MEASURING PRODUCTIVITY CHANGE IN U.S. AGRICULTURE*

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I. INTRODUCTION

To understand the sources of change in productivity, that appropriate public policy and programs can be developed to increase productivity growth, a reliable and updated measure is needed. The term "productivity" discussed here refers to total factor productivity, or the ratio of value of total agricultural output to that of all inputs used in agricultural production.

The first comprehensive work on the measurement of productivity change in U.S. agriculture was done by Loomis and Barton [9] in 1961. Since then, this index has been updated annually as an offical USDA agricultural productivity index [19]. The weakness of using index numbers lies in the arithmetic formula used. It implies a specific functional form of the production function that may not accurately describe the data. Thus, a need arises to consider an alternative estimate of productivity.

Nevel [12] and Lave [8] used Solow's [17] approach in measuring productivity change in U.S. agriculture. But their indexes were not directly comparable to the offical USDA index, because they used different sources of data, different variables and their work was not updated.

The purpose of this paper is to present an alternative estimate of productivity in U.S. agriculture for the period 1939 to 1972 with the same data used to compute the offical USDA index. A production function approach is taken in this study. Results will be compared with the offical USDA index, and the difference between the two will be discussed.

The paper is divided into five sections. In section II, different measures of total factor productivity are presented. Procedures for selecting the form of production function are discussed in section III. The parameters of the Cobb-Douglas production function are estimated in section IV and results of the estimation are used to construct a productivity index in section V. Summary and conclusions are presented in the final section.

II. MEASUREMENT OF TOTAL FACTOR PRODUCTIVITY

Total factor productivity can be measured by taking the ratio of the value of output to an aggregate input, which represents all resources used in the production process. One difficulty in computing total factor productivity lies in constructing an aggregate input to serve as a divisor.[1] Unlike quantities — hours of work, acres of land, pounds of fertilizer, the number of tractor-hours and other factors — have to be

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[1] This study considers only the aggregation problem on the input side. The same aggregation problem occurs on the output side. However, this problem is not serious in the regression analysis. Aggregation errors in outputs can be transferred to the right hand side of the regression equation and collected in the disturbance term.

combined into a single aggregate input. To overcome this difficulty, most economists combine these inputs using monetary values. Another problem involves the selection of weights. Two general approaches have been used: the index number approach and the production function approach.

Two common index number methods of combining heterogeneous inputs into an aggregate input are to use arithmetic or geometric formulas. The arithmetic formula combines inputs with constant factor prices as weights. The geometric formula combines inputs geometrically, rather than arithmetically. Relative factor shares are used as weights for aggregating inputs.

The production function approach differs from the previous one by explicitly defining the form of the production function. Although no form of production function is explicitly assumed in deriving the above two indexes, the implied function can be deduced from a functional distribution theory where the production function is implicitly assumed. Use of an arithmetic index implies that the underlying production function is linear and homogeneous.[2] An aggregate input index, based on a geometric formula, implies a Cobb-Douglas production function. The above index number approaches are therefore special cases of the production function approach. Since the validity of any productivity measure hinges on proper specification of the production function and on accuracy of parameter estimates for the function, no *a priori* restrictions should be imposed on the form of the underlying production function. Ideally, a general form of production function should be used to fit a set of data, and they should be allowed to indicate the best specific form of production function. This approach is taken below.

III. SELECTION OF THE FORM OF PRODUCTION FUNCTION

A. Forms of Production Function

The following variable-elasticity-of-substitution (VES) production function derived by Lu and Fletcher [10] is of a general form:

$$(1)\ V = Y[\delta K^{-\rho} + (1-\delta)\eta(K/L)^{-c(1+\rho)}L^{-\rho}]^{-\frac{1}{\rho}}$$

where V is output, K is capital, L is labor, $\rho = 1/b-1$, and $\eta = (1-b)/(1-b-c)$. As in the CES (constant-elasticity-of-substitution) production function, Y is the efficiency parameter, δ is the distribution parameter, and ρ is the substitution parameter. This function satifies all theoretical properties of the neoclassical theory of production. In addition, the elasticity of substitution is not constrained to be constant but rather is a function of the capital-labor ratio. When c=0, the function in (1) reduces to the CES function. When c=0 and b=1, (1) reduces the Cobb-Douglas function. When c=0 and b=0, (1) reduces to the fixed coefficient function. When c=0 and b=∞, (1) becomes a linear and homogeneous function. Furthermore, it can be shown that when c=1, (1) reduces to the linear-elasticity-of-substitution production function developed by Sato [16] and Revankar [14] independently. Thus, due to its generality, data can be fitted to the VES function and an appropriate form of production function can possibly be derived from parameter estimates.

