# Agricultural Productivity Growth in the United States: Measurement, Drivers, and Impacts

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**Abstract**

This paper provides a brief introduction to the methodology of U.S. official agricultural productivity statistics; the patterns of growth in U.S. agricultural output, input, and productivity in the post-war period; the drivers and impacts of U.S. agricultural productivity growth; and the challenges of the productivity program. U.S. agricultural output has nearly tripled since 1948 at an average growth rate of 1.63% per year from 1948 to 2009. With little growth in input, the extraordinary performance in U.S. farm production has been driven mainly by total factor productivity growth at an average annual rate of 1.52%. Since public research funding has been under pressure, how to maintain a sustainable rate of productivity growth in the long-run has become an emerging and crucial issue.

**Key Words**: Total Factor Productivity (TFP), Tòrnqvist Index, translog transformation frontier, Hedonic function, R&D

## I. Introduction

The U.S. value added gross domestic production (GDP) of agriculture and related activities (including farm, forestry, fishing, and hunting) accounted for 8.6% of aggregate GDP in 1948. With faster growth in the non-agricultural sector, and declining relative output prices in the agricultural sector, the agricultural GDP share declined to 1.2% in 2009, with farm sector production contributing three fourth of the agricultural GDP. Despite the decline of agricultural GDP share, total real farm production nearly tripled between 1948 and 2009. With a slight increase in agricultural input use, the growth of agricultural output was mainly driven by productivity growth.

The U.S. Department of Agriculture (USDA) has been monitoring the agricultural sector's productivity performance for decades as its growth is critical to sustained agricultural production as well as food security, especially as labor and land had been drawn from the farm sector to help fuel expansion of the manufacturing and service sectors in the post-war period. Measurement of the official productivity statistics has changed substantially in the last few decades (Jorgenson, 2011). Today, the Department's Economic Research Service (ERS) routinely publishes total factor productivity (TFP) statistics for the farm sector based on a sophisticated system of production accounts.

In the following section we will briefly introduce the methodologies applied in the ERS TFP estimates. Details can be found in Ball et al. (1999), and Ball, Wang, and Nehring (2013). In section III, we discuss the patterns of growth in U.S. agricultural output, input and productivity. Section IV addresses issues regarding the drivers and impacts of U.S. agricultural productivity growth. Section V concludes our discussion and summarizes the challenges and future work of USDA's productivity program.

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[*] The views expressed are those of the author and do not necessarily reflects the positions of the USDA or ERS.

## II. **The Measurement of U.S. Agricultural Productivity Growth**

The USDA-ERS's total factor productivity (TFP) index is an aggregate measure that accounts for all inputs' contribution to the sector's output growth. The TFP statistics are based on the translog transformation frontier. The translog model relates the growth rates of multiple outputs to the cost-share weighted growth rates of labor, capital, and intermediate goods. The rates of productivity growth are constructed based on the Törnqvist index approach. The TFP growth over two time periods is defined as:

$$\ln\left[\frac{TFP_t}{TFP_{t-1}}\right] = \sum\left[\frac{R_{it}+R_{i,t-1}}{2}\right]\ln\left[\frac{Y_{it}}{Y_{it-1}}\right] - \sum\left[\frac{W_{jt}+W_{j,t-1}}{2}\right]\ln\left[\frac{X_{jt}}{X_{jt-1}}\right] \qquad (1)$$

where the $Y_i$ are individual output, the $X_j$ are individual input, the $R_i$ are output revenue shares, the $W_j$ are input cost shares, and t and t-1 are time subscripts.

The measure of aggregate output begins with disaggregated data for physical quantities and market prices of crops and livestock. The output quantity for each crop and livestock category includes the quantities of commodities sold off the farm, additions to inventory, and quantities consumed in farm households as part of final demand during the calendar year. The price corresponding to each disaggregated output reflects the value of that output to the producer; that is, subsidies are added and rebates of indirect taxes are subtracted from market values. One special characteristics of the measure of total output is the inclusion of goods and services from certain 'non-agricultural' or secondary activities. These activities are defined as activities closely linked to agricultural production for which information on output and input use cannot be separately observed, including the processing and packaging of agricultural products on the farm and services relating to agricultural production, such as machine services for hire. The index of total output is formed by aggregating over agricultural goods and the output of goods, and services from secondary activities.

