Technological Structure and Technical Change in the U.S. Northeast Farm Region

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Introduction

Considerable attention has been given to the proper measurement, estimation, and analysis of the technological structure of aggregate U.S. agriculture (Binswanger, Brown, Ray, and Antle). During the last decade, duality theory-motivated studies have also analyzed regional farm production (Saez, and Shum-way). Except for the Saez study, no attempt has been made to analyze the farm production structure of the Northeast region.[1]

The purpose of this paper is to examine the structure of agricultural production in the Northeast using a multiple-output, multiple-input variable profit model. This study differs from Saez's study with respect to output-separability assumptions. Saez assumes that livestock products are separable from other farm products, and thus, he aggregates livestock products into one output measure. This study disaggregates livestock products into three output measures, i.e., meat animals, dairy products, and poultry and eggs and tests for the validity of this separability assumption. In addition, this study assumes separability in fruits and vegetables, feed grains, and other farm products. With this improved specification, this study also tries to improve on Saez's own price elasticity results which exhibited wrong signs for livestock products, fruits and vegetables, tobacco, and agricultural chemicals.

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[1] The Northeast region is defined to include the eleven states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, *Kid* Vermont.

The discussion in this paper shall proceed as follows. The second section provides a brief background of Northeast agricultural production. The third section discusses the conceptual framework and empirical specification. The fourth section presents the empirical results. The fifth section explains the technology tests for nonjointness. The sixth section discusses technical change effects. The last section presents the conclusions from the study and its implications for Northeast agriculture.

Northeast Agriculture

Over the last three decades, the Northeast farm region has experienced substantial changes in its farm production structure. For example, production of many livestock and crop products has shifted out of the Northeast to other farm regions. These changes have been brought about by a combination of factors. The increase in off-farm income and in part-time farming activities have affected the production structure of Northeast agriculture. Higher prices of farm inputs coupled with lower output prices have negatively affected the financial condition of Northeast farms. Rapid development and adoption of technology in other farm regions have also contributed to the shifts in regional farm production. In the late 1940*s, dairy products (32 percent), poultry and eggs (25 percent), and fruits and vegetables (20 percent) accounted for 77 percent of Northeast farm income, with meat animals (11 percent), food grains and other farm products (10 percent), and feed grains (2 percent) contributing the remaining 23 percent (see Table 1). In 1982, the income contribution of these six major product groups is much different. Dairy products now account for 43 per-

Table 1. Northeast Farm Region Income*

Commodity	1949	1960	1970	1982
	Percentage of Total Income			
Meat Animals	11	9	10	10
Dairy Products	32	36	41	43
Poultry and Eggs	25	21	18	15
Feed Grains	2	3	4	7
Fruits and Vegetables	20	15	15	12
Other Farm Products	10	16	12	13

* Farm income in this context is defined as cash receipts for the individual commodities.
Source of data: Economic Indicators of the Farm Sector.

cent of total Northeast farm income while the shares of poultry and eggs and fruits and vegetables have dropped to 15 percent and 12 percent, respectively. On the other hand, the income contribution of feed grains and other farm products increased to 7 percent and 13 percent, respectively. The meat animal income share remained at 10 percent.

Model Specification

Conceptual Framework

The aggregate farm production in the Northeast can be described by the transformation function

(1) $$F(Y, X, Q) = 0,$$

where: F = transformation function,

Y = vector of outputs,

X = vector of variable inputs, and

Q = vector of fixed inputs and other exogenous variables.

The transformation function F represents the interrelatedness of production decisions by relating all outputs with the chosen levels of variable inputs, given resource constraints, as represented by the fixed inputs.

The duality relationship between production functions and variable profit functions is well developed elsewhere (Lau, 1972; McFad-den). This relationship provides empirical estimates of output and input demand functions without necessarily imposing restrictive assumptions on the technology. For a given technology and endowment of fixed inputs of production, the restricted variable profit function expresses the maximized profit of farmers as a function of the prices of outputs and variable inputs and the quantities of the fixed inputs, i.e.,

(2) $$\pi = \pi(P, R, Q),$$

where: $\overline{\Pi}$ = expected profits,

P = vector of output prices,

R = vector of variable input prices, and

Q = vector of quantities of fixed inputs and other exogenous variables.

