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Featured Article

U.S. Agricultural Productivity: A Review of USDA Economic Research Service Methods

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Abstract *The USDA Economic Research Service has emerged as an acknowledged intellectual leader in the construction and integration of national and state-level productivity accounts in agriculture. The national and state-level ERS productivity measures are widely referred to and used, and international sectoral comparisons rely on the ERS production accounts for foundation methodology in constructing agricultural productivity accounts in other countries. This leadership role has endured for many decades and accelerated in response to the AAEA-USDA Task Force review of the agricultural productivity accounts (Gardner et al. 1980). It is against this backdrop of vigorous intellectual leadership that an external review committee has examined the data sources, methodology, ongoing research, documentation, and reporting of the ERS agricultural productivity accounts. Our recommendations are many and some are substantial. Two of the most important recommendations address overarching concerns of documentation and efficiency, two more consider website communication of methods and data, and four focus on the renewal and construction of the state-level accounts.*

Key words: Agricultural productivity, Economic Research Service, program review, total factor productivity.

JEL codes: D24, O30.

Productivity, along with growth, when applied to an economic story are catchwords that broadly convey the potential for enhanced well-being. Firms may be able to maintain and enhance their profitability, households may be able to enjoy a higher standard of living, and the economy may be able to accomplish more with the same resources when productivity increases.

Productivity and its movement over time is a reflection of choices such as policy makers' decisions on incentives, structural adjustments, and investments that impact firms' decision environments, and firms' resource allocation decisions as they make effective and efficient technological choices. From a policy perspective, a sector's productivity is a long-run concept that serves as a benchmark for how well the sector performs and contributes to overall economic well-being. Improvements in productivity reflect the effectiveness of investment in education, infrastructure, and scientific research.

The purpose of this article is to summarize a focused review of the USDA's Economic Research Service (ERS) agricultural productivity accounts. This review was completed in September 2014 by an external review committee appointed by ERS and comprised of the authors of this article. The overarching goals of the review were to assess current practices used in assembling the agricultural productivity accounts, and to review how the USDA (*a*) documents its efforts and facilitates the ability to replicate and ensure comparability, (*b*) describes how the community of analysts and scholars use the accounts, (*c*) cooperates with other agencies to reduce duplication, achieve consistency across statistical series, obtain information at the lowest cost, and capitalize on research and expertise, and (*d*) establishes priorities subject to resource constraints.

The development of the current ERS agricultural productivity accounts has taken place in parallel with three key manuals governing the construction of internationally comparable productivity accounts (UN 2009; Organisation for Co-operation and Economic Development (OECD) 2001b; and Eurostat 2000), and has been guided by the earlier comprehensive AAEA-USDA Task Force review of the ERS productivity accounts (Gardner et al. 1980). In 2013, partially motivated by the Office of Management and Budget's (OMB; 2011) mandate for ensuring data quality and valid procedures for developing federal statistical information resources, the ERS convened the current external review committee.

The agricultural accounts at the national and state levels are the subject of a wide range of investigations related to (*a*) how new technologies influence agricultural production and performance, (*b*) how labor, land, capital, and intermediate input use patterns evolve over time, (*c*) how readily these factors substitute for each other, and (*d*) how they are impacted by policy. The agricultural accounts are often used as a benchmark across sectors within an economy and for comparison of the sectors across states and across nations to help explain observed differences in aggregate performance. There is considerable interest in cross-country comparisons that investigate agricultural productivity and convergence in agricultural productivity across countries. Total Factor Productivity (TFP) growth is a useful measure for such comparisons.

In this article, we review the methods, estimates, and data products of the ERS agricultural productivity accounts that embed measures of TFP. We focus on the core parts of the production accounts (labor, non-land capital, land, intermediate inputs, and outputs), and on two other high-priority issues: accessibility of data products on the ERS website, and state-level productivity. We touch on several other issues related to the construction, interpretation, and assessment of the accounts. Each of these topics is covered more fully in the committee's report to ERS (Shumway et al. 2014), which is available online. The full report includes 57 recommendations in four levels of priority. In this article, we present only the 21 recommendations in the top two priority levels.

Measurement Framework

The ERS estimates the sources of growth for the farm sector within the framework of an industry-level production account using a growth accounting model. This section describes the basic underpinnings of the ERS model.[1]

The starting point of the framework is a nominal accounting identity equating the value (V) of farm output (Y) with the value of input (X) at the national level. The economic assumption underlying this accounting identity is a zero-profit condition, that is, all income generated is distributed to factors of production.[2] Input payments are subdivided into intermediate inputs (I), labor (L), non-land capital (KN), and land capital (KL). The nominal accounting identity can be written as

$$V_Y = V_X = V_I + V_L + V_{KN} + V_{KL}. \tag{1}$$

The ERS production account seeks to decompose these nominal values into constant-quality quantities (Q) and constant-quality prices (P). The industry-level production account can be written as

$$V_Y \equiv P_Y Q_Y = P_X Q_X = P_I Q_I + P_L Q_L + P_{KN} Q_{KN} + P_{KL} Q_{KL,} \tag{2}$$

where P_X *and* Q_X are aggregate input price and quantity indexes, respectively, and other variables are defined accordingly for output and input category indexes. Using these aggregate measures of output and inputs quantities, total factor productivity is defined as

$$TFP \equiv Q_Y / Q_X. \tag{3}$$

That is, total factor productivity is the ratio of the quantity of all constant-quality outputs relative to the quantity of all constant-quality inputs used in production in time t. Obviously, $\Delta \ln TFP = \Delta \ln Q_Y$ - $\Delta \ln Q_X$, so the growth rate of TFP equals the growth rate of all outputs less the growth rate of all inputs. Note that P_X and Q_X are not directly measured. The ERS account assembles estimates of each of the inputs and constructs a quantity index of total inputs Q_X.

Under specific conditions, the growth rate of measured TFP corresponds to the growth rate of technology, including innovation (Jorgenson, Ho, and Stiroh 2005). The necessary conditions for this correspondence are as follows: constant returns to scale; price taking behavior by firms; zero profits; factors paid their marginal products; and prices and quantities measured in constant-quality units.

The subsequent sections assess the ERS implementation of equation (2) piece by piece and suggest potential opportunities for improvement.

Labor

According to the ERS productivity accounts (USDA 2014, table 1), the nominal value share of hired and family labor in U.S. agricultural output has averaged about 20% over the 64-year period from 1948 to 2011. Although that share has decreased slightly in the 2002–2011 decade, the composition has

[1] Jorgenson, Gollop, and Fraumeni (1987), and Jorgenson, Ho, and Stiroh (2005) describe the growth accounting model that is widely used by productivity analysts.

[2] Differences in implementation of the state accounts are discussed in a later section.

shifted substantially toward relatively more hired labor and less operator and family labor.

Before we review the ERS implementation, we note that the accurate measurement of productivity requires that the labor quantity index should capture not only the hours worked but also reflect the marginal product of different types of labor working in the sector. While total hours worked is the preferred measure of the service flow for a given worker, it does not capture the heterogeneity of the labor force. Differences in skills, education, health, and professional experience lead to large differences in the contribution of different types of labor. It is necessary to identify the labor input by type of skill to adequately distinguish the effects of changing labor quality and productivity growth.

1980 AAEA Task Force Recommendations

The AAEA Task Force recommended that (*a*) the labor input index be based on direct sampling instead of the requirements approach, (*b*) the labor input data be handled separately for hired, operator, and family labor, each weighted to construct an aggregate by their relative wage rates, and (*c*) the Divisia index be used for aggregation with expenditure shares as weights.

Economic Research Service Response

The ERS has implemented the recommendations of the AAEA task force and has used theoretically consistent methods to develop Tornqvist (discrete approximation to the Divisia index) and Fisher labor input indexes for use in total factor productivity analysis. The implementation of these indexes has closely followed Jorgenson, Gollop, and Fraumeni (1987) as well as the OECD Productivity Manual (2001b). The ERS has undertaken a continuous process of methodological examination and improvement, as documented by the use of Tornqvist indexes for 1948–1979 in Ball (1985), Fisher indexes for 1948–1980 in Ball et al. (1997), and a revised series of Tornqvist indexes for 1948–2011 available on the ERS Agricultural Productivity website.[3]

Table 1 on the ERS Agricultural Productivity in the U.S. website (USDA 2014) presents Tornqvist price and implicit quantity indexes for labor and its sub-components, hired and self-employed (which includes unpaid operator and family labor), for the period 1948–2011. Following Jorgenson, Gollop, and Fraumeni (1987), matrices of employment, hours worked, and compensation per hour (for hired labor) cross-classified by two gender classes, eight age classes (14–15, 16–17, 18–24, 25–34, 35–44, 45–54, 55–64, and 65 years and older), education (1–8 years, 1–3 years high school, high school diploma, 1–3 years college, bachelor's degree, and post-bachelor's degree), and employment class (wage/salary worker and self-employed/unpaid family worker) are used (Wang 2013). These categories represent 192 entries and are slightly different from the cross-classifications used in Ball (1985) and Ball et al. (1997), which included an occupation dimension in the cross-classification.

