1990

Technical change in Iowa agricultural production: a conditional demand approach

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by

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A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Department: Economics
Major: Agricultural Economics

Iowa State University
Ames, Iowa

1990

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CHAPTER 1. INTRODUCTION

Situation and Problem

One of the difficult problems that researchers frequently encounter in nonexperimental agricultural production is that input data are not available by crop. A farm enterprise typically comprises different production activities. Several crops are grown but the allocation of different inputs among crops are not recorded. The farm record usually shows the total use of variable inputs such as labor and fertilizer and the amount of the major fixed factor land allocated to each crop. The most popular approach in the recent economic literature to estimate such multi-output, multi-input technologies has been to use single equation joint production functions. In this approach the relationship between output quantities and aggregate input quantities is specified. The use of the corresponding relationship between prices and quantities resulting from duality under profit maximization is yet another popular approach (Weaver, 1983, and Shumway and Chang, 1980).

Quite a number of studies presume that multi-output technologies can be described by separate production functions. The main assumption here is that these technologies are nonjoint in the inputs. With the recent developments in duality theory simple statistical tests were developed to test for input nonjointness. These tests typically rejected input nonjointness.

According to Just, Zilberman and Hochman the following assumptions are characteristic of agricultural production:

a) Allocated inputs: inputs are allocated by farmers to specific crops, e.g., labor hours and fertilizers are allocated among corn, oats, and soybean fields.

b) Physical constraints: the total quantity available from some inputs is limited by physical constraints, e.g., land is available in fixed amounts at given periods.

c) Output determination: output mix is uniquely determined by allocations of different activities, in addition to some other uncontrolable factors such as the weather.

At different points of time, researchers aimed at disaggregating total input usage to a per crop level in the context of multi-output technologies estimation. Shumway, Pope and Nash (1984) refer to the fact that when production is joint, dual methods do not permit extraction of equations for input allocations among crops while primal models allow identification of allocations because of constraints on allocatable inputs. So when allocations are sought, primal specifications are required. The problem which this study addresses falls into this category of multi-output technologies where aggregate input usages are observed at the county level but not the allocations of the different inputs to the various crops. Crops' areas are also observed. The study attempts to estimate the technologies in this multi-output enterprise situation. From these estimates the relationship between inputs, namely substitution information, will be investigated. Then the issue of technical change and its impact on the input mix will be treated within the framework of the estimated technologies.

The study follows the following organizational pattern: In Chapter 1, the introduction; in Chapter 2, the review of the literature; in Chapter 3, the description of data and definition of variables; in Chapter 4, the theoretical framework of the study and the equations to be estimated; in Chapter 5, the results and findings are discussed; and in Chapter 6, Summary and Conclusions.

Technical Change

Representing technical change by including a time variable in the production, cost and profit function is the most frequently encountered approach in empirical studies. The underlying argument is that technical advances require the passage of time. A basic advantage of this approach over others is its analytical and economic tractability.

As most measures do, this approach has its shortcomings. One valid obvious criticism is that it is a passive approach that does not clearly define the concept of technical change and does not explain the motivation behind technical change. A substantial body of literature has attempted to offer an insight into the mechanism and the motivation behind technical change. Different versions of the theory of induced innovation were proposed in this context.

Hicks' (1963) induced innovation hypothesis hinges upon the assumption that changes in the relative factor prices is a spur to invention, i.e., technical change is a pure market phenomenon. Moreover, not only do these market phenomena call for invention but they provide signals for the direction of technical change. In this regard invention is directed towards economizing the use of the factor which has become relatively expensive.

Hayami and Ruttan (1971) argued that the high land-labor ratio has played an important role in the advent and direction of innovations in the twentieth century. They compared and contrasted the patterns of agricultural growth in the U.S. and Japan. Their argument is that the high land-labor ratio in the U.S. has called for progress in mechanization to expand production and productivity by increasing the area operated by workers. On the other hand, the small land-labor ratio in Japan directed the course of innovation towards biological technology in terms of improved seeds which increased yield response to higher fertilizer levels, thereby permitting rapid growth in output in spite of the constraint on land supply.

One other attempt that closely parallels the Hicks hypothesis is that technical change is one consequence of the investment in human capital. In fact, lots of other interpretations and ideas were proposed as to what causes technical change and, as Chambers (1988) notes, strands of thought on this issue are as numerous as the strands of hairs on a person's head, and probably every economist has his own idea of what causes technical change.

One objective of this study is to assess the bias of technical change and examine its impact on the different inputs.

CHAPTER 2. REVIEW OF LITERATURE

Conditional Demands

Parti and Parti (1980) and Caves et al. (1987) used a conditional demand framework to disaggregate the total household electricity demand into component demand functions by particular appliances, even though data on specific appliance energy usage did not exist. This econometric method of estimation has the following merits as compared to the engineering methods:

1) It is amenable to adjustment when changes of income and prices occur.
2) It incorporates the economic behavior of consumers (or producers).
3) It is less expensive.

Through direct appliance metering such equations can be estimated:

$$E_i = f_i(v) \qquad i=1, ..., N \qquad [2.1]$$

where

E_i = electricity use through appliance i

f_i = household energy demand function for appliance i

v = vector of arguments.

For linear f_i equation (1) could be written as:

$$E_i = \sum_{j=0}^{m} b_{ji}\, v_j \qquad i = 1, ..., N \qquad [2.2]$$

where $v_0 = 1$ and b_{ji} are the M + 1 parameters of the i^{th} demand function.

The E_i's are not observed, yet the methodology used allows the estimation of the parameters of equation [2.2]. These parameters are the basis of the estimated elasticities, and, together with the observed v_j (j = 0, ..., M) they are also used to obtain the expected levels of consumption, E_i. As total household consumption is the sum of energy used by all the appliances, the E (total consumption) can be written as:

$$E = E_0 + \sum_{i=1}^{N} E_i \qquad [2.3]$$

where

E_i = energy consumed through appliance i

E_0 = energy consumed through a set of unspecified appliances

for each E_i (i = 1, ..., N);

$E_i = f_i(v)$ if appliance i is owned by the household, [2.4]

0 otherwise;

more compactly,

$$E_i = f_i\,(v)\,A_i, \qquad i = 1, \ldots, N \qquad [2.5]$$

where A_i is a dummy variable taking the value of one if the household possesses the appliance and zero otherwise. Energy used through unspecified appliances is given by:

$$E_0 = f_0\,(v) \qquad [2.6]$$

If equations [2.5] and [2.6] are linear, [2.3] can be written as

$$E = \sum_{i=0}^{N} \sum_{j=0}^{m} b_{ij}\left(v_j\, A_j\right) \qquad [2.7]$$

Parti and Parti used linear regression techniques to estimate this equation. The regressors are the $v_j (j = 1, ..., M)$, the appliance dummy variable and the interaction terms. The estimated regression coefficients for this equation are the estimates of the conditional demand functions and of the demand for energy through the unspecified group of appliances. The technique allows for estimation of average energy usage of individual appliances as follows:

$$\overline{E_i} = b_{0i} + \sum_{j=1}^{m} b_{ij} (v_{ij}) \qquad i=0, ..., N \qquad [2.8]$$

Where $\overline{E_{ij}}$ = estimated average energy usage through the i^{th} appliance v_{ij} $(j=1, ..., M)$ are the average values of the M exogenous variables.

Equation [2.7] can be written as:

$$E = \sum_{i=0}^{N} b_{i0} A_i + \sum_{i=0}^{N} \sum_{j=1}^{M} b_{ij} (v_j - \overline{v_{ij}}) A_i + \sum_{i=0}^{N} \sum_{j=1}^{M} b_{ij} \overline{v_{ij}} A_j \qquad [2.9]$$

Rearranging and using equations [2.8], [2.9] can be written as:

$$E = \sum_{i=0}^{N} E_i [A_i] + \sum_{i=0}^{N} \sum_{j=1}^{M} b_{ij} [(v_j - \overline{v_{ij}}) A_i] \qquad [2.10]$$

Now, by regressing E on the variables in brackets, the coefficients on the appliance dummy variables are interpretable as estimates of average energy usage through those appliances by households possessing them.

Caves et al. (1987) used a similar analytical framework to estimate appliance specific equations from aggregate data. Their conditional demand equations express total usage as follows:

$$U_{it} = \sum_{j=1}^{M} f_{jt} (Z_{ijt}) D_{ij} + E_{it} \qquad t=1, ..., T; i=1, ..., N \qquad [2.11]$$

where

U_{it} = usage of consumer i at time t

D_{ij} = 1 if consumer i owns appliance i

= 0 otherwise

Z_{ijt} = variables that determine customers i's utilization of appliance j at time t, and E_{it} an error term.

Treating the $f_{jt}(Z_{ijt})$ as constants, B_{jt}, the above equation becomes:

$$U_{it} = \sum_{j=1}^{M} B_{jt} D_{ij} + E_{it} \quad [2.12]$$

So B_{jt} = average usage of appliance j at time t. This model can be written as a system of T equations;

$$U_{.t} = DB_{.t} + e_{.t} \qquad t=1, ..., T \quad [2.13]$$

where

$U_t = (U_{1t}, U_{2t}, ..., U_{nt})$ = N x 1 vector of observed usage.

D = N x M a matrix of ownership variables

$B_t = (B_{1t}, ..., B_{Mt})$ = M x 1 vector of unobserved parameters.

Multi-output Technologies: Jointness and Nonjointness in Production

According to Henderson and Quandt, jointness exists whenever two or more products are produced in varying proportions by a single production process. Technical rather than organizational grounds distinguish jointness. In a joint production process of s (outputs) and n (inputs) the implicit production function has the form:

$$F(y_1, \ldots, y_s, x_1, \ldots x_n) = 0 \qquad [2.14]$$

Or, in vector notation: $F(Y, X) = 0$ where Y and X are respectively vectors of outputs and inputs to which restrictions implying nonjoint production do not apply. Not every production process that involves multiple outputs and inputs is joint or requires an extended analysis of joint products. If two products y_1 and y_2 are produced in a fixed proportion $y_1/y_2 = k$, then the single product analysis is applicable by defining a compound unit of output $ky_1 + y_2$ with a price $kp_1 + p_2$. For a distinction between jointness and nonjointness, this definition used by Lau is popular. The production function is nonjoint in inputs if there exist individual production functions f_i such that

$$y_i = f_i\,(x_{i1}, \ldots, x_{im}) \text{ and } x_j = \sum_{i=1}^{m} x_{ij} \qquad j = 1, \ldots, N \qquad [2.15]$$

imply $\quad F\,(y_1, \ldots, y_m; x_1, \ldots, x_n) = 0.$

This definition implies no technical economies or diseconomies since economic considerations are only with respect to inputs. If all inputs are allocated to the individual production functions $f_{i(.)}$, then the aggregate specification $F(Y, X) = 0$ would imply the same technological information where the production function is defined over the aggregate inputs $x_j = \sum_{i=1}^{m} x_{ij}$.

Shumway, Pope, and Nash (SPN) (1984) documented allocatable fixed inputs or quasi-fixed inputs as another source of jointness besides technical interdependence. They point to the fact that the two sources of jointness have different modelling implications. According to SPN, when the production process is joint then the use of the dual approach does not permit derivation of the input allocations among crops.

Primal specifications, on the other hand, are capable of extracting allocation information when production is joint only because of the physical constraints on allocatable inputs. For the case of two commodities produced independently with n variable inputs and one allocatable fixed input, the Lagrangian primal problem is:

$$L = p_1 f_1 (x_1, z_1) + p_2 f_2 (x_2, z_2) - \sum_{i=1}^{2} \sum_{j=1}^{n} r_j x_{ij} + \lambda \left(\bar{z} - \sum_{i=1}^{2} z_i\right) \qquad [2.16]$$

Z_i is the allocation of the fixed factor to the i^{th} crop, where x_i is the vector of variable inputs, and x_{ij} is the amount of input j used in producing crop i. P_i and r_j are output and input prices, respectively. $\bar{z}$ is the total amount of the fixed factor. z_i is the allocation of the fixed factor to the i^{th} crop. λ is the lagrangian multiplier.

Maximization of L gives each x_{ij}, z_j and lambda (λ) as a function of all product prices, variable input prices and the total quantity of the fixed input. However, with dual specification of the same problem input demand allocations can not be derived. This is because the partial derivative of the constrained profit maximization problem with respect to r_j yields $-\sum_i x_{ij}$ rather than $-x_{ij}$ from the following;

$$L = p_1 f_1 \left[x_1^* (p, r, \bar{z}), z_1^* (p, r, \bar{z})\right] + p_2 f_2 \left[x_2^* (p, r, \bar{z}), z_2^* (p, r, \bar{z})\right] - \sum_{i=1}^{2} \sum_{j=1}^{n} r_j x_{ij}^* (p, r, \bar{z})$$
$$+ \lambda^* (p, r, \bar{z}) \left[\bar{z} - \sum_{i=1}^{2} z_i (p, r, \bar{z})\right]; \qquad [2.17]$$

and,

$$\partial L^* / \partial_{rj} = - \sum_{i=1}^{2} \dot{x}_{ij} = -\dot{x}_j \; ;$$

Chambers and Just (1989) developed a method by which they recaptured variable input allocations using profit functions. They first specified parametric representations of the crop specific profit functions;

$$\pi^i (p_i, w, z^i) = \text{Max} \{P_i y_i - W X^i : y_i \varepsilon Y^i (x^i, z^i)\} \qquad [2.18]$$

This is a departure from traditional approaches, which failed to capture allocations using multi-crop profit functions. Provided the profit functions π^i are well behaved (i.e., differentiable, homogeneous, nondecreasing in P and nonincreasing in w), applying Shephard's lemma yields:

$$\frac{\partial \pi^i(P_i,w,z^i)}{\partial P_i} = y_i(P_i,w,z^i) \qquad i=1, ..., m \qquad [2.19]$$

$$-\frac{\partial \pi^i(P_i,w,z^i)}{\partial w_j} = x_j^i(P_i,w,z^i) \qquad i=1, ..., m; j=1, ..., n$$

where y_i and x^i_j are the profit maximizing levels of output supply and input demand given the allocations of the fixed input z^i. This means that the profit maximizing allocations of a variable input to crop i is the same as the allocation of this input when the fixed inputs are set at their optimum levels.

Using the crop specific profit functions the multicrop profit function was defined by choosing the fixed input allocations to maximize the sum of profits from producing the various crops subject to the constraint on the fixed input quantities:

$$\pi(P,w,z) = \underset{z^1,...,z^m}{\text{Max}} \left\{ \sum_i^m \pi^i(P_i, w, z^i) : \sum_i^m z^i = z \right\} \qquad [2.20]$$

from the envelope theorem and Shephard's lemma

$$x_j(P,w,z) = -\frac{\partial\pi(P,w,z)}{\partial w_j} = -\sum_i^m \frac{\partial\pi^i(P,w,\bar{z}^i)}{\partial w_j} = \sum_i^m x_j^i(P_i,w,\bar{z}^1) \qquad j=1, ..., n \qquad [2.21]$$

$$y_i(P,w,z) = \frac{\partial\pi(P,w,z)}{\partial P_i} = \frac{\partial\pi^i(P_i,w,\bar{z}^i)}{\partial P_i} = y_i(P_i,w,\bar{z}^1) \qquad i=1, ..., m$$

Here $x_i(P,w,z)$ and $y_i(P,w,z)$ are the optimal multicrop demands and supplies.

Equation [2.21] contains the necessary parameters to allow for consistent estimation of the crop-specific profit functions. However, it does not use all the available information about the producer's behavior, since it does not recognize that fixed inputs are allocated across crops to equalize their marginal quasi-rents or shadow prices.

From [2.20] the optimum fixed inputs allocations were obtained from first order conditions as follows:

$$\frac{\partial\pi^i(P_i,w,\bar{z}^i)}{\partial z_s^i} = \frac{\partial\pi^1(P_1,w,\bar{z}^1)}{\partial z_s^1} \qquad i=2, ..., m; s=1, ..., k \qquad [2.22]$$

To achieve maximum estimation efficiency, [2.22] and [2.21] were estimated jointly. Then the variable inputs allocations follow directly by applying Shephard's lemma to the estimated crop-specific profit functions.

Thus from information on the fixed input allocations, total variable inputs and outputs and inputs prices, variable input allocations across crops could be recovered. So the SPN problem that dual specifications do not allow the extraction of allocation information, is solved.

