Productivity Growth in U.S. Agriculture: 1948-2013

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ABSTRACT

It is widely reported that productivity growth is the main contributor to output growth in U.S. agriculture. This article provides estimates of output growth over the postwar period and decomposes that growth into the contributions of input growth and productivity growth. The analysis is based on recently revised production accounts for agriculture. Our findings are fully consistent with those reported in the literature. Productivity growth dominates input growth as a source of output growth in the sector.

THE RISE IN AGRICULTURAL productivity has long been chronicled as the single most important source of output growth in the U.S. farm sector.[2] Though their methods differ in important ways, the major sectoral productivity studies by Kendrick and Grossman (1980), Jorgenson, Gollop, and Fraumeni (1987), Jorgenson (1990), and Jorgenson and Gollop (1992) share this common conclusion. In a more recent study, Jorgenson, Ho, and Stiroh (2005) find that productivity growth over the 1977-2000 period accounted for nearly 80 per cent of output growth in agriculture. This compares with only 19 per cent for the economy as a whole (Bureau of Labor Statistics, U.S. Department of Labor). Moreover, the rate of productivity growth over this period in agriculture (1.9 per cent) was nearly 3 times the corresponding rate in the non-farm economy (0.69 per cent).

The U.S. Department of Agriculture (USDA) has been monitoring the industry's productivity performance for decades. In fact, the USDA in 1960 was the first agency to introduce multifactor productivity measurement into the Federal statistical program. Today, having incorporated recommendations made by an American Agricultural Economics Association taskforce (USDA, 1980) and by a second more recent panel (Shumway *et al.*, 2014), the department's Economic Research Service (ERS) bases its official productivity statistics on a sophisticated system of production accounts.[3] The USDA model of productivity growth is based on the translog transformation frontier. It relates the growth

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2 The term "productivity" used in this article refers to the increase in output growth not accounted for by input growth, also known as total factor productivity or multifactor productivity.

3 The more recent review was motivated by Office of Management and Budget (OMB) guidelines for ensuring the quality and integrity of information disseminated by Federal agencies (OMB, 2011).

rates of multiple outputs to the cost-share weighted growth rates of labour, capital, and intermediate inputs.

The applied USDA model is quite detailed. The changing demographic character of the agricultural labour force is used to construct a quality-adjusted index of labour input. Similarly, much asset-specific detail underlies the measure of capital input. The index of capital input is formed by aggregating over the various capital assets using cost-share weights based on asset-specific rental prices. The contributions of feed and seed, chemicals, energy, and purchased services to output growth are captured in the index of intermediate inputs. An important innovation is the use of hedonic price indexes in constructing measures of fertilizer and pesticides consumption. The result is a USDA time series of total factor productivity (TFP) indexes now spanning the 1948-2013 period.

This article provides a complete discussion of the steps taken to construct the revised system of accounts and measures of productivity. We then compare the contributions of input growth and productivity growth to output growth in the farm sector. The important role of productivity growth in agriculture becomes immediately apparent.

We also examine the importance of changing input quality as a source of output growth. The observation, first made by Griliches (1964) some fifty years ago, that improved labour quality of the agricultural labour force is an important determinant of the sector's output growth is confirmed in this analysis.

The article's major conclusion is that productivity growth has been the principal source of output growth in agriculture over the postwar period. Averaging nearly 1.5 per cent per year, growth in productivity accounted for more than 95 per cent of the growth in output.

Changes in input quality have made significant contributions to input growth and, therefore, output growth. The net effect of quality change in all three inputs (i.e., labour, capital, and intermediate inputs) was a 0.12 per cent per year contribution to output growth. In fact, quality change was the sole reason for any positive contribution arising through growth in aggregate input.

Production Accounts

The USDA's Economic Research Service (ERS) has constructed accounts for the farm sector consistent with a gross output model of production (Ball, 1985; Ball *et al.*, 1997, 1999). Output is defined as gross production leaving the farm, as opposed to real value added. Inputs are not limited to labour and capital but include intermediate inputs. Intermediate goods produced and consumed within the farm sector are self-cancelling transactions and, therefore, do not enter either output or input accounts.

The ERS defines the farm sector the same way as does the National Income and Product Accounts (NIPA). This means that minor goods and services (i.e. secondary outputs) produced in the agricultural sector that are primary to other industries were included in the primary industry's output. For example, machine services performed by farmers, a secondary output for farms, were excluded from agriculture and included in agricultural services.

In this article, however, we take the existence of certain (inseparable) secondary activities into account when measuring the productive activity of the sector. These activities are defined as activities whose costs cannot be separately observed from those of the primary agricultural activity (as defined by the System of National Accounts (United Nations, 1993)). Examples include machine services for hire, custom feeding of livestock, farm forestry, and recreational activities involving the means of production. The output of the sector thus results from two kinds of activities: agricultural activities, whether primary or secondary, and non-agricultural (or secondary) activities of farms.