Intermediate inputs consist of goods and purchased services—such as feed, seed, livestock inputs, agricultural chemicals, fuel, natural gas, electricity, purchased contract labor services, purchased custom machine services, and machine and building repairs and maintenance—used in production during the calendar year whether withdrawn from beginning inventories or purchased from outside the farm sector. Data on current dollar consumption and prices are drawn from different sources including ERS, the Bureau of Labor Statistics (BLS), the Bureau of Economic Analysis (BEA), and the National Agricultural Statistics Service (NASS).

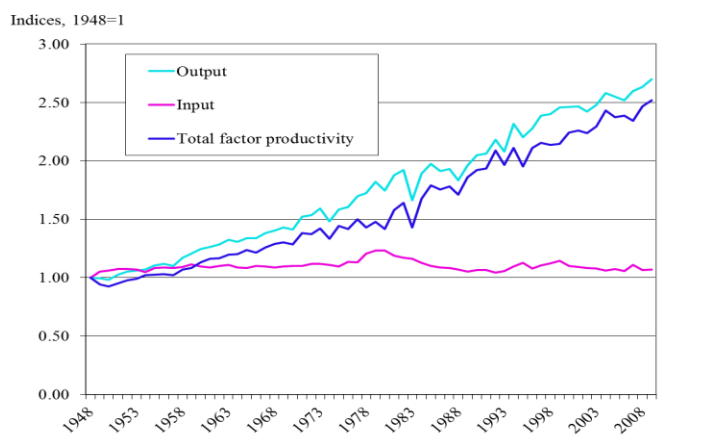
Since pesticides and fertilizers have undergone significant changes in input quality over time, and since the input price and quantity series used in a study of productivity must be denominated in constant-efficiency units, ERS has developed price indexes for fertilizers and pesticides using hedonic methods. Under this approach, a good or service is viewed as a bundle of characteristics which contributes to the productivity derived from its use. Its price represents the valuation of the characteristics "that are bundled in it", and each characteristic is valued by its "implicit" price. Besides agricultural chemicals, contract labor services are becoming increasingly important in agricultural production. Since farmers contract with labor brokers to assemble crews, there is little data on hours worked. Only data on nominal expenditures for contract labor are collected. In order to account for the contribution of contract labor services to agricultural production we must construct an appropriate deflator. Given that the compensation of contract workers will likely vary with differences in demographic characteristics such as age, experience, gender, and education, we construct a deflator for contract labor using hedonic methods based on data from the National Agricultural Workers Survey (NAWS). A Törnqvist index of total intermediate input is formed by weighting the growth rates of each category of intermediate input described above by their value shares in the overall value of intermediate inputs.

The USDA labor accounts incorporate the demographic cross-classification of the agricultural labor force developed by Jorgenson, Gollop, and Fraumeni (1987). Matrices of hours worked and compensation per hour have been developed for laborers cross-classified by gender, age, education, and employment class—hired labor versus self-employed and unpaid family workers. The index of labor input is constructed based on Törnqvist index approach and using cost shares for each category as the weights. Construction of the measure of capital input begins with estimating the capital stock for each component of capital input. For depreciable assets, the capital stocks are the cumulation of past investments adjusted for discards of worn-out assets and loss of efficiency of assets over their service life. The capital stocks of land are measured as implicit quantities derived from balance sheet data. Beginning inventories of crops and livestock are treated as capital inputs. December average prices from the previous year are used to value commodities held in inventory. Indexes of capital input are formed by aggregating over the various capital assets using as weights the cost shares based on asset-specific rental prices. Service prices for capital input are formed implicitly as the ratio of the total current dollar value of capital service flows to the quantity index.

## III. **Patterns of Growth in U.S. Agricultural Output, Input, and TFP**

According to USDA-ERS productivity statistics, the U.S. agricultural output grew at an average annual rate of 1.63% from 1948 to 2009. With a slight input growth of 0.11 percent per year, TFP growth accounts for most of U.S. agricultural output growth, at an annual average rate of 1.52 percent (see figure 1). Input growth was further disaggregated into four components—growth in labor, capital, land, and intermediate goods (materials). Among four input categories, labor use declined by 78 percent and land use by 27 percent over those 61 years, intermediate goods use grew by 140 percent. The positive growth in intermediate goods (including fertilizer, pesticides, fuel, and purchased services) reflects the substitution of those inputs for other inputs.

**Figure 1 Trends of growth in U.S. agricultural output, input, and TFP**




Source: USDA, Economic Research Service data product, Agricultural Productivity in the United States.