Just, Zilberman, and Hochman (JZH) (1983) report that the most common case of data availability in agriculture is when the total use of variable inputs is observed but the allocations to various crops are not. Another commonly observed variable is the major fixed factor allocation. JZH developed a method for modelling nonjoint production technologies with fixed but allocatable inputs. They were able to extract allocation information on the variable inputs. Agricultural production is characterized by:

a) Allocated inputs: inputs are allocated by farmers to specific production activities.

b) Physical constraints: The quantity available of a given input at a given time is limited.

c) Output determination: The output mix is uniquely determined by the allocation of inputs to the various crops, plus some other uncontrollable factors.

So, a relationship of the form:

$$f(y_1, ..., y_k) = g(x_1, ..., x_j)$$

is not amenable to econometric or economic analysis because it lacks the necessary information about output aggregation and input allocation. In the general multi-output production function;

$$h(X, Y) = 0$$

where Y is kx1 vector of outputs, x is kxj matrix with elements x_{kj} representing the allocation of input $X = (x_1, ..., x_j)'$ and;

$$\sum_{k=1}^{k} x_{kj} = x_j \qquad j=1, ..., J.$$

This form is not easily tractable for most purposes; thus the common approach has been either to assume input/output separability meaning that;

$$h(X, Y) = f(Y) - f(X)$$

or to assume production nonjointness. With the assumptions of allocated inputs, output determination and physical constraints the following functions can be estimated:

$$y_k = f_k(x_{k1}, ..., x_{kj}) \qquad k = 1, ..., K \qquad [2.23]$$

with the additive physical relationship of the form;

$$\sum_{k=1}^{k} x_{kj} = x_j \qquad \text{holding for } j = 1, ..., J$$

To demonstrate their approach JZH used a Cobb-Douglas specification of the form:

$$Y_{ikt} = \prod_{j=1}^{J} x_{ijkt}^{\alpha_{jk}} e^{\beta_{kt} + r_k^{m_i} + \varepsilon_{ikt}^{y}} \qquad [2.24]$$

where; t = time, i denotes farmer, m_i is a human capital measure, α_{jk} are production elasticities for input j in crop k, and the error term is:

$$\varepsilon_{ikt}^{y} \sim N(0, \delta_k).$$

Then they defined the expected price as $p_{kt} = p_k(z_{it})$, Z_{it} being a set of information available at time t for farmer i. So expected revenue will be:

$$R_{ikt} = E\,(p_{kt}\ y_{ikt}) = P_k\,(z_{it}) \prod_{j=1}^{J} x_{ijkt}^{\alpha_{jk}} e^{\beta_{kt} + r_k^{m_i} + \delta_k^{r/2}}$$

From expected profit maximization, they derived the first order conditions and solved for the allocations x_{ijk} to form a system of equations in which unobserved ingredients are replaced through the first order conditions. One of the limitations of their approach is the fact that the first order conditions are nonlinear, which adds to the burden of estimation.

Technical Change and the Production Function

Rate of technical change and Hicks neutrality

Chambers noted that viewing technical change as shifts in the production function over time is the most exploited definition of technical change. It is presumed that a stable relationship between output, inputs, and time exists as follows:

$$Y = f(X, t) \tag{2.25}$$

Assuming differentiability of f, the rate of technical change, T (X, t) measures the percentage change in output due to an increment of time holding the input bundle constant:

$$T(X, t) = \frac{\partial \ln f(X, t)}{\partial t} \tag{2.26}$$

The representation in [2.26] might not be always realistic because of the strong assumption that the input bundle is held constant and the technology maintains the same form over time. In other words, technical change is not embodied in a particular input; hence this kind of technical change is referred to as disembodied.

A form such as $Y_t = f_t(X_t, T)$ represents embodied technical change where $f_t(X_t, t)$ and $f_T(X_T, T)$ need not be the same functional forms and inputs X_t and X_T may have different components. Obviously analytical tractability is one sacrifice of using this kind of representation.

Hicks (1963) developed another taxonomy of technical change which is often convenient. He used the concepts of neutral, factor using and factor saving technical change. According to his theoretical framework, the type of technical change depends on the sign of the rate of change of the ratio of marginal rates of technical substitution with respect to time. He considered a production function with a pair of inputs, namely, capital and labor. Mathematically, technical change is labor saving, Hicks neutral, or labor using if:

$$\frac{d}{dt}\,MRTS = \frac{d}{dt}\frac{F_K}{F_L} \begin{matrix} > \\ = \\ < \end{matrix} 0 \qquad [2.27]$$

where $MRTS_{KL}$ is the marginal rate of technical substitution between capital and labor measured as the ratio of marginal products.

F_K is the marginal product of capital.

F_L is the marginal product of labor, and

t denotes time.

Put another way, a technology exhibits Hicks neutrality if it is expansion path preserving, i.e., if the firm expands along its expansion path. Thus, technical change affects the marginal products of both inputs at the same proportion.

Blackorby et al. (1976) distinguished between a Hicks neutral (HN) and an implicitly Hicks neutral (IHN) technical change. The latter differs from the former in that the factor proportions are fixed. Hence, technical change is IHN if at a given factor proportion the marginal rate of technical substitution is independent of time. In this case the expansion path is a ray and its slope determines the fixed factor proportion.

The two concepts of HN and IHN are equivalent if the production function is homothetic in the inputs.

Binswanger (1974) used the Hicks neutrality concept in a slightly amended version and defined technical change bias in terms of factor shares:

$$\beta_i = \frac{d\alpha_i^*}{dt}\frac{1}{\alpha_i}$$

where

α_i is the share of factor i;

$d\alpha^*$ denotes that relative factor prices are held constant;

technical change is: i-saving if $\beta_i < 0$, neutral if $\beta_i = 0$, and i-using if $\beta_i > 0$.

He argued that for short time periods it is possible to assume that the rate of technical change bias is constant. Given this, he introduced constant exogenous rates of technical change in the translog cost function as follows:

$$\begin{aligned} \ln C = \ln[h(y)] + \ln v_0 + \sum_i v_i \ \ln w_i + \frac{1}{2} \sum_i \sum_j r_{ij} \ln w_i \ln w_j \\ + v_t \ln t + \omega_t(\ln t) + \sum_i w_i \ln t \end{aligned} \qquad [2.28]$$

where

h(y) is a scale function of the output;

v_0, v_i and v_{ij} are parameters of the cost function;

w_i denotes factor prices;

t denotes time.

The share equations are obtained by differentiation as follows:

$$\frac{\partial \ln C}{\partial \ln w_i} = \alpha_i = v_i + \sum_j r_{ij} \ln w_j + \omega_i \ln t \qquad i=1, \ldots, n \qquad [2.29]$$

Totally differentiating,

$$d\alpha_i = \sum_j r_{ij} \, d\ln w_j + \omega_i \, d\ln t$$

where ω_i is the constant exogenous rate of bias for factor i.

In order to estimate the bias that is purely due to technical change, changes in factor share must be purged of the biases caused by price changes. The coefficients, ω_i, were used for this purpose to arrive at price-corrected shares;

$$d\alpha_i^* = \widehat{\omega}_i \, d\ln t \qquad i=1, \ldots, n$$

These can be used to estimate the β_i's for the particular period. Empirical results of the study showed that in the period 1912-1948 technical change has been factor using for land, machinery and fertilizer, with percentage factor share changes of +0.7, +0.85 and +1.6, respectively. On the other hand, technical change was factor saving for labor with $\Delta\alpha^*$ of -11.4%. This is consistent with the Hayami and Ruttan (1971) induced innovation argument that technical change has been biased for machinery and against labor.

Antle (1984) utilized 1910-1978 time series data in the framework of a single product aggregate translog profit function to measure the structure of the U.S. agricultural technology. He used the restricted profit function of the form:

$$\ln G(P,z) = \alpha_0 + \sum_i^n \alpha_i \ln P_i + \frac{1}{2} \sum_i \sum_j \alpha_{ij} \ln P_i \ln P_j$$

$$+ \sum_i^m \beta_i \ln z_i + \sum_i^n \sum_j^m \beta_{ij} \ln P_i \ln z_j \qquad [2.30]$$

$$+ \sum_i^m \gamma_i (\ln z_i)^2$$

where $P_i = \frac{w_i}{P}$, w_i is the i^{th} input price and P is the aggregate input price, and z_i consists of a time variable. To measure the technical change bias he developed a multifactor measure in a manner similar to Binswanger, the only difference being that he used elasticity shares instead of cost shares:

$$\beta_i \equiv \partial \ln(\varepsilon_i/\varepsilon) \,\Big|\, \partial \ln t$$

where

$$\varepsilon_i = \frac{f_i x_i}{f} \qquad \varepsilon = \sum_i \varepsilon_i$$

Technical change is biased toward (against) input i as β_i is greater (less) than zero. It is neutral with respect to i if β_i = zero. The β_i can be expressed in terms of parameters of the profit function as follows: It is shown by Lau that

$$\partial \ln \frac{G(P, z)}{\partial \ln P_i} = \frac{-\varepsilon_i}{1-\varepsilon}$$

Therefore,

$$\frac{-\varepsilon}{1-\varepsilon} = - \sum_i^n \frac{\partial \ln G}{\partial \ln P_i}, \text{ and } \frac{\varepsilon_i}{\varepsilon} = - \frac{\partial \ln G}{\partial \ln P_i} \left[-\sum_i^n \frac{\partial \ln G}{\partial \ln P_i} \right]^{-1}$$

Letting $z_1 \equiv t$, then

$$\beta_i = \frac{\partial \ln(\varepsilon_i/\varepsilon)}{\partial \ln t}$$

$$= \frac{\partial \ln\left[\frac{\partial \ln G}{\partial \ln P_i}\right]}{\partial \ln t} - \frac{\partial \ln\left[-\sum_i \frac{\partial \ln G}{\partial \ln t}\right]}{\partial \ln t}$$

Empirical results for the period 1910-1946 showed that technical change was biased toward machinery and against land, with β_i of (0.273) and (-0.193), respectively. For chemicals, β_i is not very large (0.014) and is in contradiction with Binswanger's findings of substantial bias toward chemicals (1.6).

However, the 1947-1978 findings are very similar to Binswanger's results, with β_i values of -2.302, 0.708, 6.116, and 0.077 for labor, machinery, chemicals, and land, respectively. They are also in line with the induced innovation theory of Hayami and Ruttan (1971).

<u>Total factor productivity and technical change</u>

The concept of total factor productivity (TFP) emerged a long time ago to evaluate technical change. Basically TFP is the average product of all inputs defined as: TFP = Y/X, where Y is total output and X is an index of inputs. A change in total factor productivity is usually interpreted as: 1) the rate of change of an index of output divided by an index of inputs (Jorgensen and Griliches, 1967), or 2) a rate of shift in the production function (Tinbergen, 1942, and Solow, 1957).

A host of studies (Denny et al.,1981, Diewert, 1981, and Ball, 1985) utilized the concept to measure annual growth rates and assess the effects of technical changes. Ball (1985) used a flexible multioutput/multifactor technology to assess the rate of growth of total factor productivity in U.S. agriculture from 1948-1979. He used the following index of TFP proposed by Christensen and Jorgensen (1970):

$$\ln(TFP_t/TFP_{t-1}) = 1/2 \sum_i (R_{it} + R_{i,t-1}) \ln(y_{it}/y_{i,t-1}) - 1/2 \sum_i (s_{jt} + s_{j,t-1}) \ln(x_{jt}/x_{j,t-1}) \qquad [2.31]$$

where y_i and x_j are output and input indexes, respectively. R_i and S_j are output revenue shares and input cost shares, respectively. Among the findings of the study is that TFP grew at an average annual rate of 1.75%.

CHAPTER 3. DATA AND VARIABLES

The empirical work in this study utilizes a cross-section time series data set taken from the *Iowa Farm Assessors Annual* for the period 1942/1973, covering the 99 counties of the State of Iowa. All the variables are county level aggregates.

Enumeration of the crop and livestock data is the responsibility of the Office of the County Assessor. Some adjustments are made by the assessors to correct the reported data. The adjustments amount to a small fraction of the totals and are meant to maintain comparability with previous years and to keep reasonable relationships between adjacent counties and townships.

Still, observations on some variables remain incomplete. Since these variables are of primary importance for the purpose of this study, the missing values need to be derived from other sources.

Observations on the number of persons living on farms is not reported by the assessors for the year 1944, and for the last three years of the sample. Examination of the data revealed that this variable did not vary a great deal for the county between adjacent years. Thus, the mean value of persons living on farms in each county for the years 1942, 1943, and 1945 is used as an estimate for the missing values for 1944. For the last three years it will be assumed that the results for the previous period are applicable to these years. Considering the stability of this variable over short intervals of time, this assumption seems justifiable.

A similar problem is encountered with commercial fertilizer, where the 1945 data are missing, as are data for the last seven years of the study, i.e., from

1967 to 1973. For 1945 a growth rate is calculated for fertilizer for the period 1942/1946 as follows:

growth rate = (fertilizer (1946) - fertilizer (1942)/fertilizer (1942).

This growth rate is then applied to the 1942 data, assuming a constant growth rate over these five years. So the 1945 fertilizer data will be:

fertilizer (1945) = fertilizer (1942) (1 + growth rate *3/4).

For the last seven years data from the *Census of Agriculture, Iowa* were used to supplement the assessor's data. Growth rates were calculated between 1969 and 1964, then these growth rates were applied to the 1964 assessor's data to obtain data for 1967 and 1968. Similarly, growth rates for the period 1969/1974 were applied to the 1969 data to obtain values for 1971/1973.

The capital data are also incomplete. No data are recorded by the assessors for the last three years of the study. Capital growth rates obtained from *Census of Agriculture, Iowa* were applied to the 1969 data of the assessors to approximate these three years.

The last variable that is incomplete is limestone. In a similar manner growth rates were estimated and used to approximate values for the period 1968/1973.

Table 3.1 shows a description of the variables used in the identification equations, and Tables 3.2 and 3.3 show the descriptive statistics and the correlation matrix of these variables respectively. Table 3.4 shows a description of the variables used in the production functions and Table 3.5 shows Pearson's correlation matrix of these variables. Table 3.6 shows Pearson's correlation matrix of the capital items.

Table 3.1. Description of variables used in the identification equations

Variable	Description
CornA	Total acreage of corn harvested
SBA	Total acreage of soybeans harvested for beans
OatA	Total acreage of oats harvested
HayA	Total acreage of all hay from clover, timothy, alfalfa, soybeans and others
Labor	Total number of persons living on farms
ComFert	Tons of commercial fertilizer applied
Limstn	Tons of limestone applied
NoCow	Total number of cows
NoPig	Total number of pigs
CornSQ	CornA * CornA
OatSQ	OatA * OatA
SoySQ	SBA * SBA
CornOat	CornA * OatA
CornSoy	CornA * SBA
HayCorn	HayA * CornA
HayOatA	HayA * OatA
HaySBA	HayA * SBA
OatSoy	OatA * SBA
CornCow	CornA * NoCow
CornPig	CornA * NoPig
OatCow	OatA * NoCow
OatPig	OatA * NoPig
SoyCow	SBA * NoCow
SoyPig	SBA * NoPig

Table 3.2. Descriptive statistics of variable used in the identification equations

Period	Variable	N	Mean	Std. Dev.
1942-1949	ComFert	792	1618.7696	1504.1354
	Labor	792	7672.3864	1940.4711
	HayA	792	31884.3825	11705.4942
	OatA	792	53861.9229	23857.8718
	CornA	792	108134.6148	41599.6949
	SBA	792	17315.1868	13538.5809
	NoPig	792	39911.1742	54229.2568
	NoCow	792	12376.5631	5936.4432
1950-1957	ComFert	792	4179.4710	2464.8424
	Labor	792	7392.2260	1989.7588
	HayA	792	37934.1426	11829.4305
	OatA	792	57604.6401	26250.3491
	CornA	792	104645.3005	37065.7542
	SBA	792	20454.6856	17050.9848
	NoPig	792	42688.8446	53493.9301
	NoCow	792	9340.6906	5644.6784
1958-1965	ComFert	792	7270.2475	4097.9401
	Labor	792	6568.5240	1977.1100
	HayA	792	34464.5921	11570.7393
	OatA	792	39614.6982	18144.8546
	CornA	792	109491.8156	41833.6632
	SBA	792	36129.2727	44471.2396
	NoPig	792	25124.7594	10704.7637
	NoCow	792	7454.8787	6422.4317
1966-1973	ComFert	792	16094.5520	6912.4724
	Labor	792	5507.1131	1750.3740
	HayA	792	25674.7070	13153.9259
	OatA	792	25776.5151	12436.4926
	CornA	792	107393.9267	40565.0979
	SBA	792	57954.9343	32540.5895
	NoPig	792	24552.4608	11540.5886
	NoCow	792	4702.8787	5867.8781

Table 3.3. Pearson's correlation matrix of variables used in the identification equations

