479	0.8309	0.8128	2.2657	0.8052
82	1321	0.9789	0.9404	0.8725	0.8623	2.6300	0.8521
83	1306	1.0021	0.9641	0.8928	0.8881	2.4653	0.8896
84	1321	1.0465	0.9978	0.9066	0.9212	2.6312	0.9237
85	1365	0.9835	0.9675	0.9176	0.9500	2.8683	0.9424
86	1398	0.9717	0.9820	0.9613	0.9666	2.9016	0.9692
87	1430	1.0000	1.0000	1.0000	1.0000	2.9053	1.0000
88	1521	1.0913	1.0465	1.0418	1.0390	2.9631	1.0214
89	1507	1.1200	1.0987	1.0711	1.0894	3.4015	1.0709
90	1545	1.1332	1.1336	1.1099	1.1468	3.0823	1.1228
91	1576	1.1130	1.1310	1.1391	1.1949	3.0737	1.1773
92	1607	1.1092	1.1356	1.1557	1.2268	3.1211	1.2343
93	1639	1.1284	1.1551	1.1732	1.2635	3.1753	1.2942
94	1672	1.1336	1.1721	1.1978	1.2959	3.2435	1.3569

APPENDIX II

APPENDIX II

OKLAHOMA'S SOCIAL ACCOUNTING MATRIX (SAM) 1993 ($1,000)

Row	Column	(1) Animal Agriculture	(2) Crop Agriculture	(3) Agricultural Services	(4) Mining	(5) Construction	
	COMMODITIES						
1)	Animal Agriculture	248089	10477	5815	1	0	
2)	Crop Agriculture	294328	12116	2663	0	0	
3)	Agricultural Services	47951	28607	25753	21	45645	
4)	Mining	32	680	30	171910	79909	
5)	Construction	46063	24148	12219	1059655	48089	
6)	Prepared Meats	2453	0	1904	13	0	
7)	Dairy	491	0	4	0	0	
8)	Mining	32	680	30	171910	79909	
9)	Construction	46063	24148	12219	1059655	48089	
10)	Prepared Meats	2453	0	1904	13	0	
11)	Dairy	491	0	4	0	0	
12)	Fruits and vegetables	0	0	0	0	0	
13)	Milling Products	20241	0	405	0	0	
14)	Bakery Products	0	0	0	0	0	
15)	Misc. Food Products	696	0	130	2	0	
16)	Vege. and Animal Oil	21186	0	176	5	0	
17)	Beverages	35	0	0	1	1	
18)	Textile	237	572	372	105	10422	
19)	Wood and Paper Prod.	1057	3418	171	699	152105	
20)	Printing and Publishing	118	42	200	393	2016	
21)	Chemical Petroleum	27735	74074	20919	42869	360127	
22)	Other Manufacturing	11901	8972	2458	20661	542241	
23)	Transportation	47886	9785	6555	17543	312979	
24)	Communications	3588	1288	265	2288	54560	
25)	Energy	18223	8019	2165	67001	47924	
26)	Wholesale Trade	39842	12800	5735	10096	384064	
27)	Retail Trade	547	535	172	103	209126	
28)	Hotels	2155	769	3910	8718	55075	
29)	Finance	23018	8770	2259	16583	305429	
30)	Insurance	9297	12819	1490	817	53203	
31)	Real Estate	60330	48654	3759	263767	55416	
32)	Business Services	6699	4231	10504	46262	702609	
33)	Health Services	16616	0	138	0	0	
34)	Misc. Services	1698	2279	4744	36134	184259	
	Total	952513	273053	114915	1765648	3605199	
	FACTORS						
31)	Labor	164970	163475	104797	1051075	2172104	
32)	Capital	233879	211369	126112	2259476	1463870	
33)	Land	290247	262311	156507			
	Total	689096	637155	387416	3310551	3635974	
	INSTITUTIONS						
34)	Enterprises						
	Households						
35)	Low Income						
36)	Middle Income						
37)	High Income						
	Sub-Total						
	Governments						
38)	State & Local	34358	42033	2261	246448	17482	
39)	Federal	7710	9432	507	55301	3923	
	Sub-Total	42068	51465	2768	301750	21404	
	Inst. Total	42068	51465	2768	301750	21404	

