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Measuring Agricultural Productivity

A New Look

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ABSTRACT

This paper presents revised procedures for calculating total factor productivity and measuring productivity growth in U.S. agriculture over the postwar years. Our estimates reflect (1) a disaggregated treatment of outputs and inputs and (2) indexing procedures that do not impose a priori restrictions on the structure of production. We find that productivity grew at the average annual rate of 1.75 percent during the 1948-79 period, compared with the 1.70 percent per year estimated by the U.S. Department of Agriculture. The similar estimates of productivity growth overshadow some important differences in measurement of individual inputs.

Keywords: Total factor productivity, index numbers, outputs, inputs.

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MEASURING AGRICULTURAL PRODUCTIVITY: A NEW LOOK

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INTRODUCTION

Because the major effort in measuring agricultural productivity is conducted by the U.S. Department of Agriculture (USDA), a task force on measuring agricultural productivity, under the joint auspices of the American Agricultural Economics Association (AAEA) and the USDA, has examined the sources and procedures1/ used in constructing the existing statistics. The task force has recommended changes in both conceptual and practical measurement areas. The most important changes are to move further toward a total factor productivity measure; to handle hired, operator, and family labor separately; to account for quality changes in inputs; and to adopt an indexing procedure that does not impose *a priori* restrictions on the structure of agricultural production.2/

This paper presents revised procedures for calculating total factor productivity and measuring productivity growth in U.S. agriculture over the postwar period. Our estimates reflect: (1) the improvements suggested by the AAEA task force, (2) a disaggregated treatment of outputs and inputs, and (3) indexing procedures that are consistent with the structure of production in U.S. agriculture. The methodology was developed by Christensen and Jorgenson and they implemented it for the U.S. economy for the period 1929-69. Gollop and Jorgenson implemented this approach in assessing the productivity growth of 51 industries for the period 1947-73.

We present revised measures of agricultural output for the period 1948-79. Indexes of labor input are presented for hired and self-employed and unpaid family labor. The labor input is represented as a function of different types of labor broken down by characteristics of individual workers, such as sex, age, education, employ-

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1/ The procedures used have been outlined in *Major Statistical Series of the U.S. Department of Agriculture* (1957, 1970) as well as in Loomis and Barton, Lambert, and Barton and Durost.

2/ Diewert (1976) has shown that many index number formulas exactly represent particular production functions. The widely used Laspeyres index is exact for a linear production function, which specifies *a priori* that all factors are perfect substitutes in the production process.

ment status, and occupation. We present indexes of capital input using the durable goods model in Jorgenson. At the industry level, the value of output includes the value of primary factors, labor and capital, and the value of intermediate (purchased) inputs; hence indexes of intermediate inputs are presented. We present revised estimates of total factor productivity in U.S. agriculture for the postwar period. Our results are contrasted with those taken from USDA's Economic Indicators of the Farm Sector: Production and Efficiency Statistics.

METHODOLOGY

Christensen and Jorgenson proposed the following index of total factor productivity (TFP):

$$(1)\quad \ln(TFP_t/TFP_{t-1}) = 1/2 \sum_i (R_{it}+R_{i,t-1})\ln(Y_{it}/Y_{i,t-1}) - 1/2 \sum_i (S_{it}+S_{i,t-1})\ln(X_{it}/X_{i,t-1}),$$

where the Y_i are output indexes, the X_i are input indexes, the R_i are output revenue shares, and the S_i are input cost shares. Diewert (1976) showed that (1) can be derived from a homogeneous translog transformation function that is separable in outputs and inputs, and exhibits neutral differences in productivity. Caves, Christensen, and Diewert showed that separability and neutrality are not required to derive (1) from a homogeneous translog transformation function. The translog function itself can provide a second-order approximation to an arbitrary linearly homogeneous function (Diewert, 1976).

We assume that the functions defining input and output aggregates are also of the translog form. The translog quantity aggregates can be expressed as:

$$(2)\quad \ln(X_t/X_{t-1}) = 1/2 \sum_j (S_{jt}+S_{j,t-1})\ln(X_{jt}/X_{j,t-1}).$$

Implicit price indexes are defined as ratios of value to the translog quantity indexes. This is because the translog index satisfies Fisher's weak factor reversal test only approximately. Diewert (1978) showed that the corresponding implicit price indexes can also be interpreted as a second-order approximation.

OUTPUT

We identify six categories of agricultural output. The output categories are livestock and livestock products excluding dairy, dairy, feed and food grains, other field crops, vegetables and melons, and fruits and tree nuts. A detailed classification of output is presented in table 1. Output is defined as the quantity marketed (including unredeemed Commodity Credit Corporation loans) plus the change in farmer-owned inventory and quantities consumed by farm households. The output data are adjusted for interfarm sales to avoid double counting.

Indexes in each category are based on value to the producer. Prices received by farmers, as reported in USDA's *Agricultural Statistics*, include an allowance for unredeemed Commodity Credit Corporation loans and purchases by the Government valued at the average loan rate. Payments under Government programs are excluded. Prices received by farmers are adjusted to reflect Government payments. We compute the value of output in current prices by multiplying the adjusted average prices times the output quantities.