	ComFert	Labor	HayA	OatA	CornA	SBA	NoPig	NoCow
				Period	1942-49			
ComFert	1.00000	0.21206	-.07931	0.40004	0.23303	0.33598	0.11320	0.11454
Labor		1.00000	0.47831	0.68097	0.66288	0.14637	0.75217	0.68619
HayA			1.00000	-.01421	-.15247	-.42493	0.36375	0.63654
OatA				1.00000	0.82086	0.39332	0.63467	0.36575
CornA					1.00000	0.39718	0.60777	0.14153
SBA						1.00000	0.08442	-.01088
NoPig							1.00000	0.48830
NoCow								1.00000
				Period	1950-57			
ComFert	1.00000	0.45811	0.13159	0.44440	0.56431	0.40974	-.09175	0.27738
Labor		1.00000	0.63060	0.64305	0.69615	0.08254	0.27958	0.61379
HayA			1.00000	0.24601	0.19867	-.42188	0.14372	0.62514
OatA				1.00000	0.76514	0.26731	0.28080	0.27228
CornA					1.00000	0.38309	0.14194	0.12474
SBA						1.00000	-.04532	-.28831
NoPig							1.00000	0.17713
NoCow								1.00000
				Period	1958-65			
ComFert	1.00000	0.04052	-.16636	0.29023	0.65496	0.36710	0.30670	0.08783
Labor		1.00000	0.58132	0.80728	0.70461	0.03167	0.77774	0.61375
HayA			1.00000	0.48326	0.09422	-.24242	0.53446	0.63093
OatA				1.00000	0.76512	0.04771	0.71572	0.42140
CornA					1.00000	0.22380	0.57901	0.13866
SBA						1.00000	-.05864	-.20013
NoPig							1.00000	0.47351
NoCow								1.00000
				Period	1966-73			
ComFert	1.00000	0.55778	-.36569	0.30298	0.85305	0.73040	0.37937	0.00523
Labor		1.00000	0.43447	0.78308	0.73265	0.11222	0.76032	0.59675
HayA			1.00000	0.46612	-.17137	-.61734	0.38294	0.66758
OatA				1.00000	0.50183	-.07633	0.73173	0.58850
CornA					1.00000	0.56554	0.57215	0.11147
SBA						1.00000	-.04300	-.35649
NoPig							1.00000	0.45243
NoCow								1.00000

Table 3.4. Descriptive statistics of variables used in the production functions

Period	Variable	N	Mean	Std. Dev.
1942-1949	CornP	792	5458727.1396	2483485.7619
	OatP	792	1986933.8852	10696665.5259
	SBP	792	342517.8533	275004.9633
	CornF	792	5334.3023	1544.4433
	CornL	792	5870.2869	3417.3249
	OatF	792	4264.0389	2663.9259
	OatL	792	2046.9816	1858.6360
	SoyF	792	2117.4610	1409.3043
	SoyL	792	1228.0972	768.6273
	Capital	792	2152.3535	775.5859
	AnnPrec	792	32.7204	3.1384
	MJJTemp	792	67.3289	2.1606
1950-1957	CornP	792	5545362.2644	2372523.1910
	OatP	792	2081809.5482	1110692.4972
	SBP	792	465801.0534	409482.2034
	CornF	792	10647.1040	4021.0007
	CornL	792	5577.9533	1916.1319
	OatF	792	7061.6420	3367.1336
	OatL	792	3708.2767	3319.9671
	SoyF	792	2436.4965	1597.7937
	SoyL	792	562.0366	381.7204
	Capital	792	3496.4116	1084.4249
	AnnPrec	792	29.9951	5.8871
	MJJTemp	792	68.5869	1.4454
1958-1965	CornP	792	7992639.9232	3295056.4673
	OatP	792	1775544.2395	910014.3082
	SBP	792	990780.4359	1292841.2087
	CornF	792	9055.0257	4510.9056
	CornL	792	1870.5089	1043.7822
	OatF	792	68253.2192	30914.0354
	OatL	792	1538.0559	1252.0651
	SoyF	792	6563.8359	4701.4658
	SoyL	792	1251.2504	831.2801
	Capital	792	3782.9280	1128.6475
	AnnPrec	792	33.0680	4.8377
	MJJTemp	792	68.3048	1.5281
1966-1973	CornP	792	10485209.9322	4466117.3349
	OatP	792	1424850.2399	738181.8512
	SBP	792	1868072.1309	1141799.2537
	CornF	792	11833.7502	5974.4646
	CornL	792	4199.5936	2231.9801
	OatF	792	7620.9184	4068.6286
	OatL	792	1794.0951	1389.8733
	SoyF	792	6835.6469	3993.7768
	SoyL	792	2290.4119	1957.2161
	Capital	792	3504.0889	1078.0370
	AnnPrec	792	33.3272	5.0030
	MJJTemp	792	67.6110	1.0853

Table 3.5. Pearson's correlation matrix of variables used in the production functions

Variable	CornP	OatP	SBP	CornF	CornL	OatF	OatL	SoyF	SoyL	Capital	AnnPrec	MJJTemp
						Period	1942-49					
CornP	1.00000	0.71999	0.43806	0.68259	0.83052	0.55394	0.75565	0.36904	0.16580	0.70534	-.15072	0.20651
OatP		1.00000	0.45437	0.80175	0.65476	0.65476	0.79620	0.56620	0.25077	0.79946	-.30997	0.03762
SBP			1.00000	0.54053	0.75758	0.75758	0.48568	0.72650	0.86484	0.48802	0.02871	0.02120
CornF				1.00000	0.61397	0.64170	0.65414	0.45124	0.30459	0.76408	-.15439	0.06667
CornL					1.00000	0.67632	0.92647	0.45552	0.22192	0.77645	0.00182	0.03525
OatF						1.00000	0.75220	0.58745	0.55470	0.71952	-.00040	-.04497
OatL							1.00000	0.56604	0.27212	0.79145	-.09907	0.03565
SoyF								1.00000	0.81184	0.48255	-.05207	-.01365
SoyL									1.00000	0.29012	0.12735	-.08246
Capital										1.00000	-.22437	-.06728
AnnPrec											1.00000	-.41555
MJJTemp												1.00000
						Period	1950-57					
CornP	1.00000	0.67078	0.38077	0.81641	0.52566	0.55851	0.70007	0.48478	-.00802	0.83470	-.08553	0.17992
OatP		1.00000	0.33022	0.61115	0.72999	0.64535	0.75292	0.50701	-.00343	0.67220	-.00879	-.09570
SBP			1.00000	0.16775	-.15595	0.58945	0.40622	0.73966	0.80450	0.37578	-.02068	0.06355
CornF				1.00000	0.50195	0.30538	0.66724	0.35751	-.16674	0.80597	-.02985	0.06629
CornL					1.00000	0.52475	0.55178	0.15037	-.35604	0.55283	0.02586	-.10140
OatF						1.00000	0.67991	0.67927	0.32778	0.57759	-.01775	-.00347
OatL							1.00000	0.67278	0.01509	0.64124	0.01511	0.04343
SoyF								1.00000	0.57866	0.52076	-.04640	0.12169
SoyL									1.00000	0.08819	-.11242	0.13246
Capital										1.00000	- 09981	0.19742
AnnPrec											1.00000	-.65812
MJJTemp												1.00000

Period 1958-65

CornP	1.00000	0.71954	0.29633	0.52918	0.67790	0.61744	0.57367	0.47593	0.33779	0.83079	0.05890	0.11421
OatP		1.00000	0.12762	0.53442	0.65042	0.92713	0.84411	0.13389	0.11159	0.87694	-.04149	-.19432
SBP			1.00000	0.53816	0.16817	-.09809	0.16961	0.56744	0.56646	0.19205	-.00914	0.11956
CornF				1.00000	0.56510	0.41081	0.39347	0.21899	0.08113	0.63019	-.06408	0.03049
CornL					1.00000	0.68560	0.52886	0.09658	0.05411	0.78955	-.02299	-.02344
OatF						1.00000	0.85948	-.07691	-.07177	0.81307	-.05848	-.29795
OatL							1.00000	0.10682	0.16352	0.65344	-.05191	-.31936
SoyF								1.00000	0.92628	0.27537	0.04805	0.22047
SoyL									1.00000	0.17654	-.00463	0.12715
Capital										1.00000	-.02013	-.03904
AnnPrec											1.00000	0.00854
MJJTemp												1.00000

Period 1966-73

CornP	1.00000	0.49039	0.66794	0.73945	0.66622	0.12773	0.60551	0.75662	0.44827	0.79608	0.13852	-.04869
OatP		1.00000	0.06821	-.03699	0.73771	0.80022	0.81878	0.37429	-.10365	0.76589	-.19172	-.00729
SBP			1.00000	0.65013	0.17311	-.19080	-.03404	0.83586	0.88259	0.37885	0.29080	0.11102
CornF				1.00000	0.43715	-.45338	0.17379	0.53686	0.56731	0.38647	0.08163	-.08734
CornL					1.00000	0.31437	0.81045	0.41409	-.03002	0.70704	-.18425	-.08839
OatF						1.00000	0.58052	0.12170	-.26766	0.55297	-.10041	-.06845
OatL							1.00000	0.31766	-.21230	0.79602	-.16208	-.07644
SoyF								1.00000	0.61474	0.59447	0.14446	0.07256
SoyL									1.00000	0.26067	0.28316	0.05382
Capital										1.00000	0.02307	-.01475
AnnPrec											1.00000	0.16325
MJJTemp												1.00000

Table 3.6. Pearson's correlation matrix of capital items (1942-1973)

	Tractors	Combines	Corn Pickers
Tractors	1.00	0.82	0.88
Combines		1.00	0.87
Corn Pickers			1.00

CHAPTER 4. THEORETICAL FORMULATIONS

Conditional Demands

The conditional demand framework will be utilized to arrive at the allocation equations of the three inputs: commercial fertilizer, limestone, and labor. Given the available information on the county aggregate use of these inputs and land alloted to each crop, equations will be derived to estimate the amount of each input used in each crop. The significance of these allocations is twofold:

1) The allocations will be used in the estimation of the crop production functions.

2) They reveal information about the producer behavior as regards which crop receives more emphasis in terms of input allocation. This in turn reveals information about the relative profitability of investing in the different crops.

In Chapter 2, from the study of Parti and Parti (1980), equation [2.1] relates the electricity usage by the i^{th} appliance to a set of explanatory variables (v). Equation [2.3] is obtained by taking the sum of equation [2.1] over the number of appliances owned by the household. The result is the total household consumption on one hand and the sum of the components of this consumption on the other hand.

Now viewing these equations in terms of input demands and utilizing the analogy between the two situations:

Let A_i = area alloted to crop i in acres; and

x_{ij} = amount of input j used to produce crop i;

Crop i's utilization of input j then can be represented by the quadratic;

$$x_{ij} = a_i A_i + \sum_k a_{ik} A_i A_k + a \qquad [4.1]$$

Where:

a_i and $a_{ik} = a_{ki}$ are parameters of crop i's demand equation, and

a is an error term.

If the x_{ij} are known, then it could be possible to estimate [4.1] directly through regression analysis.

This equation is similar to equation [2.1] of Parti and Parti. The total input usage is simply the sum of utilizations by all crops. So summation of [4.1] over i yields:

$$x_j = \sum_i a_i A_i + \sum_i \sum_k a_{ik} A_i A_k + a' \qquad a_{ik} = a_{ki} \qquad [4.2]$$

Where:

X_j = total usage of input j

a' is an error term.

Equation [4.2] is the conditional demand equation and is the equivalence of equation [2.3] of Parti and Parti. It defines input j's allocation to crop i subject to the conditions on the other crops.

As discussed previously, this study attempts to allocate the three inputs: commercial fertilizer, labor, and limestone. The study focuses on the three major crops in the output mix of Iowa farms: corn, oats, and soybeans.

In the preliminary runs of the identification equations hay was entered into the analysis, and the results showed a highly significant hay coefficient. So, to provide for more identification hay will be included in the first stage regressions although it will not be emphasized in the later developments.

Livestock terms will also be incorporated in the identification equations to provide for the following:

1) To gain the maximum identification information about the allocation of these inputs, especially labor, since livestock is supposed to be a relatively labor intensive enterprise.

2) To investigate any possible substitution or complementarity relation between livestock and commercial fertilizer. In this context numbers of animals on the farm enter the equations as a proxy for manure.

Taking them one at a time the identification equations or the conditional demand equations of the three inputs can be defined explicitly as follows:

1. Commercial fertilizer:

$$\begin{aligned} \text{ComFert} = {} & a_1\text{CornA} + a_2\text{OatA} + a_3\text{SBA} + a_4\text{HayA} + a_5\text{NoCow} + a_6\text{NoPig} \\ & + 0.5\, a_{11}\text{CornSQ} + a_{12}\text{CornOat} + a_{13}\text{CornSoy} + a_{14}\text{HayCorn} \\ & + 0.5\, a_{22}\text{OatSQ} + a_{23}\text{OatSoy} + a_{24}\text{HayOatA} + 0.5\, a_{33}\text{SoySQ} \\ & + a_{34}\text{HaySBA} + a_{15}\text{CornCow} + a_{25}\text{OatCow} + a_{35}\text{SoyCow} \\ & + a_{16}\text{CornPig} + a_{26}\text{OatPig} + a_{36}\text{SoyPig} + a \qquad [4.3] \end{aligned}$$

where ComFert = tons of commercial fertilizer, and

a_i and a_{ij} are parameters. a is $a \sim N(0, \delta^2)$.

2. Labor:

$$\begin{aligned} \text{Labor} = {} & b_1\text{CornSQ} + b_2\text{OatA} + b_3\text{SBA} + b_4\text{HayA} + b_5\text{NoCow} + b_6\text{NoPig} \\ & + 0.5\, b_{11}\text{CornSQ} + b_{12}\text{CornOat} + b^{13}\text{CornSoy} + b_{14}\text{HayCorn} \\ & + 0.5\, b_{22}\text{OatSQ} + b_{23}\text{OatSoy} + b_{24}\text{HayOatA} + 0.5\, b_{33}\text{SoySQ} \\ & + b_{34}\text{HaySBA} + b_{15}\text{CornCow} + b_{25}\text{OatCow} + b_{35}\text{SoyCow} \\ & + b_{16}\text{CornPig} + b_{26}\text{OatPig} + b_{36}\text{SoyPig} + b \qquad [4.4] \end{aligned}$$

where Labor = number of persons living on farms, and

b_i and b_{ij} are parameters with $b \sim N(0, \delta^2)$.

3. Limestone:

$$\begin{aligned} \text{Limstn} = {} & c_1\text{CornA} + c_2\text{OatA} + c_3\text{SBA} + c_4\text{HayA} + c_5\text{NoCow} + c_6\text{NoPig} \\ & + 0.5\, c_{11}\text{CornSQ} + c_{12}\text{CornOat} + c_{13}\text{CornSoy} + c_{14}\text{HayCorn} \\ & + 0.5\, c_{22}\text{Oat SQ} + c_{23}\text{OatSoy} + c_{24}\text{HayOatA} + 0.5\, c_{33}\text{SoySQ} \\ & + c_{34}\text{HaySBA} + c_{15}\text{CornCow} + c_{25}\text{OatCow} + c_{35}\text{SoyCow} \\ & + c_{16}\text{CornPig} + c_{26}\text{OatPig} + c_{36}\text{SoyPig} + c \qquad [4.5] \end{aligned}$$

where Limstn = tons of limestone, and

c_i and c_{ij} are parameters with $c \sim N(0, \delta^2)$.

Allocation Equations

Equations [4.3], [4.4] and [4.5] are the first stage regressions. They are designed to capture all sources of variability in input usages, so the emphasis is on the maximum possible identification.

Using the identification equations the input allocations to the three crops can be derived. The partial derivative of each of the three equations with respect to a particular crop area, yields the allocation of that input to that particular crop, at the marginal acre. These derivatives evaluated at the means of their arguments will be used as the allocation of the respective input per acre of the respective crop.

The allocation equations of the three inputs to the three crops follows:

1. Corn:

1.1 CornF = (∂ ComFert/∂ CornA) * CornA.

$$\begin{aligned} & = \text{CornA}(a_1 + 2a_{11}\text{CornA} + a_{12}\text{OatA} + a_{13}\text{SBA} + a_{14}\text{HayA} \\ & \quad + a_{15}\text{NoCow} + a_{16}\text{NoPig}) \qquad [4.6] \end{aligned}$$

where CornF is the tons of commercial fertilizer allocated to corn. a_1, a_{11}, a_{12}, a_{13}, a_{14}, a_{15}, and a_{16} are the estimated parameters of equation [4.3].