Row	Column	(1) Animal Agriculture	(2) Crop Agriculture	(3) Agricultural Services	(4) Mining	(5) Construction	
40)	**CAPITAL**						
	IMPORTS						
	Animal Agriculture	22463	949	527	0	0	
	Crop Agriculture	355571	14637	3217	0	0	
	Agricultural Services	85537	51031	45939	37	81424	
	Mining	45	947	42	239538	111345	
	Construction	1021	535	271	23480	1066	
	Prepared Meats	325	0	252	2	0	
	Dairy	108	0	1	0	0	
	Fruits and vegetables	0	0	0	0	0	
	Milling Products	320964	0	6417	1	0	
	Bakery Products	0	0	0	0	0	
	Misc. Food Products	2210	0	412	5	0	
	Vege. and Animal Oil	15295	0	127	4	0	
	Beverages	356	0	3	13	6	
	Textile	526	1267	824	232	23087	
	Wood and Paper Prod.	3196	10334	518	2114	459851	
	Printing and Publishing	403	144	681	1341	6884	
	Chemical Petroleum	2444	6528	1844	3778	31737	
	Other Manufacturing	41132	31010	8497	71411	1874137	
	Transportation	20763	4243	2842	7607	135704	
	Communications	2687	964	198	1713	40858	
	Energy	1500	660	178	5514	3944	
	Wholesale Trade	11497	3694	1655	2913	110825	
	Retail Trade	31	30	10	6	11727	
	Hotels	571	204	1035	2309	14586	
	Finance	11884	4528	1166	8562	157693	
	Insurance	8637	11909	1384	759	49426	
	Real Estate	25856	20852	1611	113043	23750	
	Business Services	2552	1612	4001	17623	267654	
	Health Services	3338	0	28	0	0	
	Misc. Services	592	795	1655	12608	64290	
41)	Total	941503	166869	85337	514613	3469995	
	COLUMN TOTAL	2625180	1128543	590437	5892562	10732572	

Row	Column	(6) Prepared Meats	(7) Dairy	(8) Fruits and Vegetables	(9) Milling Products	(10) Bakery Products	(11) Misc. Food Products
	COMMODITIES						
1)	Animal Agriculture	489262	122006	6993	372	660	2920
2)	Crop Agriculture	1752	9934	12238	63739	1454	9738
3)	Agricultural Services	257	1513	752	15	6	1602
4)	Mining	40	19	45	974	14	149
5)	Construction	5186	5354	3961	6033	3480	2164
6)	Prepared Meats	137358	234	13300	10410	2751	1177
7)	Dairy	74	81437	5312	1399	1450	2228
8)	Fruits and vegetables	4	7	757	300	111	27
9)	Milling Products	110	745	312	3858	1566	232
10)	Bakery Products	2	3283	80	9	476	107
11)	Misc. Food Products	737	1976	755	1896	2088	7127
12)	Vege. and Animal Oil	249	2994	4272	41779	5295	1974
13)	Beverages	2	19	227	130	26	23
14)	Textile	5	10	19	613	7	16
15)	Wood and Paper Prod.	3231	6269	3868	6795	5330	3385
16)	Printing and Publishing	1172	792	903	420	53	541
17)	Chemical Petroleum	1403	3112	3282	26127	2047	2754
18)	Other Manufacturing	1367	3346	8343	2699	2004	2170
19)	Transportation	7434	4535	7310	22491	4016	4722
20)	Communications	600	504	337	411	511	190
21)	Energy	5836	5290	5631	9518	3668	2253
22)	Wholesale Trade	16625	10553	10294	17589	4294	4633
23)	Retail Trade	14	35	25	24	50	10
24)	Hotels	189	199	195	5339	353	238
25)	Finance	1063	2116	989	1946	1401	872
26)	Insurance	100	348	557	589	521	220
27)	Real Estate	1424	2900	1319	1257	1562	608
28)	Business Services	13686	12260	12933	23192	21812	7751
29)	Health Services	87	521	0	0	0	0
30)	Misc. Services	678	2431	1206	3129	3749	14707
	Total	689946	284742	106216	253051	70754	74539
	FACTORS						
31)	Labor	120657	50724	47763	56287	76317	34033
32)	Capital	45966	45980	54933	28016	87094	38897
33)	Land						
	Sub-Total	166623	96704	102696	84303	163411	72930
	INSTITUTIONS						
34)	Enterprises						
	Households						
35)	Low Income						
36)	Middle Income						
37)	High Income						
	Sub-Total						
	Government						
38)	State & Local	940	1517	1072	672	661	452
39)	Federal	211	340	241	151	148	101
	Sub-Total	1151	1857	1313	823	809	553
	Inst. Total	1151	1857	1313	823	809	553