We have constructed translog indexes of output $\{Y_i\}$. These are reported in table 2. Price indexes, corresponding to the translog quantity aggregates, are defined as the ratio of the value of the output aggregate to the translog quantity index.

LABOR INPUT

In constructing a measure of labor input it is important to distinguish among components of the labor input that differ in marginal productivity. We represent labor input as a function of different types of labor input, broken down by characteristics of individual workers. Data on employment, hours worked per week, weeks worked per year, and compensation per hour, cross-classified by occupational and demographic characteristics, are developed in Gollop and Jorgenson.3/ This disaggregation is achieved by exploiting the detail available from household surveys. The household survey results are then used to distribute industry totals based on establishment surveys. For each of the 51 industries (including production agriculture), we disaggregated labor input and labor cost into cells cross-classified by the 2 sexes, 8 age groups, 5 educational groups, 2 employment classes, and 10 occupational groups. The dimensions of the labor matrix are given in table 3.

No existing household or establishment survey, including the recently expanded Current Population Survey, is designed to provide annual data on the distribution of workers among the 81,600 cells of a matrix cross-classified by the characteristics given in table 3. Existing surveys do provide marginal totals cross-classified by two, three, and sometimes four characteristics of labor input. These marginal distributions, available for each year from 1948 to 1979, provide the basis for estimates of labor input and cost.

3/ Updates were kindly provided by Professor Gollop.

Table 1--Output classification

Livestock and livestock products	Dairy	Feed and food grains	Other field crops	Vegetables and melons	Fruits and tree nut
Cattle	Milk	Rye	Cotton lint	Artichokes	Apples
Calves	Milkfat	Corn	Cottonseed	Broccoli	Avocado
Hogs		Oats	Soybeans	Celery	Bushberries
Sheep		Rice	Flaxseed	Cauliflower	Cranberries
Broilers		Sorghum	Peanuts	Carrots	Cherries, sweet
Turkeys		Wheat	Sunflowerseed, oil	Brussels sprouts	Cherries, tart
Chickens		Barley	Sunflowerseed, nonoil	Cantaloup	Dates
Eggs		Hay	Alfalfa seed	Cucumbers	Grapefruits
Wool			Bluegrass seed	Eggplants	Grapes
Mohair			Lespedeza seed	Endive	Limes
Honey			Orchard grass seed	Spinach	Lemons
Beeswax			Red clover seed	Tomatoes	Nectarines
			Rye grass seed	Garlic	Olives
			Tall fescue seed	Green peppers	Oranges
			Timothy seed	Honeydew melon	Pears
			Sugar beets	Lettuce	Peaches
			Sugar maple	Onions	Plums
			Sugarcane	Sweet corn	Pomegranates
			Corn syrup	Watermelon	Prunes
			Tobacco	Asparagus	Strawberries
			Popcorn	Cabbage	Tangelos
			Hops	Snap beans	Tangerines
			Peppermint oil		Apricots
			Spearmint oil		Almonds
			White potatoes		Filberts
			Sweet potatoes		Pecans
			Field peas		Walnuts
			Field beans		

Table 2--Output, 1948-79

Year	Animal products Translog index (1)	Dairy Translog index (2)	Feed and food grains Translog index (3)	Other field crops Translog index (4)	Vegetables and melons Translog index (5)	Fruits and treenuts Translog index (6)
	1977 = 1.000					
1948	0.556	0.865	0.442	0.527	0.906	0.705
1949	.590	.889	.254	.566	.811	.649
1950	.601	.889	.352	.475	.778	.690
1951	.658	.881	.308	.560	.789	.761
1952	.634	.885	.368	.562	.775	.669
1953	.650	.927	.345	.577	.876	.687
1954	.683	.941	.378	.559	.832	.709
1955	.713	.949	.395	.593	.814	.722
1956	.740	.968	.386	.586	.862	.754
1957	.713	.972	.426	.580	.822	.696
1958	.719	.965	.494	.568	.819	.707
1959	.762	.958	.473	.621	.880	.788
1960	.766	.969	.548	.635	.857	.694
1961	.786	.997	.468	.667	.838	.836
1962	.788	1.005	.467	.697	.875	.715
1963	.825	.999	.528	.736	.860	.694
1964	.869	1.016	.467	.714	.840	.826
1965	.858	.996	.640	.719	.843	.805
1966	.888	.964	.564	.657	.806	.855
1967	.920	.957	.730	.634	.848	.675
1968	.923	.947	.644	.703	.910	.820
1969	.925	.941	.698	.779	.832	.975
1970	.967	.949	.646	.767	.837	.840
1971	.999	.962	.833	.755	.829	.870
1972	.972	.975	.831	.842	.856	.810
1973	.959	.938	.929	.788	.884	.967
1974	.984	.941	.784	.839	.920	1.026
1975	.966	.940	.997	.862	.932	1.108
1976	1.006	.979	.940	.826	.927	1.007
1977	1.000	1.000	1.000	1.000	1.000	1.000
1978	.986	.991	.994	1.032	.978	1.048
1979	.993	1.006	1.132	1.120	1.068	1.217
Average annual rates of growth:						
1948-79	0.0187	0.0049	0.0303	.0243	.0053	.0176
1948-53	.0312	.0138	-.0496	.0181	-.0067	-.0052
1953-57	.0231	.0119	.0527	.0130	-.0159	.0032
1957-60	.0239	-.0010	.0839	.0302	.0139	.0010
1960-69	.0210	-.0033	.0269	.0227	-.0033	.0378
1969-73	.0090	-.0008	.0715	.0029	.0152	-.0021
1973-79	.0058	.0117	.0329	.0586	.0315	.0383