B. The Data

Unpublished data for output and seven inputs were obtained from USDA sources for ten farm production regions and for the U.S. from 1939 to 1972.[3] These are the same data used to compute the offical USDA productivity index.

The following is a summary of definitions and measurement of variables used in this study. Except for man-hours, all variables are measured in 1957-59 constant dollars.

Farm output (V) measures the value of farm production available for human use. It includes total livestock production and crop production.

Labor (L) is measured either by value of labor in constant dollars or in man-hours of farm work. It includes hired labor, operator and family labor.

Farm real estate (R) measures annual flow of real estate services which includes interest on equity in land, service buildings and real estate mort-

[2] A linear and homogeneous function is different from a linearly homogeneous function. The former is linear function without a constant term and the latter is a homogeneous function of degree one.

[3] The USDA divides the United States in to ten farm production regions: Northeast, Lake States, Corn Belt, Northern Plains, Appalachian, Southeast, Delta States, Southern Plains, Mountain and Pacific. For states in each region, see map on p. ii in *Changes in Farm Production and Efficiency* [19].

gages; depreciation; repairs; accidental damage on service buildings and other structures; and grazing fees on land not in farms but included in farm operations.

Mechanical power and machinery (M) include interest on the inventory value of automobiles, trucks, tractors and other farm machinery; depreciation, repairs, parts, tires, licenses and insurance on farm machinery; and other cash expenditures such as oil, fuel electricity, hardware, small hand tools, custom work, etc.

Fertilizer and liming material (F) include fertilizer plant materials and lime applied on farms.

Feed, seed, and livestock purchases (S) include crops used for feed and seed in farm production and livestock purchased from the nonfarm sector.

Taxes and interest (T) include real estate and personal property taxes and interest on livestock and crop inventories, and on operating capital.

Miscellaneous inputs (O) include fire, wind and crop-hail insurance, and charges for containers, binding materials, dairy supplies, pesticides, irrigation, veterinary, telephone, ginning, etc.

Wage rates (W) are measured by annual average composite wage rates per hour.

No adjustments were made for changes in the quality of input variables. These changes are considered to be the results of technological change.

C. Procedures for Selecting the Form of Production Function

To select the most appropriate form of production function for U.S. agriculture, regional input and output data for the period 1939 to 1972 were fitted to the following first order condition of the VES production function:

$$(2)\ \ln (V/L)_t = \ln a + b \ln W_t + c \ln (K/L)_t + u_t;$$

$$t = 39, 40, \ldots, 72;$$

where $E(u) = 0$, $E(uu') = \sigma^2 I$, and V, L. and W are farm output, farm labor, and wage rates, respectively, as defined previously. The capital variable (K) is obtained by aggregating geometrically over all inputs, as defined previously, except labor.

To allow for changes in the parameters b and c over time, cross-sectional data over ten regions were fitted to (2) for each year. Thus, 34 regression equations from 1939 to 1972 were run. Results indicate that none of the $\hat{c}$ coefficients are significantly different from zero at the ten percent level. The CES production function, then, or one of its special cases, is an appropriate form of production function.

Since none of the $\hat{c}$ coefficients was significantly different from zero, the ln, (K/L) term in (2) was dropped. Equation (2) then reduced to

$$(3)\ \ln (V/L)_t = \ln a + b \ln W_t + u_t;\ t = 39, 40, \ldots, 72;$$

which is a first order condition of the CES production function. The b coefficient is an estimate of the elasticity of substitution.

The cross-sectional data from 1939 to 1972 were fitted to (3) for each year. Results show that elasticities of substitution have fluctuated around the value of unity. All values of the elasticity of substitution are significantly different from zero at the one or five percent level, except for 1966, 1967, 1968, 1971, and 1972. But none of these coefficients is significantly different from unity at the ten percent level. Furthermore, the mean value for the elasticity of substitution for the 34 years is 1.09 with a standard deviation of 0.10. This suggests that the Cobb-Douglas production function is an appropriate form of the production function among those investigated above for U.S. agriculture data.

IV. ESTIMATION OF PARAMETERS OF THE COBB-DOUGLAS PRODUCTION FUNCTION

A. Methods

Two approaches are commonly used in the literature to estimate parameters of the Cobb-Douglas function: the multiple regression method and the factor share method. The factor share approach assumes competitive equilibrium. It has been used quite frequently to avoid the multicollinearity problem.