Row	Column	(6) Prepared Meats	(7) Dairy	(8) Fruits and Vegetables	(9) Milling Products	(10) Bakery Products	(11) Misc. Food Products
40)	**CAPITAL**						
	IMPORTS						
	Animal Agriculture	44300	11047	633	34	60	264
	Crop Agriculture	2117	12001	14784	77002	1757	11764
	Agricultural Services	459	2700	1341	27	10	2858
	Mining	56	27	62	1357	19	208
	Construction	115	119	88	134	77	48
	Prepared Meats	18195	31	1762	1379	364	156
	Dairy	16	17859	1165	307	318	489
	Fruits and vegetables	89	146	15687	6218	2309	555
	Milling Products	1749	11810	4954	61173	24830	3678
	Bakery Products	0	411	10	1	60	13
	Misc. Food Products	2341	6275	2397	6022	6631	22636
	Vege. and Animal Oil	179	2162	3084	30162	3823	1425
	Beverages	16	195	2285	1304	263	234
	Textile	11	22	43	1357	16	35
	Wood and Paper Prod.	9769	18952	11695	20542	16115	10234
	Printing and Publishing	4001	2706	3083	1434	180	1847
	Chemical Petroleum	124	274	289	2303	180	243
	Other Manufacturing	4723	11565	28836	9329	6926	7502
	Transportation	3223	1966	3170	9752	1741	2048
	Communications	450	377	253	308	383	143
	Energy	480	435	463	783	302	185
	Wholesale Trade	4797	3045	2971	5075	1239	1337
	Retail Trade	1	2	1	1	3	1
	Hotels	50	53	52	1414	94	63
	Finance	549	1092	511	1004	723	450
	Insurance	92	324	518	547	484	204
	Real Estate	610	1243	565	539	669	261
	Business Services	4213	4670	4927	8835	8309	2953
	Health Services	18	105	0	0	0	0
	Misc. Services	237	848	421	1092	1308	5131
41)	Total	103982	112460	106049	249435	79195	76964
	COLUMN TOTAL	961703	495763	316274	587612	314170	224987

	Column	(12)	(13)	(14)	(15)	(16)	(17)
Row		Vegetable & Animal Oil	Beverages	Textile	Wood and Paper Prod	Printing & Publishing	Chemical Petroleum
	COMMODITIES						
1)	Animal Agriculture	4607	852	691	3	1	4751
2)	Crop Agriculture	58578	5647	6647	15	1	2206
3)	Agricultural Services	315	18	409	14177	21	1136
4)	Mining	270	250	759	3200	111	657550
5)	Construction	2162	13168	7233	43346	7563	189879
6)	Prepared Meats	4126	214	251	38	4	1395
7)	Dairy	192	618	0	1	0	141
8)	Fruits and vegetables	7	90	0	0	0	5
9)	Milling Products	162	1208	0	143	0	253
10)	Bakery Products	7	23	0	0	0	3
11)	Misc. Food Products	21	973	0	3	0	104
12)	Vege. and Animal Oil	50905	869	18	376	2	17265
13)	Beverages	2	5319	0	2	1	13
14)	Textile	8	7	61765	8978	270	2595
15)	Wood and Paper Prod.	1018	3271	1620	104394	21882	26932
16)	Printing and Publishing	156	1540	157	567	14014	5053
17)	Chemical Petroleum	1510	6217	61840	82462	15315	1308612
18)	Other Manufacturing	2683	30605	6101	29453	5692	65530
19)	Transportation	8378	9927	5905	44832	18016	162895
20)	Communications	259	608	603	2602	1249	9485
21)	Energy	6611	5412	8839	49207	4505	154493
22)	Wholesale Trade	11897	11486	10136	40749	8113	106478
23)	Retail Trade	11	35	41	478	125	418
24)	Hotels	250	573	668	4836	4666	8108
25)	Finance	1847	4603	3062	12509	3864	34286
26)	Insurance	496	1189	627	3947	1020	8100
27)	Real Estate	319	1121	2305	6689	6234	39928
28)	Business Services	6043	38936	15477	54887	30738	233431
29)	Health Services	0	0	0	0	0	0
30)	Misc. Services	1754	5449	6772	24933	9619	90397
	Total	164592	150227	201927	532829	153023	3131442
	FACTORS						
31)	Labor	18180	68929	139281	308006	209025	571731
32)	Capital	13172	66530	54628	305951	111814	453633
33)	Land						
	Sub-Total	31352	135459	193909	613956	320839	1025364
	INSTITUTIONS						
34)	Enterprises						
	Households						
35)	Low Income						
36)	Middle Income						
37)	High Income						
	Sub-Total						
	Governments						
38)	State & Local	572	1635	1707	8069	1748	298287
39)	Federal	128	367	383	1811	392	66934
	Sub-Total	700	2002	2090	9880	2140	365221
	Inst. Total	700	2002	2090	9880	2140	365221

