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A COMPARISON OF MULTIFACTOR PRODUCTIVITY CALCULATIONS OF THE U.S. AGRICULTURAL SECTOR

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A Comparison of Multifactor Productivity Calculations of the U.S. Agricultural Sector*

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The purpose of this paper is to review the studies that have estimated multifactor productivity of the U.S. agricultural sector. Accounting for productivity growth has been increasingly important to economists ever since Robert Solow published his famous article on the U.S. aggregate growth model (Solow, 1957). At the aggregate level, productivity growth is viewed by economists as the key to raising living standards and being competitive with other countries (greater quantity, better quality goods and services are produced at lower prices for consumers). At the sectoral level, economists have been interested in comparing the productivity performances of different sectors to see which industries are growing fastest or slowest. Table 1 below shows 9 different estimates of U.S. agricultural productivity. If consensus is a guide, it would appear that the U.S. agricultural sector productivity has grown at about 1.5 to 1.9 percent per year over the last 30 to 40 years. As this paper will show, the several estimates are remarkably similar, given the methodological differences. In this paper, we will assess which methodologies we think are most appropriate and thus yield the most reliable results.

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Table 1 - Comparisons of multifactor productivity calculations for the U.S. agricultural sector

Economists	Time period	Growth rate (Pct./year)
Axiomatic (index) approach		
Brown (1978)	1947-1974	1.42[1]
Kendrick (1983)	1948-1979	3.50
Ball (1984)	1948-1979	1.75
Capalbo-Vo (1988)	1950-1983	1.22
Cox-Chavas (1990)	1950-1983	1.89[1]
USDA/ERS (1991)	1948-1989	1.58[1]
USDL/BLS (1992)	1948-1990	3.06[1]
Parametric approach		
Capalbo (1988)	1950-1983	1.4 - 1.6[2]
Jorgenson (1990)	1948-1979	1.61

[1] Calculated by the author from published (except USDL/BLS) multifactor productivity indices using the regression formula, $\ln(Y) = \beta_0 + \beta_1(T)$.
[2] Reflects Capalbo's preferred confidence interval at the 95 percent level.

In the preceding paragraph, we deliberately used the term "productivity" very loosely. Economists make the distinction between "partial" and "total-" or "multi-factor" productivity. Partial productivity refers to the growth rate of the ratio of total output relative to a single factor input (e.g., land, labor, or capital). Total- or multi-factor productivity (TFP or MFP) refers to the growth rate of the ratio of output relative to "total" or "multiple" inputs.[1] MFP is considered superior to partial productivity measurements because it does not lend itself as easily to misinterpretation. For example, when one compares labor productivity and MFP of U.S. agriculture on a chart (see USDA, 1980, p. 3), one immediately notices how much more rapidly labor productivity has grown relative to MFP; this phenomenon can be attributed to the substitution of capital for labor associated with increased mechanization.

[1] Some economists have recently argued that is doubtful that one can empirically measure "all" inputs; thus they prefer the term "multi-factor" productivity, or MFP. Jorgenson informed us that he prefers to use the simple term "productivity" as representing the state of the art research. We use the term "MFP" throughout the remainder of this paper.

In general, MFP is calculated as the "unexplained residual" or difference between measured outputs and inputs for any two periods. That is, suppose one is given the production function,

$$Y(t) = A(t)F[K(t), L(t)]$$

Assuming constant returns to scale and that factors are paid their marginal products (share S_i), then taking logarithms, differentiating with respect to time, and solving for A yields,

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - s_K\frac{\dot{K}}{K} - s_L\frac{\dot{L}}{L} \qquad (1)$$

Solow argued that the residual, A/A, represented "technical change." Both Denison and Jorgenson-Griliches followed up on Solow's original growth accounting work. Jorgenson-Griliches thought that labeling the residual as technical change was misleading, didn't provide much useful information, and in fact could be explained away by more accurate (quality-adjusted) measurements of labor and capital (i.e., MFP=0%). Denison and Jorgenson-Griliches disagreed sharply over this latter point. Jorgenson-Griliches were able to reduce the residual substantially but not completely. The issue was left unresolved as to whether the residual was an unavoidable data issue or a valid conceptual issue of technical change.[2]

Although Jorgenson-Griliches did not succeed in their efforts to explain away MFP for the U.S. economy, Griliches applied this same philisophical approach at the sectoral

[2] Jorgenson-Griliches wrote, "While better data may decrease further the role of total factor productivity in accounting for the observed growth in output, they are unlikely to eliminate it entirely." To this comment, Denison replied, "Better data may always raise or lower an estimate. But this sentence implies an undocumented belief that they would probably *reduce* the estimated growth in total factor productivity... The idea that productivity may not have changed at all is as farfetched as ever." (Brookings, 1972, pp. 89, 95).

level for the U.S. agriculture (Griliches 1960, 1963). Since then, economists have been trying to refine the methodology by which agricultural productivity should be calculated. This paper will show that the debate over how best to do this has intensified in the last decade or so.