It is assumed that farmers operate in a competitive input-output market[2] and are rational and risk-neutral producers. Imposed regularity conditions imply that the profit function is finite, nonnegative, real valued, continuous, smooth, monotonic, convex in prices, twice differentiable, bounded and linear homogeneous in output and variable input prices (McFadden). Hotelling's lemma means that output supply and input demand depend on the prices of output and variable inputs and on other exogenous variables, i.e.;

(3) $$\frac{\partial \pi}{\partial P} = Y(P, R, Q) \text{ and}$$
$$\frac{\partial \pi}{\partial R} = -X(P, R, Q).$$

Input demand and output supply equations can then be formed based on equations (3) and (4).

Functional Form

The derivation of an unrestricted set of output supply and input demand relationships and the analysis of these relationships' technological structure can be obtained through the use of a flexible functional form. Flexible functional forms as a group place few a priori restrictions on the properties of the underlying production process, instead allowing the testing of these properties. Several flexible function forms are used in past studies, the most common of which are the translog and generalized Leontief. This study models the variable profit function for multiple outputs and inputs using the normalized quadratic form (Lau, 1976).

[2] In the Northeast where dairy production is predominant, the assumption of competitive output markets may not hold true for dairy products- This means that dairy output price is not exogenous. However, endogenous variables, if lagged in the estimation process, are treated as exogenous variables (Kmenta). Since output prices in this study are lagged one period, deviation from the competitive output assumption for dairy products should not seriously affect the results of this study.

$$(5)\quad \pi^* = \alpha_0 + \sum_{i=1}^{m} b_i P^*_i + \sum_{j=1}^{n-1} e_j R^*_j + \sum_{z=1}^{s} d_z Q_z + \tfrac{1}{2}\Big[\sum_{i=1}^{m}\sum_{h=1}^{m} b_{ih} P^*_i P^*_h + \sum_{j=1}^{n-1}\sum_{k=1}^{n-1} c_{jk} R^*_j R^*_k + \sum_{z=1}^{s}\sum_{t=1}^{s} d_{zt} Q_z Q_t\Big] + \sum_{i=1}^{m}\sum_{j=1}^{n-1} e_{ij} P^*_i R^*_j + \sum_{i=1}^{m}\sum_{z=1}^{s} f_{iz} P^*_i Q_z + \sum_{j=1}^{n-1}\sum_{z=1}^{s} g_{jz} R^*_j Q_z,$$

where: $\pi^* = \pi/R_n$,
$P^*_i = P_i/R_n$, and
$R^*_i = R_i/R_n$.

The use of the normalized quadratic functional form provides several advantages. Since the transformation and profit functions are quadratic, their respective Hessians are matrices of constants. Lau (1976) shows that the relationship between the primal and dual Hessian matrices allows the technological characteristics of the primal to be derived from the dual and vice versa. This implies that the normalized quadratic functional form is self dual. Furthermore, the first derivatives of equation (5) with respect to the normalized output and input prices are linear in normalized prices and in quantities of fixed inputs. These derivatives are the output supply and input demand equations.

$$(6a)\quad \frac{\partial \pi^*}{\partial P^*_i} = Y_i = b_i + \sum_{h=1}^{m} b_{ih} P^*_h + \sum_{j=1}^{n-1} e_{ij} R^*_j + \sum_{z=1}^{s} f_{iz} Q_z \quad \text{for all } i = 1 \ldots m.$$

$$(6b)\quad \frac{\partial \pi^*}{\partial R^*_j} = -X_j = e_j + \sum_{i=1}^{m} e_{ij} P^*_i + \sum_{k=1}^{n-1} c_{jk} R^*_k + \sum_{z=1}^{s} g_{jz} Q_z \quad \text{for all } i = 1 \ldots n-1.$$

The system of equations to be estimated simultaneously consists of equations (6a) and (6b). An error term is added to each equation to reflect stochastic effects on profit maximizing behavior. Input demand and output supply elasticities can be derived from the estimated equations (6a) and (6b).

Variable Measurement and Data Construction

Profits were defined as gross farm income minus total variable farm production and operating expense. Income and expense data for the Northeast agricultural sector were obtained from the *Economic Indicators of the Farm Sector* (EIFS) and *Farm Income Situation Reports*. Jointly dependent variables are output and variable input quantities while predetermined variables are output and variable input prices, quantities of fixed inputs and other exogenous variables.