Data for hired farm workers (employment, hours worked, and compensation) are from the National Income and Product Accounts (NIPA), developed by the Bureau of Economic Analysis (BEA). Total hours worked for self-employed and unpaid farm workers are from the Census of Population

[3] *Among other changes, the revised series uses new data for labor and land.*

and the Current Population Survey. Wages for self-employed and unpaid family workers are imputed using the mean wage of hired workers in the same cross-classification.

Control totals for hours worked and compensation for hired workers are from NIPA and from a special tabulation by the Bureau of Labor Statistics (BLS) for self-employed and unpaid family workers.

Many farms hire labor services from contract providers. The workers are not employees of the farm, and hence are not counted as hired labor. Rather, they are reported as purchased contract labor services in the intermediate inputs category, and farm survey respondents are able to report expenses but not employment or hours for such workers. Because there is no available data on hours worked, the ERS estimates implicit quantities of purchased contract labor services by dividing expenditures by a hedonic wage index. The data consist of nominal expenditures on contract labor. The ERS uses a wage deflator index based on hedonic methods.[4] The hedonic framework is used to estimate wage as a function of labor characteristics using data from the BLS National Agricultural Workers Survey. The framework includes gender, years of experience, education, language skills, legal status, employer type, task type, geographic, and time controls. Heckman's procedure is used to correct for sample selection bias.

Our Assessment

The ERS implementation of the labor index, while broadly consistent with previous vintages, deviates in some ways from previously published approaches. For example, because of limited data, the ERS labor cross-classifications no longer contain the occupation dimension. Further, to be consistent with a change in survey questions in the Current Population Survey, updates after 1992 treat degree attained as the defining characteristic of educational attainment, compared to years of schooling in the previous estimates. See Jorgenson, Ho, and Stiroh (2005) for methods of bridging the two treatments.

Jorgenson, Ho, and Samuels (2014) develop U.S. industry-level production accounts for 65 industries, including agriculture, for the period 1947–2010. While the long-term trend is broadly consistent, their evolution of the agricultural sector labor index differs from that of ERS. Given the overlap in source data and methods between ERS and Jorgenson, Ho, and Samuels (2014), the relative merits of the two procedures for creating the labor index warrant careful examination.

Non-land Capital

The nominal value share of non-land capital in U.S. agricultural output has averaged about 12% over the 64-year period from 1948 to 2011 (USDA 2014, table 1). That share has decreased to 10% in the 2002–2011 decade. Like labor, a key feature of the capital input measure is that a shift in the composition of capital towards an asset type with a higher marginal product constitutes an increase in the quality-constant capital input used in production. Ignoring this type of composition shift would result in a

[4] *Prior to the year 2000, ERS used "piece rate information" from the USDA National Agricultural Statistics Service (NASS) to deflate these expenditures, but this information is no longer available.*

systematic bias in estimated TFP. Fortunately, research on productivity measurement has established methods to adjust for composition changes in capital services, and ERS has, for the most part, adopted these procedures. Also, like labor, there are many complexities in reliably measuring the service flow from capital.

1980 AAEA Task Force Recommendations and Subsequent Guidance

The AAEA Task Force made several recommendations that relate to non-land capital inputs. These recommendations include measuring total factor productivity (and not reporting partial measures), improving the quality of data on the stocks of machinery and equipment, and modifying structures and capital equipment depreciation procedures to better reflect the "economic value of services at each point of an item's lifetime" (Gardner et al. 1980).

Since the 1980 review of measurement of U.S. agricultural productivity, there have been substantial developments in the measurement of productivity, particularly in the measurement of capital inputs. Of particular note in the 1980s were the first release by BLS (U.S. Department of Labor 1983; USDOL) of total factor productivity estimates for aggregate sectors and the publication of Jorgenson, Gollop, and Fraumeni's (1987) book on U.S. productivity and economic growth. Later, the OECD issued two manuals dealing with capital measurement (OECD 2001a; 2009) and one dealing with productivity measurement (OECD 2001b). Beginning in 2003, the European Union KLEMS project (Van Ark, O'Mahony, and Ypma 2007) began to develop industry-level production accounts for European countries; subsequently, this effort was extended to other countries through the World KLEMS project.[5]

Economic Research Service Current Practice and Our Assessment

The ERS's methodology for measuring non-land capital quantity and price is broadly consistent with the recommendations of the AAEA Task Force, the OECD manuals, as well as approaches used in recent productivity literature; it is thus largely reasonable and defensible. Nevertheless, the review committee, supported by stakeholder feedback (Sliker 2014b), has identified one internal inconsistency and a deviation from broadly accepted practice, which are addressed in more detail below.

Capital Measurement: General Issues

The measurement of capital differs from the measurement of hired labor in that wages paid to hired labor are recorded, whereas rent paid to capital frequently is unrecorded because capital is more often owned than leased. In that respect, capital is similar to operator and family labor. Further, the flow of services from the productive capital stock is unobserved, and the size of the productive capital stock is based on the accumulation of past as well as current investments. These fundamental differences give rise to a number of difficulties in capital measurement. The objective of the procedures used by ERS with regard to this input category is to estimate an implicit value flow from investments in capital.

[5] *See http://www.worldklems.net/index.htm for information on World KLEMS.*

The construction of the capital input begins with construction of the capital stock. The perpetual inventory method is typically used to develop real capital stock estimates,

$$K_t = I_t + (1 - \delta_{t-1})K_{t-1}, \tag{4}$$

where K_t is real productive capital stock in period t, I_t is real gross investment in period t, and δ_t is the rate of efficiency decline (deterioration) in period t. The importance of implementing capital stock construction by industry and by asset type has been demonstrated in many empirical applications.

The next step is to construct the user cost of capital for each asset, which is also called the rental price of capital services. This price represents the transformation of the acquisition price of capital to the per-period usage price,

$$p_{K,t} = p_{I,t}(r_t + p_D) - (p_{I,t} - p_{I,t-1}), \tag{5}$$

where $p_{K,t}$, the user cost of capital, is the cost of using the capital asset in period t, $p_{I,t}$ is the period t market price of a new asset, r_t is the period t opportunity cost of employing capital elsewhere and is often called the rate of return, p_D is the period t rate of loss in the value of the asset as it ages, and $(p_{I,t} - p_{I,t\text{-}1})$ measures capital gains, losses, or revaluation of the asset between period t and $t - 1$. Some statistical agencies and researchers include tax in the user cost formula. User costs are then multiplied by the real productive stocks to create nominal capital inputs (or capital flows) by asset, which are used as productive capital stock weights in an index number formula to create an aggregate real capital input. The theory of production equates these weights to be consistent with the marginal product of each capital asset.

In our review of non-land capital inputs, we focus on these two themes of capital stocks and user cost of capital.

Capital Stock

To construct a measure of capital input (capital flow), the capital stock must first be measured. To determine the capital stock, the ERS uses three major sources for nominal investment data on equipment and structures: BEA fixed-assets data for years prior to 1975, NASS Farm Production Expenditures Survey data for 1975–1992, and Agricultural and Resource Management Survey (ARMS) data for 1993 to the present. There are five categories of ERS farm nominal investment data: autos from 1926, trucks from 1926, farm tractors from 1929, buildings from 1871, and other machinery (an aggregate) from 1914.

Because BEA and BLS also develop selected agricultural capital input series, we compared some of the ERS data and assumptions to those used by the other reporting agencies. Although the ERS relies on BEA fixed-asset data through 1974, the committee found substantial differences between the BEA fixed-asset data reported on their website and the ERS data, even prior to 1975.[6] No perceptible pattern of differences was found, except that the ERS data prior to 1975 tend to be lower for equipment and higher for buildings than the BEA fixed assets data.[7] Beginning in 1975, the ERS data are almost always lower for both equipment and structures.

[6]*Most of the BEA fixed-asset data were available at http://www.bea.gov/national/FA2004/Details/Index.html when this article was written (last accessed August 20, 2014). The current link is http://www.bea.gov/iTable/index_FA.cfm. Some of the data on this new link may have been revised.*

We also compared the BEA fixed assets category for all equipment except autos and farm tractors (other equipment) with the ERS other equipment category from 1947 to the present. With one exception, the percentage of ERS other equipment relative to ERS total equipment is consistently lower than the percentage of BEA other equipment relative to BEA total equipment. Differences are as high as 13 percentage points before 1993. The BEA other equipment category includes computers and software after 1977 and wind and solar power after 1992, while the corresponding ERS category does not.

The ERS assumes that average service lives are 10 years for autos, 9 for farm tractors, 17 for other machinery, and 38 for buildings. The ERS average lifetimes for farm tractors and buildings match the average lifetimes used by BEA. The BEA does not use an explicit average service life for autos; rather, it develops deterioration rates from information on new and used auto prices (see U.S. Department of Commerce 2013).[8] In addition, the BEA "autos" category refers to all autos listed under private nonresidential equipment, rather than just those used in the agricultural sector. This category excludes autos that are classified as durables owned by consumers. The average service lives used by BLS are also generally the same as the ERS service lives. The exception is that BLS uses an average service life of 8 years for tractors (USDOL 1983).