Output

The development of a measure of output begins with disaggregated data on prices and quantities of agricultural goods. For each category of output, the quantity includes the quantities sold off the farm (including unredeemed Commodity Credit Corporation loans), additions to inventory, and quantities consumed in farm households during the calendar year. The corresponding price reflects the value of that output to the producer, as subsidies are added and indirect taxes are subtracted from market values.[4] The measure of output also includes goods and services of non-agricultural (or secondary) activities when these activities cannot be distinguished from the primary agricultural activity. Tornqvist (or translog) indexes of output are formed by aggregating over agricultural goods output and the output of goods and services of inseparable secondary activities using revenue-share weights based on shadow prices.

Intermediate Input

Intermediate input consists of goods used in production during the calendar year, whether from beginning inventories or purchased from outside the farm sector.[5] Measures of intermediate inputs are formed as translog indexes over a set of goods and services. Price and quantity data corresponding to purchases of feed and seed are available from the USDA and directly enter the calculation of intermediate goods.[6] Data on current dollar consumption of petroleum fuels, natural gas, and electricity in agriculture are also available.[7] Prices for individual petroleum fuels are taken from annual issues of A*gricultural Prices* (U.S. Department of Agriculture). The *Monthly Energy Review* (Energy Information Administration, U.S. Department of Energy) is the source for natural gas and electricity prices. The corresponding quantity measure for each energy source is calculated implicitly as the ratio of expenditures and price. Fertilizers and pesticides also are important intermediate inputs, but their data require adjustment since these inputs have undergone significant changes in input quality over the study period. Since input price and quantity series used in a study of productivity must be denominated in constant-efficiency units, price indexes for fertilizers and pesticides are constructed using hedonic regression techniques.

A price index for fertilizers is estimated by regressing the prices of single nutrient and multi-grade fertilizer materials on the proportion of nutrients contained in the materials; prices of pesticides are regressed on differences in physical characteristics such as toxicity, persistence in the environment, and leaching potential.[8]

The corresponding quantity indexes for fertilizers and pesticides are formed implicitly by taking the ratio of the value of each aggregate to the corresponding hedonic price index. Finally, price and implicit quantity indexes are constructed for purchased services, such as contract labour services, purchased machine services, and maintenance and repairs.[9] Available data consist of nominal expenditures. To decompose expen-

4 Prices received by farmers, as reported in USDA's Agricultural Prices, include an allowance for net Commodity Credit Corporation loans and purchases by the government under the marketing loan program valued at the average loan rate. However, direct payments under the federal commodity programs are not reflected in the data.

5 We assume that intermediate goods produced and consumed within the farm (e.g. grain for livestock feeding) are from beginning stocks. Therefore, the measure of output is equated with gross production.

6 Purchases of livestock are recorded as additions to the stock of "goods in progress" and not as intermediate input. Similarly, cash receipts are net of livestock purchases.

7 Expenditures for motor fuels are net of excise tax rebates.

ditures for contract labour services into price and quantity components, we estimate a hedonic wage function where hourly earnings are expressed as a function of demographic characteristics including sex, age, education, and experience, as well as legal status and type of employment (hired versus contract labourers).[10] Purchased machine services are a close substitute for own capital input.[11] Therefore, we construct the implicit quantity of machine services as the ratio of expenditures to an index of rental prices of agricultural machinery (i.e. farm tractors; agricultural machinery excluding tractors). Translog indexes of intermediate input are constructed by weighting the growth rates of each category of intermediate inputs described above by their value share in the overall value of intermediate inputs.

Labour Input

Current USDA labour accounts for the farm sector incorporate the demographic cross-classifications of the agricultural labour force developed by Jorgenson, Gollop, and Fraumeni (1987) (Ball *et al.*, 1997). Matrices of hours worked and compensation per hour are developed for labourers cross-classified by sex, age, education, and employment class (employee versus self-employed and unpaid family workers).

This is accomplished using the RAS procedure popularized by Jorgenson, Gollop, and Fraumeni (1987:72-76) by combining the farm sector matrices initially produced in that study with demographic information taken from the Census of Population (Bureau of the Census, U.S. Department of Commerce). The result is a set of annual hours worked and hourly compensation matrices with cells cross-classified by sex, employment class, age, and education, and with each matrix controlled to the USDA hours and compensation totals, respectively.