Growth in intermediate inputs averaged 1.43% per year over the 1948-2009 period, and contributed 0.69 percentage points of the annual output growth (table 1). Capital service flows, including service flows from durable equipment and farm buildings, also contributed to output growth positively in most sub-periods. Nonetheless, the negative growth in capital goods during two periods, 1981-1990 and 1991-2000, and slow growth in the following period may have resulted in capital obsolescence and slower growth in agricultural productivity in the post-energy shocks period over the last three decades (Ball, Schimmelpfennig, and Wang (2013)). Labor input in agriculture contracted at an average annual rate of -2.51% over the postwar period, and it contributed negatively to output growth at a rate of -0.52% annually. Land is the other input that contributed negatively to annual output growth, at an annual rate of -0.08%. The overall shift in the input mix, away from labor and toward machinery and intermediate inputs, may also reflect trends in relative prices, with those factors becoming cheaper, relative to labor (figure 2).

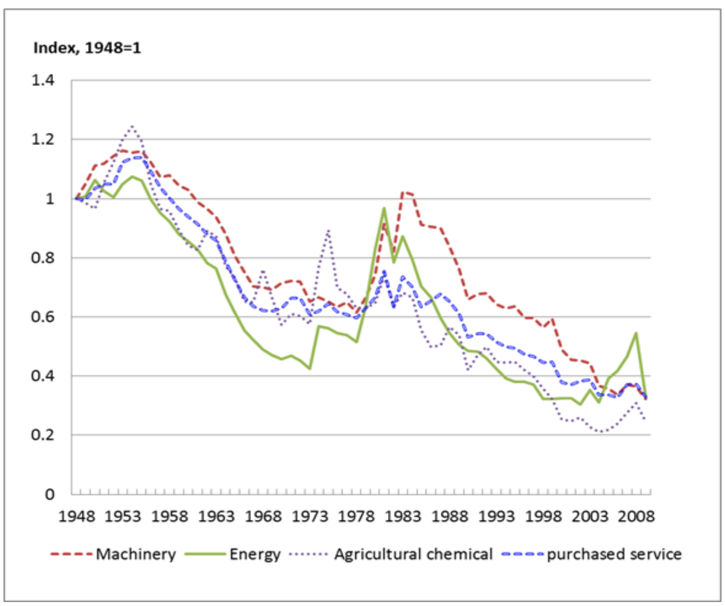
**Table 1. Sources of agricultural output growth in the U.S. (annual average rate in %)**

| | 1948 -2009 | 1948 -1953 | 1953 -1957 | 1957 -1960 | 1960 -1966 | 1966 -1969 | 1969 -1973 | 1973 -1979 | 1979 -1981 | 1981 1990 | 1990 -2000 | 2000 -2007 | 2007 -2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Output growth | 1.63 | 1.18 | 0.96 | 4.03 | 1.21 | 2.24 | 2.65 | 2.26 | 1.54 | 0.96 | 1.84 | 0.77 | 1.88 |
| Sources of growth | | | | | | | | | | | | | |
| Input growth | 0.11 | 1.34 | 0.28 | 0.50 | 0.05 | -0.08 | 0.46 | 1.64 | -1.85 | -1.22 | 0.31 | 0.14 | -1.80 |
| Labor | -0.52 | -0.81 | -1.08 | -0.83 | -0.81 | -0.61 | -0.38 | -0.19 | -0.22 | -0.43 | -0.34 | -0.35 | -0.64 |
| Capital | 0.02 | 0.54 | 0.15 | 0.03 | 0.08 | 0.32 | 0.14 | 0.32 | 0.23 | -0.61 | -0.21 | 0.05 | 0.35 |
| Land | -0.08 | 0.02 | -0.17 | -0.16 | -0.07 | -0.22 | -0.29 | 0.00 | -0.12 | -0.09 | 0.00 | -0.08 | -0.12 |
| Intermediate goods | 0.69 | 1.58 | 1.38 | 1.45 | 0.85 | 0.43 | 0.99 | 1.50 | -1.74 | -0.09 | 0.87 | 0.52 | -1.39 |
| Total factor productivity | 1.52 | -0.16 | 0.68 | 3.53 | 1.16 | 2.32 | 2.19 | 0.62 | 3.39 | 2.19 | 1.53 | 0.63 | 3.68 |

Note: The subperiods are measured from cyclical peak to peak in aggregate economic activity.

Data Source: Economic Research Service

**Figure 2 Relative input price indices**




Data source: ERS productivity account and authors' calculation.