The ERS estimates deterioration and retirements using methodology almost identical to that used by BLS. The deterioration function is hyperbolic with β equal to 0.75 for buildings and 0.5 for equipment. The ERS retirement function is a truncated normal distribution with the range equal to double the average service life, that is, from 1 to 20 for autos, 1 to 18 for farm tractors, 1 to 34 for other machinery, and 1 to 76 for buildings. The spread adopted by BLS is only slightly different: .02 to 1.98 times the average service life (USDOL 1983, pp. 44–45). This is the only difference between ERS and BLS methodology with respect to deterioration and retirements.

The ERS uses a perpetual inventory method to construct stocks. This methodology is also widely used by others. However, Sliker (2014b), as discussed below, questions whether the aggregation procedure over individual assets is internally consistent.

User Cost of Capital

Constructing the capital input (capital flows) requires measurement of the user cost of capital in addition to the capital stock. To measure the user cost of non-land capital, the real rate of return, r, to capital must be determined. The real rate of return is calculated as the nominal yield on investment grade corporate bonds, less the expected (forecasted) rate of inflation as measured by the implicit deflator for GDP. Rather than using an actual rate of return, an ex-ante real rate of return is obtained by expressing inflation as an ARIMA process. This is a defensible approach. However, the ERS choice to use the

[7]There are several possible reasons for these differences: The BEA fixed-asset data base used by ERS has not been re-collected since it was first obtained in 1985 although BEA has revised the earlier data since then. The BEA title in the farm category under "total structures" is simply "farms", so it is not clear if this category only refers to nonresidential farm structures. There is a separate category under the farm industry labeled "lodging", with zeroes in all entries. Patterns also differ for the equipment subcategories of tractors and autos.

[8]In this review, the word deterioration is consistently used to refer to the decline in efficiency of an asset as it ages and the word depreciation to the decline in the price of an asset as it ages. This distinction is discussed later.

GDP deflator as the expected rate of inflation measure is unusual. In widely used approaches, the rate of asset capital gain (inflation) is measured by an asset-specific deflator. The choice of the GDP deflator may have been dictated by problems that researchers frequently face when capital gains produce an asset-specific real rate of return that varies widely and may even be negative in some years. However, that can be resolved by following BLS in the use of a smoothing function that takes the average rate of asset inflation over several years. Incorporating asset-specific capital gains is particularly important for assets with rapidly changing prices, such as computers.

The formula for r is $((1 + \text{bond rate})/(1 + \text{expected inflation})) - 1$, where the bond rate is the average across all maturities for AAA rated bonds. The choice of the AAA bond rate as the nominal opportunity cost of invested funds stems from the fact that Farm Credit bonds are almost always rated AAA. This choice is defensible, as the Farm Credit system is a major player in the agricultural credit market. In the construction of the user cost of capital, r is held constant for a particular vintage of capital goods. No attempt is made to separate corporate and noncorporate capital input, although the implicit rental prices differ because of differences in tax structures. The BEA provides BLS with a corporate/noncorporate split, so such a split could be implemented.

The ERS does not incorporate any tax terms into its user cost formula. This differs from the practice of BLS (Harper 1999), the Australian Bureau of Statistics (2013), and Jorgenson, Gollop, and Fraumeni (1987). The ERS' decision to exclude tax terms may have been made because it complicates the user cost of capital equation, or because of data availability issues. Whatever the reason, an explanation is warranted.

Construction of the user cost of capital also requires a measure of depreciation. With the perpetual inventory method of constructing capital stocks, real gross investment is accumulated and reduced by deterioration in the efficiency of the capital stock, which differs conceptually from depreciation (i.e., decline in the price of the asset as it ages).[9] The ERS has made reasonable assumptions typically employed by others (e.g., BLS) to measure deterioration and create measures of capital stock. However, rather than explicitly including a depreciation term, the ERS takes a different approach to implementing the measurement of user cost.[10] The ERS components represent the opportunity cost of invested funds and the discounted stream of the sum of capacity deterioration.[11]

As other experts and the ERS agree, the productive stock should be multiplied by user cost to obtain capital input. Deterioration functions are used to derive capital stocks. The user cost expression, which is a revenue concept, is the expected annual marginal revenue product arising from the capital asset at the time of investment. Age/price functions underlie the revenue (depreciation) concept. Harper (1999) uses a concave age/efficiency formulation for deterioration and shows that the age/price formulation for depreciation is convex.

The ERS user cost methodology was outlined by Ball (2014b) and shared with individuals at BEA and BLS. A BEA response (Sliker 2014a) expressed

[9] *In this discussion, the term deterioration is used to refer to the capital stock concept and the term depreciation is used to refer to the user cost of capital or capital input concept.*

[10] *Ball et al. (1997) cite Coen (1975) for their procedure.*

[11] *This approach is at variance with the work of several other capital measurement experts who defend the age-price approach (e.g., Harper 1982, 1999; Ho, Jorgenson, and Stiroh 1999; OECD 2009), but Sliker (2014a, 2014b) appears to reconcile the two approaches.*

little concern about the appearance of deterioration in the user cost of capital expression, and provided what appears to be an internally consistent justification for the ERS method of measuring productive stock and the capital rental rate. Of greater concern in Sliker (2014a) was the ERS methodology reported in Ball et al. (2008) concerning ”construction of a cohort-average replacement function as a weighted average of individual replacement functions, where the weights are the frequencies of each lifespan in the cohort's original installation.” Since neither Sliker's recommended cohort aggregation procedure, nor the ERS user cost of capital formulation have been widely vetted, both warrant additional review by experts in the field before changes are made or final conclusions reached. Vetting is important to determine if changes should be made to ERS methodology, as well as to inform other productivity researchers.

Measures of the real capital input are constructed using Tornqvist indexes. This is a procedure employed commonly in the literature and by statistical agencies.

Inventories

Inventories impact the output, intermediate input, and capital input accounts. Additions to inventories are documented as output, withdrawals from inventories as intermediate inputs, and the stock of inventories as capital input. Inventories include durable assets that produce output, such as milk cows and fruit trees, as well as nondurable items. NASS surveys from the early 1980s (since discontinued) were used to benchmark farmer-owned inventory stocks. Price deflators for inventory investment come from NASS. It is assumed that inventories, including durable assets such as milk cows, breeding livestock, and fruit and nut trees do not deteriorate or depreciate. The ERS considered treating milk cows and breeding livestock as a durable asset that declines in efficiency over time (Ball and Harper 1990), but decided against doing so because of questions about the reliability of the source data (Ball 2014a). The construction of inventory capital stock and capital input otherwise parallels the methodology for equipment and structures.

Research at BEA

Researchers at BEA are developing more comprehensive measures of farm output, as well as investment and capital stock for the NIPA (Soloveichik 2014). Some of the findings from the research project might influence BEA methodology and be beneficial to ERS productivity accounts. Open research issues include (*a*) treatment of working farm animals, long-lived farm plants, and land improvements as capital assets, (*b*) introducing quality adjustments for some of these assets, and (*c*) valuing farmland based on agricultural rental rates rather than market value. The total impact of such refinements in methods and the data requirements to support them is research in progress (Soloveichik 2014).

Land

According to the ERS production accounts (USDA 2014, table 1), the nominal value share of land services in U.S. agricultural output has averaged about 17% over the 64-year period from 1948 to 2011. This share has decreased to 13% in the 2002–2011 decade. Land (owned and rented), along with structures, equipment, and inventories, is a component of the capital index. Many of the procedures described in the previous section on non-land capital apply to land. Although land does not depreciate, stocks of land from the Census of Agriculture are used as a basis for calculating the flow of services. For owned land, the price of the service is the user cost of capital as developed for other capital equipment and structures, except that depreciation is assumed to be zero. The ERS treats the total payments to land as a residual, which implies an interest rate for land that differs from other capital assets.

1980 AAEA Task Force Recommendations

The AAEA Task Force (Gardner et al. 1980, p. 33, 46) recommended several changes in the procedures used to convert land stock to a service flow; they recommended that the flow to stock conversion be based either on the estimated ratio of base-period cash rental value to stock value, or on a single interest rate throughout the data series. Whichever is used, the task force recommended that it be used as the conversion rate for all land. The ratio of cash rental value to stock value was previously used only for the equity portion of land owned; the task force recommended that property taxes as a fraction of land value be added to the conversion factor. The task force further recommended that service flows from public lands be based on a shadow-rent estimate of rental value of comparable private lands, rather than on federal grazing fees.

Economic Research Service Current Practice

Procedures used by ERS to develop indexes of farmland for the purpose of total factor productivity measurement are theoretically consistent with international standards. They follow best practices as described in Jorgenson, Gollop, and Fraumeni (1987) and in the OECD capital and productivity manuals (2009; 2001b). Reasonable procedures (e.g., Tornqvist and Fisher indexes) and data sources (e.g., state, agricultural statistical district, county, irrigated, non-irrigated, grazing) have been used to develop these indexes per descriptions in Ball (1985), Ball et al. (1997), and Ball et al. (1999). The procedures reflect a continuous process of revision and improvement to capture changes in the composition of land, as evidenced by estimates that now reflect lower levels of aggregation.