Translog indexes of labour input are constructed for the 1948-2013 period using the demographically cross-classified hours and compensation data. Under the translog approach, labour hours having larger marginal productivity (wages) are given higher weights in forming the index of labour input than are hours having lower marginal productivities. Doing so

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8 A hedonic price function expresses the price of a good or service as a function of the quantities of the characteristics it embodies. Therefore, the hedonic price function for pesticides may be written as $w_p = W(X,D)$, where w_p is pesticide price, X is a vector of characteristics or quality variables, and D is a vector of variables to be defined. The characteristics included in the regression are the application rate, chronic score, half-life, absorption, water solubility and vapour pressure. The application rate measures the chemical's potency. Hazardous characteristics are measured by chronic toxicity scores, and persistence is measured by the pesticide's half-life. The chronic toxicity index is the inverse of the water quality threshold (which measures the concentration in parts per billion) and serves as an indicator for environmental risk. The lower the index, the lower is the potential environmental risk for the chemical. The persistence indicator is defined by the share of pesticides with a half-life less than 60 days (the lower the indicator, the less persistent the pesticide is) and by the degree to which the pesticide binds to soil particles (sorption coefficient, Koc). The leaching potential is measured by water solubility (the amount in milligrams of pesticides that would dissolve in one liter of water, mg/L) and vapour pressure (how readily a chemical will evaporate) measured in millimeters of mercury (mm Hg). Other variables (denoted by D) are included in the hedonic regression, and their selection depends on the objectives of the study. If the main objective of the study is to obtain price indexes adjusted for quality, as in our case, the only variables that should be included in D are time dummy variables, which will capture all price effects other than quality. After allowing for differences in the levels of the characteristics, the part of the price difference not accounted for by the included characteristics will be reflected in the time dummy coefficients.

9 Premiums less subsidies for publically-provided disaster insurance are included in the cost of purchased services, while indemnities are included in the value of output (Shumway et al., 2014).

10 See Wang *et al.* (2013) for further discussion.

11 Purchased machine services exhibit a counter-cyclical pattern, suggesting substitution of purchased machine services for own capital input (Ball, Schimmelpfennig, and Wang, 2013).

explicitly adjusts the time series of labour input for changes in quality of labour hours as originally defined by Jorgenson and Griliches (1967). As a result, the price and quantity series for labour input are measured in constant-quality units.[12]

Capital Input

This study requires time series measures of capital input and capital rental prices. Construction of these series begins with estimating the capital stock and rental price for each component of capital input. For depreciable assets, the perpetual inventory method is used to develop capital stocks from data on investment. For land and inventories, capital stocks are measured as implicit quantities derived from balance sheet data. Implicit rental prices for each asset type are based on the correspondence between the purchase price of the asset and the discounted value of future service flows derived from that asset.

Capital Stock of Depreciable Assets

The perpetual inventory method cumulates investment data measured in constant prices into a measure of capital stock. Data on investment in current prices are obtained from the ERS Resource and Rural Economy Division.[13] The Bureau of Labor Statistics Producer Price Indexes for passenger cars, motor trucks, wheel-type farm tractors, and agricultural machinery excluding tractors are employed as investment deflators. For structures, the implicit price deflator is taken from the U.S. national income and product accounts.

Under the perpetual inventory method, the capital stock at the end of each period, say K_t, is measured as the sum of past investments, each weighted by its relative efficiency, say d_τ:

$$(1)\quad K_t = \sum_{\tau=0}^{\infty} d_\tau I_{t-\tau}$$

In equation (1), we normalize initial efficiency d_0 at unity and assume that relative efficiency declines so that:

$$(2)\quad d_0 = 1,\ d_\tau - d_{\tau-1} \le 0,\ \tau = 0, 1 \ldots, T$$

We also assume that every capital good is eventually retired or scrapped so that relative efficiency declines to zero:

$$(3)\quad \lim_{\tau \to \infty} d_\tau = 0$$

The decline in efficiency of capital goods gives rise to needs for replacement investment to maintain the productive capacity of the capital stock. The proportion of a given investment to be replaced at age τ, say m_τ, is equal to the decline in efficiency from age $\tau - 1$ to age τ:

$$(4)\quad m_\tau = -(d_\tau - d_{\tau-1}),\ \tau = 1, \ldots, T$$

These proportions represent mortality rates for capital goods of different ages. Replacement requirements, say R_t, are a weighted sum of past investments:

$$(5)\quad R_t = \sum_{\tau=1}^{\infty} m_\tau I_{t-\tau},$$

where the weights are the mortality rates.

Taking the first difference of expression (1) and substituting (4) and (5), we can write:

$$(6)\quad K_t - K_{t-1} = I_t - \sum_{\tau=1}^{\infty} (d_\tau - d_{\tau-1}) I_{t-\tau}$$
$$= I_t - \sum_{\tau=1}^{\infty} m_\tau I_{t-\tau}$$

12 See Jorgenson and Gollop (1992) for a discussion of the theoretical basis for adjusting labour input for compositional shifts in the labour force.