Aggregate agricultural production in the Northeast was assumed to be weakly separable in six output and five variable input categories. The six outputs are meat animals, dairy products, poultry and eggs, feed grains, fruits and vegetables and other farm products which include food grains. The variable inputs are hired labor, farm capital services, agricultural chemicals, feed, seed, and livestock, and other miscellaneous inputs.

Income for meat animals is the sum of cash receipts from cattle and calves, hogs, and sheep and lambs. Dairy product income includes receipts from wholesale and retail milk. Poultry and egg cash receipts come from sale of broilers, eggs, turkeys and farm chickens. Feed grain income contains the cash receipts from corn, hay, grain sorghum, barley, and oats. The major income components of fruits and vegetables come from cash receipts for noncitrus products (apples, grapes, peaches), potatoes, sweet corn, and other truck crops such as tomatoes and onions. Income for the other farm product category was estimated as the total receipts for all agricultural products less the sum of the first five products' cash receipts. Food grains and oil-bearing crops were among the major products included in this category.

Expense data by state for the five variable inputs were gathered from various issues of EIFS. Farm capital services expense is defined as the sum of repairs and operations of capital items, interest costs, taxes, and depreciation expense. Agricultural chemicals[3] include fertilizer and lime expense. Feed, seed, and livestock expense is the sum of these individual input purchases. Expense data for hired labor were gathered directly from the EIFS. Other miscellaneous input expense is denned as the difference between total variable production expense less expenditures for hired labor, farm capital services, agricultural chemicals, and feed, seed, and livestock.

Since regional prices were not readily available for the Northeast region as a whole, implicit regional output and variable input prices were derived by dividing the regional income and expense data by their respective output and input quantities. Quantity levels of the six outputs and four variable inputs (except hired labor) were obtained from the EIFS (Production and Efficiency Report). The farm labor quantity index reported in the EIFS includes both hired and family (operator) labor while the expense data refer only to hired labor. Thus, hired labor quantity for each of the eleven Northeast states were gathered from the *Agricultural Statistics* (AS).

Fixed inputs included are farm real estate and family (operator) labor. Other exogenous variables are real government payments[4] and time. Farm real estate includes, among others,[5] all farmlands and service buildings. Both farm real estate and government payments (sum of all government payments to the region) were obtained from EIFS. Family labor data were gathered from the AS. Government payments are used to capture the aggregate effects of various government policies, while time represents temporal shifts in technology due to technical change. All variables except time are expressed as index numbers (1967-100) for the period 1949-1982.

It is assumed that farmers decide on production plans given their subjective evaluations of future output prices. This implies that output supply is a function of expected prices rather than actual market prices. To incorporate this phenomenon in the model, output prices were lagged one year in the estimation process. However, Northeast farmers are assumed to face current input prices for their variable inputs. The input price of farm capital services was used as the numeraire (normalization variable) in this study. Efficient estimation was obtained by using Zellner's joint generalized least squares method for seemingly unrelated equations. The estimates were iterated until they converge so that they are asymptotically equivalent to maximum likelihood estimates and the parameter estimates are invariant to whichever variable price is chosen as the deflator (Barten).

Estimation

Empirical Results

Parameter estimates of equations (6a) and (6b) are given in Table 2. All own-price coefficients of the normalized prices are consistent with theoretical expectations. An indication of the goodness of fit of the estimated model is the R-square obtained from each output and input equation. These measures are .69 for meat animals, .82 for dairy products, .88 for poultry and eggs, .88 for feed grains, .64 for fruits and vegetables, .79 for other farm products, .98 for hired labor, .92 for miscellaneous inputs, .98 for agricultural chemicals, and .70 for feed, seed, and livestock.

Output supply and input demand elasticities estimated at their means are shown in Table 3. All own-output supply elasticities were positive while own-input demand elasticities were all negative except for the numeraire. All elasticities derived were inelastic. Among the output supply elasticities, feed grain and fruits and vegetables elasticities were the highest. Agricultural chemicals and miscellaneous inputs were more responsive to farm input price fluctuations than hired labor and feed, seed, and livestock. In terms of the structure of production, the following input relationships were derived. All variable inputs except for farm capital were found to have substitute relationships with each other. Farm capital was found to have a complementary relationship with all variable inputs except agricultural chemicals.