Table 3--Characteristics of labor input

Sex:	
(1)	Male
(2)	Female
Age:	
(1)	14-15 years
(2)	16-17 years
(3)	18-24 years
(4)	25-34 years
(5)	35-44 years
(6)	45-54 years
(7)	55-64 years
(8)	65 years and over
Education:	
(1)	1-8 years grade school
(2)	1-3 years high school
(3)	4 years high school
(4)	1-3 years college
(5)	4 or more years college
Employment class:	
(1)	Wage/salary worker
(2)	Self-employed/unpaid family worker
Occupation:	
(1)	Professional, technical, and kindred workers
(2)	Farmers and farm managers
(3)	Managers and administrators, except farm
(4)	Clerical workers
(5)	Sales workers
(6)	Craftsmen and kindred workers
(7)	Operatives
(8)	Service workers, including private household
(9)	Farm laborers
(10)	Laborers, except farm

To construct annual matrices cross-classified by the industrial, occupational, and demographic characteristics listed in table 3 for employment, hours worked per week, weeks worked per year, and average compensation per hour, Gollop and Jorgenson introduce a multiproportional matrix model, generalizing the "RAS" method introduced by Stone and formalized by Bacharach as the biproportional matrix model.

Based on the employment, hours, weeks, and labor-compensation data described above, translog indexes of labor input $\{L_i\}$ for hired, and self-employed and unpaid family labor are reported in columns (3) and (6) of table 4.

The translog indexes of labor input can be decomposed into quality and quantity components.4/ For each of the components of labor input (Gollop and Jorgenson disaggregate hired, and self-employed and unpaid family labor input into 800 cells each) the flow of labor services is proportional to hours worked $\{H^i_\ell\}$, where the constants of proportionality $\{Q^i_{L\ell}\}$ transform hours worked into a flow of labor services. We can define hours worked $\{H_i\}$ as the unweighted sum of the components:

$$(3) \quad H_{it} = \sum_{\ell=1}^{800} H^i_{\ell t}, \; i = 1,2.$$

Similarly, we can define indexes of the quality of hours worked $\{Q^i_L\}$ that transform measures of hours worked into translog indexes of labor input:

$$(4) \quad L_{it} = Q^i_{Lt} \; H_{it}, \; i = 1,2.$$

Using equations (2) and (4) we can express the indexes of the quality of hours worked as

$$(5) \quad \ln(Q_{Lt}/Q_{L,t-1}) = 1/2 \sum_{\ell=1}^{800}(S_{\ell t}+S_{\ell,t-1})\ln(H_{\ell t}/H_{\ell} ,$$

$$- \ln(H_{it}/H_{i,t-1}), \; i = 1,2.$$

4/ Detailed discussions of quality indexes and applications to disaggregated labor data can be found in Chinloy, and Gollop and Jorgenson.

Table 4--Labor input, 1948-79

Year	Hired workers: Hours worked (1)	Hired workers: Labor quality (2)	Hired workers: Translog index (3)	Self-employed and unpaid family workers: Hours worked (4)	Self-employed and unpaid family workers: Labor quality (5)	Self-employed and unpaid family workers: Translog index (6)
			1977=1.000			
1948	2.189	0.728	1.594	3.291	0.799	2.793
1949	2.026	.731	1.482	3.212	.803	2.733
1950	2.109	.746	1.575	2.958	.827	2.599
1951	2.038	.727	1.482	2.838	.815	2.467
1952	1.953	.724	1.413	2.713	.832	2.398
1953	1.888	.711	1.342	2.650	.829	2.333
1954	1.774	.715	1.269	2.619	.829	2.304
1955	1.749	.716	1.253	2.553	.829	2.246
1956	1.622	.715	1.159	2.404	.874	2.121
1957	1.539	.717	1.104	2.221	.884	1.963
1958	1.550	.726	1.125	2.051	.897	1.839
1959	1.517	.713	1.082	2.054	.899	1.846
1960	1.516	.768	1.164	1.825	.947	1.729
1961	1.520	.778	1.182	1.795	.911	1.635
1962	1.470	.805	1.183	1.713	.915	1.568
1963	1.453	.809	1.175	1.613	.901	1.453
1964	1.298	.828	1.075	1.533	.902	1.382
1965	1.214	.846	1.027	1.506	.904	1.362
1966	1.094	.882	.965	1.351	.927	1.252
1967	.995	.896	.892	1.315	.930	1.223
1968	.950	.898	.853	1.323	.930	1.230
1969	.952	.849	.808	1.268	.935	1.186
1970	.938	.991	.930	1.207	.981	1.184
1971	.926	.997	.905	1.191	.951	1.133
1972	.925	.981	.907	1.177	.963	1.133
1973	.945	.985	.931	1.167	.972	1.134
1974	1.005	.988	.993	1.109	.978	1.085
1975	1.010	1.004	1.014	1.080	.994	1.073
1976	1.030	1.005	1.035	1.022	1.002	1.024
1977	1.000	1.000	1.000	1.000	1.000	1.000
1978	1.073	.988	1.061	.936	1.003	.939
1979	1.038	.991	1.029	.831	1.011	.840
Average annual rates of growth:						
1948-79			-.0141			-.0388
1948-53			-.0344			-.0360
1953-57			-.0488			-.0432
1957-60			.0176			-.0423
1960-69			-.0406			-.0419
1969-73			.0354			-.0112
1973-79			.0167			-.0141