Verified by our examination of detailed spreadsheets, constructing the index of land stock begins with county-level data. County-level acreage data from the Census of Agriculture for all land types except "land in house lots, ponds, roads, wasteland, etc." is used. For intercensal years, the quantity of land in each county is adjusted by the percentage change in state-level land area using the NASS June Area Survey. When new census data become available, a spline technique is used to estimate usable land area by county and revise previous data between census years.

Price of land at the county level is the average value of land per acre. The Census of Agriculture provides information about the value of land and buildings. However, it does not separate out the value of land from the value of buildings at the county level, nor does it provide information on the value of land by use (cropland, pasture, etc.). The value of land per acre at the county level is obtained by multiplying the value of land and buildings for the county from the Census of Agriculture by the ratio of the value of land to the value of land and buildings for the state. The ratio of the value of land to the value of farm real estate has been taken from the NASS Agricultural Economics and Land Ownership Survey (AELOS). That survey, an irregular census follow-on, was last conducted in 1999 and will not be conducted again until winter 2015. To date, the 1999 ratios have been used for subsequent years. As an alternative, the ERS has explored the possibility of using ARMS data to estimate the ratio of the value of farmland (including trees and vines) to the value of farmland and buildings for the state. Because ARMS has small samples in some states, the ERS is considering using two-year moving averages for the ratio. The resulting estimates using ARMS data for years close to 1999 are consistent with those based on 1999 AELOS data.

The annual rate of change of prices in each county is aggregated using shares of each county in total state value of land as weights to obtain a state annual rate of change in prices. The same procedure is used to obtain a national price index. A Tornqvist state-level price index of county-level land prices is computed before computing a Tornqvist national price index. Acreage shares of each land type in each county (state) are used as the index weights. Land stocks at each level are implicit quantity indexes obtained as the value of land divided by the price index of land.

Only the implicit quantity indexes of land stocks are used from this aggregation in the productivity accounts. The value of service flows from land is obtained as a residual when imposing the accounting identity at the national level. Thus, land is the residual claimant of revenues after all other inputs have been paid.

Our Assessment

Generally appropriate procedures are being employed by ERS to obtain land stock indexes in the national accounts. However, some questions and opportunities to improve the reliability of measurement remain.

The definition of farmland particularly warrants reconsideration. The ERS land series currently uses the Census of Agriculture definition of "land in farms". Because cropland has remained relatively stable while non-cropland has declined substantially over time, their index reflects the component that is changing—non-cropland. This results in the ERS land stock index tracking the acreage of woodland, pastures, and other non-cropland more closely than the acreage of cropland (Soloveichik 2014). Consideration should also be given to including grazed public land managed by the Bureau of Land Management and the Forest Service when creating the land stock index (Pardey, Andersen, and Acquaye 2006).

The use of county-level data when computing the land stock index has added an important element of precision in measurement. Nevertheless, the use of county averages for land value ignore quality differences within a land type within the county. Ways to capture land quality differences within the county should be explored.

Intermediate Inputs

In the production accounts, much of what is regarded as variable inputs in agricultural production is aggregated into the intermediate inputs category. This aggregate is composed of fertilizer, lime, pesticide, fuel and lubricants, electricity, natural gas, feed, seed, custom services, machinery leasing, purchased contract labor services, and miscellaneous expenses associated with agricultural production activities. More than half of the nominal value of U.S. agricultural output has been expended on purchases of intermediate inputs over the 64-year period from 1948 to 2011 (USDA 2014, table 1). This share has increased from 52% over that entire period to 58% during the 2002–2011 decade. The composition has also changed—value shares of pesticides, fertilizer, and energy has increased considerably.

The major issues of concern with regard to accurate measurement of intermediate inputs for the purpose of the productivity accounts are:

- Addressing input quality changes.
- Reconciling ERS and BLS producer price index series.
- Considering supplemental data and protocols when the quality of primary data sources is in doubt.
- Valuing the on-farm consumption of inputs.

1980 AAEA Task Force Recommendations and Subsequent Guidance

The AAEA Task Force (Gardner et al. 1980) made several recommendations with respect to intermediate inputs; they recommended that feed, seed, and livestock service flows that are farm outputs used as inputs on the same farm not be counted as either input or output for productivity measurement purposes. The components of feed, seed, and livestock purchases resulting from resources committed in the nonfarm sector should be counted as inputs to agricultural production. Agricultural chemicals needed additional attention to the extent that some chemicals should be counted as part of veterinary expenses, feed additives, and growth hormones. Index number procedures should move away from the Laspeyres to the Divisia. This was mentioned specifically for pesticides, fertilizers and aggregate inputs. Input quality adjustments should be made to ensure that inputs are measured in constant-quality units. The ERS was commended for using the gross output approach to productivity measurement rather than the net (value-added) approach used in most non-farm productivity measures.

An important source of additional guidance on intermediate inputs is the OECD Productivity Manual (OECD 2001b, chapter 6) regarding intermediate input measurement and valuation. This publication identifies input-output tables as the principal tool for creating a full set of intermediate input price and quantity indexes. The OECD considers this to be a preferred mechanism that ensures the consistent treatment of intermediate and primary inputs and produces measures that are consistent with the accounts for the economy as a whole. When the quantity indexes of intermediate products are weighted by their value share in total inputs, input substitution toward intermediate inputs with higher marginal products is accounted for as a change in the composition of intermediate inputs.

From the perspective of productivity measurement, the choice of valuation should reflect the price that is most relevant for producer decision making. For goods intended for intermediate consumption, the OECD (2001b) and UN (2009) manuals recommend valuing them for the consumer at the purchasers' prices (which includes taxes, transport, and other charges paid by the purchaser).

Economic Research Service Current Practice

All of the AAEA Task Force recommendations have been adopted. The ERS practice is also generally consistent with the OECD manual.

The ERS values intermediate inputs at the purchasers' prices as recommended by the OECD (2001b) and UN (2009) manuals. The core intermediate input data are input expenditures collected from ARMS data. Prices are collected by ARMS for only a few inputs. The most commonly used source of prices for intermediate inputs is the NASS Prices Paid Survey, which collects price data using telephone enumerated surveys. Prices paid for farm inputs are collected annually through a survey of establishments selling production input items to agricultural producers. The NASS prices paid index does not include adjustments for changes in item quality or product enhancements (USDA 2011, pp. 1–7).

Fertilizer, lime, and pesticides comprise the agricultural chemical input subcategory. Fertilizer quality changes are addressed by using a hedonic price index that is documented in Fernandez-Cornejo and Jans (1995), and in Ball, Hallahan, and Nehring (2004). The BLS also develops a price index for fertilizer. For comparison purposes, the correlation between the BLS price index and the ERS fertilizer hedonic price index is 0.93 over the period 1948–2011. However, the growth rates between these series correlate at only 0.51.

The NASS reports the price per ton of "lime spread on the field" as well as lime expenditures. The ERS constructs implicit quantities; this is a fairly homogenous input that is not likely to require quality adjustments.

Nominal expenditures are reported by NASS for pesticides, and hedonic prices accounting for quality changes are constructed by ERS (Fernandez-Cornejo and Jans 1995; Fernandez-Cornejo et al. 2014), as are implicit quantities. The BLS also develops a pesticide price index that has a correlation of 0.90 with the ERS index over the entire period, but not as high for major subperiods. In particular, in the post-1973 period, the BLS price index changes at a slower rate than the ERS hedonic price. The correlation between the growth rates of these two series is only 0.40; it is not clear if these differences are due entirely to the ERS accounting for changes in quality.

The NASS provides expenditure data for fuels and lubricants, including minor fuels (e.g., coal and wood), as well as expenditures for the major energy components: gasoline, diesel, liquefied petroleum gas, natural gas, oil and lubricants, and electricity. The NASS is also the source of price data for gasoline, diesel, and liquefied petroleum gas. Natural gas and electricity price data are sourced from the Energy Information Administration. Oil and lubricants price data are sourced from BLS. The ERS constructs a price index and an implicit quantity for fuels and lubricants by deflating total expenditures net of taxes.[12] The BLS also develops price indexes for several of these fuel types. For comparison purposes, four of the five series track closely over the period—the correlation between the growth rates in the BLS and ERS price series over the entire period is 0.80 for gas, 0.91 for diesel, 0.68 for LP gas, 0.84 for natural gas, and 0.95 for electricity.

The NASS series for feed expenditures use the BLS price index for animal feed other than pet food and the NASS prices paid index for seed as deflators to obtain quantity estimates. The BLS deflator does not include on-farm

[12] *Farmers are eligible to claim a refund of excise taxes on fuel.*

consumption. The ERS includes the on-farm consumption of feed, as is the practice for the EUROSTAT (2000) and the UN (2009) manuals. The ERS treats all on-farm feeding as being drawn from opening stocks. The price of feed fed on the farm is the opportunity cost, for example, the price of corn fed is the price received by the farmer for corn sold off the farm, net of price supports since the payments are not dependent on end use. The total feed and seed input is an index of purchased and on-farm use. This results in a different input price than the purchasers' price proposed by the OECD (2001b) manual since marketing margins and transportation costs of animal feed are not included in the BLS price index for animal feeds.

The accumulation of crop and livestock inventories is added to the quantity sold in the output category and subtracted from the intermediate input category. The drawdown of inventories affects both categories in the opposite direction. These intermediate inventories also refer to seed, feed, etc. The only questionable practice is the treatment of livestock changes as changes in inventory instead of capital.