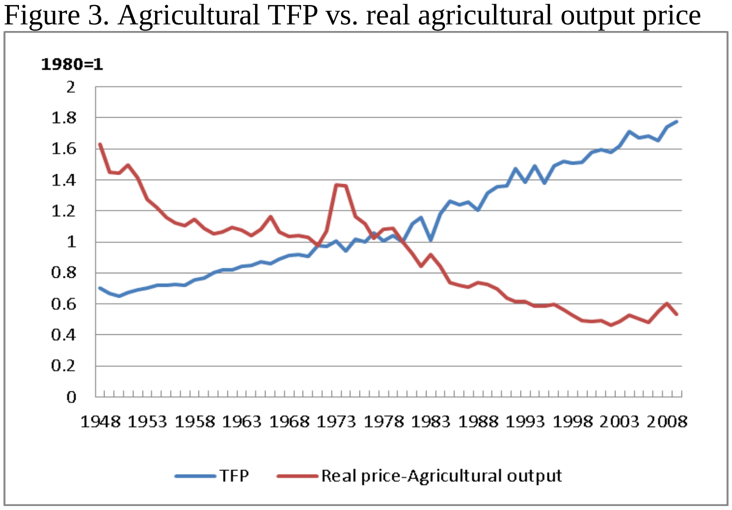
Still, TFP measures have limitations. As Jorgenson and Griliches (1967) proposed, understanding the sources of TFP growth is at least as important as measuring it. In the following section we will discuss the factors that may affect TFP growth as well as the impacts of a rising or falling TFP growth.

## IV. Drivers and Impacts of U.S. Agricultural Productivity Growth

TFP growth is mainly driven by technology innovation in the long run. However, in the short term TFP growth can fluctuate considerably from year to year, largely in response to weather events. Researchers have often attributed long-run TFP growth to innovations that are embodied in quality improvement in inputs, such as seed, agricultural chemicals, farm machinery, livestock breeds, feeds, and etc.; better organization of production that may result in a more efficient use of new technologies (White and Hoppe (2012)); and other farm production related activities. While both public and private agricultural research funding contribute to productivity growth significantly (Wang et al. (2013)) and are believed to be major drivers behind innovation, Wang et al. (2012) found that extension activities and public infrastructure investments can also help to promote technology dissemination and TFP growth. In addition, agricultural and trade policies and the regulatory environment can influence TFP growth as well (O'Donoghue (2011)). On the other hand, short term shocks—including weather changes, energy shocks (Wang and McPhail (2012)), and short term policy shocks such as the payment-in-kind (PIK) program of 1983—can also influence measured agricultural productivity in any given year, even if they do not influence long-term trends in productivity growth.

The continuing growth in TFP has assured sustained agricultural output growth even as input use has declined, and has led to declining real prices of agricultural commodities even as input prices have risen. Figure 3 shows the TFP index and an index of real agricultural output price over the last six decades. With growing trend in TFP series, the real agricultural output price index fell over time, except during the energy price shocks of the early 1970s. On the other hand, if productivity growth slackens, farmers may need to intensify use of inputs including agricultural chemicals and land to produce more output in the absence of innovation. Slower productivity growth could then lead to environmental stresses as well as higher commodity prices, which would impose the greatest damage on low-income households who spend much of their income on food.

Figure 3. Agricultural TFP vs. real agricultural output price




Data Sources: Author's calculation based on data from ERS and BLS.

V. **Conclusion**

The U.S. is one of the world's largest agricultural producers. Statistics show that the U.S. is not only helping to feed the world but is also a significant consumer of farm produce. Whether the U.S. can maintain sustainable TFP growth in the long-run will not only affect U.S. food markets but could also influence global food security. U.S. agricultural output has nearly tripled since 1948 at an average growth rate of 1.63% per year through 2009. With little growth in input, the extraordinary performance in U.S. farm production has been driven mainly by total factor productivity growth at an average annual rate of 1.52%.

Public research investment can fuel innovation and promote productivity growth. Heisey, Wang, and Fuglie (2011) have argued that, if U.S. public agricultural R&D spending remains constant in nominal terms and fails to keep up with inflation, annual TFP growth would eventually be halved by 2050. With public research funding under pressure, how to maintain a sustainable productivity growth in the long-run has become an emerging and crucial issue.

TFP measurement is important for effective analyses of agricultural production and price trends. But our measures depend on accurate survey data covering a wide range of inputs and outputs, and surveys face continuing challenges. While we continue to improve the quality of TFP statistics, how to develop appropriate statistical method to reduce the impact of data discrepancy has become a major challenge in our productivity work.

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