13 The series on investment in farm structures includes capital outlay on housing provided employees. Accordingly, housing service flows are viewed as a component of output.

$$= I_t - R_t$$

The change in capital stock in any period is equal to the acquisition of investment goods less replacement requirements.

To estimate replacement, we must introduce an explicit description of the decline in efficiency. This function, d, may be expressed in terms of two parameters, the service life of the asset, say L, and a curvature or decay parameter, say β. Initially, we will hold the value of L constant and evaluate the efficiency function for various values of β. One possible form for the efficiency function is given by:

$$(7)\ d_\tau = \frac{(L-\tau)}{(L-\beta\tau)},\ 0 \le \tau \le L,\ d_\tau = 0,\ \tau \ge L$$

This function is a form of a rectangular hyperbola that provides a general model incorporating several types of depreciation as special cases.

The value of β is restricted only to values less than or equal to one. Values greater than one yield results outside the bounds established by the restrictions on d. For values of β greater than zero, the function d approaches zero at an increasing rate. For values less than zero, d approaches zero at a decreasing rate.

Little empirical evidence is available to suggest a precise value for β. However, two studies (Penson, Hughes, and Nelson, 1977; Romain, Penson, and Lambert, 1987) provide evidence that the decline in efficiency occurs more rapidly in the later years of service, corresponding to a value of β in the zero-one interval. For purposes of this study, it is assumed that the efficiency of a structure declines slowly over most of its service life until a point is reached where the cost of repairs exceeds the increased service flows derived from the repairs, at which point the structure is allowed to deteriorate rapidly ($\beta = 0.75$). The decay parameter for durable equipment ($\beta = 0.50$) assumes that the decline in efficiency is more uniformly distributed over the asset's service life.

Consider now the efficiency function that holds β constant and allows L to vary. The concept of variable lives is related to the concept of investment used in this study where investment is composed of different types of capital goods. Each of the different types of capital goods is a homogeneous group of assets in which the actual service life L is a random variable reflecting quality differences, maintenance schedules, or simply chance variation. For each type of capital good there exists some mean service life $\overline{L}$ around which there is a distribution of the actual service lives of the assets in the group. In order to determine the actual capital available for production, the actual service lives and the relative frequency of assets with these service lives must be determined. It is assumed that this distribution may be accurately depicted by the standard normal distribution.

One property of the normal distribution is related to the infinite nature of the distribution. Without adjustment, the distribution would yield cases where assets were discarded prior to their purchase or assets with unrealistically long service lives. In order to eliminate these extremes, some adjustment is warranted. This adjustment involves truncation of the normal at some point before and after $\overline{L}$. The values of the normal are then adjusted upward within the allowed range of service lives.

In this study, we truncate the distribution at points two standard deviations before and after the mean.[14] Two standard deviations are assumed to be 0.98 times the mean service life. This dispersion parameter was chosen to conform to the observation that assets are occasionally found that are considerably older than the mean service life and that a few assets are acci-

14 Mean service lives correspond to 85 per cent of the U.S. Department of the Treasury's *Bulletin F* lives.

dentally damaged when new. Once the frequency of a service life L is known,[15] the decay function for that particular service life is calculated using the assumed value of β. This step is repeated for all possible service lives. An aggregate efficiency function is then constructed as a weighted sum of the individual efficiency functions using as weights the frequency of occurrence. This function not only reflects changes in efficiency but also the discard distribution around the mean service life of the asset.

Capital Stock of Land

To obtain a constant-quality stock of land, we compile data on acres of land in farms and average value (excluding buildings) per acre for each county in each state using information gleaned from the Census of Agriculture. Data for years intermediate to the censuses are obtained by interpolation.[16] The Census definition of land in farms includes all grazing land (including reservation grazing land, land in grazing associations, and land leased for grazing) except public lands leased for grazing on a per-head basis.[17] From total land in farms, we exclude the land area in roads and house lots and miscellaneous areas such as marches, open swamps, and bare rock areas.[18]

The Census of Agriculture reports data on the value of farm real estate (i.e. land and structures); it does not provide data on land values separately. Historically, the value of farm real estate was partitioned into its components using information from the Agricultural Economics and Land Ownership Survey (AELOS). However, AELOS was last conducted in 1999. More recently, we have relied on the annual Agricultural Resource Management Survey (ARMS) to derive estimates of the value of land from data on the value of farm real estate.

Inventories

Beginning inventories of crops and livestock are treated as capital inputs.[19] The number of animals on farms is available from annual surveys, as are the stocks of grains and oilseeds (National Agricultural Statistics Service, USDA).[20] December average prices, available from *Agricultural Prices*, are used to value commodities held in inventory.