Communication with ERS suggests that embodied technical change is not being addressed in the NASS seed price indexes. Since NASS is not adjusting for seed quality change, this leads to overstating recent prices and understating quantity; the ERS plans to develop a hedonic price index for seed.

Purchased services are another major component of the intermediate input series. Expenditures for repairs and maintenance of machinery and buildings use the BLS deflators to construct implicit quantities. Purchased machine services use the index of machine rental prices, implying that purchased machine services are a perfect substitute for services from owned capital. No data on actual prices of purchased machine services are collected. Other purchased services include (*a*) transportation, marketing, and warehousing that use the BLS price index series for farm product warehousing and storage, and (*b*) veterinary and pharmaceuticals. Custom livestock feeding uses a feed price index obtained from an "informal" survey as a deflator.[13] Other management expenses use the BLS employment cost index for wages and salaries, professional, and related services.

Miscellaneous expenses include two general categories. The first is irrigation expenditures from public sellers of water and the cost maintenance index for water projects compiled by the Bureau of Reclamation. The second is general production expenses (tools, shop equipment, and other unallocated expenses) that use the BLS price index for hardware as a deflator.

The last component is purchased contract labor services. A hedonic price index is used to develop an implicit quantity index from ARMS expenditure data.

Our Assessment

The ERS approach to computing intermediate input accounts is sophisticated and generally follows best practice. Opportunities for strengthening the series include examining the robustness of the ERS intermediate input series to the use of alternative sources of price deflators and investigating the logic and practical effect of how ERS intermediate input measurement compares to that based on input-output tables.

[13] *This is a phone survey of livestock feeding operations. It is not conducted annually and the survey is not stratified by size of operation, geographic location, or time of year.*

The price and quantity series for energy, fertilizer and lime, pesticides, purchased services, and other intermediate inputs are available on the ERS website. No Priority 1 or 2 recommendations apply to intermediate inputs.

Outputs

Accurately measuring the prices and quantities of agricultural output is critical for the accurate measurement of productivity growth. Because a large body of research uses output and input price and quantity measures as basic data, it is important that the aggregates, as well as the individual commodities and inputs be measured accurately.

1980 AAEA Task Force Recommendations

Several of the AAEA Task Force (Gardner et al. 1980) recommendations with regard to input categories also applied to outputs. The task force recommended that ERS (*a*) account for quality changes to provide a close-to-total productivity measure, (*b*) switch from a Laspeyres index procedure to a Tornqvist index procedure that adjusts weights every year, (*c*) focus on TFP for all agricultural output and not develop TFP measures for individual outputs, (*d*) use comparable definitions for cross-sectional comparisons across states or nations, (*e*) utilize most reliable data sources, and (*f*) report more analysis and fewer numbers. The task force also commended ERS for focusing on total factor productivity using gross output measures and using an index number approach rather than switching to a production function approach (since TFP changes account for technical and allocative efficiency changes, as well as technical change).

Only two of the Task Force recommendations were uniquely output-oriented: (*a*) define the boundary between the agricultural sector and food production based on the first point of assembly, and (*b*) include net indemnity payments from publicly-provided disaster insurance in the measure of output. With regard to the first, the report notes that the first point of assembly may be after the first point of sale due to processing work done on the farm after the crops have matured and sold (such as harvesting) or before the point of sale (such as boxing eggs). The objective of this recommendation was to establish a definition of farm output that was consistent across commodities.

For the most part, the task force recommendations were consistent with the later OECD Productivity Manual (OECD 2001b), which notes that data quality is enhanced when output and input measures are based on the same statistical sources. From the perspective of productivity measurement, it is important that output is measured independently, but using the same statistical sources ensures consistency in measures. At the industry level, the manual finds that gross industry output, sectoral industry output (gross output less intrasectoral transfers), and industry value-added measures are all useful in productivity measurement. Sectoral and value-added measures converge at the aggregate level for the country as a whole. However, both maintain restrictive assumptions that are not imposed by the gross industry output measure.

Economic Research Service Current Practice

Output is measured as the sum of marketings at first assembly point, net inventory accumulation, and consumption by farm households, consistent with the concept of gross industry output. Prices received data are from NASS and reflect prices at the first point of assembly. The gross measure has become the standard now used by many government agencies when developing productivity accounts, but BLS continues to use the sectoral concept.

The most appropriate data available are generally used to construct the output series. Production and marketing data are collected by NASS through surveys of farms. Prices received data are collected by NASS from surveys of purchasers at the first point of assembly (e.g., packers, dealers, auction houses). Use of these data result in a stable product definition of output, that is, raw agricultural product measured at the sector border between agriculture and processing. Discontinuation of the NASS Farm Labor Survey has resulted in the discontinuation of the state-level accounts because other labor data of sufficient quality and breadth do not exist.

Net distorting payments (deficiency, diversion, loan deficiency, market gains, certificate gains, milk income loss payments) are added to individual commodity output prices, and distorting taxes (dairy assessment) are subtracted. Non-distorting flex payments are treated as transfer payments and not included in output price. Although potentially distorting, counter-cyclical payments are also ignored because the flex payment data are aggregated across outputs.

As recommended by the AAEA Task Force, the ERS has continued to use an index number approach and has switched from Laspeyres indexes for aggregation, to Tornqvist indexes that reflect weights in each year. The output side of the ERS account uses revenue shares of each item as a weight in computing Tornqvist price indexes, reflecting the underlying assumptions of the production possibility frontier model (Jorgenson, Ho, and Stiroh 2005). Implicit quantity indexes are computed by dividing total value or cost by the respective Tornqvist price index. This practice ensures there is no jump or drop in measured productivity due to a change in price-distorting government policy. The ERS has discontinued reporting partial productivity measures (such as labor productivity), and they do not develop productivity measures for individual farm outputs; rather, they use comparable definitions for cross-sectional comparisons.

In addition to reporting productivity account statistics, the ERS has given greater attention to explaining the construction of the statistics, analyzing the accounts, and exploring alternatives for improving them. However, while considerable attention has been given to measuring quality changes in inputs, quality changes in outputs has not been addressed in the productivity accounts.

Our Assessment

Own-account capital formation, whether building a house for a farm employee, accumulating inventories, investing in land improvements such as tiling, or spending on farmer safety, should conceptually be treated consistently on both sides of the account. For example, if the labor and intermediate materials used in tiling is on the input side of the account, the land improvement should be on the output side of the account. Alternatively, the input should be netted out of the input side of the account. The ERS includes imputed rental value of employer-provided housing and inventory accumulation and the value of feed sold and purchased as both input and output. Land improvements, however, are currently included only in the input quantity measure but not in output quantity. With recently discovered data, investment in land improvements will soon be incorporated into the ERS output measure.

Although the ERS accounts for most distorting government programs in commodity output prices, the distorting effects of crop insurance are not accounted for. With the subsidy, the effect of crop insurance is to increase the effective output price for the insured crop. By increasing effective price while simultaneously reducing risk, crop insurance can be expected to induce increases in both outputs and inputs. Under perfect foresight, the measured change in outputs less change in inputs reflects the change in productivity growth. Under decreasing returns to scale (and no change in technology) this would result in a decrease in productivity, but under constant returns to scale, as assumed in the national agricultural productivity accounts, the subsidy would have no effect on measured productivity. Consequently, it is possible it will not appreciably affect the productivity measures. What is clear, though, is that subsidized crop insurance increases the effective price of the insured crop in addition to reducing risk and is thus distorting. The subsidy augments market price and should be included in the calculation of the effective price received by farmers.

We concur with the way that the ERS uses market and distortion policy-adjusted commodity prices. Prices inclusive of distorting subsidies and exclusive of distorting taxes are used to aggregate across outputs. Market price (alternatively, opportunity cost) is used to value on-farm consumption because the policy distortions are not dependent on use of the output. The only issue is that the distorting effects of crop insurance discussed above should be reflected when aggregating across outputs.

The Divisia index is an exact aggregator for a linear homogeneous translog production function, so it has considerable appeal when production is well represented by the translog production function. The Tornqvist discrete approximation is used in implementation of the Divisia index. The Tornqvist index uses two-year rolling average revenue shares (expenditure shares for inputs) as the weights in computing geometric means of the individual commodity (input) data. This index, recommended by the AAEA Task Force and implemented by the ERS, is an important improvement over the Laspeyres index previously used, which uses base weights over extended time periods. However, it is not clear that the geometric mean is an improvement over the arithmetic mean calculation of the Laspeyres. That depends on the nature of the underlying functional form of U.S. agricultural production.

There has been little comparative research in the last few decades on the form of the agricultural production function. Research on dual models of agricultural production have generally found that the translog has not fared better than alternatives such as the quadratic or generalized Leontief (e.g., Perroni and Rutherford 1998; Anderson et al. 1996; Shumway and Lim 1993), both of which are better represented by an arithmetic mean than a geometric mean aggregator function. Further, empirical evidence of theoretical consistency and policy-relevant implications of the dual production models are both sensitive to choice of functional form (e.g., Baffes and Vasavada 1989).