1.2 CornL = (∂ Labor/∂ CornA) * CornA.

$$= \text{CornA}\,(a_1 + 2a_{11} + a_{12}\text{OatA} + a_{13}\text{SBA} + a_{14}\text{HayA} + a_{15}\text{NoCow} + a_{16}\text{NoPig}) \qquad [4.7]$$

where CornL is the amount of labor allocated to corn. b_1, b_{11}, b_{12}, b_{13}, b_{14}, b_{15}, and b_{16} are the estimated parameters of equation [4.4].

1.3 CornLi = (∂ Limstn/∂ CornA) * CornA

$$= \text{CornA}(c_1 + 2c_{11}\text{CornA} + c_{12}\text{OatA} + c_{13}\text{SBA} + c_{14}\text{HayA} + c_{15}\text{NoCow} + c_{16}\text{NoPig}) \qquad [4.8]$$

where CornL is the tons of limestone allocated to corn. c_1, c_{11}, c_{12}, c_{13}, c_{14}, c_{15}, and c_{16} are the estimated parameters of equation [4.5].

2. Oats:

2.1 OatF = (∂ ComFert/∂ OatA) * OatA.

$$= \text{OatA}\,(a_2 + a_{12}\text{CornA} + 2a_{22}\text{OatA} + a_{23}\text{SBA} + a_{24}\text{HayA} + a_{25}\text{NoCow} + a_{26}\text{NoPig}) \qquad [4.9]$$

where OatF is the tons of fertilizer allocated to oats. a_2, a_{12}, a_{22}, a_{23}, a_{24}, a_{25}, and a_{26} are the estimated parameters of equation [4.3].

2.2 OatL = (∂ Labor/∂ OatA) * OatA

$$= \text{OatA}\,(b_2 + b_{12}\,\text{CornA} + 2b_{22}\text{OatA} + b_{23}\text{SBA} + b_{24}\text{HayA} + b_{25}\text{NoCow} + b_{26}\text{NoPig}) \qquad [4.10]$$

where OatL is the amount of labor allocated to oats. b_2, b_{12}, b_{22}, b_{23}, b_{24}, b_{25}, and b_{26} are the estimated parameters of equation [4.4].

2.3 OatLi $= (\partial \text{ Limstn}/\partial \text{ OatA}) * \text{OatA}.$

$$= \text{OatA } (c_2 + c_{12}\text{CornA} + 2c_{22}\text{OatA} + c_{23}\text{SBA}, + c_{24}\text{HayA} + c_{25}\text{NoCow} + c_{26}\text{NoPig}) \quad [4.11]$$

where OatLi is the tons of limestone allocated to oats. c_2, c_{12}, c_{22}, c_{23}, c_{24}, c_{25}, and c_{26} are the estimated parameters of equation [4.5].

3. Soybean:

3.1 SoyF $= (\partial \text{ ComFert}/\partial \text{ SBA}) * \text{SBA}.$

$$= \text{SBA } (a_3 + a_{13}\text{CornA} + a_{23}\text{OatA} + 2a_{33}\text{SBA}, + a_{34}\text{HayA} + a_{35}\text{NoCow} + a_{36}\text{NoPig}) \quad [4.12]$$

where SoyF is the tons of fertilizer allocated to soybean. a_3, a_{13}, a_{23}, a_{33}, a_{34}, a_{35}, and a_{36} are the estimated parameters of equation [4.3].

3.2 SoyL $= (\partial \text{ Labor}/\partial \text{ SBA}) * \text{SBA}.$

$$= \text{SBA } (b_3 + b_{13}\text{CornA} + b_{23}\text{OatA} + 2b_{33}\text{SBA}, + b_{34}\text{HayA} + b_{35}\text{NoCow} + b_{36}\text{NoPig}) \quad [4.13]$$

where SoyL is the amount of labor allocated to soybean. b_3, b_{13}, b_{23}, b_{33}, b_{34}, b_{35}, and b_{36} are the estimated parameters of equation [4.4].

3.3 SoyLi $= (\partial \text{ Limstn}/\partial \text{ SBA}) * \text{SBA}.$

$$= \text{SBA } (c_3 + c_{13}\text{CornA} + c_{23}\text{OatA} + 2c_{33}\text{SBA}, + c_{34}\text{HayA} + c_{35}\text{NoCow} + c_{36}\text{NoPig}) \quad [4.14]$$

where SoyLi is the amount of limestone allocated to soybean. c_3, c_{13}, c_{23}, c_{33}, c_{34}, c_{35}, and c_{36} are the estimated parameters of equation [4.5].

The identification equations [4.3], [4.4], and [4.5] are to be estimated over eight-year intervals. So, for the thirty-two years of the study, each equation will be estimated four times. In the same manner each allocation equation will be estimated four times using the relevant identification equation.

Production Functions

The transcendental logarithmic function (translog) (Christensen, Jorgensen and Lau, 1971) will be used to estimate the production functions for the three crops:

$$\ln y_k = \alpha_{0k} + \sum_i \alpha_{ik} \ln x_{ik} + .5 \sum_i \sum_j \beta_{ijk} \ln x_{ik} \ln x_{jk} \qquad [4.15]$$

where y_k = output of the k^{th} crop, k=1,2,3;

x_{ik} = amount of the i^{th} input used to produce the k^{th} crop;

α_{0k}, α_{ik}, and β_{ijk} are parameters.

The inputs that will be used in the above equation are: tractors, combines, labor and commercial fertilizer.

The two items of capital will be aggregated into a crude capital measure, simply by adding up all items. In this regard Heady (1946) and Heady and Dillon (1961) found that machinery and equipment are usually so highly correlated that they should be grouped to form a single input category.

This aggregation increases the degrees of freedom and makes computations more feasible.

A Pearson's correlation matrix (Table 3.6) shows a high correlation between the two items. This tends to support the argument for the aggregation scheme. The alternatives of using a capital value measure or a cost of capital use, are precluded by lack of price data and information on the vintage, depreciation and maintenance costs of the capital stock.

To control for weather, two weather attributes will be appended to equation [4.15]. These are annual precipitation and the mean temperature in the months of May, June, and July. In an attempt to account for the differences in soil quality among the different locations, a set of dummy variables is designed for the nine districts of the state as follows:

$$\text{if district} = d, \text{ then } D_d = 1; \qquad d = 1, \ldots, 8$$
$$\text{else } D = 0$$

These dummies are supposed to pick up variation in soil qualities in general, however, other attributes or variates, such as differences in managerial ability, crop cultural practices, and extension services, may be caught in the process.

The complete specification of [4.15], after controlling for weather and soil quality, is:

$$\ln y_k = \alpha_{0k} + \sum_i \alpha_{ik} \ln x_{ik} + .5 \sum_i \sum_j \beta_{ijk} \ln x_{ik} \ln x_{jk} + \lambda \text{AnnPrec} + \Psi \text{MJJTemp} + \sum_d \theta_d D_d$$

where: AnnPrec = annual precipitation;

MJJTemp = mean temperature in the months of May, June and July; and

d = district.

These production functions will be estimated for the same 8-year intervals as the identification equations. The same functions will also be estimated using the aggregate input levels to compare and contrast with [4.15], however, the same specification will be used. For the purposes of econometric estimation an error term should be appended to each equation.

Elasticities of Complementarity

This measure will be computed between pairs of the three inputs: capital, labor, and fertilizer. Basically it measures the percentage responsiveness of relative factor prices to a one percent change in the factor input ratio.

$$C_{ij} = \frac{\partial \ln(w/r)}{\partial \ln(x_i/x_j)}$$

where C_{ij} is the elasticity of complementarity between inputs x_i and x_j. r and w are the two input prices respectively.

From the production function the calculation formula is as follows:

$C_{ij} = b_{ij}/s_i s_j + 1$ and

$C_{ii} = (b_{ii} + s_i^2 - s_i)/s_i^2$.

Where s_i is factor i's share in total output and b_{ii} and b_{ij} are the second order coefficients of the production function. From [4.15]:

$$s_i = \frac{\partial \ln y_k / \partial \ln x_{ik}}{r} = \frac{\alpha_i + \sum_j \beta_{ij} \ln x_j}{r}$$

where

$$r = \sum_i \frac{\partial \ln y_k}{\partial \ln x_{ik}} \qquad i=1, \ldots, n$$

own and cross, input demand elasticities, will also be computed from the formulas:

$$\varepsilon_{ii} = \frac{\left(\beta_{ii} + s_i^2 - s_i\right)}{s_i}$$

$$\varepsilon_{ij} = \frac{\left(\beta_{ij} + s_i s_j\right)}{s_i}$$

where ε_{ii} is input i's elasticity of demand and ε_{ij} is the cross demand elasticity between inputs i and j. β_{ii} and s_i are same as defined above.

Technical Change Bias

As preceded four production functions will be estimated for the four time periods: 1942-1949, 1950-1957, 1958-1965, and 1966-1973.

Technical change will be examined in two ways. First, total factor productivity (TFP) will be estimated for each two adjacent periods holding the input bundle fixed. In other words, the production function will be evaluated for the two time periods--different states of technology--under comparison at a fixed input level, and the difference between the two values reflects a shift in the production function solely due to time.

This difference is actually an index of the relative effectiveness of a given input bundle in producing output for different states of technology.

$$\lambda_i = \ln(y_{\bar{x}})_t - \ln(y_{\bar{x}})_{t-1} \qquad i = 1,2,3 \qquad t = 2,3,4$$

Where λ is an index of the relative effectiveness of the input bundle x.

$(y_x)_t$ is the production function evaluated at time t using the input bundle x.

$(y_x)_{t-1}$ is the production function evaluate at t-1 using same input bundle x.

Now for our four periods three such indexes will be evaluated.

Technical change makes the input bundle more effective, less effective, or leaves its effectiveness unchanged if λ is more than, less than, or equal to zero, respectively. Since farmers are expected to move toward superior technologies, I would expect that the relative effectiveness of a given input would be enhanced through time. Accordingly, positive values of λ are expected.

The above index, being an average, is an overall measure for the relative effectiveness of the whole input bundle. It is not very informative in addressing the question of the impact of technical change on input use or productivity.

Thus, our second measure of technical change is one that provides an answer to the above question. From the production function [4.15]:

$$d\ln y_k/d\ln x_{ik} = \partial y_k/\partial x_{ik} * x_{ik}/y_k,$$

so the marginal product of x_i, mpx_{ik} is,

$$mpx_{ik} = \partial y_k/\partial x_{ik} = d\ln y_k/d\ln x_{ik} * y_k/x_{ik} = (\alpha_{ik} + \sum_j \beta_{ijk} \ln x_{jk}) * y_k/x_{ik}.$$

Similarly, $mpx_{jk} = \partial y_k/\partial x_{jk} = (\alpha_{jk} + \sum_i \beta_{ijk} \ln x_{ik}) * y_k/x_{jk}$.

The marginal rate of technical substitution between x_i and x_j is:

$$MRTS_{xixj} = mpx_{ik}/mpx_{jk}.$$

Geometrically, MRTS at a point is the slope of isoquant at that particular point.

Now let $(mp\bar{x}_i/mp\bar{x}_j)_t$ be the MRTS or the slope of isoquant at time t, and $(mp\bar{x}_i/mp\bar{x}_j)_{t-1}$ be the slope at time $t-1$, where the bar over the variable indicates a fixed level of the input and the two time subscripts represent different states of technology.

The bias of technical change will be measured by the change in the slope of isoquant between two production periods (two states of technology), at a fixed input level.

Technical change would be biased for x_i, neutral, or biased against x_i if:

$$(mp\overline{x_j} / mp\overline{x_j})_t \gtreqless (mp\overline{x_j} / mp\overline{x_j})_{t-1}$$

Table 4.1. Description of variables of the production functions

Variable	Description
LOatF	log (oats fertilizer)
LOatL	log (oats labor)
LCapital	log (capital)
LOatFSQ	log (oat fertilizer) * log (oat fertilizer)
LOatLSQ	log (capital) * log (oat labor)
LCapSQ	log (capital) * log (capital)
OatLF	log (oat labor) * log (oat fertilizer)
OatFCap	log (oat fertilizer) * log (capital)
OatLCap	log (oat labor) * log (capital)
LCornF	log (corn fertilizer)
LCornL	log (corn labor)
LCornFSQ	log (corn fertilizer) * log (corn fertilizer)
LCornLSQ	log (corn labor) * log (corn labor)
CornLF	log (corn labor) * log (corn fertilizer)
CornFCap	log (corn fertilizer) * log (capital)
CornLCap	log (corn labor) * log (capital)
LSoyF	log (soybean fertilizer)
LSoyL	log (soybean labor)
LSBFSQ	log (soybean fertilizer) * log (soybean fertilizer)
LSBLSQ	log (soybean labor) * log (soybean labor)
SBLF	log (soybean labor) * log (soybean fertilizer)
SBFCap	log (soybean fertilizer) * log (capital)
SBLCap	log (soybean labor) * log (capital)
AnnPrec	Annual precipitation
MJJTemp	Average temperature for May, June, and July
D_1	Northwest district (dummy)
D_2	North Central district (~)
D_3	Northeast district (~)
D_4	West Central district (~)
D_5	Central district (~)
D_6	East Central district (~)
D_7	Southwest district (~)
D_8	South Central district (~)

CHAPTER 5. EMPIRICAL RESULTS AND DISCUSSIONS

Identification Equations

The identification equations for the three inputs fertilizer, limestone, and labor were estimated. Each was estimated for the four time periods as discussed in Chapter 4.

First, it should be noted that the purpose of these equations is to identify sources of variability in the aggregate input usage and to derive prediction equations to estimate the individual crops' input utilizations. Some parameters were not significant at the conventional significance levels. However, I chose to keep all variables in the equation. My decision to include all parameters in the equation regardless of the precision of the estimate was based upon the following arguments:

1) The data set is the population itself and hence no statistical inference is involved.
2) For all estimated equations, the parameters are jointly significant as indicated by the F-tests of significance for the whole model.
3) No future forecasts beyond the time period of the study are involved. The allocation equations are designed to predict input allocations using the same setting of independent variables used in the identification equations. In this case we have a smaller prediction error than if a future value is to be forecast.
4) The purpose is to explore the performance of a conditional demand framework for production function estimation, so a premium is placed on keeping the same specification for all applications.

Except for the limestone equation (Tables 5.3.1 through 5.3.4), the results were very good in terms of the explanatory power of the models. The explanatory power of the limestone equation decreased over time with R-squares of (0.54), (0.54), (0.50), and (0.16) for the four time periods, respectively. This suggests that limestone is difficult to allocate on the basis of land use. Actually limestone does not have a fertilization role, it is added as a soil conditioner and may be added due to soil type and not due to crop choice. So in light of these results and due to its poor performance in the preliminary estimates, limestone was removed from the final specifications of the production functions. The commercial fertilizer identification equation (Tables 5.1.1 through 5.1.4) did extremely well except for the first period in which a relatively small R-square of (0.39) is observed. To a lesser extent this is also the case for the second period which had an R-square of (0.57). These two periods showed relatively high coefficients of variability of (73.3) and (39.1) respectively, which suggests examining the distribution of the dependent variable, commercial fertilizer, for outliers. However, no outliers could be detected. Given the purpose of these equations, and given the reasonable consistency of the parameter estimates across periods, I elected to use all four estimates.

As for the labor identification equation (Tables 5.2.1 through 5.2.4), the results are quite satisfactory with an R-square of (0.89) for the first period and (0.87) for the other three periods.

Basically the identification or conditional demand equations express the input demands for each crop, given the conditions on the other crops input demands. For instance, the commercial fertilizer conditional demand equation contains all the parameters that allow for the estimation of fertilizer allocation to corn given the conditions on allocations to oats and soybeans.

Parameter estimates for the two equations, commercial fertilizer and labor, were consistent throughout the four periods. Since both equations have the same specification for all periods, similar interpretations follow, and similar kinds of information can be extracted. The only difference is that they have different dependent variables.

The cross partial derivative $\frac{\partial^2 \text{Comfert}}{\partial A_i \partial A_j}$, evaluates the effect of a one acre change in the area of crop j on the fertilizer allocation per one acre of crop i, areas of other crops held constant. With respect to corn and oats the values of the derivative are (1.41 E-07, -3.09 E-07, -5,13 E-07, and -1.51 E-07) for the four periods, respectively. With the exception of period one, the interpretation is that, expanding oats acreage would increase the productivity of fertilizer in corn production, thus lowering the marginal fertilizer input in corn production..