The indexes $\{Q_L^i\}$ reflect the changes in the composition of hours worked. Unweighted indexes of hours worked are given in table 4, columns (1) and (4). The ratios between the translog indexes of labor input and the indexes of hours worked, presented in table 4, columns (2) and (5), measure the change in labor quality.

The product of the price and quantity indexes of labor input must be equal to the value of total labor compensation. We define the price indexes corresponding to the translog indexes of labor input as the ratio of labor compensation (or imputed compensation) to the translog quantity index.

CAPITAL INPUT

We compute translog quantity indexes of capital input from data on service flows from capital stocks and rental prices for capital services. For property with an active rental market, the price of capital services may be observed directly as the rental price for use of the asset. The product of the rental price and the quantity of the asset used is the outlay on capital services or property compensation. An alternative method for separation of price and quantity components of outlay on capital services is to infer the level of capital stocks at each point in time from data on flows of investment up to that point. Rental prices for capital services, which are required to construct an index of capital input, can be inferred from data on prices of capital goods and property compensation. The basis for this approach is the durable goods model in Jorgenson. We estimate the level of capital stock for 12 assets: autos, motor trucks, farm tractors, other machinery excluding tractors, nonresidential structures, land, beef cows, dairy cows, bulls, stock sheep, hogs for breeding, and farm inventories. Data on property compensation are controlled to industry totals from the national income accounts. We combine data on property compensation and the value of capital with information on property tax rates and estimates of depreciation and revaluation of existing stocks of capital goods to obtain estimates of rates of return to capital. Data on rates of return and the price of capital goods are used to obtain prices of capital services from each asset.

Capital Stocks

For equipment and structures we employ the perpetual inventory method, assuming that replacement requirements follow a declining balance pattern for each asset, so that the relationship between investment and capital stock takes the form:

$$(6)\ A_t = I_t + (1-\delta)\ A_{t-1},$$

where δ is the rate of replacement.

Data on investment in automobiles, motor trucks, farm tractors, and agricultural machinery excluding tractors, in current prices, are taken from <u>Economic Indicators of the Farm Sector: Income</u>

and Balance Sheet Statistics. Investment data is on a net purchase basis (net of trade-in value). The Bureau of Labor Statistics (BLS) producer price indexes for passenger cars, motor trucks, wheel-type farm tractors, and agricultural machinery excluding tractors are employed as investment deflators.5/ Estimates of investment in nonresidential structures are obtained from the Bureau of Economic Analysis' Capital Stock Study. Investment data are reported in current and constant prices. These data are employed to obtain an implicit price index for nonresidential structures. The capital stock benchmarks for depreciable investment are taken to be zero in 1935 for automobiles; zero in 1936 for motor trucks, zero in 1938 for farm tractors, and zero in 1927 for agricultural machinery excluding tractors. The benchmark for investment in nonresidential structures is taken to be zero in 1902. The service lives for equipment and structures correspond to those of Bulletin F published by the Treasury Department. We assume that economic depreciation can be approximated by the double declining balance method; the appropriate rate of replacement for each capital good is $\delta_i = 2/n_i$ where n_i is the lifetime of the asset.

Data on investment in breeding livestock are not maintained. Stocks of breeding livestock are calculated by multiplying the number of breeding livestock at the beginning of each year by the average price per head. The average price for each class of livestock is derived by multiplying the price per head for each age cohort times the percentage that cohort is of the total herd. Depreciation is estimated separately for beef and dairy cows, bulls, and stock sheep on the difference between the acquisition price of the animal and salvage or cull-slaughter price.6/

To estimate the stock of land in constant prices we compute translog price and implicit quantity indexes of land in farms, using as prices land values (excluding buildings) per acre. It was assumed that farmland within a State was homogeneous in quality; hence, aggregation was at the State level.

The stock of farm inventories at yearend 1976 was derived by multiplying yearend 1976 quantities by December 1976 prices. This stock was moved forward to 1978 by adding, and back to 1947 by

5/ Griliches (1963) notes that the USDA indexes of prices paid by farmers for machinery and motor vehicles have an upward bias relative to other similar price indexes.