Capital Rental Prices

An important innovation in measuring capital input is the rental price of capital originated by Jorgenson (1963, 1973). However, this rental price is based on the particular assumption that the pattern of capacity depreciation is characterized by a decaying geometric series. The remaining task is to generalize the representa-

15 Very little data exist on the form of the distribution around the mean service life. The only study available was conducted by Winfrey (1935) detailing the actual service lives of a group of assets. Winfrey's S-3 distribution had a bell-shaped appearance somewhat akin to the normal distribution. No rigorous tests were performed to determine if the distribution was, in fact, a normal distribution, but based on this admittedly sparse evidence it is assumed that there exists a normal distribution about the mean life of a particular type of asset. This assumption is used mostly for convenience since tables of values for the normal distribution are readily available.

16 Interpolation involves fitting a cubic spline curve to the observed values. A cubic spline is a segmented function consisting of third-degree (cubic) polynomial functions joined together so that the entire curve and its first and second derivatives are continuous.

17 Service flows from public lands are estimated from grazing fees paid (Bureau of Land Management and Forest Service) and are included in intermediate input.

18 Land enrolled in the Conservation Reserve Program (CRP) is a component of capital stock, while conservation services are considered a component of output.

19 Net additions to inventory during the calendar year are included in the measure of output.

20 The estimates are of stocks in all positions. To obtain estimates of producer-owned stocks, we subtract quantities of commodities held by commercial (i.e., non-farm) entities, as well as commodities used as collateral for Commodity Credit Corporation loans.

tion of the rental price to allow for any pattern of capacity depreciation.

To accomplish this task, we draw on the literature on investment demand (Arrow, 1964; Coen, 1975; Penson, Hughes, and Nelson, 1977; Romain, Penson, and Lambert, 1987). Assume that firms buy and sell assets so as to maximize the present value of the firm.

Let w_k denote the price the firm must pay for a new unit of capital, p the price the firm receives for each unit of output, and r the real discount rate. An increase in the capital stock, K, by one unit will increase output in each period by $\partial y/\partial K$, the marginal product of capital. Gross revenue in each period will rise by $p(\partial y/\partial K)$, but net revenue will rise by only $p(\partial y/\partial K) - w(\partial R_t/\partial K)$, where $\partial R_t/\partial K$ is the increase in the replacement in period t required to maintain the capital stock at the new level. Firms should add to the capital stock if the present value of the new revenue generated by an additional unit of capital exceeds the purchase price of the asset. This can be stated algebraically as:

$$(8)\quad \sum_{t=1}^{\infty}\left(p\frac{\partial y}{\partial K} - w_k\frac{\partial R_t}{\partial K}\right)(1+r)^{-t} > w_k$$

To maximize net present value, firms will continue to add to capital stock until this equation holds as an equality. This requires that:[21]

$$(9)\quad p\frac{\partial y}{\partial K} = rw_k + r\sum_{t=1}^{\infty} w_k\frac{\partial R_t}{\partial K}(1+r)^{-t} = c$$

The expression for c is the implicit rental price of capital corresponding to the mortality distribution, m. The rental price consists of two components. The first term, rw_k, represents the opportunity cost associated with the initial investment. The second term, $r\sum_{t=1}^{\infty} w_k\frac{\partial R_t}{\partial K}(1+r)^{-t}$, is the present value of the cost of all future replacements required to maintain the productive capacity of the capital stock, multiplied by the discount rate, r.

Expression (9) can be simplified as follows. Let F denote the present value of the stream of capacity depreciation on one unit of capital according to the mortality distribution, m.

$$(10)\quad F = \sum_{\tau=1}^{\infty} m_\tau(1+r)^{-\tau}$$

It can be shown that:

$$(11)\quad \sum_{t=1}^{\infty}\frac{\partial R_t}{\partial K}(1+r)^{-\tau} = \sum_{t=1}^{\infty} F^t = \frac{F}{(1-F)}$$

so that:

$$(12)\quad c = \frac{rw_k}{(1-F)}$$ [22]