Row	Column	(12) Vegetable & Animal Oil	(13) Beverages	(14) Textile	(15) Wood & Paper Prod	(16) Printing & Publishing	(17) Chemical Petroleum
40)	**CAPITAL**						
	IMPORTS						
	Animal Agriculture	417	77	63	0	0	430
	Crop Agriculture	70766	6822	8030	19	1	2665
	Agricultural Services	561	31	730	25290	38	2027
	Mining	376	349	1057	4459	155	916228
	Construction	48	292	160	960	168	4207
	Prepared Meats	547	28	33	5	0	185
	Dairy	42	135	0	0	0	31
	Fruits and vegetables	142	1868	0	4	0	112
	Milling Products	2563	19153	6	2261	3	4007
	Bakery Products	1	3	0	0	0	0
	Misc. Food Products	68	3089	0	10	0	329
	Vege. and Animal Oil	36751	627	13	272	2	12465
	Beverages	21	53478	3	22	5	127
	Textile	17	16	136817	19888	598	5749
	Wood and Paper Prod.	3078	9888	4897	315610	66154	81421
	Printing and Publishing	531	5258	538	1937	47854	17253
	Chemical Petroleum	133	548	5450	7267	1350	115326
	Other Manufacturing	9275	105779	21087	101799	19672	226488
	Transportation	3633	4304	2560	19439	7812	70629
	Communications	194	456	451	1949	935	7103
	Energy	544	445	727	4049	371	12713
	Wholesale Trade	3433	3314	2925	11758	2341	30725
	Retail Trade	1	2	2	27	7	23
	Hotels	66	152	177	1281	1236	2147
	Finance	953	2377	1581	6458	1995	17702
	Insurance	461	1104	583	3666	948	7525
	Real Estate	137	480	988	2867	2672	17112
	Business Services	2302	14832	5896	20909	11709	88924
	Health Services	0	0	0	0	0	0
	Misc. Services	612	1901	2363	8699	3356	31540
41)	Total	137671	236811	197138	560906	169381	1675195
	COLUMN TOTAL	334316	524498	595064	1717571	645382	6197222

Column		(18)	(19)	(20)	(21)	(22)	(23)
Row		Other Manufacturing	Transportation	Communications	Energy	Wholesale Trade	Retail Trade
	COMMODITIES						
1)	Animal Agriculture	592	134	0	0	0	7
2)	Crop Agriculture	102	133	0	1	0	3
3)	Agricultural Services	459	342	10	120	78	118
4)	Mining	67653	1019	0	233788	14	23
5)	Construction	494835	195454	157869	784401	18285	149175
6)	Prepared Meats	15310	611	0	15	0	69
7)	Dairy	19	170	0	2	0	20
8)	Fruits and vegetables	0	71	0	1	0	1
9)	Milling Products	14	9	0	0	1	4
10)	Bakery Products	1	160	0	2	0	37
11)	Misc. Food Products	16	132	0	4	2	6
12)	Vege. and Animal Oil	569	18	0	0	0	2
13)	Beverages	12	313	1	4	6	334
14)	Textile	37830	2358	94	85	209	201
15)	Wood and Paper Prod.	67905	2340	259	609	5027	8939
16)	Printing and Publishing	4484	4117	1132	569	1715	650
17)	Chemical Petroleum	538529	165006	1942	61696	3088	9672
18)	Other Manufacturing	1365653	46187	20575	12156	2263	5189
19)	Transportation	307627	575342	5984	60837	11691	24740
20)	Communications	34702	29619	119626	2505	5705	18416
21)	Energy	278830	41247	10501	207372	6514	54300
22)	Wholesale Trade	363421	34349	2505	13255	6776	4823
23)	Retail Trade	1911	14344	71	490	344	1752
24)	Hotels	68974	21167	79540	2558	13652	21537
25)	Finance	109788	66410	14523	25887	11063	25819
26)	Insurance	25187	23287	311	14922	645	3020
27)	Real Estate	71702	66949	20570	54528	12693	122494
28)	Business Services	563117	173138	35730	43185	70036	284016
29)	Health Services	0	0	0	0	0	0
30)	Misc. Services	280276	258909	38992	24938	23156	52957
31)	Total	4702217	1723332	510233	1543931	192964	788325
	FACTORS						
31)	Labor	4276119	2089636	446110	967967	1956105	2785369
32)	Capital	1708310	748317	353121	1452979	466850	865961
33)	Land						
	Sub-Total	5984430	2837953	799231	2420945	2422955	3651330
	INSTITUTIONS						
34)	Enterprises						
	Households						
35)	Low Income						
36)	Middle Income						
37)	High Income						
	Sub-Total						
	Governments						
38)	State & Local	116104	149206	119817	175061	609393	816376
39)	Federal	26053	33481	26886	39282	136744	183189
	Sub-Total	142157	182686	146703	214343	746136	999566
	Inst. Total	142157	182686	146703	214343	746136	999566