The specification of functional form may also have implications for productivity measures, in particular when prices change substantially. While the Tornqvist can be supported as a valid aggregation scheme for productivity measurement, even if the translog fails to represent the technology as well as other functional forms, alternatives warrant consideration.[14] For example, the chained Fisher index is consistent for both extremes of substitutability, that is, linear and Leontief aggregator functions (Diewert 1976).[15]

State-level Productivity

During the 1990s and 2000s, the ERS prepared state-level productivity measures. They began with the year 1960 and ultimately included estimates through 2004. They also provided underlying price and quantity data series for outputs, inputs, and several disaggregated categories of each component. Since September 2013, the historical estimates have been publicly available on the ERS Agricultural Productivity in the U.S. website (USDA 2014). The productivity measures and the accompanying price and quantity series have been widely used by the research community. However, due to the loss of important data surveys, these productivity accounts are not currently being updated.

1980 AAEA Task Force Recommendation

The AAEA Task Force (Gardner et al. 1980) recommended that the ERS continue to develop regional total productivity measures.

Economic Research Service Response

The ERS responded to the AAEA Task Force recommendation by developing state-level productivity measures for the contiguous 48 states. These accounts have been used extensively in a wide variety of research studies and have been influential in policy analysis as well. The accounts constitute a high quality panel data set that facilitates econometric model estimation at the national level with greater precision than could be achieved with only the national-level accounts. The accounts also permit the examination of state and regional issues of importance to local legislators and producer groups.

Unfortunately, the productivity measures have not been updated since 2004, largely because the NASS Farm Labor Survey was discontinued, thus limiting the ERS's ability to develop spatially reliable measures of the labor input.

The state accounts posted on the website were developed using procedures generally similar to the national agricultural accounts. Our review of procedures will focus on those that differ from the development of the national accounts. For the national accounts, data on outputs, land input, capital stocks, and capital input are first compiled for each state before being aggregated to the national level. Other components of the national accounts are not developed first at the state level.

Data from the NASS surveys on output cash receipts, quantities marketed, gross production, and inventory change are compiled by commodity

[14] For example, differentiating the nominal accounting identity and grouping quantities gives a Tornqvist aggregate when the technology exhibits constant returns to scale.

[15] Recent work seeking to explain TFP growth in U.S. agriculture has been based on a variety of functional forms, including translog cost functions (Plastina and Fulginiti 2012; Wang et. al. 2012), normalized quadratic value functions (Onofri and Fulginiti 2008), and square-rooted quadratic output distance functions (Fulginiti 2010).

in each state before being aggregated to the national level. Data on government payments from the USDA Farm Service Agency's Kansas City office are also compiled by commodity in each state before being aggregated to the national level.

Spatial quality-adjusted price indexes and implicit quantity indexes of land are calculated using a hedonic approach to account for differences in land characteristics across states. The value of land per acre is estimated as a function of soil acidity, salinity, moisture stress, irrigation, population accessibility (population density and distance) and other characteristics, as well as state dummy variables. Implemented using county-level data, a quality-adjusted price index is computed from which county-level implicit quantities of land are obtained.

Tornqvist indexes of land prices and implicit quantities at the state level are obtained based on the county-level information. While the value of service flows at the national level is a residual from the imposition of constant returns to scale, the value of service flows at the state level are the state-level stocks multiplied by the rental rate for land. The rental rate is the expected real rate of return multiplied by the state's land price index. The expected real rate of return for land is an *ex ante* rate of return calculated in the same way as for non-land capital; it is the nominal average yield on investment grade corporate bonds (AAA rated bonds), less the inflation rate captured by the implicit GDP deflator, where inflation is modeled as an ARIMA process.

Measures of capital stocks and capital input are developed for each state. Capital stock for each asset type is constructed using the perpetual inventory method. User costs for each asset type are obtained following the same procedure as for the U.S. aggregate. Investment data is obtained from the ERS Resource and Rural Economics Division. The BLS asset price deflators from the Producer Price Index for automobiles, motor trucks, wheel-type farm tractors, and agricultural machinery excluding tractors are used as investment deflators. The implicit price deflator for nonresidential structures is from NIPA. Aggregation for each state is accomplished by aggregating over the different capital assets using the asset-specific user cost indexes as weights.

The ARMS provides expenditure data for intermediate inputs. For the state accounts, hedonic price functions of fertilizer and pesticides are estimated for individual states and the United States. These input groups and energy have been updated for the states through 2008. For the national accounts, the hedonic price functions are conducted at the national level rather than being aggregated across states. This could lead to some of the inconsistency between the state and national accounts discussed below. Data on purchased inputs and investment also come from ARMS.

Until 2002, the NASS Farm Labor Survey was used as the primary source of data on hired, self-employed, and family labor. This survey provided sufficient detail to reliably estimate state-level labor quantities and prices. The same type of matrices for hours worked and hourly compensation were developed for each state as for the United States, controlling for hours worked and compensation totals based on USDA data for the state. The farm sector matrices used for the U.S. aggregate were combined with state-specific demographic information available from the Census of Population following Jorgenson, Gollop, and Fraumeni (1987). Using the cross-classified data, indexes of labor input were constructed by state.

Since the NASS Farm Labor Survey was discontinued in 2002, an adequate source of information for updating the cells in the matrices has not been available. At the nationwide level for the United States, information is now obtained from the Current Population Survey, but sample size is too small to use this source to update matrix elements of the worker classification at the state level. The discontinuation of this survey played a major role in the decision to discontinue updating the state-level productivity accounts after 2004.

Hired labor data used in the national accounts now come from BEA. Self-employed labor data are from BLS and are based on the Census of Population and the Current Population Survey. Unfortunately, these sources do not provide sufficient detail to reliably estimate state-level labor quantities and prices via the cross-classification method. However, some alternatives could provide minimally sufficient reliability to surmount this obstacle. The BLS funds a survey of hired labor. If interagency access to the data can be obtained by ERS, it could provide a sufficient information base to compute state-level hired labor quantities and prices. The American Community Survey provides additional data that could be useful in combination with other sources. The ARMS data separate hours worked by hired and self-employed labor. While it will not be possible to develop state-level labor quantity and price series with the matrix element accuracy that is possible from the NASS Farm Labor Survey, sufficient data sources appear to be available to provide estimates of sufficient quality to enable the state-level productivity accounts to be reinstated.[16]

The ERS currently uses the multilateral chain-linked Caves-Christensen-Diewert index to construct state-level input and output price indexes in each state and year. This index solves the intransitivity problem of binary indexes, but O'Donnell (2013) documents that it does not satisfy the circularity property and is thus biased; he demonstrates that three alternative multilateral indexes (Lowe, geometric Young, and Färe-Primont) satisfy nine desirable properties, including transitivity and circularity.

Our Assessment

The lack of data of sufficient quality is most acute for labor because it hinders the development of reliable state-level labor price and quantity series. The loss of reliable farm labor data has been primarily responsible for discontinuing the widely used and important state-level price, quantity, and productivity series. This is a great hindrance to high quality research on the economics of U.S. agriculture, which is important for public and private decision making.

Our assessment, which is supported by input from several stakeholders, is that the state-level accounts are too important to be discontinued. They provide the foundation for the U.S. aggregate accounts and give more detail, consistency, and robustness to the U.S. aggregate. While U.S. aggregate accounts trace performance across time, they do not provide understanding of performance across space. The state-level series are essential to understand differences in regional performance driven by differences in endowments and comparative advantage across the U.S. regions. These

[16]As noted by an anonymous reviewer, sufficient labor data should be available to produce reliable state-level labor price and quantity indexes for at least the 15 ARMS detail states.

panel data are important in econometric analysis by achieving greater statistical efficiency and reliability, and they are widely used.[17]

Alternative spatial aggregation indexes that satisfy all nine desirable properties of spatial aggregation indexes, including identity, transitivity and circularity, warrant exploration.

The state-level price and quantity indexes have been developed using procedures generally consistent with those used to develop U.S. indexes (Ball et al. 1999). However, there are two important differences: (*a*) gross receipts equal gross expenditures in the U.S. series but not in the individual state series, nor in the sum of the state receipts and expenditures, and (*b*) the sum of gross state receipts (expenditures) is not equal to U.S. gross receipts (expenditures).

The first is due to imposing the assumption of constant returns to scale on the national production function but not on the state production functions. The second is partially explained by incorporating interstate deliveries of output from farms in one state to farms in another in the state accounts but not in the national account (Ball et al. 1999). This would imply that the U.S. gross output receipts and gross input expenditures should always be smaller than the sum of the corresponding state series. That is not the case in the online data series. In some years one or both is smaller and in other years larger. On average, U.S. input expenditures are smaller, but output receipts are larger. Consequently, greater consistency between the two series is needed, as well as a clearer explanation of reasons why they are not totally consistent.

Data Availability and Website

Timeliness, transparency, and public access to the agricultural productivity series at each stage in the development of the aggregate output and input series is vital, both because of its value for analysis and policy purposes, and because it invites research and exploration on ways to more accurately develop the productivity accounts.

1980 AAEA Task Force Recommendation

The AAEA Task Force (Gardner et al. 1980) recommended that the productivity statistics be made readily available in electronic form.