6/ Depreciation charges are not included in the service flows from hogs kept for breeding because the salvage value exceeds the acquisition price.

subtracting, the estimated annual changes in farm inventories in current prices. A translog price index for farm inventories was constructed for use as an investment deflator. Our estimates of farm inventories differ from corresponding estimates in Economic Indicators of the Farm Sector: Income and Balance Sheet Statistics because of several definitional differences. The most important differences are the inclusion in crop and livestock inventories in the balance sheet of: (1) breeding livestock, and (2) commodities used as collateral for Commodity Credit Corporation loans. Breeding livestock replacements are regarded as partially completed capital goods and are treated as inventory items. The annual changes in farm inventories that enter into gross farm product are calculated as the changes during the year in physical quantities of crops and market livestock multiplied by average annual prices.

Property Compensation

The price of capital services $\{P_{Kt}\}$ can be expressed in terms of the price of the capital good $\{P_{At}\}$, the rate of return $\{r_t\}$, depreciation $\delta\{P_{At}\}$, asset revaluation $\{P_{At}\} - \{P_{A,t-1}\}$, and property taxes $\{\tau_t\}$:

$$(7)\quad P_{Kt} = P_{A,t-1}r_t + \delta P_{At} - (P_{At} - P_{A,t-1}) + P_{At}\tau_t.$$

This relationship results from representing the price of acquisition of capital goods as the discounted value of future rentals.

The outlay on capital services can be expressed as the sum of outlays on all types of capital services. For each asset the outlay is the product of the rental price and the corresponding quantity of capital:

$$(8)\quad P_{Kt} A_{t-1} = [P_{A,t-1}r_t + \delta P_{At} - (P_{At}\ P_{A,t-1}) + P_{At}\tau_t]\ A_{t-1}.$$

Given data on property compensation, the acquisition price of capital, depreciation, and property taxes, this expression determines the rate of returns $\{r_t\}$ and, therefore, the price of capital services. If there is more than one type of asset, the value of property compensation is equal to the sum of capital services over all assets.

The rate of returns can be expressed as:

$$(9)\quad r_t = \frac{P_{kt}A_{t-1} - [\delta P_{At} - (P_{At} - P_{A,t-1}) + P_{At}\tau_t]\ A_{t-1}}{P_{A,t-1}\ A_{t-1}}.$$

The rate of returns is equal to the ratio of property compensation less depreciation, plus capital gains, and less property taxes, to the value of capital at the beginning of the period.

Property compensation is defined in terms of data available in the national income accounts:

Farm property compensation

= national income originating in farming

+ capital consumption allowances

+ indirect business taxes

+ government payments to nonoperator landlords

- labor compensation

- imputed compensation of self-employed and unpaid family labor.

Self-employed and unpaid family (class 2) workers are imputed the mean wage received by hired (class 1) workers with the same characteristics. Depreciation, capital gains, property taxes, and the value of assets are sums over all assets.

Indexes of Capital Input

We have outlined the development of data on capital stocks and the rental prices of capital services. Rental prices for farmland, beef cows, and farm inventories were negative in some years. Factor shares in the value of property compensation fluctuated greatly from year to year. The source of these counterintuitive results is the volatility of asset prices. It is important to consider the revaluation of assets in computing the real cost of capital services; however, most capital gains are not realized. To account for this, expected capital gains were used. Expected prices for each asset are expressed as an ARIMA 7/ process. Expected capital gains for each asset were estimated on the difference between expected and lagged observed asset prices. Rental prices were then computed using expected asset prices. Calculated factor shares were less volatile and positive. Based on the capital stock and property compensation data decribed above, translog indexes of service flows from durable equipment,

7/ An ARIMA model expresses the value of a time series at time t as a function only of past values of the function (autoregressive terms), and current and past disturbances (moving average) terms. The model was estimated using the TROLL ARIMA program.

real property, and farm-produced durables are presented in table 5.

The translog indexes of capital input $\{K_i\}$ can be decomposed into quality and quantity components. For each of the components of capital input the flow of capital services is proportional to capital stock $\{A^i_{k,t-1}\}$, where the constants of proportionality $\{Q^i_{Kk}\}$ transform capital stock into a flow of capital services. We can define capital stock as the unweighted sum of its components:

$$(10) \quad A_{i,t-1} = \sum_k A^i_{k,t-1}, \quad i = 1,2,3.$$

Similarly, we can define indexes of the quality of capital stock $\{Q^i_K\}$ that transform measures of hours worked into translog indexes of capital input:

$$(11) \quad K_{it} = Q^i_{Kt} A^i_{K,t-1}, \quad i = 1,2,3.$$

Using equations (2) and (11) we can express the indexes of the quality of capital stock as:

$$(12) \quad \ln(Q^i_{Kt}/Q^i_{K,t-1}) = 1/2 \sum_k (S^i_{kt}+S^i_{k,t-1}) \ln(A^i_{k,t-1}/A^i_{k,t-2})$$

$$-\ln(A_{i,t-1}-A_{i,t-2}), \quad i = 1,2,3.$$

The indexes $\{Q^i_K\}$ reflect the changes in the composition of capital stock within each capital aggregate. Capital quality remains unchanged if all components of capital stock within an aggregate capital input are growing at the same rate. Capital quality rises if components with higher flows of capital input per unit of capital stock are growing more rapidly, and falls if components with lower flows are growing more rapidly. Unweighted indexes of capital stock are reported in columns (1), (4), and (7) of table 5. The ratios between the translog indexes of capital input and the indexes of capital stock, reported in columns (2), (5), and (8) of table 5, measure the change in capital quality.