In a similar manner, the cross derivative $\frac{\partial^2 \text{Labor}}{\partial A_i \partial A_j}$ evaluates the effect of a one acre change in the area of crop j on the labor allocation to crop i. For corn and oats three out of four such derivatives were positive, meaning that the expansion of oat's area results in more labor being allocated to corn. The interpretation is that increasing acreage in a crop rotation results in more labor being necessary for corn production. Similar results were obtained for increasing hay and soybean production on labor requirements for corn production.

To investigate the relationship between fertilizer and the proxy variables, NoCow and NoPig, which are used to index farm manure, two approaches are tried. The first one estimates the effect on total fertilizer usage due to a change in the number of either animals. This in effect means evaluating the derivatives $\frac{\partial \text{Comfert}}{\partial \text{NoCow}}$ and $\frac{\partial \text{Comfert}}{\partial \text{NoPig}}$ at the sample means. Estimates of the NoCow effect are (0.05, 0.11, 0.34, and -0.08) for the four periods, respectively. For the NoPig the estimates are (0.30, 0.71, 0.52, and -0.11), respectively, so in general, farm manure and commercial fertilizer tend to complement each other, as indicated by the positive derivatives, except in period four. The second approach is crop specific. It entails evaluating the effect of a change in the number of either animals on the fertilizer allocation to a particular crop. Basically, this means evaluating the derivatives $\frac{\partial^2 \text{Comfert}}{\partial A_i \, \partial \text{NoCow}}$ and $\frac{\partial^2 \text{Comfert}}{\partial A_i \, \partial \text{NoPig}}$. When these were evaluated for the three crops for the four periods--a total of 24 derivatives--half of them were positive and the other half were negative. For each crop, signs alternate without a clear pattern, thus no solid conclusion could be drawn.

From each identification equation, the input allocations are estimated at the sample means of the variables, using the allocation equations [4.6] through [4.14]. Allocations of the j^{th} input per one acre of the i^{th}crop are obtained from the derivative $\frac{\partial x_j}{\partial A_i}$. These are shown in Tables 5.0.1 through 5.0.3. Some of the allocations are negative. This also happened when allocations were estimated for each year. In particular, for oats, fertilizer allocations were negative in the third period, and so were the labor allocations in the first three periods. For soybeans, labor allocations in the last period were also negative. Nonetheless, the relative value of the estimated input allocations may still be reliable, even if the actual values are not. The negative values make it impossible to use the logarithmic transformation necessary for estimation in the translog form.

To make the logarithmic transformations possible, the absolute value of the minimum estimated allocations was added to the allocated input value. This measure, in effect, shifts the distribution of the allocated input values to the right without affecting its shape.

Estimated Production Functions

Equation [4.15] is estimated for each crop for the four time periods. Each equation was first estimated using the unallocated aggregate input levels as the input level for each crop. Estimates of these functions are reported in Tables A.1 through A.12 in the Appendix. Estimates of the production functions using unallocated input levels did well in terms of explanatory power and significance and stability of parameters. However, for oats and soybeans, most of the implied marginal products were negative, as shown in Tables A.13 through A.15 in the Appendix. These negative values yield unreasonable output elasticity estimates and make the assessment of technical change bias difficult. It will be informative to examine how these estimates compare to those obtained using the implied input allocations from the conditional demand framework.

In general, estimates using the allocated inputs were superior to estimates from the aggregate unallocated inputs. The former has relatively better fits and more reasonable implied marginal products.

Corn production functions

Estimates of the corn production functions for the four time periods are shown in Tables 5.4.1 through 5.4.4. High R-squares of (0.87), (0.85), (0.85), and (0.91) are obtained for the four periods respectively, which means most of the variability in output is captured with the set of explanatory variables and the assumed functional form.

All the output elasticities (input shares) are significant at the (0.05) significance level except for labor in the fourth period. Also, all elasticities showed the expected signs, except capital in the first period, as can be seen in

Table 5.4.5. As for the magnitudes of these input shares, a roughly downwards trend over time can be observed in the labor shares (from .95 in period one to .13 in period four). In a less regular pattern, capital share is increasing over time with estimates of (-0.71), (0.09), (0.91) and (0.49). For fertilizer the pattern is not regular. Thus, one can deduce a trend towards mechanization or replacement of labor by capital over time. This point will be elaborated later when I discuss the effect of technical change.

Elasticities of complementarity

These are estimated for the four time periods and are shown in Table 5.4.6.

All diagonal elements have the right signs except capital in the first and fourth periods and labor in the third period. Perhaps the most intuitively appealing and interesting among these relations are the capital-labor relationships. Thus, they will be highlighted here as well as in the discussions of the other two crops.

Periods two, and three show that labor and capital are complements with estimates of (6.4181), and (5.1125), respectively, while periods one and four show a substitution relationship between the two inputs with estimates of (-0.1258) and (-4.6084), respectively.

All the own input demand elasticities displayed the right signs, except labor in the third period (Table 5.4.7). Estimates of the cross demand elasticities between capital and labor support the conclusion drawn above on the complementarity between these inputs.

Oats production functions

The four production functions (Tables 5.5.1 through 5.5.4) have high explanatory powers of (0.90), (0.80), (0.96), and (0.95) respectively, and most of the coefficients are significant at the (0.05) level.

All of the input shares and hence the marginal products are positive, Table 5.5.5 and all the shares except that of labor in the second period, are significant at the 0.05 level. Relative use of labor is decreasing throughout the four periods with estimates of (0.44), (0.32), (0.30) and (0.18) respectively. The fertilizer share displayed an upward trend with estimates of (0.26), (0.59), (0.22), and (0.60). No clear pattern could be observed regarding capital's share.

Elasticities of complementarity

These appear in Table 5.5.6. Two of the own elasticities have counterintuitive signs, namely, capital in the first and last periods.

Labor and capital behaved as substitutes in periods one and three with estimates of (-6.0612) and (-0.9334) respectively, and as complements in the second and fourth periods with estimates of (10.6285) and (3.8651) respectively. With the exception of period two, fertilizer and labor acted as substitutes. Estimates of the input demand elasticities (Table 5.5.7) support these results.

Soybean production functions

Again, very high explanatory powers were obtained (Tables 5.6.1 through 5.6.4). R-squares of (0.96), (0.97), (0.95), and (0.97) were observed for the four periods, respectively.

The inputs shares are displayed in Table 5.6.5. All except three shares are significant at the (0.05) level. However, four out of the twelve estimates showed negative signs, which will complicate the assessment of technical change as will be discussed later in this chapter.

Elasticities of complementarity

Due to the negative input shares four of the own elasticities displayed the wrong signs. These are fertilizer and labor in period one and capital in the third and fourth periods (Table 5.6.6). In all of the four periods capital and labor behaved as complements except in period one. However, the estimates of the cross demand elasticities (Table 5.6.7) contradicted some of these results. Because estimates obtained from negative shares are not meaningful, I would not place much emphasis on soybean results in my conclusions.

Technical Change

Estimates of the relative effectiveness of a given input bundle between adjacent time periods (different technologies) for the three crops are shown in Tables 5.7 through 5.9. As shown previously in Chapter 4 the index:

$$\lambda_i = \ln(y_{\bar{x}})_t - \ln(y_{\bar{x}})_{t-1}$$

denotes increasing, constant, or decreasing effectiveness of a given input bundle depending on whether $\lambda \gtreqless 0$.

Both corn and oats data show that total factor productivity (TFP) has deteriorated between period one and period two, with λ values of (-0.5195) and

(-.6908) for the two crops respectively. Between the same two periods evidence of progressive technical advancement is revealed in the soybean data, as indicated by a λ value of (0.8385).

Between periods two and three it is only the corn data that supported evidence of progressive technical change, with an estimated λ of (0.3562). On the other hand, oats and soybean data evidenced regressive technical change between these periods, with λ estimates of (-0.0067) and (-0.1898) for the two crops, respectively.

Evidence of progressive technical change is obtained for the three crops between periods three and four. Oats data in particular supports this evidence with a high λ value of (1.4108). Corn and soybean indexes are (.0937) and (0.4624) respectively. Some of these results, especially those resulting from comparisons between periods two and three, suggest that farmers are choosing inferior technologies. Since this is unlikely to be the case, some doubts are raised about the performance of data in period three. Poor performance of data in this period affects comparisons between the second and third periods as well as between the third and fourth periods. Therefore, I compute another set of total factor productivity estimates that compares periods one and two and periods two and four, excluding period 3.

These estimates are reported in Tables 5.13 through 5.15. Results comparing periods one and two are the same as those in Tables 5.7 through 5.9. The comparison of periods two and four for the three crops showed that farmers are choosing more sound technologies in terms of more effective use of a given input bundle. This is indicated by the positive λ values of (0.6363), (0.2669) and (0.2956) for corn, oats, and soybeans, respectively.

Bias of Technical Change

As I indicated earlier in this chapter, the fact that some of the estimated marginal products are negative makes the assessment of technical change bias a little bit difficult. However, since these marginal products are estimated at the means of their arguments, one would expect their values to be positive at some data points.

In interpreting the results of Tables 5.10 through 5.12 more faith should be placed in periods and crops where positive marginal products were obtained. The justification is that one expects the estimates to be more reliable for those crops and periods. Thus, the results drawn hereafter are mostly from corn and oats data.

Earlier in Chapter 4, I indicated that technical change would be biased for x_1, neutral, or biased against x_1 if:

$$\left(\frac{mp\overline{x_1}}{mp\overline{x_2}}\right)_t \begin{matrix} > \\ = \\ < \end{matrix} \left(\frac{mp\overline{x_1}}{mp\overline{x_2}}\right)_{t-1}$$

In Table 5.11 results show that mp_K/mp_L has increased from (0.9419) in period one to (2.4591) in period two, and from (0.6396) in period three to (1.1542) in period four. Similar results are in Table 5.10, where mp_K/mp_L increased between period two and three from (0.8250) to (13.2614). Thus, according to our measure above, technical change has been biased for capital and against labor for these time periods.

From Table 5.10, a change in mp_f/mp_L from (0.8739) to (2.1256) between periods one and two, and from (0.4995) to (1.1477) between periods three and four indicates that technical change has been biased for fertilizer and against labor. A similar conclusion may be drawn from Table 5.11 by comparing periods one and two.

These results are very similar to previous findings by most of the recent literature on the issue of technical change and its bias (Hayami and Ruttan (1971), Binswanger (1974), Antle (1984), and Capalbo et al. (1986).

However, some of the other results are counter to the above. They are also not consistent with expectations on the effect of technical change. In Table 5.12 results indicate that technical change is biased for labor and against capital between periods one and two, with mp_K/mp_L of (0.2212) and (0.1316), and between periods two and three, with estimates of (0.0347) and (0.0003) respectively. In Table 5.10, a similar result is also obtained by comparing periods three and four. Results reveal that most of these unanticipated results were associated with comparisons relying on the production functions estimated in period three.

As I did with the total factor productivities, I re-evaluated the marginal products ratios excluding period three. Comparisons are made between periods one and two and periods two and four. This alternative comparison is shown in Tables 5.16 through 5.18. The results of the comparison of periods one and two are the same as those in Tables 5.10 through 5.12. All three crops supported the evidence that technical change has been biased towards capital and against labor between periods two and four. In addition, the estimates for oats and soybeans indicated that technical change has been biased toward fertilizer and against labor. For corn the relative bias was against fertilizer.

An additional indicator of technical change may be a reduction in the variance of output. I included measures of weather and regional dummy variables in each estimated production equation. Across most equations, in general, production is becoming less sensitive to weather over time. This is apparent from the declining magnitude and significance of the weather variables, as indicated by the t-values. The interpretation to this declining weather impact is that, through the development of less weather sensitive varieties, yields have become less dependent upon the presence of ideal growing conditions.

Table 5.0.1. ComFert allocations (per acre), evaluated at the means of 8 year intervals

Period	Corn	Oats	Soybeans
1	0.0196	0.0622	0.0618
2	0.0134	0.0194	0.0891
3	0.1180	-0.1239	0.0876
4	0.0848	0.0099	0.0606

Table 5.0.2. Limestone allocations (per acre), evaluated at the means of 8 year intervals

Period	Corn	Oats	Soybeans
1	0.2869	0.1060	0.5566
2	0.3789	-0.3491	0.0858
3	0.1219	-0.2149	0.1238
4	0.2566	0.4766	0.0352

Table 5.0.3. Labor allocations (per acre), evaluated at the means of 8 year intervals

Period	Corn	Oats	Soybeans
1	0.0388	-0.0107	0.0185
2	0.0618	-0.0216	0.0248
3	0.0158	-0.0188	0.0150
4	0.0116	0.0268	-0.0065

Table 5.1.1. Commercial fertilizer identification equation, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	1077.3236	1.901 *
HayA	-0.0565	-3.350 ***
SBA	0.0891	4.434 ***
OatA	-0.0123	-0.780
CornA	0.0174	1.705 *
NoPig	-0.0149	-3.063 ***
NoCow	0.1303	3.171 ***
CornSQ	-1.9864 E-07	-3.049 ***
OatSQ	-2.6684 E-07	-1.309
SoySQ	-2.3826 E-06	-7.014 ***
CornOat	1.4145 E-07	0.809
CornSoy	1.6510 E-07	0.743
HayCorn	-3.5515 E-07	-1.064
HayOat	2.0539 E-06	3.644 ***
HaySBA	-2.3860 E-08	-0.035
OatSoy	2.3164 E-06	6.888 ***
CornCow	3.7984 E-07	0.533
OatCow	-3.6025 E-06	-2.303 **
SoyCow	-3.3080 E-06	-2.519 **
SoyPig	-6.2173 E-07	-4.861 ***
OatPig	1.3072 E-09	0.011
CornPig	1.4165 E-07	1.949 *
R-square = 0.3942		
ADJ R-SQ = 0.3777		
F Value = 23.862		

*Significant at the 0.1 level.

**Significant at the 0.05 level

***Significant at the 0.01 level.

Table 5.1.2. Commercial fertilizer identification equation, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	1487.4321	1.899 *
HayA	-0.0993	-4.476 ***
SBA	0.0043	0.270
OatA	0.0193	0.912
CornA	0.0094	0.698
NoPig	-0.0042	-1.006
NoCow	0.2294	3.595 ***
CornSQ	6.3526 E-08	0.700
OatSQ	-1.1432 E-07	-3.379 ***
SoySQ	-8.5247 E-07	-5.050 ***
CornOat	-3.0934 E-07	-2.098 **
CornSoy	-1.2258 E-07	-0.523
HayCorn	-4.7230 E-07	-1.414
HayOat	2.0213 E-06	3.952 ***
HaySBA	2.6737 E-06	2.804 **
OatSoy	1.2341 E-06	3.724 ***
CornCow	3.8451 E-06	3.897 ***
OatCow	-6.7489 E-06	-5.272 ***
SoyCow	-1.0521 E-06	-0.545
SoyPig	-2.2827 E-07	-2.548 **
OatPig	3.7797 E-09	0.042
CornPig	-8.1907 E-09	-0.114
R-square = 0.5721		
ADJ R-SQ = 0.5604		
F Value = 49.021		

*Significant at 0.1 level.