Row	Column	(18) Other Manufacturing	(19) Transportation	(20) Communications	(21) Energy	(22) Wholesale Trade	(23) Retail Trade
40)	**CAPITAL**						
	IMPORTS						
	Animal Agriculture	54	12	0	0	0	1
	Crop Agriculture	123	161	0	1	0	4
	Agricultural Services	818	610	17	214	138	211
	Mining	94267	1419	0	325759	20	32
	Construction	10965	4331	3498	17381	405	3306
	Prepared Meats	2028	81	0	2	0	9
	Dairy	4	37	0	0	0	4
	Fruits and vegetables	8	1466	0	14	5	23
	Milling Products	222	145	0	1	15	61
	Bakery Products	0	20	0	0	0	5
	Misc. Food Products	50	420	0	12	6	18
	Vege. and Animal Oil	410	13	0	0	0	2
	Beverages	123	3143	10	36	59	3358
	Textile	83798	5223	208	188	463	446
	Wood and Paper Prod.	205293	7073	782	1843	15199	27026
	Printing and Publishing	15312	14060	3866	1942	5856	2220
	Chemical Petroleum	47460	14542	171	5437	272	852
	Other Manufacturing	4720078	159634	71112	42015	7822	17935
	Transportation	133384	249462	2595	26378	5069	10727
	Communications	28009	22181	89584	1876	4272	13791
	Energy	22945	3394	864	17065	536	4468
	Wholesale Trade	104868	9912	723	3825	1955	1392
	Retail Trade	107	804	4	27	19	98
	Hotels	18267	5606	21066	678	3616	5704
	Finance	56684	34287	7498	13365	5712	13330
	Insurance	23399	21633	289	13863	599	2806
	Real Estate	30729	28692	8816	23369	5440	52497
	Business Services	214516	65956	13611	16451	26680	108194
	Health Services	0	0	0	0	0	0
	Misc. Services	97791	90336	13605	8701	8079	18477
41)	Total	5911713	744655	238317	520446	92238	286996
	COLUMN TOTAL	16740517	5488627	1694484	4699666	3454293	5726216

Column		(24)	(25)	(26)	(27)	(28)	(29)
Row		Hotels	Finance	Insurance	Real Estate	Business Services	Health Services
	COMMODITIES						
1)	Animal Agriculture	6154	0	5	23	88	1510
2)	Crop Agriculture	4746	0	2	98	4	678
3)	Agricultural Services	3856	71	23	11375	116	430
4)	Mining	32	0	0	50	348	12
5)	Construction	108323	103794	31728	705524	85068	81604
6)	Prepared Meats	97715	0	48	353	160	14911
7)	Dairy	77482	0	14	261	32	5353
8)	Fruits and vegetables	2760	0	1	10	2	351
9)	Milling Products	1011	0	3	5	75	317
10)	Bakery Products	27706	0	26	109	39	2346
11)	Misc. Food Products	16465	0	4	56	8	1493
12)	Vege. and Animal Oil	858	0	1	4	4	434
13)	Beverages	7055	0	1	28	5	242
14)	Textile	1445	957	92	33	565	3784
15)	Wood and Paper Prod.	6811	3145	659	1533	18346	5474
16)	Printing and Publishing	2056	13448	5417	2911	23326	8545
17)	Chemical Petroleum	7700	3724	1288	10605	32086	222411
18)	Other Manufacturing	12399	12695	4201	6279	69977	68472
19)	Transportation	21665	147212	27375	15480	84591	35159
20)	Communications	8622	40885	21140	7824	54224	15925
21)	Energy	41404	20549	6172	5935	20125	39385
22)	Wholesale Trade	30817	6995	1877	2964	21201	30496
23)	Retail Trade	441	455	291	1630	1102	745
24)	Hotels	182150	27832	36656	20550	70739	14753
25)	Finance	26954	447978	77942	76383	43747	12782
26)	Insurance	1302	34567	395969	153216	5423	8653
27)	Real Estate	79485	87124	55249	340471	94427	199605
28)	Business Services	179878	445646	128315	187441	541283	196463
29)	Health Services	13	0	0	0	15	42524
30)	Misc. Services	24276	100005	25572	17284	87045	47482
31)	Total	981582	1497092	820074	1568433	1254170	1062338
	FACTORS						
31)	Labor	1527386	1004605	688209	269942	2883054	3980618
32)	Capital	391152	379429	284434	4092840	1483645	940987
33)	Land						
	Sub-Total	1918538	1384034	972642	4362782	4366699	4921605
	INSTITUTIONS						
34)	Enterprises						
	Households						
35)	Low Income						
36)	Middle Income						
37)	High Income						
	Sub-Total						
	Governments						
38)	State & Local	210473	81111	255043	970756	71011	25110
39)	Federal	47229	18201	57230	217831	15934	5634
	Sub-Total	257701	99312	312273	1188587	86946	30744
	Inst. Total	257701	99312	312273	1188587	86946	30744