INTERMEDIATE INPUT

At the industry level, the value of output includes the value of primary factors, labor and capital, and the value of intermediate inputs. We define four categories of intermediate inputs: (1) energy, (2) agricultural chemicals, (3) feed and seed, and (4) miscellaneous inputs. Data on fuel consumption in agriculture by type of fuel and agricultural sector are available from <u>National Energy Accounts: Energy Flows in the United States, 1947 through</u>

Table 5--Capital input, 1948-79

Year	Durable equipment: Capital stock (1)	Durable equipment: Capital quality (2)	Durable equipment: Translog index (3)	Real property: Capital stock (4)	Real property: Capital quality (5)	Real property: Translog index (6)	Farm produced durables: Capital stock (7)	Farm produced durables: Capital quality (8)	Farm produced durables: Translog index (9)
					1977=1.000				
1948	0.352	1.040	0.366	1.130	0.718	0.811	0.678	1.100	0.746
1949	.427	1.063	.454	1.137	.719	.818	.709	1.120	.796
1950	.495	1.085	.537	1.141	.732	.835	.687	1.128	.775
1951	.552	1.087	.600	1.142	.748	.854	.710	1.115	.792
1952	.598	1.085	.649	1.145	.751	.860	.731	1.109	.811
1953	.626	1.064	.666	1.148	.760	.873	.756	1.115	.843
1954	.653	1.067	.697	1.150	.775	.891	.751	1.126	.846
1955	.662	1.062	.703	1.151	.788	.907	.763	1.111	.848
1956	.671	1.057	.709	1.148	.798	.916	.769	1.091	.839
1957	.663	1.048	.695	1.137	.807	.918	.753	1.097	.825
1958	.655	1.044	.684	1.140	.812	.926	.778	1.064	.828
1959	.667	1.037	.692	1.136	.824	.936	.790	1.053	.832
1960	.683	1.032	.705	1.097	.871	.955	.790	1.078	.852
1961	.677	1.025	.694	1.083	.893	.967	.806	1.077	.868
1962	.674	1.019	.687	1.077	.905	.975	.812	1.073	.871
1963	.679	1.021	.693	1.072	.913	.979	.831	1.064	.884
1964	.693	1.020	.707	1.075	.920	.989	.845	1.060	.896
1965	.711	1.019	.725	1.070	.928	.993	.820	1.076	.882
1966	.738	1.016	.750	1.066	.933	.995	.852	1.046	.891
1967	.770	1.016	.782	1.061	.941	.998	.845	1.034	.874
1968	.809	1.009	.816	1.055	.951	1.003	.863	1.022	.882
1969	.822	1.006	.827	1.050	.955	1.003	.858	1.024	.879
1970	.829	1.002	.831	1.044	.959	1.001	.872	1.017	.887
1971	.840	.996	.837	1.041	.962	1.001	.858	1.028	.882
1972	.845	.993	.839	1.036	.964	.999	.903	1.008	.910
1973	.863	.992	.856	1.032	.965	.996	.926	1.008	.933
1974	.919	.990	.910	1.034	.968	1.001	.970	.997	.967
1975	.958	.989	.947	1.032	.972	1.003	.998	1.006	1.004
1976	.976	.992	.968	1.014	1.021	.995	1.043	.998	1.041
1977	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1978	1.017	1.005	1.022	.996	1.012	1.008	1.019	.996	1.015
1979	1.048	1.007	1.055	.997	.974	.971	1.018	.991	1.009
Average annual rates of growth:									
1948-79	--	--	.0342	--	--	.0058	--	--	.0097
1948-53	--	--	.1197	--	--	.0147	--	--	.0244
1953-57	--	--	.0107	--	--	.0126	--	--	-.0054
1957-60	--	--	.0048	--	--	.0132	--	--	.0107
1960-69	--	--	.0177	--	--	.0054	--	--	.0035
1969-73	--	--	.0086	--	--	-.0018	--	--	.0149
1973-79	--	--	.0348	--	--	-.0042	--	--	.0131

1977, prepared by Jack Fawcet Associates Inc. Data are reported for the years 1947, 1954, and 1958-77. Fuel consumption in succeeding years is obtained from annual issues of Farm Production Expenditures. For the intervening years, fuel consumption is estimated as the sum of fitted values for consumption in both crop and livestock sectors. Consumption of natural gas and liquified petroleum gas is a function of specific production activities, including grain drying, irrigation, and livestock brooding. Consumption of gasoline and diesel fuel is regressed on stocks of gasoline and diesel tractors, stocks of gasoline and diesel self-propelled harvesting equipment, and time. Fuel prices were made available by William Hong of the Energy Information Administration, Department of Energy.