**Significant at 0.05 level.

***Significant at 0.01 level.

Table 5.1.3. Commercial fertilizer identification equation, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	3013.5526	3.084 ***
HayA	-0.1681	-5.836 ***
SBA	0.0228	1.808 *
OatA	0.0218	0.666
CornA	0.0550	3.799 ***
NoPig	-0.1948	-4.533 ***
NoCow	0.4368	6.869 ***
CornSQ	-3.9236 E-07	-3.805 ***
OatSQ	2.9374 E-07	0.456
SoySQ	-1.2254 E0-07	-10.699 ***
CornOat	-5.1318 E-08	-0.117
CornSoy	4.6224 E-07	4.021 ***
HayCorn	8.2661 E-07	1.849 *
HayOat	2.1972 E-06	0.213
HaySBA	1.6590 E-06	2.709 **
OatSoy	-1.9047 E-06	-6.267 ***
CornCow	-1.3457 E-06	-1.604
OatCow	-1.7839 E-07	-0.098
SoyCow	-2.5316 E-06	-2.058 **
SoyPig	2.2223 E-06	3.722 ***
OatPig	-3.5482 E-06	-2.952 ***
CornPig	2.8966 E-06	5.052 ***

R-square = 0.7801

ADJ R-SQ = 0.7741

F Value = 130.062

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.1.4. Commercial fertilizer identification equation, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	-917.8383	-0.702
HayA	0.0444	1.061
SBA	0.0445	2.334 **
OatA	0.1371	2.413 **
CornA	0.1393	6.373 ***
NoPig	-0.0939	-1.252
NoCow	0.0551	0.445
CornSQ	1.5722 E-07	1.251
OatSQ	-5.7581 E-09	-0.004
SoySQ	-5.8056 E-08	-0.359
CornOat	-1.5114 E-06	-2.367 **
CornSoy	-1.6199 E-07	-0.574
HayCorn	1.7170 E-07	0.308
HayOat	-3.1766 E-06	-2.027 **
HaySBA	-1.999 E-06	-2.500 **
OatSoy	2.0320 E-07	0.305
CornCow	-2.0408 E-06	-1.826 *
OatCow	7.7720 E-06	2.268 **
SoyCow	2.0454 E-06	1.211
SoyPig	2.9867 E-06	3.853 ***
OatPig	2.7912 E-06	1.502
CornPig	-7.2519 E-07	-1.018

R-square = 0.8517

ADJ R-SQ = 0.8477

F Value = 210.600

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.2.1. Labor identification equation, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	1907.5232	6.174 ***
HayA	0.0386	4.192 ***
SBA	0.0470	4.293 ***
OatA	-0.0499	-5.809 ***
CornA	0.0224	4.018 ***
NoPig	0.01249	4.686 ***
NoCow	0.1099	4.905 ***
CornSQ	-7.3898 E-08	-2.080 **
OatSQ	-1.0141 E-08	-0.091
SoySQ	-5.2091 E-07	-2.813 ***
CornOat	3.6831 E-07	3.863 ***
CornSoy	8.1791 E-08	0.675
HayCorn	-5.4404 E-08	-0.299
HayOat	1.5652 E-07	0.509
HaySBA	7.9809 E-07	2.159 **
OatSoy	2.1100 E-07	1.151
CornCow	9.0909 E-07	2.339 **
OatCow	-8.2419 E-07	-1.338
SoyCow	-1.7309 E-06	-2.418 **
SoyPig	-3.1279 E-07	0.162
OatPig	1.0736 E-08	0.162
CornPig	-4.5049 E-08	-1.137

R-square = 0.8918

ADJ R-SQ = 0.8889

F Value = 302.258

*Significant at the 0.1 level.

**Significant at the 0.05 level.

**Significant at the 0.01 level.

Table 5.2.2. Labor identification equation, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	1158.6422	3.283 ***
HayA	0.0284	2.845 ***
SBA	0.0348	4.832 ***
OatA	-0.0516	-5.421 ***
CornA	0.0385	6.355 ***
NoPig	0.0087	4.615 ***
NoCow	0.2430	8.448 ***
CornSQ	-2.8214 E-07	-6.901 ***
OatSQ	9.8676 E-08	6.472 ***
SoySQ	-3.4701 E-09	-0.046
CornOat	6.1345 E-07	9.233 ***
CornSoy	-1.8824 E-07	-1.782 *
HayCorn	7.6588 E-07	5.087 ***
HayOat	-9.1714 E-07	-3.979 ***
HaySBA	3.7449 E-07	1.392
OatSoy	-6.8641 E-08	-0.460
CornCow	-9.4870 E-07	-2.134 **
OatCow	8.4250 E-08	0.146
SoyCow	-1.1732 E-08	-0.013
SoyPig	-9.8408 E-09	-0.244
OatPig	-1.0334 E-07	-2.530 **
CornPig	2.6669 E-08	0.827

R-square = 0.8666
ADJ R-SQ = 0.8630
F Value = 238.289

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.2.3. Labor identification equation, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	2594.2406	7.286 ***
HayA	-0.0386	-3.683 ***
SBA	0.0051	1.113
OatA	-0.0008	-0.064
CornA	-0.0022	-0.421
NoPig	0.0810	5.170 ***
NoCow	0.1918	8.276 ***
CornSQ	-1.3242 E-08	0.352
OatSQ	-5.6381 E-07	2.402 **
SoySQ	-2.6345 E-08	-6.313 ***
CornOat	-1.2482 E-07	-0.778
CornSoy	2.9481 E-08	0.704
HayCorn	7.0052 E-07	4.301 ***
HayOat	-3.8184 E-07	-1.018
HaySBA	8.5677 E-07	3.839 ***
OatSoy	2.8349 E-08	0.256
CornCow	-1.4865 E-07	-0.486
OatCow	-1.0607 E-06	-1.603
SoyCow	-9.5977 E-07	-2.141 **
SoyPig	-6.3026 E-07	-2.897 ***
OatPig	-2.6706 E-07	-0.610
CornPig	-1.0412 E-07	-0.498

R-square = 0.8746

ADJ R-SQ = 0.8711

F Value = 255.638

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.2.4. Labor identification equation, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	2121.7615	5.197 ***
HayA	-0.0305	-2.263 **
SBA	-0.0107	-1.587
OatA	-0.0004	-0.021
CornA	0.0048	0.652
NoPig	0.0957	3.467 ***
NoCow	0.1923	5.009 ***
CornSQ	-6.1996 E-08	1.238
OatSQ	-5.2390 E-07	-1.134
SoySQ	-2.1024 E-07	2.960 ***
CornOat	9.5270 E-07	4.302 ***
CornSoy	-1.5937 E-07	-1.382
HayCorn	3.8413 E097	1.941 *
HayOat	-8.1171 E-07	-1.507
HaySBA	9.1025 E-07	3.333 ***
OatSoy	-7.2297 E-07	-2.702 ***
CornCow	-1.3783 E-06	-3.940 ***
OatCow	1.8308 E-06	1.762 *
SoyCow	-3.4961 E-07	-0.677
SoyPig	2.4582 E-07	0.923
OatPig	-3.0233 E-07	-0.448
CornPig	-7.5454 E-07	-3.074 ***

R-square = 0.8698

ADJ R-SQ = 0.8640

F Value = 150.432

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.3.1. Limestone identification equation, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	21966.3285	3.007 ***
HayA	-0.4777	-2.196 **
SBA	0.3814	1.472
OatA	-0.7691	-3.788 ***
CornA	0.0448	0.341
NoPig	0.1880	2.995 ***
NoCow	0.6801	1.284
CornSQ	-3.1871 E-06	-3.795 ***
OatSQ	-4.7375 E-06	-1.803 *
SoySQ	-1.5199 E-05	-3.471 ***
CornOat	6.3263 E-06	2.806 ***
CornSoy	5.2825 E-06	1.845 *
HayCorn	-4.1322 E-06	-0.961
HayOat	2.5484 E-05	3.507 ***
HaySBA	3.0692 E-05	3.511 ***
OatSoy	8.1365 E-06	1.877 *
CornCow	1.3669 E-05	1.487
OatCow	-3.1972 E-05	-2.194 **
SoyCow	-8.0266 E-05	-0.474
SoyPig	-1.0366 E-05	-6.287 ***
OatPig	-7.9735 E-07	-0.510
CornPig	8.3690 E-07	0.893
R-square = 0.5381		
ADJ R-SQ = 0.5255		
F Value = 42.721		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.3.2. Limestone identification equation, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	6853.0924	1.111
HayA	0.2062	1.273
SBA	-0.1655	-1.417
OatA	-0.4846	-3.139 ***
CornA	0.2687	2.734 ***
NoPig	0.1762	5.755 ***
NoCow	-0.0465	-0.100
CornSQ	-3.6450 E-06	-5.501 ***
OatSQ	1.0902 E-06	4.412 ***
SoySQ	-1.8354 E-06	-1.489
CornOat	2.8832 E-06	2.678 ***
CornSoy	-3.5468 E-06	-2.072 **
HayCorn	5.9744 E-06	2.449 **
HayOat	-4.6679 E-06	-1.249
HaySBA	9.2771 E-06	2.128 **
OatSoy	7.1716 E-06	2.963 ***
CornCow	1.3154 E-05	1.825 *
OatCow	-9.1061 E-06	-0.974
SoyCow	-4.9075 E-06	-0.348
SoyPig	-1.3852 E-06	-2.117 **
OatPig	-2.6586 E-06	-4.016 ***
CornPig	1.1395 E-06	2.181 **

R-square = 0.5356

ADJ R-SQ = 0.5229

F Value = 42.289

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.3.3. Limestone identification equation, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	-3164.0578	-0.910
HayA	0.2440	2.380 **
SBA	0.0620	1.382
OatA	-0.3598	-3.087 ***
CornA	0.0991	1.921 *
NoPig	0.4804	3.140 ***
NoCow	-0.1075	-0.475
CornSQ	-1.3482 E-06	-3.673 ***
OatSQ	-2.8785 E-06	-1.255
SoySQ	-6.6687 E-08	-1.636
CornOat	3.5421 E-06	2.259 **
CornSoy	-5.7281 E-07	-1.400
HayCorn	-1.3022 E-06	-0.818
HayOat	1.7033 E-06	0.465
HaySBA	9.6104 E-06	4.408 ***
OatSoy	-1.7961 E-06	-1.660 *
CornCow	-4.1707 E-07	-0.140
OatCow	1.3488 E-07	0.021
SoyCow	1.8488 E-05	4.221 ***
SoyPig	-1.0785 E-05	-5.075 ***
OatPig	-4.9239 E-06	-1.151
CornPig	3.9320 E-06	1.927 *
R-square = 0.4984		
ADJ R-SQ = 0.4847		
F Value = 36.429		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.3.4. Limestone identification equation, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	-1451.6274	-0.280
HayA	0.5623	3.390 ***
SBA	0.1673	2.212 **
OatA	1.0832	4.811 ***
CornA	0.0027	0.032
NoPig	-0.5598	-1.884 *
NoCow	-1.6978	-3.457 ***
CornSQ	-1.9354 E-06	-3.887 ***
OatSQ	-4.6974 E-06	-0.897
SoySQ	-1.6434 E-06	-2.562 **
CornOat	4.1478 E-06	1.639
CornSoy	3.1996 E-06	2.864 ***
HayCorn	1.8825 E-06	0.853
HayOat	-9.8846 E-06	-1.592
HaySBA	-9.1227 E-06	-2.880 ***
OatSoy	-1.0693 E-05	-4.054 ***
CornCow	-1.2959 E-06	-0.293
OatCow	1.8192 E-05	1.340
SoyCow	2.1757 E-05	3.250 ***
SoyPig	1.1056 E-05	0.360
OatPig	5.8279 E-05	-0.791
CornPig	5.1781 E-06	1.835 *

R-square = 0.1560
ADJ R-SQ = 0.1330
F Value = 6.777

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.4.1. Corn production function, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	-14.0735	-3.096 ***
LCornF	2.1339	1.988 **
LCornL	3.2851	4.538 ***
LCapital	-1.1493	-1.167
LCornFSQ	-0.0509	-1.526
LCRNLSQ	-0.0097	-0.135
LCapSQ	-0.7522	-4.584 ***
CornLF	-0.8028	-6.211 ***
CornFCap	0.8144	3.500 ***
CornLCap	0.5936	3.720 ***
LAnnTemp	2.3752	9.272 ***
LAnnPrec	-0.8156	-8.501 ***
R1	-0.2154	-5.501 ***
R2	-0.2216	-5.876 ***
R3	-0.2448	-6.850 ***
R4	-0.1589	-3.917 ***
R5	-0.0548	-1.391
R6	0.0605	1.674 *
R7	-0.1802	-4.383 ***
R8	-0.2136	-5.678 ***

R-Square = 0.8665

ADJ R-SQ = 0.8632

F Value = 263.649

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.4.2. Corn production function, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	-21.9221	-4.508 ***
LCornF	2.6535	3.040 ***
LCornL	2.4612	3.818 ***
LCapital	-1.2415	-0.990
LCornFSQ	0.0535	2.340 **
LCRNLSQ	0.0035	0.190
LCapSQ	0.029	0.286
CornLF	-0.3378	-5.291 ***
CornFCap	0.0049	0.043
CornLCap	0.0971	0.933
LAnnTemp	3.4207	7.106 ***
LAnnPrec	0.1038	2.074 **
R1	-0.0115	-0.341
R2	0.0258	0.737
R3	-0.2765	-7.711 ***
R4	-0.0593	-1.763 *
R5	0.0724	2.088 **
R6	0.0274	0.770
R7	-0.1559	-4.412 ***
R8	-0.2131	-6.128 ***

R-Square = 0.8515

ADJ R-SQ = 0.8479

F Value = 233.017

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.4.3. Corn production function, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	-30.8472	-5.549 ***
LCornF	-1.0189	-1.714 *
LCornL	-0.2624	-0.342
LCapital	8.3895	4.665 ***
LCornFSQ	0.0241	1.865 *
LCRNLSQ	0.0706	1.401
LCapSQ	-0.6227	-3.338 ***
CornLF	-0.1715	-3.061 ***
CornFCap	0.2346	1.897 *
CornLCap	0.0964	0.590
LAnnTemp	2.9591	9.425 ***
LAnnPrec	0.2099	4.499 ***
R1	0.1591	4.596 ***
R2	0.1623	4.582 ***
R3	-0.2044	-5.659 ***
R4	0.2057	6.149 ***
R5	0.1976	5.641 ***
R6	0.0406	1.141
R7	0.1489	4.416 ***
R8	-0.1844	-5.097 ***
R-Square = 0.8489		
ADJ R-SQ = 0.8451		
F Value = 228.206		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.4.4. Corn production function, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	-18.8474	-4.937 ***
LCornF	3.7300	9.061 ***
LCornL	1.8894	4.457 ***
LCapital	0.6607	0.704
LCornFSQ	0.0637	8.411 ***
LCRNLSQ	0.0428	3.789 ***
LCapSQ	0.4711	5.611 ***
CornLF	0.0099	0.348
CornFCap	-0.5565	-10.312 ***
CornLCap	-0.3651	-4.973 ***
LAnnTemp	0.1454	0.425
LAnnPrec	0.3651	9.327 ***
R1	0.0055	0.221
R2	0.0964	3.808 ***
R3	-0.0718	-2.401 ***
R4	-0.0731	-2.758 ***
R5	0.0187	0.719
R6	0.0188	0.705
R7	-0.1348	-5.254 ***
R8	-0.1680	-6.506 ***
R-Square = 0.9112		
ADJ R-SQ = 0.9090		
F Value = 417.072		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.4.5. Corn input shares and marginal products

	Shares			Marginal Products		
Period	Fertilizer	Labor	Capital	Fertilizer	Labor	Capital
1	0.7569 (62.09)[a]	0.9531 (259.80)	-0.7100 (138.22)	635.926	727.652	-1478.2
2	0.7176 (407.67)	0.1861 (44.18)	0.0963 (4.22)	408.213	202.147	166.8
3	0.0622 (5.56)	0.0257 (1.03)*	0.9121 (227.72)	61.010	122.139	2141.1
4	0.3794 (740.93)	0.1337 (14.42)	0.4869 (284.52)	420.529	417.662	1822.5

[a]Number in parentheses indicates F-values.

*Not significant at the 0.05 level.

Table 5.4.6. Corn, elasticities of complementarity c_{ii} and c_{ij} [a]

Period 1	Factor	Fertilizer	Labor	Capital
1942-1949	fertilizer	-0.4100	-0.1128	-0.5154
	labor		-0.1052	-0.1258
	capital			0.9163
Period 2	**Factor**	**Fertilizer**	**Labor**	**Capital**
1950-1957	fertilizer	-0.2896	-1.5295	1.0709
	labor		-4.2724	6.4181
	capital			-6.2571
Period 3	**Factor**	**Fertilizer**	**Labor**	**Capital**
1958-1965	fertilizer	-8.8479	-106.2953	5.1352
	labor		68.9798	5.1125
	capital			-0.8449
Period 4	**Factor**	**Fertilizer**	**Labor**	**Capital**
1966-1973	fertilizer	-1.1932	1.1952	-2.0125
	labor		-4.0851	-4.6084
	capital			0.9334

[a]Factors i and j are q-complements if $c_{ij} > 0$ and q-substitutes if $c_{ij} < 0$.

Table 5.4.7. Corn, own and cross demand elasticities ε_{ii} and ε_{ij} [a]

Period 1	Factor	Fertilizer	Labor	Capital
1942-1949	fertilizer	-0.3103	-0.0854	-0.3901
	labor	-0.1075	-0.1003	0.1170
	capital	-0.3660	-0.0872	-0.6506
Period 2	Factor	Fertilizer	Labor	Capital
1950-1957	fertilizer	-0.2078	-1.0976	0.7685
	labor	-0.2846	-0.7951	1.1944
	capital	0.1031	0.6181	-0.6026
Period 3	Factor	Fertilizer	Labor	Capital
1958-1965	fertilizer	-0.5503	-6.6110	0.3194
	labor	-2.7315	1.7728	0.1314
	capital	4.6838	4.6631	-0.7706
Period 4	Factor	Fertilizer	Labor	Capital
1966-1973	fertilizer	-0.4527	0.4534	-0.7625
	labor	0.1598	-0.5462	-0.6161
	capital	-0.9799	-2.2438	-0.4545

[a]Factors i and j are P-complements if $\varepsilon_{ij} > 0$ and P-substitutes if $\varepsilon_{ij} < 0$.