Row	Column	(24) Hotels	(25) Finance	(26) Insurance	(27) Real Estate	(28) Business Services	(29) Health Services
40)	**CAPITAL**						
	IMPORTS						
	Animal Agriculture	557	0	0	2	8	137
	Crop Agriculture	5733	0	3	118	5	819
	Agricultural Services	6879	126	40	20292	207	767
	Mining	45	0	0	70	484	16
	Construction	2400	2300	703	15633	1885	1808
	Prepared Meats	12944	0	6	47	21	1975
	Dairy	16992	0	3	57	7	1174
	Fruits and vegetables	57198	0	16	197	32	7278
	Milling Products	16036	0	43	83	1197	5032
	Bakery Products	3469	0	3	14	5	294
	Misc. Food Products	52290	0	13	179	26	4742
	Vege. and Animal Oil	620	0	1	3	3	313
	Beverages	70933	2	9	278	47	2436
	Textile	3201	2119	203	73	1251	8382
	Wood and Paper Prod.	20591	9507	1993	4635	55464	16549
	Printing and Publishing	7022	45923	18499	9940	79652	29178
	Chemical Petroleum	679	328	114	935	2828	19601
	Other Manufacturing	42854	43878	14519	21701	241860	236659
	Transportation	9394	63830	11870	6712	36678	15245
	Communications	6457	30617	15831	5859	40606	11925
	Energy	3407	1691	508	488	1656	3241
	Wholesale Trade	8892	2018	542	855	6118	8800
	Retail Trade	25	26	16	91	62	42
	Hotels	48242	7371	9708	5443	18735	3907
	Finance	13916	231291	40241	39436	22587	6600
	Insurance	1210	32113	367860	142339	5038	8039
	Real Estate	34065	37339	23678	145916	40469	85545
	Business Services	68523	169769	48881	71404	206198	74841
	Health Services	3	0	0	0	3	8542
	Misc. Services	8470	34893	8922	6030	30371	16567
41)	Total	523046	715142	564227	498831	793501	580453
	COLUMN TOTAL	3680867	3695580	2669216	7618633	6501316	6595140

Column		(30)		(31)	(32)	(33)	
Row		Misc. Services	Total	Labor	Capital	Land	Total
	COMMODITIES						
1)	Animal Agriculture	2120	908133				
2)	Crop Agriculture	889	487712				
3)	Agricultural Services	1665	186861				
4)	Mining	376	1219257				
5)	Construction	527706	4923469				
6)	Prepared Meats	20013	324833				
7)	Dairy	5917	182617				
8)	Fruits and vegetables	320	4825				
9)	Milling Products	1120	31794				
10)	Bakery Products	10844	45260				
11)	Misc. Food Products	1660	36354				
12)	Vege. and Animal Oil	614	149869				
13)	Beverages	281	14083				
14)	Textile	3997	137651				
15)	Wood and Paper Prod.	12316	478808				
16)	Printing and Publishing	59089	155596				
17)	Chemical Petroleum	126462	3224614				
18)	Other Manufacturing	241113	2613385				
19)	Transportation	172468	2185380				
20)	Communications	46210	487451				
21)	Energy	92367	1229296				
22)	Wholesale Trade	87049	1311912				
23)	Retail Trade	46059	281384				
24)	Hotels	69764	726113				
25)	Finance	127601	1491494				
26)	Insurance	62210	824052				
27)	Real Estate	309963	2012852				
28)	Business Services	460729	4550438				
29)	Health Services	0	59914				
30)	Misc. Services	187975	1562805				
	Total	2678897	31848212				
	FACTORS						
31)	Labor	2168387	30400863				
32)	Capital	582994	19352336				
33)	Land		709066				
	Sub-Total	2751381	50462265				
	INSTITUTIONS						
34)	Enterprises				12510953		12510953
	Households						
35)	Low Income			2300827	942433	34583.000	3277843
36)	Middle Income			14718190	3905837	258595.717	18882622
37)	High Income			14344040	2999799	390121.000	17733960
	Sub-Total			31363057	7848069	683300	39894425
	Governments						
38)	State & Local	43324	4302699	747114	586084	25766	1358964
39)	Federal	9722	965496	5379601	-1592770		3786831
	Sub-Total	53045	5268195	6126715	-1006686	25766	5145795
	Inst. Total	53045	5268195	37489772	6841383	709066	45040220

Column (30) (31) (32) (33)

Row		Misc. Services	Total	Labor	Capital	Land	Total
40)	**CAPITAL**						
	IMPORTS						
	Animal Agriculture	192	82227				
	Crop Agriculture	1074	589193				
	Agricultural Services	2971	333332				
	Mining	524	1698905				
	Construction	11693	109097				
	Prepared Meats	2651	43029				
	Dairy	1298	40048				
	Fruits and Vegetables	6630	99996				
	Milling Products	17756	504162				
	Bakery Products	1358	5667				
	Misc. Food Products	5273	115455				
	Vege. and Animal Oil	443	108198				
	Beverages	2824	141589				
	Textile	8855	304915				
	Wood and Paper Prod.	37235	1447556				
	Printing and Publishing	201775	531321				
	Chemical Petroleum	11145	284180				
	Other Manufacturing	833355	9032592				
	Transportation	74780	947557				
	Communications	34605	365035				
	Energy	7601	101161				
	Wholesale Trade	25119	378562				
	Retail Trade	2583	15779				
	Hotels	18477	192308				
	Finance	65880	770058				
	Insurance	57794	765553				
	Real Estate	132841	862651				
	Business Services	175511	1733458				
	Health Services	0	12035				
	Misc. Services	65587	545279				
41)	Total	1807828	22160897				
	COLUMN TOTAL	7291151	109739561	37489772	19352336	709066	57551174