The multiple regression method is less restrictive. The weakness of the multiple regression method is that, especially when many input variables are included in the production function, independent variables tend to be highly correlated with each other so that their separate effects on the dependent variable cannot be estimated. This method has been used successfully by Griliches [5] on cross-sectional data. Since seven input variables will be included in the production function in this study, a combination of time series and cross-sectional data will be used to reduce the multicollinearity problem.

Several alternative methods of combining time series and cross-sectional data have been used in the literature [1, 6, 7, 11, 13, 21]. In this study, the analysis-of-covariance method is selected in the measurement of productivity change. Here, the measured productivity index is computed from time effects of the regression equation and thus is less subjected to random errors which, in the traditional residual method, are allocated in the productivity index [15].

In the two-factor model discussed previously, it was concluded that the Cobb-Douglas production function best describes the production relationship between farm output and capital and labor inputs in U.S. agriculture. Since it is difficult to extend the VES production function to include more than two factors of production, it is assumed that results obtained from the two-factor model will hold for the model with more than two factors of production.[4] Under this assumption, data from the ten regions from 1939 to 1972 were fitted to the following analysis-of-covariance model:

$$(4) \quad \ln V_{it} \times \ln \alpha_0 + \alpha_1 \ln L_{it} + \alpha_2 \ln R_{it} + \alpha_3 \ln M_{it} + \alpha_4 \ln F_{it} + \alpha_5 \ln S_{it} + \alpha_6 \ln T_{it} + \alpha_7 \ln 0_{it} + \sum_{t=40}^{72} \mu_t Y_t + u_{it}; \quad i = 1, 2, \ldots, 10, \; t = 39, 40, \ldots, 72.$$

where V is farm output and L, R, M, F, S, T, and 0 are inputs as defined previously. The subscript i denotes the i^{th} region t denotes time period measured in years. The Y_t variables are time dummy variables, defined as follows:

$Y_{40} = 1$ if the observation is in 1940,
$= 0$ otherwise,

$Y_{41} = 1$ if the observation is in 1941,
$= 0$ otherwise,

and so on. The dummy variable for the base year (Y_{39}) was omitted to avoid singularity in the sums of squares and cross products matrix. Its effect on productivity is included in the intercept term (α_0). The μ coefficients are time effects which estimate changes in levels of technical efficiency in comparison with the base year.

B. Results of the Fitted Production Function

Regressions of (4) were run for the data of ten farm production regions for the period 1939 to 1972. Man-hours and constant dollar expenditures of labor were used alternately as a measure of labor in the regression. Since the results using the two different measures of labor were quite similar, only results of regressions using man-hours are shown in Table 1.

Table 1. ESTIMATES OF THE PRODUCTION FUNCTIONS FOR U.S. AGRICULTURE, 1939-72

Variables	Regression Coefficient	Std. Error of Reg. Coef.
Labor	0.140**	0.031
Real Estate	0.316**	0.026
Machinery	0.251**	0.036
Fertilizer	0.021*	0.010
Feed and Seed	0.067**	0.020
Tax and Interest	0.169**	0.027
Miscellaneous	0.032	0.025
Time Dummies		
Y_{40}	0.018	0.037
Y_{41}	0.033	0.037
Y_{42}	0.110**	0.037
Y_{43}	0.075*	0.038
Y_{44}	0.088*	0.039
Y_{45}	0.063	0.039
Y_{46}	0.073	0.040
Y_{47}	0.042	0.042
Y_{48}	0.085	0.046
Y_{49}	0.026	0.048
Y_{50}	0.006	0.050
Y_{51}	0.019	0.053
Y_{52}	0.037	0.054
Y_{53}	0.058	0.055
Y_{54}	0.048	0.056
Y_{55}	0.085	0.058
Y_{56}	0.092	0.059
Y_{57}	0.081	0.061
Y_{58}	0.156*	0.062
Y_{59}	0.165**	0.063
Y_{60}	0.199**	0.063
Y_{61}	0.214**	0.064
Y_{62}	0.219**	0.066
Y_{63}	0.253**	0.067
Y_{64}	0.245**	0.068
Y_{65}	0.268**	0.070
Y_{66}	0.239**	0.072
Y_{67}	0.272**	0.073
Y_{68}	0.282**	0.074
Y_{69}	0.298**	0.076
Y_{70}	0.308**	0.076
Y_{71}	0.363**	0.077
Y_{72}	0.357**	0.078
Constant	2.629	
R^2	0.964	
Std. Error of Est.	0.081	
No. of observations	340	

*** Five percent level of significance.**
**** One percent level of significance.**

[4] Several new forms of VES production functions which allow for more than two factors have been introduced recently [2, 3, 4, 18, 20]. It is, however, still difficult to estimate the parameters of the production functions when there are as many as seven factors considered in this study.