For fertilizer and lime, the basic data are annual estimates of tonnage of consumption of nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) as published in Commercial Fertilizers Consumption. Tonnage of lime is obtained from the National Lime Institute. We assume that prices per ton of different plant nutrients, when purchased in mixed form, are the same as their prices when purchased in the form of direct application materials. Our measure of pesticide usage is based upon current expenditures as estimated by the USDA. Estimated expenditures are deflated by a translog price index made available by Arnold Aspelin of the Economic Analysis Branch, U.S. Environmental Protection Agency.

Livestock feed expenditures are deflated by a translog price index of feed concentrates and hay. A similar procedure is used in estimating the seed and miscellaneous inputs in constant prices. Miscellaneous inputs include grazing fees, machine hire and custom work, transportation and marketing expenses, ginning fees, veterinary fees, and other miscellaneous inputs. Translog quantity indexes of the four categories of intermediate inputs are reported in table 6.

TOTAL FACTOR PRODUCTIVITY

Using equation (1) we compute total factor productivity indexes for U.S. agriculture for the postwar period. These indexes are reported in table 7 along with average annual rates of growth for the 1948-79 period and intermediate periods. The latter correspond to peaks in postwar business cycles. Also in table 7 are indexes of productivity taken from Economic Indicators of the Farm Sector: Production and Efficiency Statistics.

The two series are quite similar, given the differences in methodology. To disaggregate labor input into components that differ in marginal productivity, we measure wage rates and hours worked by characteristics of individual workers. Separate indexes of hired, and self-employed and unpaid family labor are then constructed, each weighted by its relative wage rate. The

Table 6--Intermediate inputs by translog index, 1948-79

Year	Energy	Agricultural chemicals	Feed and seed	Miscellaneous
	1977=1.000			
1948	0.413	0.143	0.476	0.518
1949	.440	.154	.485	.565
1950	.457	.172	.490	.553
1951	.477	.186	.520	.630
1952	.510	.200	.526	.650
1953	.532	.211	.541	.678
1954	.547	.223	.550	.695
1955	.559	.237	.590	.733
1956	.572	.249	.591	.773
1957	.574	.250	.667	.793
1958	.593	.264	.748	.885
1959	.617	.302	.743	.917
1960	.634	.304	.767	.955
1961	.646	.329	.783	.974
1962	.669	.359	.827	.984
1963	.701	.403	.830	.998
1964	.685	.442	.832	1.006
1965	.745	.473	.850	1.032
1966	.740	.535	.896	1.015
1967	.759	.622	.959	1.031
1968	.788	.668	.980	1.049
1969	.813	.705	1.047	1.055
1970	.832	.729	1.093	1.052
1971	.864	.794	1.068	1.097
1972	.906	.832	1.046	1.083
1973	.898	.867	1.029	1.107
1974	.902	.915	.945	.987
1975	.970	.872	.892	.934
1976	1.002	1.007	.951	.958
1977	1.000	1.000	1.000	1.000
1978	1.021	1.007	1.067	.999
1979	.971	1.097	1.123	1.109
Average annual rates of growth:				
1948-79	.0276	.0657	.0277	.0246
1948-53	.0506	.0778	.0256	.0538
1953-57	.0190	.0424	.0523	.0392
1957-60	.0331	.0652	.0466	.0620
1960-69	.0276	.0935	.0346	.0111
1969-73	.0249	.0517	-.0043	.0120
1973-79	.0130	.0392	.0146	.0003

Table 7--Total factor productivity, 1948-79

Year	Translog index	USDA
	1977=1.000	
1948	0.606	0.628
1949	.568	.603
1950	.581	.604
1951	.613	.605
1952	.613	.627
1953	.626	.636
1954	.641	.644
1955	.661	.666
1956	.689	.679
1957	.698	.683
1958	.714	.739
1959	.736	.738
1960	.757	.770
1961	.766	.779
1962	.768	.787
1963	.811	.816
1964	.819	.811
1965	.858	.853
1966	.831	.827
1967	.860	.853
1968	.853	.871
1969	.878	.875
1970	.855	.866
1971	.914	.936
1972	.919	.937
1973	.925	.947
1974	.919	.898
1975	.983	.987
1976	.947	.975
1977	1.000	1.000
1978	.987	1.024
1979	1.044	1.063
Average annual rates of growth:		
1948-79	.0175	.0170
1948-53	.0065	.0025
1953-57	.0272	.0178
1957-60	.0270	.0400
1960-69	.0165	.0142
1969-73	.0130	.0198
1973-79	.0202	.0193

USDA weights all workhours equally, regardless of differences in education, age, sex, and occupation of workers. The USDA labor input data are not determined from surveys of hours worked or of workers committed to agricultural production. The labor input is calculated on a requirements basis, using estimated quantities of labor required for various production activities. The resulting index of labor input declines at a rate in excess of 4 percent per year; the translog index of labor input declines at an annual rate of 3.17 percent.

The USDA constructs an index of mechanical power and machinery and an index of real estate. The mechanical power series consists of repairs, depreciation, interest on investment, and fuel and electricity. Service flows from farm real estate consist of the rental value for the equity portion of real estate, interest on real estate mortgages, grazing fees on public lands, and repairs and depreciation on service buildings.