Economic Research Service Current Practice

The above recommendation has been fully accomplished: all data are maintained electronically. Aggregates and sub-aggregates are publicly available and accessible from their website. Details about individual commodities and inputs are generally available on request.

The ERS Agricultural Productivity in the U.S. website (USDA 2014) is the primary vehicle for disseminating ERS productivity-related products, including the data, results, methodology, and related research. The website includes downloadable Excel files with productivity measures and quantity and price indexes for the United States and for each of the contiguous 48 states.

For the United States, the website includes (*a*) productivity measures for several time periods, sources of growth (output and input with input

[17] *For example, a Google search of Ball's productivity research yielded 80 publications, the 4th most highly cited of which was Ball et al. (1999), which developed and explained the state-level quantity and price series developed by ERS for TFP analysis.*

decomposed into labor, capital, and materials and further decomposed into quantity and "quality" growth), and (*b*) annual price and quantity indexes for the output and input aggregates, as well as several output and input sub-aggregates.[18]

The sub-aggregates are tiered. There are three sub-aggregates in the first output tier: livestock, crops, and farm-related output.[19] In the second tier, livestock is disaggregated into meat animals, dairy, and poultry and eggs; crops are disaggregated into food grains, feed crops, oil crops, vegetables and melons, fruits and nuts, and other crops.[20]

The first input tier consists of three sub-aggregates: capital, labor, and intermediate inputs. In the second tier, capital is disaggregated into durable equipment, service buildings, land, and inventories; labor is disaggregated into hired and self-employed labor; intermediate inputs are disaggregated into farm-origin, energy, fertilizer and lime, pesticides, purchased services, and other intermediate inputs.

The U.S. indexes have been published on the website for several years. As of December 2015, they were provided for the years 1948–2013. They are currently updated every other year.

State-level productivity, price, and quantity estimates that cover 1960–2004 have been available for nearly a decade, but were first published on the ERS website in September 2013. As with the U.S. aggregate information, they include productivity measures for several time periods, and annual price and quantity indexes for the output and input aggregates, as well as several output and input sub-aggregates. The output price and quantity sub-aggregates are the same as the first tier of U.S. sub-aggregates—livestock, crops, and farm-related output. The input price and quantity sub-aggregates have two full tiers and a third, partial tier. The first input tier is the same as for the United States—capital, labor, and intermediate inputs. In the second tier, capital is disaggregated into land and capital services excluding land; labor is disaggregated into hired and self-employed labor; intermediate inputs are disaggregated into energy, chemical inputs, and other intermediate inputs. In the third partial tier, chemical inputs are disaggregated into fertilizer and lime, and pesticides.

The availability of productivity data on the website is a substantial improvement in making the agricultural productivity accounts and major quantity and price indexes used in their development publicly available.

The Agricultural Productivity homepage is accessible via the ERS homepage (http://www.ers.usda.gov/) under "Topics->Farm Economy-> Agricultural Productivity". It includes a brief overview of the program with appropriate program contacts clearly posted at the bottom of the page. The core U.S. and state-level accounts data and methodology page (Agricultural Productivity in the U.S.) is accessible from the Agricultural Productivity homepage under the "Related Data" links.

In addition, there is a link for "International Agricultural Productivity". This webpage contains international data and productivity estimates for 174

[18] *The ERS definition of quality in table 2 is the difference between weighting schemes in input aggregation. Some others developing productivity estimates refer to this as "composition".*

[19] *The farm-related output also includes output of goods and services from certain non-agricultural or secondary activities closely related to agricultural production and for which output and input information cannot be separated from agricultural production.*

[20] *Other crops include sugar crops, maple, seed crops, miscellaneous field crops, hops, mint, greenhouse and nursery, and mushrooms.*

countries for the period 1961–2010 and a documentation and methods section. Country-level productivity estimates, gross agricultural production, and factor shares and quantities of inputs and regional-level productivity estimates are included in the downloadable data spreadsheets.

Our Assessment

The creation of the Agricultural Productivity in the U.S. website is a valuable contribution to the user community. This website makes productivity assessments and core data series publicly and immediately available. However, they are not updated in a timely way. The U.S. agricultural productivity series are currently updated every other year. Prior to the most recent update, they were three years out of date. The posted state-level agricultural series extends only through 2004. The productivity accounts and associated data have too much value not to be updated in a more timely fashion.

Basic documentation is available on the website and is accessible, although the review committee found that many important details are missing. In particular, details about the source data and current methodology is thin. The committee struggled with the available documentation to understand how current estimates were built up from the available source data. It is imperative that more details of the accounts and their sub-aggregate components be posted to the website. The desired goal would be to provide sufficient detail to enable outside users to replicate the results from the underlying source data and to use the source data for additional purposes.

The Agricultural Productivity homepage gives a brief overview of farm productivity, but does not put the program in context of the USDA mission, nor does it couch agricultural productivity statistics within the larger context of industry-level productivity analysis. The ERS should consider including this information in some form on its website.

Other Important Issues

Additional attention is given in the committee's full online report (Shumway et al. 2014) to several other important issues. These include quality adjustments (particularly of seeds and outputs), choice of residual claimant (producer-provided inputs) to clear the accounts, accounting for research and development conducted within the agricultural sector, cross-country comparisons, and alternative assumptions and methods for computing the productivity accounts.

Conclusions

The ERS has emerged as an acknowledged intellectual leader in the construction and integration of national and state-level productivity accounts in agriculture. The national ERS productivity measures are widely referred to and used, and international sectoral comparisons rely on the ERS production accounts for foundation methodology in constructing agricultural productivity accounts in other countries.

This leadership role has endured for many decades and accelerated in response to the AAEA Task Force review of the agricultural productivity accounts (Gardner et al. 1980). Procedures used to construct the productivity accounts underwent a major overhaul following that review, and the bulk of the AAEA Task Force recommendations were implemented by the mid-1980s. Despite limited personnel and resources, a vigorous research program was initiated and has continued over more than three decades to examine additional ways to improve the sectoral productivity accounts and to extend their reach and value.

It is against that backdrop of vigorous intellectual leadership that the external review committee has examined the data sources, methodology, ongoing research, documentation, and reporting of the agricultural productivity accounts. Our recommendations are many and some are substantial. In order to guide implementation of the recommendations, we grouped them into four levels of priority based on our collective perception of their importance relative to the cost (in intellectual difficulty, time, and resources) of implementation. We conclude with the 22 recommendations in the top two priority levels. The full set of 57 prioritized recommendations is available in the online report (Shumway et al. 2014).

Priority 1 Recommendations

Overarching

(1) Fully document and keep current all procedures followed, from data sources through measurement of productivity change, to enable a non-expert to reproduce the accounts.
(2) Cooperate with other agencies to reduce duplication, achieve consistency across statistical series, obtain information at the lowest cost, and capitalize on research and expertise.

Website

(1) Provide detailed documentation online and note ad hoc adjustments to data or deviations from the general procedure (e.g., if fixes were required due to negative implied capital rental rates).
(2) Expand the website to provide timely access to more detailed data and procedural detail underlying the quantity and price aggregate and sub-aggregate national and state-level statistics.

State-level

(1) Continue to develop and publish the state-level total productivity measures as well as price and quantity series.
(2) Cooperate with other governmental agencies to achieve the lowest-cost method of collecting data of sufficient quality to enable the state-level accounts to be extended and maintained.
(3) Investigate the possibility of using information in the American Community Survey to update matrix elements in the state labor accounts.
(4) Ensure consistency between the national and state accounts where possible, and explain circumstances that prevent total consistency where it is not possible.

Priority 2 Recommendations

Labor

(1) Investigate the reasons for differences in the labor input calculations from those of Jorgenson, Ho, and Samuels (2014).

(2) Investigate the American Community Survey as an alternative, possibly complementary, data source, potentially in collaboration with BEA/BLS.

Non-land Capital

(1) Examine non-land capital nominal investment data in consultation with BEA researchers.
(2) Consider using one or more asset deflators in the calculation of expected inflation.
(3) Review investment deflators to determine if sources have been updated or revised since the data was last collected.
(4) Review average service lives of assets with BEA and BLS to determine if revisions should be made.
(5) Investigate whether the indexes of capital service flows during the 1975–1984 period reflect actual changes in capital service use rather than changes in the behavior of the bonds rate used in calculating the user cost of capital.

Land

(1) Explore ways to include within-county land-type adjustments, as well as quality changes given by, for example, irrigation or other improvements in farmland.
(2) Consistent with the recommendation for non-land capital, replace the GDP deflator used to capture general effects of inflation with a price index for land.

Outputs

(1) To account for the distorting effect of crop insurance when outputs are aggregated, add the insurance indemnity to the insured crop's price and deduct the farmer's premium.
(2) Revisit measurement issues related to own-account capital formation, specifically consistency between the output and input sides of the account.

Quality Adjustments

(1) Explore methods for incorporating quality adjustments to seeds and consider whether seed quality change should be treated solely as an input, or both an output and an input.

Cross-country comparisons

(1) Clarify that ERS cross-country comparisons are really research work, and establish whether they are an integral part of the ERS agenda.

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References

Anderson, D.P., T. Chaisantikulawat, A.T.K. Guan, M. Kebbeh, N. Lin, and C.R. Shumway. 1996. Choice of Functional Form for Agricultural Production Analysis. *Review of Agricultural Economics* 18 (2): 223–31.