Model Validation

The validity of the profit function as an empirical approximation of Northeast farm behavior

[3] The EIFS (farm expense data) includes pesticides in the miscellaneous account while the EIFS (Production and Efficiency Report) includes pesticides in the agricultural chemicals data. This data limitation should be considered in the interpretation of the results of this study.

[4] Estimated by deflating current government payments by the general inflation index.

[5] Farm real estate also includes grazing fees and repairs on service buildings.

Table 2. Parameter Estimates of Output Supply and Input Demand Equations for Northeast Agriculture.

Intercept	18.66	29.72	8.79	- 146.30	58.90	-27.77	- 196.98	148.47	-53.21	209.16
	(71.33)	(31.53)	(42.83)	(100.08)	(67.57)	(57.70)	(28.12)	(49.77)	(40.67)	(76.08)
Prices										
Meat Animals (MA)	.07									
	(.08)									
Dairy Products (DP)	-.05	.05								
	(.03)	(.04)								
• poultry and Eggs (PE)	-.03	-.07	.04							
	(.04)	(-02)	(.05)							
Feed Grains (FG)	-.02	-.005	.04	.14		Symritietric				
	(-05)	(.02)	(-03)	(.08)						
Fruits & Vegetables (FV)	-.07	.04	-.12	^.07	.15					
	(-05)	(.03)	(.04)	(.05)	(-07)					
Other Farm Products (OP)	.01	.05	.005	.06	.07	rms				
	(.04)	(.02)	003)	(-04)	(.04)	(-05)				
Hired Labor (HL)	-.15	-.17	-.14	-.04	.05	-.04	.36			
	(-08)	(-04)	(.04)	(.07)	(-07)	(-06)	(.16)			
Miscellaneous Inputs (MI)	-.02	-.02	.09	.01	-.04	-.07	-.16	.32		
	(-05)	(.04)	(.05)	(.04)	(-05)	(.05)	(-08)	(-09)		
Agricultural Chemicals (AC)	- .09	-.01	-.02	-.02	-.004	.08	-.06	-.06	.24	
	(-03)	(-02)	(.03)	(-02)	(.03)	(-03)	(.05)	(.04)	(-04)	
Feed, Seed, & Livestock (FS)	-.01	.13	.06	-.07	.10	.03	-.004	-.10	-.08	.15
	(.04)	(.04)	(.06)	(.03)	(.04)	(.04)	(-06)	(.06)	(.04)	(.07)
Fixed Inputs										
Family Labor	54.26	11.26	45.47	27.10	18.29	30.73	- 168.98	-69.31	12.84	4.13
	(32.10)	(14.42)	(20.02)	(45.26)	(31.24)	(26.08)	(35.50)	(23.42)	(13.17)	(19.01)
Land	34.02	25.59	-.18	88.37	3.29	19.18	-41.19	-45.54	51.59	-23.21
	(52.55)	(23.68)	(32)	(76.53)	(52.40)	(43.94)	(56.40)	(37.54)	(20.83)	(31.14)
Exogenous Factors										
Government Payments	-9.43	10.74	6.83	-6.49	10.60	10.78	-2.06	-18.80	21.39	-12.51
Time	(1-09)	(.48)	(.65)	(1.53)	(-102)	(-87)	(1-12)	(.75)	(.43)	(-63)
R^2	.68	.82	.88	.88	.64	.79	.98	.92	.98	.70

Variable inputs are measured in negative units; standard errors in parenthesis.

can be verified in terms of the monotonicity, convexity, linear homogeneity, and symmetry conditions. Monotonicity requires that the estimated output and input choice levels have the proper signs while convexity implies that the Hessian of the estimated parameter matrix should be positive definite. For purposes of empirical estimation, the properties of linear homogeneity and symmetry have been maintained throughout the study. The estimated profit function exhibited the monotonicity property but violated the convexity condition, This indicates that the estimated results are not consistent with the implied hypothesis of profit maximization. This inconsistency can be caused by a number of factors such as measurement errors in the data due to aggregation, inadequacies in model specification, and the inability of the model to capture qualitative effects.