Row	Column	(34) Enterprises	(35) Low Income Households	(36) Middle Income Households	(37) High Income Households	(38) State & Local Gov't	(39) Federal Gov't
	COMMODITIES						
1)	Animal Agriculture		3764	10352	7384	1107	0
2)	Crop Agriculture		20055	36885	20600	1691	0
3)	Agricultural Services		11319	22970	13881	10042	22
4)	Mining		314	636	364	1144	6159
5)	Construction		0	0	0	1515267	72765
6)	Prepared Meats		150183	275706	153193	15916	449
7)	Dairy		71937	131956	73162	15119	54
8)	Fruits and vegetables		5009	9197	5113	450	146
9)	Milling Products		3604	6629	3703	160	32
10)	Bakery Products		66327	121867	67877	6857	559
11)	Misc. Food Products		47078	88901	44066	2085	269
12)	Vege. and Animal Oil		3133	5749	3192	500	4
13)	Beverages		9438	23278	16319	164	195
14)	Textile		74231	194342	127977	6857	401
15)	Wood and Paper Prod.		17988	45058	35604	13279	545
16)	Printing and Publishing		12593	40179	30633	14732	76
17)	Chemical Petroleum		377741	771983	436961	182869	41078
18)	Other Manufacturing		109607	333065	248188	69037	118148
19)	Transportation		147334	339156	279271	75361	2729
20)	Communications		146429	278526	149898	36367	12355
21)	Energy		433292	801985	460538	192342	18385
22)	Wholesale Trade		290599	657563	411811	93129	5341
23)	Retail Trade		768587	2355346	2034216	6231	176
24)	Hotels		462636	1378474	1020756	66386	19719
25)	Finance		305711	812176	495018	100085	0
26)	Insurance		192479	442738	269420	3706	0
27)	Real Estate		961956	2267821	1586265	75307	1705
28)	Business Services		203605	514313	329241	241661	277478
29)	Health Services		1505050	3450566	1552761	12509	14022
30)	Misc. Services		669880	1481192	1270757	41153	181847
	Total		7071879	16898609	11148169	2801513	774659
	FACTORS						
31)	Labor		16365	48348	42357	3678641	3303198
32)	Capital						
33)	Land						
	Sub-Total		16365	48348	42357	3678641	3303198
	INSTITUTIONS						
34)	Enterprises						
	Households						
35)	Low Income	130952				817924	4943792
36)	Middle Income	704593				1655936	2828256
37)	High Income	898689				476555	768053
	Sub-Total	1734234				2950415	8540101
	Government						
38)	State & Local	253679	133592	779829	923840	3561733	1970587
39)	Federal	1445944	205350	2139901	2794059		2945493
	Sub-Total	1699623	338942	2919730	3717899	3561733	4916080
	Inst. Total	3433857	338942	2919730	3717899	6512148	13456181

Row	Column	(34) Enterprises	(35) Low Income Households	(36) Middle Income Households	(37) High Income Households	(38) State & Local Gov't	(39) Federal Gov't
40)	**CAPITAL**	9077096	-1258011	-2887856	276546		
	IMPORTS						
	Animal Agriculture		341	937	669	100	0
	Crop Agriculture		24228	44560	24887	2043	0
	Agricultural Services		20191	40975	24762	17914	40
	Mining		437	886	508	1594	8582
	Construction		0	0	0	33576	1612
	Prepared Meats		19894	36521	20293	2108	60
	Dairy		15776	28938	16044	3316	12
	Fruits and vegetables		103808	190599	105955	9322	3024
	Milling Products		57155	105123	58716	2535	502
	Bakery Products		8305	15260	8499	859	70
	Misc. Food Products		149515	282342	139951	6620	855
	Vege. and Animal Oil		2262	4151	2305	361	3
	Beverages		94892	234052	164083	1651	1958
	Textile		164431	430492	283485	15190	888
	Wood and Paper Prod.		54383	136220	107639	40146	1649
	Printing and Publishing		43001	137202	104605	50306	260
	Chemical Petroleum		33290	68034	38509	16116	3620
	Other Manufacturing		378833	1151167	857808	238612	408352
	Transportation		63883	147054	121089	32676	1183
	Communications		109655	208578	112253	27234	9252
	Energy		35656	65997	37899	15828	1513
	Wholesale Trade		83855	189745	118831	26873	1541
	Retail Trade		43101	132082	114074	349	10
	Hotels		122527	365083	270343	17582	5223
	Finance		157839	419327	255578	51674	0
	Insurance		178815	411309	250294	3443	0
	Real Estate		412267	971923	679828	32275	731
	Business Services		77562	195924	125422	92059	105703
	Health Services		302323	693124	311907	2513	2817
	Misc. Services		337689	746674	640593	20745	91670
41)	Total		3095914	7454279	4996827	765619	651130
	COLUMN TOTAL	12510953	9265090	24433110	20181800	13757922	18185168