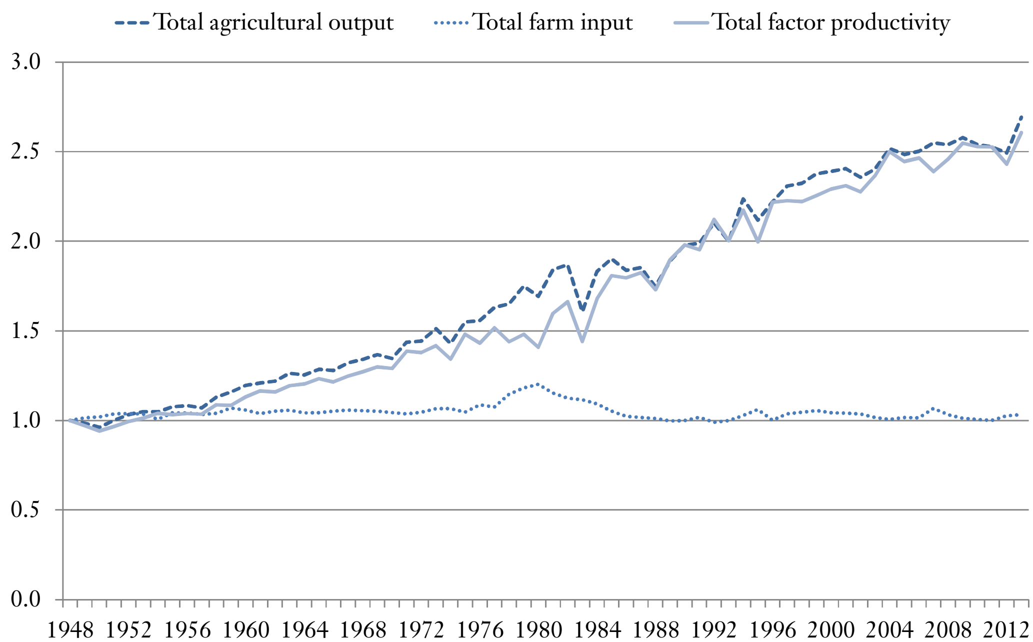
The real rate of return, r, in equation (12) is calculated as the nominal yeild on investment grade corporate bonds,[23] less the rate of asset price inflation (i.e. capital gain).[24] An *ex ante* real rate is obtained by expressing inflation as an ARIMA process.[25] Implicit rental prices are

21 If $r > 0$, then $\sum_{t=1}^{\infty}(1+r)^{-t} = \frac{1}{1-\left(\frac{1}{1+r}\right)} - 1 = \frac{1}{r}$. Substituting this result in (8) and rearranging yeilds (9).

22 For the special case where $d_\tau = \delta(1-\delta)^{\tau-1}$, which was assumed by Jorgenson (1963, 1973), $F = \sum_{\tau=1}^{\infty}\delta(1-\delta)^{\tau-1}(1+r)^{-\tau} = \delta/(r+\delta)$ and $c = w_k(r+\delta)$, which is the expression for the rental price commonly found in the literature.

23 The nominal rate is taken to be the average yield on Moody's AAA bonds over all maturities (Federal Reserve Board).

Chart 1: Trends in Output, Farm Input, and Productivity in U.S. Agriculture, 1948=1, 1948-2013



Source: USDA's Economic Research Service.

then calculated for each (depreciable) asset type using the expected real rate of return.[26]

The user cost of inventories is obtained using equation (12), assuming zero decay. The cost of land service flows is derived using the accounting identity where the value of total product is equal to the total factor outlay.

Translog quantity indexes of capital input are estimated by aggregating over the various capital assets using cost-share weights based on asset-specific rental prices. Rental prices for capital input are generated implicitly as the ratio of the total value of capital service flows to the translog quantity index. As is the case for labour

24 Use of asset-specific capital gains when calculating real rates of return was recommended by Shumway et al. (2014). Previously, the USDA used a broad measure of inflation, the implicit deflator for gross domestic product, to calculate the real rate of return, arguing that expected real rates of return should be equal across all assets (Ball et al., 1997; 1999).

25 Price inflation is expressed as an AR(1) process. We use this specification after examining the correlation coefficients for autocorrelation, partial and inverse autocorrelation, and performing the unit root and while noise tests.

26 A more common approach to measuring the user cost of capital is to use an ex post rate of return (Jorgenson and Griliches, 1967; Christensen and Jorgenson, 1969; Jorgenson, Gollop and Fraumeni, 1987). This unknown rate of return can be found by using the condition that the sum of returns across all assets equals observed total profit (alternatively, gross operating surplus). However, many have expressed concern with the ex post approach (Schreyer, Bignon, and Dupont, 2003). They note that investment decisions must be made in advance of having all the relevant information. Firms employ some notion of the required rate of return when deciding how much to invest, and this required rate may differ from the realized rate. Moreover, they must base their decisions on expected, not actual, capital gains and losses. Using the ex post measure would imply either that all expectations are realized or that the quantities of capital can be instantaneously adjusted to the desired level after all uncertainties have been resolved. Neither assumption appears plausible a priori. It is for this reason that we adopt the ex ante approach when measuring user costs.