Table 3. Estimated Output Supply and Input Demand Elasticities for Northeast Agriculture.*

	Elasticity with Respect to the Price of										
Product/Factor	MA	DP	PE	FG	FV	OP	HL	MI	AC	FS	FK
Meat Animals (MA)	.06	-.05	-.04	-.01	-.07	.02	-.13	-.01	-.12	-.01	.36
Dairy Products (DP)	-.05	.06	-.11	-.01	.05	.06	-.17	-.03	-.02	.15	.07
Poultry and Eggs (PE)	-.03	-.08	.07	.05	– IT	.01	.06	.09	-.03	-.16	.15
Feed Grains (FG)	-.02	-.01	.07	.20	-.08	.09	-.05	.01	-.04	-.09	-.08
Fruits and Vegetables (FV)	-.08	.04	-.16	-.09	.21	.08	.05	-.05	-.01	.12	-.11
Other Farm Products (OP)	.01	.06	.01	.08	.08	.01	-.04	-.08	.12	.04	-.21
Hired Labor (HL)	.11	.12	-.06	.04	-.05	.03	-.28	.13	.06	.01	-.11
Miscellaneous Inputs (MI)	.02	.03	-.12	-.01	.04	.08	.15	-.34	.08	.10	-.03
Agricultural Chemicals (AC)	.11	.01	.03	.03	.01	-.11	.07	.07	-.41	.11	.08
Feed, Seed, and Livestock (FS)	.01	-.14	.20	.09	-.13	-.04	.01	.12	.13	-.18	-.07
Farm Capital (FK)	-.42	-.31	-.18	.06	.23	.31	-.16	-.06	.10	-.08	.51

Table 4. Technology Test Statistics

Hypothesis	Log-Likelihood Ratio (d.f.)*		Critical Values for Chi-Square	
	Northeast	U.S.	.05	.01
Nonjointness in all individual outputs	42.35 (15)	51.66 (15)	25.00	30.58
Nonjointness among live-stock products	12.05 (3)	2.05 (3)	7.71	11.34
Nonjointness among field crops	16.15 (3)	5.30 (3)	7.81	11.34
Nonjointness between live-stock and field crops	16.36 (9)	42.19 (9)	16.92	21.67

* The Log-Likelihood ratio test is calculated as:

$$n * \log(|MM'|) - (|NN'|) \sim \chi^2 \text{ (no. of restrictions)},$$

where |MM'| and (NN'| are the determinants of the restricted and unrestricted variance-covariance matrices, respectively; n is the number of observations.

Technology Tests

If a technology can be shown to be nonjoint, economic modelling of the production structure is simplified considerably. A nonjoint technology implies that choice decision rules for a product are independent of the choice decision rules of other products being evaluated. Simply stated, this restriction implies that one cannot aggregate all individual products into a generalized output measure if production is characterized by nonjointness.

Lau (1972) has shown that nonjointness for all outputs implies that all mixed partial derivatives of the normalized profit function with respect to a particular output price and all other output prices is zero, i.e.,

$$(7) \quad \frac{\partial^2 \pi^*}{\partial P^*_i \partial P^*_h} = \frac{\partial Y_i}{\partial P^*_h} = b_{ih} = 0$$

for all i $\neq$ 1 ... m.

In this study, four possible output combinations were tested for nonjointness. These include nonjointness for all six output categories, nonjointness among livestock products, nonjointness among field crop products, and nonjointness between field crops and livestock products. Table 4 shows that the log-likelihood ratio test rejected nonjointness for all outputs at the .01 critical level. The same results were found for the tests of nonjointness among livestock products and among field crops. On the other hand, nonjointness between crops and livestock was not rejected at the same level of significance. These results indicate that the Northeast farm structure is characterized by jointness in production. In particular, production among livestock and among field crops are joint while production between livestock and field crops is nonjoint.

Technical Change

The Hicksian measure of biased technical change between every input pair is given as (Weaver and Lass)

$$(8) \quad X_j \begin{Bmatrix} \text{saving} \\ \text{neutral} \\ \text{using} \end{Bmatrix} \text{relative to } X_k \text{ if } B_{jk}$$

$$= \frac{-\partial \ln \frac{X_j}{X_k}}{\partial \ln t} \begin{Bmatrix} \text{greater} \\ \text{equal} \\ \text{less} \end{Bmatrix} \text{than zero.}$$

For the normalized quadratic profit function form, this measure can be expressed as

$$9) \quad B_{jk} = \left(\frac{\partial^2 \pi^*}{\partial R^*_j \partial t} \cdot \frac{1}{x^*_j} \right) - \left(\frac{\partial^2 \pi}{\partial R^*_k \partial t} \cdot \frac{1}{x^*_k} \right) \cdot t,$$

where X^*_j and X^*_k are predicted quantities of input j and k.