Table 5.5.1. Oats production function, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	40.7003	8.873 ***
LOatF	0.5562	0.939
LOatL	5.1490	8.364 ***
LCapital	-8.5055	-6.436 ***
LOatFSQ	0.0155	1.123
LOatLSQ	0.2428	10.539 ***
LCapSQ	0.9739	8.279 ***
OatLF	-0.1292	-3.300 ***
OatFCap	0.0392	0.328
OatLCap	-0.9382	-9.173 ***
LAnnTemp	-2.4363	-9.629 ***
LAnnPrec	-1.9237	-21.462 ***
R1	0.3390	8.194 ***
R2	0.3443	9.256 ***
R3	0.6095	17.727 ***
R4	0.0878	2.132 **
R5	0.1752	4.709 ***
R6	0.3543	10.007 ***
R7	-0.1813	-4.623 ***
R8	-0.0777	-2.127 **
R-Square = 0.9030		
ADJ R-SQ = 0.9006		
F Value = 378.157		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.5.2. Oats production function, 1950-1958

Variable	Parameter Estimate	t-value
Intercep	-19.6349	-2.103 **
LOatF	8.0356	8.713 ***
LOatL	-2.2080	-3.181 ***
LCapital	6.9161	3.279 ***
LOatFSQ	0.0747	5.169 ***
LOatLSQ	0.0011	0.074
LCapSQ	0.0512	0.365
OatLF	0.0431	1.206
OatFCap	-1.1156	-9.286 ***
OatLCap	0.2656	3.231 ***
LAnnTemp	-5.6736	-7.682 ***
LAnnPrec	-0.2875	-3.638 ***
R1	-0.0941	-1.672 *
R2	0.0251	0.464
R3	0.6402	11.643 ***
R4	-0.2297	-4.303 ***
R5	0.0018	0.034
R6	0.2693	5.000 ***
R7	-0.2315	-4.562 ***
R8	-0.1298	-2.444 **

R-Square = 0.8009

ADJ R-SQ = 0.7960

F Value = 163.446

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.5.3. Oats production function, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	-5.9179	-1.013
LOatF	-0.1531	-0.153
LOatL	3.1890	5.939 ***
LCapital	-0.0440	-0.039
LOatFSQ	0.0060	0.625
LOatLSQ	0.0942	7.849 ***
LCapSQ	0.0361	0.334
OatLF	-0.1699	-7.128 ***
OatFCap	0.1782	1.439
OatLCap	-0.2807	-4.420 ***
LAnnTemp	1.2297	4.993 ***
LAnnPrec	-0.0234	-0.742
R1	0.2014	8.829 ***
R2	0.2018	8.881 ***
R3	0.2765	10.309 ***
R4	0.0720	3.184 ***
R5	0.1162	5.042 ***
R6	0.1915	8.065 ***
R7	-0.0646	-2.926 ***
R8	0.0426	1.830 *

R-Square = 0.9606

ADJ R-SQ = 0.9597

F Value = 991.663

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.5.4. Oats production function, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	2.6693	0.458
LOatF	3.7448	6.780 ***
LOatL	-0.0540	-0.105
LCapital	-2.1727	-1.478
LOatFSQ	0.0515	9.096 ***
LOatLSQ	0.0552	4.739 ***
LCapSQ	0.2863	2.690 ***
OatLF	-0.1660	-7.301 ***
OatFCap	-0.3474	-4.429 ***
OatLCap	0.1130	1.651 *
LAnnTemp	0.0833	0.237
LAnnPrec	-0.3204	-7.865 ***
R1	0.3319	13.159 ***
R2	0.2222	8.654 ***
R3	0.1086	3.877 ***
R4	0.2605	10.182 ***
R5	0.2927	11.425 ***
R6	0.1057	3.876 ***
R7	0.1158	4.520 ***
R8	0.1067	3.774 ***

R-Square = 0.9498

ADJ R-SQ = 0.9486

F Value = 769.366

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.5.5. Oats input shares and marginal products

	Shares			Marginal Products		
Period	Fertilizer	Labor	Capital	Fertilizer	Labor	Capital
1	0.2573 (35.39)[a]	0.4401 (235.30)	0.3019 (7.53)	13.297	59.377	38.662
2	0.5946 (232.27)	0.3189 (143.45)	0.0865 (1.70)*	123.560	190.267	54.722
3	0.2183 (24.55)	0.3038 (160.12)	0.4774 (213.42)	48.337	395.978	253.263
4	0.6012 (1939.10)	0.1815 (157.97)	0.2173 (37.80)	77.798	154.874	94.930

[a]Numbers in parentheses indicate F-values.

*Not significant at the 0.05 level.

Table 5.5.6. Oats, elasticities of complementarity c_{ii} and c_{ij} [a]

Period 1	Factor	Fertilizer	Labor	Capital
1942-1949	fertilizer	-2.6524	-0.1410	1.5046
	labor		-0.0186	-6.0612
	capital			8.373
Period 2	**Factor**	**Fertilizer**	**Labor**	**Capital**
1950-1957	fertilizer	-0.4705	1.2273	-20.6904
	labor		-2.125	10.6285
	capital			-3.7178
Period 3	**Factor**	**Fertilizer**	**Labor**	**Capital**
1958-1965	fertilizer	-3.4549	-1.5618	2.7081
	labor		-1.2710	-0.9334
	capital			-0.9344
Period 4	**Factor**	**Fertilizer**	**Labor**	**Capital**
1966-1973	fertilizer	-0.5209	-0.5213	-1.6542
	labor		-2.834	3.8651
	capital			2.4613

[a]Factors i and j are q-complements if $c_{ij} > 0$ and q-substitutes if $c_{ij} < 0$.

Table 5.5.7. Oats, own and cross demand elasticities ε_{ii} and ε_{ij} [a]

Period 1	Factor	Fertilizer	Labor	Capital
1942-1949	fertilizer	-0.6825	-0.0363	0.3871
	labor	-0.062	0.0172	-2.6676
	capital	0.4543	-0.0621	2.5278
Period 2	Factor	Fertilizer	Labor	Capital
1950-1957	fertilizer	-0.2798	0.7246	-12.3025
	labor	0.3914	-0.6777	3.3894
	capital	-1.7897	0.9194	-0.3216
Period 3	Factor	Fertilizer	Labor	Capital
1958-1965	fertilizer	-0.7542	-0.3409	0.5912
	labor	0.4745	-0.3861	-0.2836
	capital	1.2942	-0.4461	-0.4465
Period 4	Factor	Fertilizer	Labor	Capital
1966-1973	fertilizer	-0.3132	-0.3134	-0.9975
	labor	-0.0946	-0.5144	0.7015
	capital	-0.3605	0.8399	0.5348

[a]Factors i and j are P-complements if $\varepsilon_{ij} > 0$ and P-substitutes if $\varepsilon_{ij} < 0$.

Table 5.6.1. Soybean production function, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	-0.0023	-0.001
LSoyF	-2.5751	-2.539 **
LSoyL	1.5589	1.570
LCapital	0.3588	0.479
LSBFSQ	-0.0265	-1.691 *
LSBLSQ	0.4114	12.185 ***
LCapSQ	-0.1644	-3.034 ***
SBLF	-0.3940	-10.291 ***
SBFCap	0.7295	5.887 ***
SBLCap	-0.4090	-3.502 ***
LAnnTemp	2.4648	8.181 ***
LAnnPrec	-0.2395	-1.322
R1	-0.0288	-0.623
R2	-0.0083	-0.191
R3	-0.1565	-3.733 ***
R4	-0.2385	-5.474 ***
R5	-0.0065	-0.147
R6	0.0746	1.691 *
R7	-0.2913	-6.197 ***
R8	-0.1369	-3.068 ***
R-Square = 0.9620		
ADJ R-SQ = 0.9610		
F Value = 1027.605		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.6.2. Soybean production function, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	7.1943	1.300
LSoyF	-0.9121	-1.458
LSoyL	0.7003	1.058
LCapital	0.6933	0.548
LSBFSQ	0.1221	7.433 ***
LSBLSQ	0.1663	7.768 ***
LCapSQ	-0.1005	-1.202
SBLF	-0.2712	-14.593 ***
SBFCap	0.1442	2.145 **
SBLCap	0.0017	0.026
LAnnTemp	-0.2455	-0.424
LAnnPrec	0.1687	2.651 ***
R1	0.0069	0.158
R2	-0.0262	-0.608
R3	0.3495	-7.644 ***
R4	0.0008	0.018
R5	0.0313	0.708
R6	-0.0270	-0.568
R7	0.0001	0.002
R8	-0.1617	3.788 ***

R-Square = 0.9659

ADJ R-SQ = 0.9651

F Value = 1151.267

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.6.3. Soybean production function, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	-0.2454	-0.040
LSoyF	5.6227	3.863 ***
LSoyL	-4.5329	-3.063 ***
LCapital	0.2056	0.141
LSBFSQ	-0.1815	-1.623
LSBLSQ	-0.0231	-0.269
LCapSQ	0.0109	0.109
SBLF	0.2043	1.059
SBFCap	-0.3602	-1.929 *
SBLCap	0.3797	2.077 **
LAnnTemp	0.2316	0.546
LAnnPrec	-0.1236	-2.110 **
R1	0.1580	3.821 ***
R2	0.0976	2.314 **
R3	-0.0334	-0.707
R4	0.1017	2.468 **
R5	0.2448	5.532 ***
R6	-0.0185	-0.405
R7	0.0346	0.865
R8	-0.0017	-0.037

R-Square = 0.9543
ADJ R-SQ = 0.9531
F Value = 847.800

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.6.4. Soybean production function, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	1.8217	0.510
LSoyF	0.9024	2.470 **
LSoyL	0.6313	2.460 **
LCapital	-1.6751	-1.759 *
LSBFSQ	0.0733	10.266 ***
LSBLSQ	0.0463	13.701 ***
LCapSQ	0.1116	1.552
SBLF	-0.1420	-15.362 ***
SBFCap	-0.0713	-1.488
SBLCap	0.0407	1.192
LAnnTemp	2.0974	6.790 ***
LAnnPrec	0.0527	7.130 ***
R1	0.0717	3.075 ***
R2	0.0756	3.171 ***
R3	-0.0424	-1.645 *
R4	0.0886	3.989 ***
R5	0.2103	9.191 ***
R6	0.0843	3.408 ***
R7	0.0675	3.048 ***
R8	0.0113	0.435
R-Square = 0.9710		
ADJ R-SQ = 0.9703		
F Value = 1361.300		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table 5.6.5. Soybean input shares and marginal products

	Shares			Marginal Products		
Period	Fertilizer	Labor	Capital	Fertilizer	Labor	Capital
1	-0.0562 (2.51)*[a]	0.7612 (594.33)	0.2950 (137.36)	-13.498	314.866	69.642
2	0.3605 (147.34)	0.5260 (485.50)	0.1135 (7.85)	88.249	558.164	19.366
3	1.0958 (342.16)	-0.0106 (0.03)*	-0.0852 (2.92)*	149.987	-7.619	-20.243
4	0.6670 (866.31)	0.5516 (1361.72)	-0.2186 (36.19)	143.378	353.837	-91.624

[a]Numbers in parentheses indicate F-values.

*Not significant at the 0.05 level.

Table 5.6.6. Soybeans, elasticities of complementarity c_{ii} and c_{ij} [a]

Period 1	Factor	Fertilizer	Labor	Capital
1942-1949	fertilizer	10.4034	10.21	-43.0014
	labor		0.0802	-0.8214
	capital			-4.2789
Period 2	Factor	Fertilizer	Labor	Capital
1950-1957	fertilizer	-0.8344	-0.4302	4.5242
	labor		-0.3001	3.4154
	capital			-15.612
Period 3	Factor	Fertilizer	Labor	Capital
1958-1965	fertilizer	-0.0637	-16.5886	-4.8581
	labor		-110.2496	421.4314
	capital			14.2387
Period 4	Factor	Fertilizer	Labor	Capital
1966-1973	fertilizer	-0.3345	0.6140	1.489
	labor		-0.6607	0.6625
	capital			7.9100

[a]Factors i and j are q-complements if $c_{ij} > 0$ and q-substitutes if $c_{ij} < 0$.

Table 5.6.7. Soybeans, own and cross demand elasticities ε_{ii} and ε_{ij} [a]

Period 1	Factor	Fertilizer	Labor	Capital
1942-1949	fertilizer	-0.0425	-0.5738	2.4167
	labor	-7.7719	0.0610	-0.6252
	capital	-13.7100	-0.2423	-1.2623
Period 2	Factor	Fertilizer	Labor	Capital
1950-1957	fertilizer	-0.3008	-0.1551	1.5737
	labor	-0.2263	-0.1579	0.5410
	capital	0.4955	0.1167	-1.7720
Period 3	Factor	Fertilizer	Labor	Capital
1958-1965	fertilizer	-0.0098	-20.3686	3.1319
	labor	-0.1972	1.1686	4.4672
	capital	0.2435	35.9060	-1.2131
Period 4	Factor	Fertilizer	Labor	Capital
1966-1973	fertilizer	-0.2231	0.4096	0.9932
	labor	0.3387	-0.3644	0.3654
	capital	-0.3255	-0.1448	-1.7291

[a]Factors i and j are P-complements if $\varepsilon_{ij} > 0$ and P-substitutes if $\varepsilon_{ij} < 0$.

Table 5.7. Corn, total factor productivities

Time Period	TFP	λi
Period (1,1)[b]	15.3869	-0.5915
Period (2,1)	14.7954	
Period (2,2)	15.4192	0.3562
Period (3,2)	15.7754	
Period (3,3)	15.7889	0.0937
Period (4,3)	15.8826	

Table 5.8. Oats, total factor productivities

Time Period	TFP	λi
Period (1,1)[b]	14.2703	-0.6908
Period (2,1)	13.5795	
Period (2,2)	14.3383	-0.0067
Period (3,2)	14.3316	
Period (3,3)	14.1819	1.4108
Period (4,3)	15.5927	

Table 5.9. Soybeans, total factor productivities

Time Period	TFP	λi
Period (1,1)[b]	12.250	0.8385
Period (2,1)	13.0885	
Period (2,2)	12.5353	-0.1898
Period (3,2)	12.3455	
Period (3,3)	13.393	0.4624
Period (4,3)	13.8554	

[b]Each pair (i,j) represents the following: the first number represents the production function estimated over period i and the second number represents the average input level in period j.

Table 5.10. Corn, ratios of marginal products[a]

Period	MP_K/MP_L	MP_F/MP_L	MP_K/MP_F
Period (1,1)[b]	-2.0315	0.8739	-2.3245
Period (2,1)	0.4922	2.1258	0.2315
Period (2,2)	0.8250	2.0194	0.4085
Period (3,2)	13.2614	-0.4793	-27.4393
Period (3,3)	17.5303	0.4995	35.0947
Period (4,3)	7.5320	1.1477	6.5627

Table 5.11. Oats, ratios of marginal products[a]

Period	MP_K/MP_L	MP_F/MP_L	MP_K/MP_F
Period (1,1)[b]	0.9419	0.1779	-1.8043
Period (2,1)	2.4591	2.9093	0.8763
Period (2,2)	0.2876	0.9791	0.2937
Period (3,2)	-0.1185	0.0380	-3.1177
Period (3,3)	0.6396	0.0162	39.4937
Period (4,3)	1.1542	-0.1086	-10.6260

Table 5.12. Soybeans, ratios of marginal products[a]

Period	MP_K/MP_L	MP_F/MP_L	MP_K/MP_F
Period (1,1)[b]	0.2212	-5.1628	-0.0429
Period (2,1)	0.1361	1.6575	0.0821
Period (2,2)	0.0347	0.2194	0.1581
Period (3,2)	0.00003	-0.0235	-1.3389
Period (3,3)	2.6569	-0.1350	-19.6857
Period (4,3)	-0.1442	-0.5040	0.2862

[a]MP_k, MP_L, and MP_F are the marginal products of capital, labor, and fertilizer, respectively.

[b]Each pair (i,j) represents the following: the first number represents the production function estimated over period i and the second number represents the average input level in period j.