Australian Bureau of Statistics. 2013. Australian System of National Accounts: Concepts, Sources and Methods. 5216.0. Australia.

Baffes, J., and U. Vasavada. 1989. On the Choice Of Functional Forms in Agricultural Production Analysis. *Applied Economics* 21 (8): 1053–61.

Ball, V.E. 1985. Output, Input, and Productivity Measurement in U.S. Agriculture 1948–79. *American Journal of Agricultural Economics* 67 (3): 475–86.

——. 2014a. Personal Communication to the ERS Agricultural Productivity Account Review Committee, March 14.

——. 2014b. Review Panel Capital. Personal Communication to the ERS Agricultural Productivity Account Review Committee, March 24.

Ball, V.E., J.C. Bureau, R. Nehring, and A. Somwaru. 1997. Agricultural Productivity Revisited. *American Journal of Agricultural Economics* 79 (4): 1045–63.

Ball, V.E., F.M. Gollop, A. Kelly-Hawke, and G.P. Swinand. 1999. Patterns of State Productivity Growth in the U.S. Farm Sector: Linking State and Aggregate Models. *American Journal of Agricultural Economics* 81 (1): 164–79.

Ball, V.E., C. Hallahan, and R. Nehring. 2004. Convergence of Productivity: An Analysis of the Catch-up Hypothesis within a Panel of States. *American Journal of Agricultural Economics* 86 (5): 1315–21.

Ball, V.E., and M.J. Harper. 1990. *Neoclassical Capital Measures Using Vintage Data: An Application to Breeding Livestock*. Washington DC: U.S. Department of Agriculture, Economic Research Service.

Ball, V.E., W. Lindamood, R. Nehring, and C.S.J. Mesonada. 2008. Capital as a Factor of Production in OECD Agriculture: Measurement and Data. *Applied Economics* 40 (10): 1253–77.

Coen, R. 1975. Investment Behavior, the Measurement of Depreciation, and Tax Policy. *American Economic Review* 65 (March): 59–74.

Diewert, W.E. 1976. Exact and Superlative Index Numbers. *Journal of Econometrics* 4 (2): 115–45.

Eurostat. 2000. *Manual on the Economic Accounts for Agriculture and Forestry EAA/EAF (Rev. 1.1)*. Luxembourg: Office for Official Publications of the European Communities. Available at: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-27-00-782/EN/KS-27-00-782-EN.PDF (accessed 29 December 2015).

Fernandez-Cornejo, J., and S. Jans. 1995. Quality-adjusted Price and Quantity Indices for Pesticides. *American Journal of Agricultural Economics* 77 (3): 645–59.

Fernandez-Cornejo, J., R. Nehring, C. Osteen, S.J. Wechsler, A. Martin, and A. Vialou. 2014. *Pesticide Use in U.S. Agriculture: 21 Selected Crops, 1960–2008*. Washington DC: U.S. Department of Agriculture, Economic Research Service, Economic Information Bulletin No. 124.

Fulginiti, L.E. 2010. Estimating Griliches'k-Shifts. *American Journal of Agricultural Economics* 92 (1): 86–101.

Gardner, B., D. Durost, W. Lin, Y-C. Lu, G. Nelson, and N. Whittlesey. 1980. *Measurement of U.S. Agricultural Productivity: A Review of Current Statistics and Proposals for Change*. Washington DC: U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, Technical Bulletin No. 1614.

Harper, M.J. 1982. *The Measurement of Productive Capital Stock, Capital Wealth, and Capital Services*. Vol. 128. Washington DC: U.S. Bureau of Labor Statistics.

——. 1999. Estimating Capital Inputs for Productivity Measurement: An Overview of U.S. Concepts and Methods. *International Statistical Review* 67 (3): 327–37.

Ho, M.S., D.W. Jorgenson, and K.J. Stiroh. 1999. U.S. High-tech Investment and the Pervasive Slowdown in the Growth of Capital Services. Unpublished manuscript, Kennedy School of Government, Harvard University, September.

Jorgenson, D.W., F.M. Gollop, and B.M. Fraumeni. 1987. *Productivity and U.S. Economic Growth*. Boston, MA: Harvard University Press.

Jorgenson, D.W., M.S. Ho, and J.D. Samuels. 2014. What Will Revive U.S. Economic Growth? Lessons from a Prototype Industry-level Production Account for the United States. *Journal of Policy Modeling* 36 (4): 674–91.

Jorgenson, D.W., M.S. Ho, and K.J. Stiroh. 2005. *Productivity, Volume 3: Information Technology and the American Growth Resurgence*. Boston, MA: MIT Press Books 3.

O'Donnell, C. 2013. Alternative Indexes for Multiple Comparisons of Quantities and Prices. Working Paper WP05/2012 (Version 21, May), Centre for Efficiency and Productivity Analysis, University of Queensland. Available at: http://www.uq.edu.au/economics/cepa/docs/WP/WP052012.pdf (accessed 29 December 2015).

Onofri, A., and L.E. Fulginiti. 2008. Public Inputs and Dynamic Producer Behavior: Endogenous Growth in U.S. Agriculture. *Journal of Productivity Analysis* 30 (1): 13–28.

Organisation for Economic Co-operation and Development. 2001a. *Measuring Capital, Capital Stocks, Consumption of Fixed Capital, and Capital Services*. OECD Manual, Paris.

——. 2001b. *Measuring Productivity, Measurement of Aggregate and Industry-level Productivity Growth*. OECD Manual, Paris.

——. 2009. *Measuring Capital*. OECD Manual, Paris.

Pardey, P., M. Andersen, B. Craig, and A. Acquaye. 2006. U.S. Agricultural Input, Output and Productivity Series, 1949–2002, Version 4, InSTePP series. Available at: http://www.instepp.umn.edu/products/instepp-primary-data-documentation-us-agricultural-input-output-and-productivity-series (accessed 29 December 2015).

Plastina, A., and L. Fulginiti. 2012. Rates of Return to Public Agricultural Research in 48 U.S. States. *Journal of Productivity Analysis* 37 (2): 95–113.

Shumway, C.R., B.M. Fraumeni, L.E. Fulginiti, J.D. Samuels, and S.E. Stefanou. 2014. Measurement of Agricultural Productivity: A 2014 Review of Current Statistics and Proposals for Change. Report of the Agricultural Productivity Review Committee to the USDA Economic Research Service. Reproduced as School of Economic Sciences Working Paper 2015–12, Washington State University. Available at: http://ses.wsu.edu/wp-content/uploads/2015/06/WP2015-12.pdf (accessed 29 December 2015).

Shumway, C.R., and H. Lim. 1993. Functional Form and U.S. Agricultural Production Elasticities. *Journal of Agricultural and Resource Economics* 18 (2): 266–76.

Sliker, B. 2014a. Email Exchange with V. Eldon Ball, March 19–April 14; Personal communication to the ERS Productivity Account Review Committee, April 14.

——. 2014b. Individual and Cohort Capital from the Point of View of the Primal. Personal communication to the ERS Agricultural Productivity Account Review Committee, April 16, revised June 18.

Soloveichik, R. 2014. Comment on the ERS's Total Factor Productivity Research. Personal communication to the ERS Agricultural Productivity Account Review Committee, July 30.

United Nations. 2009. 2008 System of National Accounts. Available at: http://unstats.un.org/unsd/nationalaccount/sna2008.asp (accessed 29 December 2015).

U.S. Department of Agriculture, Economic Research Service. 2014. Agricultural Productivity in the U.S. Available at: http://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us.aspx (accessed 29 December 2015).

U.S. Department of Agriculture, National Agricultural Statistical Service. 2011. Price Program: History, Concepts, Methodology, Analysis, Estimates and Dissemination. Available at: http://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Prices/Chapter%20One%20Overview%20v10.pdf (accessed 29 December 2015).

U.S. Department of Commerce. 2013. BEA Depreciation Estimates. Bureau of Economic Analysis. Available at: http://www.bea.gov/national/pdf/fixed%20assets/BEA_depreciation_2013.pdf (accessed 29 December 2015).

U.S. Department of Labor. 1983. *Trends in Multifactor Productivity, 1948–81*. Washington DC: Bureau of Labor Statistics, Bulletin 2178.

Van Ark, B., M. O'Mahony, and G. Ypma. 2007. The EU KLEMS Productivity Report. An Overview of Results from the EU KLEMS Growth and Productivity Accounts for the European Union, EU Member States and Major Other Countries in the World, March. Available at: http://www.euklems.net/data/eu_klems_productivity_report1.pdf (accessed 29 December 2015).

Wang, S.L. 2013. Labor Measurement in USDA Productivity Accounts. Personal communication to the ERS Agricultural Productivity Account Review Committee, September 30.

Wang, S.L., V.E. Ball, L.E. Fulginiti, and A. Plastina. 2012. Accounting for the Impacts of Public Research, R&D Spill-ins, Extension, and Roads. In *U.S. Regional Agricultural Productivity Growth, 1980–2004*, Chapter 2, ed. K. Fuglie, V.E. Ball, and S.L. Wang. Cambridge, MA: CAB International.