Estimates for equation (9) are shown in Table 5. Technical change in the Northeast farm region appeared to be farm capital-using relative to all inputs. It was also hired labor-saving against all other variable inputs except agricultural chemicals. Technical change appeared to be feed, seed, and livestock-using relative to all inputs except for farm capital. It was agricultural chemical-saving relative to all other inputs. Technical change was also miscellaneous input-using against hired labor and agricultural chemicals but was miscellaneous input-saving against feed, seed, and livestock and farm capital. Over 65 percent of farm income in the Northeast is derived from livestock products. These estimated measures of technical change indicate the increasing use of inputs geared toward livestock production in the Northeast.

Table 5. Biases (Bj_k) in Relative Input Utilization Due to Technical Change.*

Input j/k	Miscellaneous Inputs	Agricultural Chemicals	Feed, Seed & Livestock	Farm Capital
Hired Labor	.8368	-.1562	.0421	.6100
Misc. Inputs	***	-.1765	.0210	.5897

* estimated at their mean values
** symmetric in absolute value but opposite in sign
*** not applicable

Conclusion and Implications of Study

The overall objective of this paper was to analyze the structure of agricultural production in the Northeast. Specifically, input demand and output supply elasticities were estimated for six output groups and five variable input categories. All elasticities were found to be inelastic and all own-price elasticities (except for the numeraire variable) were consistent with theoretical expectations. The empirical results were consistent with the regularity properties imposed by the conceptual model except for the convexity condition. The violation of the convexity property indicates the inconsistency of the results with the maintained hypothesis of profit maximization. Hence, the results of this study should be interpreted with caution.

Technology tests indicate that the Northeast farm technology is characterized by some degree of jointness in production. Particularly, production among livestock products and among field crops were found to be characterized by a joint production process. This indicates the diversified nature of farming in the Northeast. However, production between livestock products and field crops was found to be nonjoint. This implies that livestock production can be modelled independently of the production decision for field crop products. This may be true for poultry and egg production but may not be necessarily true for dairy and meat animal production since dairy and meat animal farms normally produce part of their feed grain and forage requirements.

The nonjointness results for the Northeast were different from those found for the U.S. (Gempesaw).[6] The U.S. as a whole exhibited nonjointness within crops and within livestock but jointness between crops and livestock. This difference suggests that results from the country as a whole may not apply to the Northeast because the structure of Northeast agriculture is different.

The effects of technical change on input use were capital and feed, seed, and livestock-using. It was also hired labor and agricultural chemical-saving. This indicates the increasing use of inputs which are biased towards livestock production rather than crop production. This could be one reason why the dairy and livestock industries have increased their contribution to total Northeast farm income.

The interrelatedness of the results from this system-wide analysis of farm production is important in policy formulation. The impact of a single price change on all other variables can easily be determined in such an integrated framework. Furthermore, the estimates derived from this study fully support the contention that short-term price changes do not drastically affect the response of farm output supply and input demand given the quasi-fixed nature of agricultural production.

[6] Similar technology tests were also conducted on aggregate U.S. agriculture in a separate study. See Table 4 for the NE and U.S. test results.

References

Antle, J. M. "The Structure **of U.S. Agricultural Technology,** 1910—78." *American Journal of Agricultural Economics.* 66(1984):414-421.

Barten, A. P. "Maximum **Likelihood** Estimation of a Complete System **of Demand Equations."** *European Economic Review.* l(1969):7-73.

Binswanger, H. P. "A Cost Function Approach **to the Measurement of Factor Demand and Elasticities of** Substitution." *American Journal of Agricultural Economics.* 56(1974):377-386.

Brown, R. S. "Productivity, Returns and the Structure of Production in the U.S. Agriculture, 1947-1974." Ph.D. thesis. University **of Wisconsin-Madison, 1978.**