As outlined above, the value of capital services is the sum of nominal returns to capital less capital gains, plus depreciation, and plus property taxes. The USDA, instead of measuring these items directly, considers annual expenditures associated with the capital input. The implicit assumption is that the yearly payments related to the use of the capital asset equals the value of the service flow from that asset in that year. This is clearly not the case. Depreciation measures the present value of all future declines in efficiency. The USDA uses capital consumption estimates which measure replacement. Counting repairs and maintenance expenditures implies that replacement is counted twice, since it is these repairs to maintain efficiency that replacement measures. Interest on investment or mortgages is intended as a proxy for returns to capital. While this may be true over a long period of time, annual returns to capital bear little relation to the debt service charge. No allowance is made for revaluation of assets in the USDA measure. Finally, taxes are included in the USDA measurement of capital services. These conceptual differences in measuring capital input lead to some difficulty in comparison. We develop a separate index of fuel consumption, but include taxes as a part of the service flow from capital. The USDA treats taxes as a separate input but includes fuel consumption in the index of capital input. We combine our measure of durable equipment and fuel consumption via a translog index. We find that the translog index grows at nearly twice the rate of the USDA index.

Our methodology for computing productivity growth does not require the assumption that inputs and outputs are separable or that productivity differences are neutral. If we impose these assumptions, our estimates of productivity are not altered. However, under these assumptions we can interpret the terms on the right-hand side of (1) as indexes of aggregate output and aggregate input. These indexes and their rates of growth are presented in table 8. Aggregate output grew at an average annual rate of 1.99 percent from 1948 to 1979, while aggregate input grew at 0.24 percent. Hence, growth in aggregate input accounts for about 12 percent of the growth in output, and increases in productivity account for about 88 percent of the growth in output. For comparison purposes we also present in table 8 the USDA indexes of aggregate output and aggregate input. Aggregate output grew 1.83 percent per year, less rapidly than the translog index of output. Increases in aggregate input account for only 7 percent of the growth in output.

SUMMARY AND CONCLUSIONS

We present revised procedures for calculating total factor productivity and contrast our estimates of productivity growth for the postwar period with the official USDA estimates. The average annual growth of productivity was 1.75 percent, compared with 1.70 percent reported in Economic Indicators of the Farm Sector: Production and Efficiency Statistics. The similar estimates of productivity growth overshadow some important differences in measurement of individual inputs, primarily labor and capital. The estimated growth rates for these inputs are substantially greater than those reported by the USDA. The USDA series does not reflect quality changes in the labor input. Service flows from capital are assumed to be equal to the sum of the depreciation and interest on the constant dollar value of the stock of capital, plus repairs and maintenance. USDA's use of a market rate of interest to estimate returns to capital items raises a question as to whether or not the selected series is representative representative of actual returns to investment in that asset. Griliches (1960) argued that the interest rate used by the USDA is too low. Returns to investment in agriculture also fluctuate greatly from year to year, instead of growing smoothly like most interest rate series. This problem is avoided by first estimating the rate of return to capital. This procedure provides a consistent method for measuring returns to all unpaid factors, taking account of the relationship between the price of each asset and the value of services flowing from it.

Our estimates of productivity growth do not require that inputs and outputs are separable. However, if we impose this assumption, our estimates of productivity are not altered. Under this assumption we can construct indexes of aggregate output and aggregate input. We find that growth in total factor productivity predominates in explaining growth in output.

Table 8--Aggregate output and aggregate input, 1948-79

Year	Output: Translog index	Output: USDA	Input: Translog index	Input: USDA
			1977=1.000	
1948	0.574	0.63	0.947	1.00
1949	.543	.62	.956	1.03
1950	.553	.61	.952	1.02
1951	.584	.63	.953	1.05
1952	.586	.66	.956	1.05
1953	.599	.66	.956	1.04
1954	.616	.66	.960	1.03
1955	.638	.69	.965	1.03
1956	.649	.69	.942	1.01
1957	.645	.67	.923	.99
1958	.660	.73	.925	.98
1959	.687	.74	.934	1.00
1960	.704	.76	.930	.98
1961	.707	.76	.923	.98
1962	.711	.77	.926	.98
1963	.746	.80	.919	.98
1964	.744	.79	.909	.98
1965	.786	.82	.917	.96
1966	.760	.79	.914	.96
1967	.800	.83	.930	.98
1968	.806	.85	.945	.98
1969	.835	.85	.950	.97
1970	.831	.84	.972	.97
1971	.884	.92	.967	.98
1972	.892	.91	.971	.98
1973	.903	.93	.976	.98
1974	.890	.88	.969	.98
1975	.951	.95	.967	.97
1976	.942	.97	.995	.99
1977	1.000	1.00	1.000	1.00
1978	1.001	1.04	1.014	1.01
1979	1.065	1.11	1.019	1.04
Average annual rates of growth:				
1948-79	.0199	.0183	.0024	.0013
1948-53	.0085	.0093	.0019	.0078
1953-57	.0185	.0038	-.0088	-.0123
1957-60	.0292	.0420	.0025	-.0034
1960-69	.0190	.0125	.0024	.0011
1969-73	.0196	.0225	.0068	.0026
1973-79	.0275	.0295	.0072	.0099

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