Table 1: Sources of Growth: U.S. Farm Sector (Average Annual Contribution to Growth Rates, Percentage Points)

	1948-2013	1948-1953	1953-1957	1957-1960	1960-1966	1966-1969	1969-1973	1973-1979	1979-1981	1981-1990	1990-2000	2000-2007	2007-2013
Output growth (%)	1.52	0.96	0.49	3.72	1.11	2.24	2.51	2.44	2.58	0.79	1.89	0.92	0.91
Sources of growth													
Labour	-0.49	-0.83	-1.11	-0.88	-0.86	-0.65	-0.41	-0.19	-0.23	-0.45	-0.21	-0.40	-0.18
Capital	-0.06	0.57	-0.02	0.00	0.04	0.16	-0.10	0.23	0.11	-0.78	-0.20	-0.06	0.13
Materials	0.60	0.95	1.11	1.63	0.73	0.49	0.84	1.67	-1.08	-0.37	0.84	0.78	-0.49
Total Factor Productivity	1.47	0.27	0.52	2.96	1.19	2.24	2.18	0.73	3.78	2.39	1.46	0.60	1.45
Source decomposition													
Labour													
Hours	-0.61	-1.06	-1.24	-0.92	-1.14	-0.95	-0.46	-0.21	-0.20	-0.52	-0.41	-0.45	-0.24
Quality	0.12	0.23	0.12	0.04	0.28	0.30	0.05	0.01	-0.03	0.07	0.19	0.05	0.07
Capital													
Stocks	-0.08	0.27	-0.15	-0.12	0.01	-0.15	-0.25	0.20	-0.09	-0.35	-0.09	-0.12	-0.07
Quality	0.02	0.30	0.12	0.13	0.04	0.32	0.15	0.03	0.20	-0.42	-0.11	0.06	0.20
Materials													
Quantity	0.62	1.04	0.92	1.71	0.71	0.37	0.87	1.97	-1.55	-0.31	0.84	0.79	-0.44
Quality	-0.02	-0.09	0.19	-0.08	0.02	0.12	-0.03	-0.29	0.47	-0.06	0.00	-0.01	-0.05

Source: USDA's Economic Research Service

input, the resulting measure of capital input is adjusted for changes in asset quality.

Productivity Growth

Input growth typically has been the dominant source of output growth for the aggregate economy and for each of its producing sectors. Jorgenson, Gollop, and Fraumeni (1987) find this to be the case for the aggregate economy for every sub-period over the period 1948-79. Denison (1979) draws a similar conclusion for all but one sub-period, covering the longer period 1929-76. In their sectoral analysis, Jorgenson, Gollop, and Fraumeni (1987) find that output growth relies most heavily on input growth in 42 of 47 private business sectors over the 1948-79 period, and in a more aggregated study (Jorgenson and Gollop, 1992) that extends through 1985, in 8 of 9 sectors. Finally, Jorgenson, Ho, and Stiroh (2005) provide estimates of the sources of output growth for 44 sectors of the U.S. economy for the period 1977-2000. Input growth completely dominates in 36 of these sectors.

Agriculture turns out to be one of the few exceptions, as can be seen in Chart 1. Productivity growth dominates input growth. This is confirmed in the top panel of Table 1 which reports the source decomposition of output growth in the farm sector over the full 1948-2013 period and twelve peak-to-peak sub-periods.[27] Applying the translog model, output growth equals the sum of contributions of labour, capital, and materials input and productivity growth. The contribution of each input equals the product of the input's growth rate and its respective share in total cost.

The singularly important role of productivity growth in agriculture is made all the more remarkable by the dramatic contraction in

27 The sub-periods are not chosen arbitrarily but are measured from cyclical peak to peak in aggregate economic activity. Since the data reported for each sub-period are average annual growth rates, the unequal lengths of the sub-periods do not affect the comparisons across sub-periods. This convention and these sub-periods have been adopted by the major productivity studies. See, for example, Jorgenson, Gollop, and Fraumeni (1987).

labour input in the sector, a pattern that persists through every sub-period.[28] Over the full 1948-2013 period, labour input declined at an average annual rate of 2.2 per cent, a rate unmatched by any of the 50 non-farm sectors evaluated by Jorgenson, Gollop, and Fraumeni (1987). When weighted by its 0.22 share in production costs, the contraction in labour input contributes an average -0.49 percentage points per year to output growth.

Capital input (including land and inventories) in the sector exhibits a different history. Its contribution to output growth alternates between positive and negative over the 1948-2013 period. On average, however, capital, like labour, contracts over the full period. Its negative growth contributes an annual -0.06 percentage points to output growth.

The negative contributions of both labour and capital are particularly striking given the positive contributions offered through improvements in both labour and capital quality, the reallocation of labour hours and capital stocks to higher marginal productivity uses. As revealed in Table 1, farms have higher-quality labour. This primarily is due to a more educated farm labour force.[29] Increased labour quality made a positive contribution to output in 11 of 12 sub-periods, averaging 0.12 percentage points per year over the full 1948-2013 period. Quality improvements in capital added another 0.02 percentage points, yet neither improved labour nor capital quality was sufficient to offset the contractions in the corresponding input. Increased labour quality offsets less than 20 per cent of the decline in raw labour hours; improvements in capital quality offset about 25 per cent of the decline in capital stocks.