Table 5.13. Corn total factor productivities excluding period 3

Time Period	TFP	λ_i
Period (1,1)[b]	15.3869	-0.5915
Period (2,1)	14.7954	
Period (2,2)	15.4192	0.6363
Period (4,2)	16.0555	

Table 5.14. Oats total factor productivities excluding period 3

Time Period	TFP	λ_i
Period (1,1)[b]	14.2703	-0.6908
Period (2,1)	13.5795	
Period (2,2)	14.3383	0.2669
Period (4,2)	14.6052	

Table 5.15. Soybeans total factor productivities excluding period 3

Time Period	TFP	λ_i
Period 1	12.25	0.8385
Period 2	13.0885	
Period 2	12.5353	0.2956
Period 4	12.8309	

[b]Each pair (i,j) represents the following: the first number represents the production function estimated over period i and the second number represents the average input level in period j.

Table 5.16. Corn, ratios of marginal products excluding period 3[a]

Period	MP_K/MP_L	MP_F/MP_L	MP_K/MP_F
(1,1)[b]	-2.0315	0.8739	-2.3245
(2,1)	0.4922	2.1258	0.2315
(2,2)	0.8250	2.0194	0.4085
(4,2)	4.2544	1.2512	3.4001

Table 5.17. Oats, ratios of marginal products excluding period 3[a]

Period	MP_K/MP_L	MP_F/MP_L	MP_K/MP_F
(1,1)[b]	0.9419	0.1779	-1.8043
(2,1)	2.4591	2.9093	0.8763
(2,2)	0.2876	0.9791	0.2937
(4,2)	1.2338	8.0341	0.1536

Table 5.18. Soybeans, ratios of marginal products excluding period 3[a]

Period	MP_K/MP_L	MP_F/MP_L	MP_K/MP_F
(1,1)[b]	0.2212	-5.1628	-0.0429
(2,1)	0.1361	1.6575	0.0821
(2,2)	0.0347	0.1581	0.2194
(4,2)	0.0541	0.7493	0.0722

[a]MP_k, MP_L, and MP_F are the marginal products of capital, labor, and fertilizer, respectively.

[b]Each pair (i,j) represents the following: the first number represents the production function estimated over period i and the second number represents the average input level in period j.

CHAPTER 6. SUMMARY AND CONCLUSIONS

This study investigated the performance of the conditional demand model in an input demand setting for agricultural firms. The conditional demand framework was used to allocate aggregate inputs to individual crop production activities. The data set utilized in the study was composed of observations on the 99 counties of the State of Iowa for the time period 1942-1973. Two inputs, namely fertilizer and labor, were allocated to the three crops--corn, oats and soybeans using the conditional demand methodology.

Individual production functions were then estimated for the three crops. The estimates were obtained for eight year periods for the 32 years of the study. Four equations were fitted for each crop for the periods 1942-1949, 1950-1957, 1958-1965, and 1966-1973.

From the estimated technologies two issues were addressed. First, the relationship between capital and labor was investigated via the elasticities of complementarity and input demand elasticities. In this regard the empirical results from the most reliable estimates, namely estimates of corn and oats production functions, have shown that:

1. Capital and labor were substitutes during the period 1942-1949. The substitutability evidence was stronger for oats.

2. In the second period, the two inputs behaved as complements. Again oats data provided a stronger complementarity evidence.

3. For the third period, while a strong complementarity evidence is shown for corn estimates, oats data showed a small degree of substitutability between capital and labor.

4. In period four, again contrasting results were obtained from the two crops. This time a complementarity evidence was provided by oats data while corn data showed that the two inputs are substitutes.

The second issue tackled in this study was the technical change issue. The growth in total factor productivity was estimated between adjacent periods and the bias of technical change was also investigated. The findings in this respect are:

1. There was regressive technical advancement between the first two periods as shown by deterioration in total factor productivity.

2. All three crops provided evidence of progressive technical change between periods two and four.

It was found that technical change has been biased for capital and against labor. For soybeans and oats, technical change was also biased toward fertilizer. This result is consistent with other findings from previous studies that addressed the technical change issue.

3. Weather and regional factors have become less important over time, indicating that technical change has also lowered the sensitivity of crop production to growing conditions and soil quality.

The performance of input allocations using the conditional demand framework in this thesis would support further exploration into its use in other settings. In particular, production equations using the allocated inputs had better fit and more reasonable implied marginal products than did production equations using unallocated aggregate input levels for fertilizer and labor.

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ACKNOWLEDGMENTS

First of all thanks to the Almighty God, Allah the Greatest, for his help and guidance.

I would like to express my sincere thanks to my major professor, Dr. Peter Orazem, for suggesting the subject of this thesis and for his support, encouragement, and directions throughout my M.S. program. The experience I gained under his supervision will be gratefully and permanently remembered.

I am also very thankful to the other members of my committee, Dr. Arne Hallam and Dr. Mack Shelley, for their valuable suggestions and comments throughout the development of this thesis.

I also thank the Sudanese taxpayer for paying so dearly to provide this opportunity for me to get a learning experience which is hopefully rewarding.

Back at home, I would like to thank my parents for their blessings and support and for the faith they have always placed in me. To them this work is dedicated. My sisters and brothers deserve thanks for their emotional support throughout the course of my study.

Last, but certainly not least, I am indebted to Pat Monroe whose typing of this thesis is received with the upmost appreciation.

APPENDIX

Table A.1. Corn production function using aggregate input levels, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	-2.3631	-0.219
Fert	-0.8809	-3.147***
Labor	-3.0154	-0.991
LCapital	5.1554	2.828***
FertSq	-0.0161	-5.002***
LaborSq	0.3376	1.292
LCapSq	-0.1105	-0.945
FertLabor	0.0293	0.579
FertCap	0.0918	2.084**
LaborCap	-0.3716	-1.194
LAnnTemp	2.6899	7.630***
LAnnPrec	-0.3208	-2.569**
R1	0.3782	8.315***
R2	0.3032	6.640***
R3	0.0624	1.284
R4	0.3500	7.551***
R5	0.3305	7.111***
R6	0.2073	4.507***
R7	0.2233	4.734***
R8	0.0420	0.885
R-Square = 0.7550		
ADJ R-SQ = 0.749		
F Value = 125.223		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.2. Corn production function using aggregate input levels, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	-8.1460	-0.981
Fert	-0.3537	-0.569
Labor	-1.9472	-1.291
LCapital	5.7451	4.104***
FertSq	0.1264	4.232***
LaborSq	0.1501	1.713*
LCapSq	-0.1658	-1.317
FertLabor	0.0235	0.220
FertCap	-0.2185	-2.098**
LaborCap	-0.0723	-0.373
LAnnTemp	1.3082	1.985**
LAnnPrec	0.0234	0.366
R1	0.2517	6.063***
R2	0.2352	5.022***
R3	0.0015	0.036
R4	0.2420	6.161***
R5	0.2886	6.883***
R6	0.2211	5.231***
R7	0.2253	5.216***
R8	-0.0570	-1.288

R-Square = 0.7654

ADJ R-SQ = 0.7596

F Value = 132.565

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.3. Corn production function using aggregate input levels, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	-17.3472	-3.832***
Fert	0.9924	2.784***
Labor	-1.0798	-0.620
LCapital	7.0358	3.963***
FertSq	0.1292	7.140***
LaborSq	-0.5259	-1.838*
LCapSq	-0.5207	-1.667*
FertLabor	0.3043	2.779***
FertCap	-0.6788	-5.235***
LaborCap	0.9419	1.694*
LAnnTemp	-0.1804	-0.636
LAnnPrec	0.0686	1.859*
R1	-0.0080	-0.284
R2	-0.0663	-2.213**
R3	-0.3197	-11.555***
R4	0.0887	3.363***
R5	0.0750	2.718***
R6	-0.0154	-0.554
R7	0.1681	6.160***
R8	0.0131	0.452
R-Square = 0.9071		
ADJ R-SQ = 0.9048		
F Value = 396.797		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.4. Corn production function using aggregate input levels, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	3.5896	0.771
Fert	3.8967	6.439***
Labor	-2.5561	-1.557
LCapital	4.0972	2.488***
FertSq	-0.0049	-0.088
LaborSq	0.2278	0.767
LCapSq	-0.0940	-0.237
FertLabor	-0.1511	-0.874
FertCap	-0.2218	-0.922
LaborCap	0.0074	0.012
LAnnTemp	-3.6682	-11.940***
LAnnPrec	-0.4968	-8.853***
R1	-0.0103	-0.344
R2	-0.0333	-1.040
R3	-0.1463	-4.798***
R4	-0.0613	-2.113**
R5	0.0629	2.121**
R6	0.0244	0.820
R7	0.0982	3.388***
R8	0.0428	1.346
R-Square = 0.9328		
ADJ R-SQ = 0.9302		
F Value = 347.266		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.5. Oats production function using aggregate input levels, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	34.7621	3.400***
Fert	-0.2510	-0.945
Labor	-2.1693	-0.752
LCapital	1.0200	0.590
FertSq	-0.0131	-4.276***
LaborSq	0.1470	0.594
LCapSq	-0.0845	-0.762
FertLabor	-0.0484	-1.006
FertCap	0.1056	2.529**
LaborCap	0.0319	0.108
LAnnTemp	-2.8057	-8.392***
LAnnPrec	-1.9176	-16.188***
R1	0.9201	21.328***
R2	0.7468	17.243***
R3	0.6835	14.820***
R4	0.6024	13.701***
R5	0.5039	11.434***
R6	0.4271	9.789***
R7	0.0829	1.854*
R8	0.1142	2.533**

R-Square = 0.8440

ADJ R-SQ = 0.8402

F Value = 219.835

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.6. Oats production function using aggregate input levels, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	0.9662	0.066
Fert	-0.9083	-0.832
Labor	3.5359	1.334
LCapital	7.4523	3.030
FertSq	0.0237	0.452
LaborSq	0.1338	0.869
LCapSq	0.0925	0.418
FertLabor	0.1447	0.769
FertCap	-0.0784	-0.428
LaborCap	-0.8378	-2.459
LAnnTemp	-7.8885	-6.813
LAnnPrec	-0.3321	-2.947
R1	0.5693	7.805
R2	0.4012	4.876
R3	0.3781	5.040
R4	0.3408	4.938
R5	0.3600	4.886
R6	0.2828	3.807
R7	0.1028	1.355
R8	0.1644	2.113

R-Square = 0.6071
ADJ R-SQ = 0.5975
F Value = 62.789

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.7. Oats production function using aggregate input levels, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	-12.2769	-1.758*
Fert	-4.0238	-7.315***
Labor	-15.4466	-5.749***
LCapital	28.5234	10.413***
FertSq	-0.0849	-3.042***
LaborSq	0.8701	1.971**
LCapSq	-0.921	-1.912*
FertLabor	0.9058	5.361***
FertCap	-0.3190	-1.595
LaborCap	-0.9823	-1.145
LAnnTemp	-2.5687	-5.864***
LAnnPrec	-0.1189	-2.088**
R1	0.3854	8.855***
R2	0.3416	7.379***
R3	0.2076	4.863***
R4	0.2224	5.464***
R5	0.2266	5.323***
R6	0.1242	2.894***
R7	-0.1483	-3.522***
R8	0.1084	2.406**
R-Square = 0.8752		
ADJ R-SQ = 0.8721		
F Value = 284.928		

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.8. Oats production function using aggregate input levels, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	-11.8703	-1.067
Fert	-1.5504	-1.072
Labor	-16.6877	-4.254***
LCapital	21.1574	5.376***
FertSq	-0.5206	-3.839***
LaborSq	0.5525	0.779
LCapSq	-0.8860	-0.936
FertLabor	1.2888	3.118***
FertCap	-0.0083	-0.015
LaborCap	-0.6073	-0.412
LAnnTemp	2.9495	4.017***
LAnnPrec	0.6466	4.820***
R1	0.3721	5.190***
R2	0.4960	6.469***
R3	0.2710	3.719***
R4	0.3210	4.622***
R5	0.2708	3.820***
R6	0.1697	2.383**
R7	-0.3690	-5.322***
R8	0.0312	0.411

R-Square = 0.7588

ADJ R-SQ = 0.7492

F Value = 78.656

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.9. Soybean production function using aggregate input levels, 1942-1949

Variable	Parameter Estimate	t-value
Intercep	-93.7735	-2.816***
Fert	0.5657	0.654
Labor	27.7968	2.956***
LCapital	-9.7929	-1.738*
FertSq	0.0035	0.353
LaborSq	-1.5345	-1.901*
LCapSq	0.7225	1.999**
FertLabor	-0.2064	-1.317
FertCap	0.1491	1.095
LaborCap	-0.0440	-0.046
LAnnTemp	2.2734	2.087**
LAnnPrec	2.2162	5.742***
R1	-0.2664	-1.896*
R2	0.0279	0.198
R3	-1.1706	-7.790***
R4	-1.1099	-7.748***
R5	-0.0047	-0.033
R6	-1.1594	-8.155***
R7	-2.2312	-15.303***
R8	-0.7427	-5.056***

R-Square = 0.5342

ADJ R-SQ = 0.5227

F Value = 46.592

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.10. Soybean production function using aggregate input levels, 1950-1957

Variable	Parameter Estimate	t-value
Intercep	55.7221	1.885*
Fert	-1.7120	-0.774
Labor	12.1593	2.263**
LCapital	-6.0052	-1.204
FertSq	0.6902	6.486***
LaborSq	-1.9274	-6.173***
LCapSq	1.3411	2.990***
FertLabor	1.4505	3.802***
FertCap	-2.6503	-7.141***
LaborCap	0.9403	1.361
LAnnTemp	-15.3651	-6.545***
LAnnPrec	-0.6658	-2.914***
R1	-0.6685	-4.520***
R2	-1.1761	-7.049***
R3	-2.7000	-17.748***
R4	-1.0528	-7.523***
R5	-0.5015	-3.357***
R6	-1.8656	-12.385***
R7	-1.6206	-10.532***
R8	-0.0106	-0.067

R-Square = 0.5765

ADJ R-SQ = 0.5661

F Value = 55.321

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.11. Soybean production function using aggregate input levels, 1958-1965

Variable	Parameter Estimate	t-value
Intercep	-36.0502	-1.666
Fert	-3.7356	-2.192**
Labor	34.8942	4.193***
LCapital	-17.3392	-2.043**
FertSq	0.5456	6.306***
LaborSq	-1.0100	-0.739
LCapSq	4.4210	2.962***
FertLabor	1.4971	2.860***
FertCap	-2.1694	-3.500***
LaborCap	-3.9472	-1.486
LAnnTemp	-3.7016	-2.728**
LAnnPrec	-0.6657	-3.771***
R1	-0.3192	-2.368**
R2	-0.8408	-5.863***
R3	-1.8004	-13.612***
R4	-0.6417	-5.088***
R5	-0.1765	-1.339
R6	-1.1935	-8.972***
R7	-0.4266	-3.270***
R8	0.2194	1.572

R-Square = 0.5852

ADJ R-SQ = 0.5750

F Value = 57.333

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.12. Soybean production function using aggregate input levels, 1966-1973

Variable	Parameter Estimate	t-value
Intercep	-41.3194	-2.758**
Fert	-10.2026	-5.237***
Labor	6.7985	1.287
LCapital	17.9428	3.385***
FertSq	-0.5533	-3.030***
LaborSq	1.9648	2.055**
LCapSq	2.3522	1.845*
FertLabor	1.8615	3.343***
FertCap	0.7667	0.990
LaborCap	-7.3273	-3.692***
LAnnTemp	-0.0391	-0.040
LAnnPrec	-0.4331	-2.397**
R1	0.0214	0.222
R2	-0.1716	-1.662*
R3	-0.7649	-7.792***
R4	-0.3099	-3.313***
R5	0.0589	0.617
R6	-0.4569	-4.762***
R7	0.0941	1.009
R8	0.3681	3.596***

R-Square = 0.7359
ADJ R-SQ = 0.7253
F Value = 69.653

*Significant at the 0.1 level.

**Significant at the 0.05 level.

***Significant at the 0.01 level.

Table A.13. Corn, marginal products from aggregate (unallocated inputs) production functions

Period	Fertilizer	Labor	Capital
1	-467.69	267.685	1979.99
2	190.90	241.613	1000.90
3	377.18	102.977	1763.10
4	460.56	-78.447	1523.79

Table A.14. Oats, marginal products from aggregate (unallocated inputs) production functions

Period	Fertilizer	Labor	Capital
1	-68.683	95.59	673.902
2	63.164	84.07	524.794
3	-47.481	-105.37	970.153
4	-49.607	52.64	610.255

Table A.15. Soybeans, marginal products from aggregate (unallocated inputs) production functions

Period	Fertilizer	Labor	Capital
1	-19.886	-57.44	286.802
2	102.923	-163.10	329.986
3	147.831	-312.51	441.238
4	146.960	-387.22	372.727