All regression coefficients for the seven input variables have "correct" signs and, except for the miscellaneous input, are significantly different from zero at the one or five percent level. The sum of the production elasticities is 0.996. With the exception of the 1940-41 and 1945-1957 periods, all coefficients of year-dummy variables are significant at the one or five percent level.

The coefficient of a year-dummy variable for the year t estimates the difference in intercepts between year t and the base year. The insignificant coefficients of year-dummy variables for 1940 to 1941 and 1945 to 1957 imply that the production efficiency in these years had not changed significantly from the base year. From 1958 to 1972 the coefficients of the year dummy variables are statistically significantly different from zero. The magnitude of the coefficients also increases over time. These results indicate that production efficiency in these years has increased over time.[5]

V. CONSTRUCTION OF THE AGRICULTURAL PRODUCTIVITY INDEX

As indicated earlier, the μ_t coefficient estimates changes in productivity between the t^{th} year and the base year. Thus, the productivity index can be constructed from the μ_t coefficient. Year-to-year changes in productivity were computed by dividing the exponential value of each year's intercept by that of the base year's intercept. The ratio of these terms for each year was then expressed as a percent of the base year ratio. Results are shown in Table 2. For comparison, the USDA productivity index is presented in column 3.

Since the USDA index employs 1967 as the base year, this study also employs the same base year for comparison purposes. It is apparent that the two indexes agree quite well from 1952 to 1972. However, these two indexes diverge considerably back toward 1939.

The reason for this divergence for years prior to 1952 is probably due to a change made in 1955 in the price weights used in computing the USDA productivity index. All input and output data used in this study and in computing the USDA productivity index are measured in 1957-59 constant dollars. However, from 1939 to 1955, all data were originally measured in 1947-49 prices. To combine the two segments of the series and to express them in terms of 1957-59 constant dollars, the USDA "spliced" the two segments of series in the year 1955. Thus, in fact, two price weights were used in computing the USDA index: 1947-49 prices for 1939-1955 data and 1957-59 prices for 1955-1972 data. A change in price weights changes the relative factor prices, which implies a change in the relative marginal productivities of inputs. Thus, changes in total factor productivity are implied.[6] On the other hand, weights used in this study remain unchanged. Therefore, it is likely that the difference between the two index series before 1955 is due to a change in price weights in computing the USDA productivity index.

Table 2. PRODUCTIVITY CHANGE IN U.S. AGRICULTURE, 1939 to 1972 (1967=100)

Year	LU	USDA	Year	LU	USDA
1939	76.20	58	1956	83.56	82
1940	77.54	60	1957	82.63	80
1941	78.76	62	1958	89.03	86
1942	85.06	69	1959	89.86	88
1943	82.17	68	1960	92.99	90
1944	83.22	70	1961	94.38	90
1945	81.16	69	1962	94.84	91
1946	81.97	71	1963	98.17	95
1947	79.45	69	1964	97.35	94
1948	82.92	75	1965	99.57	97
1949	78.22	74	1966	96.78	96
1950	76.68	73	1967	100.00	100
1951	77.64	75	1968	101.03	102
1952	79.10	78	1969	102.62	103
1953	80.73	79	1970	103.64	102
1954	79.95	79	1971	109.53	110
1955	82.91	82	1972	108.89	111

VI. SUMMARY AND CONCLUSIONS

The purpose of this paper was to measure pro-

[5]It is possible to change the level of significance of year dummy variables by changing the arbitrarily chosen base year, say to 1972, but the resulting productivity index will remain unchanged. Therefore, the statistical significance of the year-dummy variables is not important in the construction of the productivity index.

[6]If agriculture is operating competitively, the factors of production are paid the values of their marginal products. Changes in relative factor price in the linear and homogeneous production function model imply changes in relative marginal productivities.

ductivity change in U.S. agriculture for the period 1939 to 1972 using a production function approach.

Rather than assuming a specific form of production function *a priori,* this study fitted U.S. agricultural data to a general form of production function and determined the most appropriate form of production function by testing the significance of values of estimated parameters. Although results indicate that the Cobb-Douglas function is the most appropriate form among those investigated, the form was determined by data, not by assumption.

The analysis-of-covariance method was used to combine a time series of ten farm production regions from 1939 to 1972. Regression coefficients of time dummy variables were used to construct the productivity index. The index measured in this study was then compared with the official USDA productivity index.

Results indicate that there is not much difference between the productivity index measured in this study and the USDA index from 1952 to 1972. However, there is a considerable difference in these two index series before 1952. The primary reason for the difference may be due to a change in the price weights in 1955 used in computing the USDA index.

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