	Column	(40)		(41)			
Row		CAPITAL	TOTAL	EXPORTS	ROW TOTAL		
	COMMODITIES						
1)	Animal Agriculture	3431	26039	1691008	2625180		
2)	Crop Agriculture	2064	81296	559536	1128543		
3)	Agricultural Services	4284	62518	341059	590437		
4)	Mining	10784	19400	4653906	5892562		
5)	Construction	4054606	5642638	166464	10732572		
6)	Prepared Meats	4544	599990	36881	961703		
7)	Dairy	17	292246	20901	495763		
8)	Fruits and vegetables	134	20049	291399	316274		
9)	Milling Products	124	14252	541566	587612		
10)	Bakery Products	1281	264769	4143	314170		
11)	Misc. Food Products	475	182874	5759	224987		
12)	Vege. and Animal Oil	3113	15691	168754	334316		
13)	Beverages	0	49395	461021	524498		
14)	Textile	7037	410846	46566	595064		
15)	Wood and Paper Prod.	24497	136971	1101791	1717571		
16)	Printing and Publishing	121	98333	391454	645382		
17)	Chemical Petroleum	8313	1818945	1153660	6197222		
18)	Other Manufacturing	655508	1533554	12593578	16740517		
19)	Transportation	45524	889374	2413873	5488627		
20)	Communications	21549	645125	561907	1694484		
21)	Energy	0	1906543	1563828	4699666		
22)	Wholesale Trade	311768	1770210	372173	3454293		
23)	Retail Trade	59472	5224028	220803	5726216		
24)	Hotels	0	2947971	6783	3680867		
25)	Finance	0	1712990	491098	3695580		
26)	Insurance	0	908342	936823	2669216		
27)	Real Estate	76633	4969687	636094	7618633		
28)	Business Services	42591	1608888	341989	6501316		
29)	Health Services	0	6534908	319	6595140		
30)	Misc. Services	116	3644945	2083402	7291151		
	Total	5337986	44032815	33858535	109739561		
	FACTORS						
31)	Labor		7088909		37489772		
32)	Capital				19352336		
33)	Land				709066		
	Sub-Total		7088909		57551174		
	INSTITUTIONS						
34)	Enterprises				12510953		
	Households						
35)	Low Income		5892668	94579	9265090		
36)	Middle Income		5188785	361703	24433110		
37)	High Income		2143297	304543	20181800		
	Sub-Total		13224750	760825	53880000		
	Government						
38)	State & Local		7623260	472999	13757922		
39)	Federal		9530747	3902094	18185168		
	Total		17154007	4375095	31943090		
	Inst. Total		30378757	5135919	98334043		

	Column		(40)		(41)		
Row		CAPITAL	TOTAL	EXPORTS	ROW TOTAL		
40)	**CAPITAL**		5207776	2789519	7997295		
	IMPORTS						
	Animal Agriculture	311	2358		84585		
	Crop Agriculture	2494	98212		687405		
	Agricultural Services	7642	111524		444856		
	Mining	15026	27032		1725937		
	Construction	89844	125033		234130		
	Prepared Meats	602	79478		122506		
	Dairy	4	64089		104137		
	Fruits and vegetables	2783	415491		515486		
	Milling Products	1973	226003		730165		
	Bakery Products	160	33154		38821		
	Misc. Food Products	1510	580793		696248		
	Vege. and Animal Oil	2247	11328		119526		
	Beverages	0	496636		638225		
	Textile	15589	910075		1214990		
	Wood and Paper Prod.	74059	414097		1861652		
	Printing and Publishing	412	335785		867106		
	Chemical Petroleum	733	160301		444481		
	Other Manufacturing	2265620	5300392		14332984		
	Transportation	19739	385623		1333180		
	Communications	16137	483110		848145		
	Energy	0	156893		248054		
	Wholesale Trade	89963	510808		889370		
	Retail Trade	3335	292952		308731		
	Hotels	0	780758		973066		
	Finance	0	884417		1654475		
	Insurance	0	843861		1609414		
	Real Estate	32843	2129866		2992517		
	Business Services	16225	612895		2346352		
	Health Services	0	1312683		1324718		
	Misc. Services	58	1837430		2382709		
41)	Total	2659308	19623077		41783974		
	COLUMN TOTAL	7997295	106331335	41783973	315406045		

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VITA

Aleligne Kefyalew Amera

Candidate for the Degree of

Doctor of Philosophy

Thesis: TECHNICAL CHANGE AND RESEARCH AND DEVELOPMENT IN FOOD PROCESSING

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Biographical.

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Experience: Employed by the Institute of Agricultural Research, Department of Agricultural Economics, Ethiopia, from January, 1986 to August, 1993; by Oklahoma State University, Department of Agricultural Economics as a graduate research assistant 1994 to March, 1998; by Toyota Motors Credit Corporation as an Econometrician April, 1998 to present.

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