Material input's contribution, as reported in Table 1, was positive in 10 of the 12 sub-periods and averaged a substantial positive rate equal to 0.60 per cent per year. Though large, this positive contribution just offsets the negative contributions from labour and capital. The net contribution of all three inputs was only 0.05 percentage points per year, leaving responsibility for positive growth in farm sector output largely to productivity growth in all but the 1973-79 and 2000-07 sub-periods.

Examining Table 1 makes clear that the 1973-79 period was an outlier. Output, labour, and capital growth rates did not deviate much from trend. Material input, however, exhibited significant positive growth at a rate far in excess of the incremental growth in output, accounting single handedly for the measured decline in the rate of productivity growth. This anomaly appears to be due to rapid growth in export demand during the period which resulted in the increased consumption of intermediate goods as well as a significant withdrawal of goods from inventory. Both led to a reduction in productivity growth. First, while additional intermediate inputs generated additional output, the incremental growth in materials input exceeded the incremental growth in output. Second, one-for-one transfers of final goods from inventory to market embed zero productivity growth.

The early 2000s saw the emergence of biofuels as a source of demand for grains and oilseeds.

28 Annual data on the price and implicit quantity of labour, capital, and materials inputs are available at http://www.ers.usda.gov/datafiles/Agricultural_Productivity_in_the_US/National_Tables/table01.xlsx

29 As discussed earlier, labour hours are cross-classified by sex, age, education, and employment class. Analysis of the changing composition of hours over the 1948-2013 period reveals that, among the four sources, education was the only dimension making a positive contribution to labour quality. As overall labour hours declined, demographic shifts in the sex, age, and class of employment composition of hours worked left higher proportions of hours worked in cells representing lower marginal productivity sex, age, and class cohorts. In contrast, the decline in hours worked was coincident with an increase in the proportion of more highly educated workers. This was sufficient to offset the negative effects of changes in sex, age, and class composition of hours and result in the persistent pattern of improving labour quality.

Corn used in ethanol production in 2007 accounted for roughly one-quarter of total demand. The land area planted to corn increased some 15 million acres (or roughly 20 per cent) between 2006 and 2007, resulting in the cultivation of more marginal lands. Despite significant year-over-year increases in fertilizer and pesticides consumption, yields per acre were largely unchanged.

In spite of these anomalous sub-periods, productivity growth was truly extraordinary over the 1948-2013 period. As indicated in Table 1, it averaged 1.47 per cent per year. Cumulated over the full sixty-five year period, this average annual rate (compounded annually) implies that farm sector productivity in 2013 was 160 per cent above its 1948 level. Given the cumulative 3.3 per cent increase in total input between 1948 and 2013, productivity growth caused agricultural output to grow significantly in every sub-period so that by 2013 farm output was 170 per cent above its level in 1948.

Summary and Conclusions

This article compares the contributions of input growth and productivity growth to output growth in postwar U.S. agriculture. We also examine the importance of changing input quality as a source of output growth.

The contribution of each input to output growth is measured as the product of the input's growth rate and its respective share in total cost. Over the postwar period, labour input in agriculture declined at an average annual rate of 2.2 per cent. When weighted by its 0.22 share in production costs, the contraction in labour input contributed an average -0.49 percentage points per year to output growth.

Capital input increased dramatically during the immediate postwar period, reflecting rapid mechanization of agriculture. Service flows from durable equipment increased at a 9 per cent annual rate from 1948 to 1953. But the average growth rate over the full 1948-2013 period was slightly less than 1 per cent per year. Land input declined at a 0.46 per cent average annual rate. Over the full 1948-2014 period, however, capital input declined 0.18 per cent per year. Its negative growth contributed an annual -0.06 percentage points to output growth.

Unlike labour and capital, growth in intermediate inputs made a positive contribution to output growth, averaging 0.60 percentage points per year. Though large, this positive contribution just offsets the negative contributions from labour and capital. The net contribution of all three inputs was only 0.05 percentage points per year, leaving responsibility for positive growth in farm sector output almost entirely (96.7 per cent) to productivity growth.

Changes in input quality have made significant contributions to input growth and, therefore, output growth. The net effect of quality change in all three inputs (i.e. labour, capital, and materials) was a 0.12 per cent per year contribution to output growth.

Although small in size, the contributions through input quality are quite significant. The 0.12 per cent contribution each year equals roughly one-tenth the annual contribution of productivity growth. Moreover, quality change is the sole reason for any positive contribution arising through growth in aggregate input. Had it not been for quality change, average annual growth in aggregate input would have been negative.

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