As many economists have pointed out, the U.S. Department of Agriculture's Economic Research Service (ERS) began publishing MFP statistics in 1960; up until 1983, ERS was the only government agency to produce MFP statistics. The U.S. Department of Labor's Bureau of Labor Statistics (BLS) began publishing multifactor productivity statistics in 1983 (Mark-Waldorf, 1983). Teigen et al. have pointed out that the ERS productivity calculations can be traced to the career work of Glen T. Barton (Teigen et al., p. 2).[3] Barton and Cooper first published MFP statistics for U.S. agriculture in 1948 (Barton-Cooper, 1948); 12 years later, Barton and Loomis published the ERS Technical Bulletin, Productivity of Agriculture, United States, 1870-1958 (Barton-Loomis, 1960). While ERS was praised for taking the lead in calculating MFP statistics, it was criticized from the beginning by Griliches. ERS was later criticized by Christensen (1975), the National Academy of Sciences (NAS, 1975), the American Agricultural Economics Association Task Force (USDA, 1980), and Shumway (1988). V. Eldon Ball has been widely recognized and praised in recent years for his research and leadership in helping ERS address these criticisms and change the way it calculates MFP (see USDA, 1991). We will frequently refer to the AAEA Task Force report throughout

[3] Outside of ERS, similar work was done to measure MFP for the agricultural sector at about the same period. Schultz (1953), using ERS data, devoted a chapter to this topic in his book, The Economic Organization of Agriculture. Johnson (1950) also estimated MFP for the U.S. agricultural sector and showed that 75 percent of increased output was attributable to increased inputs. Ruttan (1954) used an axiomatic (index number) methodology to estimate productivity growth for the U.S. meatpacking industry and found that inputs requirements fell by about 25 percent over the 1919-1947 period. He adopted the Johnson production function methodology in developing a "consistency model" to project the impact on resource requirements of alternative rates of productivity growth for the period 1950-1975 (Ruttan, 1956) and an estimate of regional productivity growth (Stout and Ruttan, 1957).

the remainder of this paper, since it gave the most thorough critique of ERS' methodologies and provides a good standard against which to evaluate the recent changes in ERS' methodology as well as a standard to evaluate the other economists' independent calculations.

Methodology

There have been 2 approaches to measuring MFP: the axiomatic (index) approach and the parametric (production function) approach. Of the 9 studies shown in Table 1 earlier, 7 have used some version of the axiomatic approach, while 2 have used the parametric approach. Diewert (1976) has shown that many of the indices are really "exact" counterparts for particular production functions (explained below).

Axiomatic approach

In the axiomatic approach, MFP is calculated as the difference between the weighted sum of output indices minus the weighted sum of input indices. Because the indices are summed and determine the aggregate rates of growth, they are sometimes referred to as "aggregator functions."[4] How the weights are derived, and how often they are updated, is a critical part of this approach. One must take into consideration the statistical and economic properties when constructing the indices.

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[4] Some of the indices examined below are aggregated arithmetically or geometrically, which are consistent with linear or Cobb-Douglas production functions.

There are many index forms, dating as far back to Fisher's work on index numbers (Fisher, 1922). Three of the more commonly used quantity indices are the Laspeyres, Paasche, and Fisher-ideal indices (comparison period is subscripted by "T"):[5]

$$\textit{Laspeyres:}\quad \frac{\sum P_0 * X_T}{\sum P_0 * X_0} * 100 \qquad \textit{(base year prices)}\ (2)$$

$$\textit{Paasche:}\quad \frac{\sum P_T * X_T}{\sum P_T * X_0} * 100 \qquad \textit{(current year prices)}\ (3)$$

$$\textit{Fisher-ideal:}\quad [\textit{Laspeyres} + \textit{Paasche}]^{1/2} * 100$$

$$= [\frac{\sum P_0 * X_T}{\sum P_0 * X_0} + \frac{\sum P_T * X_T}{\sum P_T * X_0}]^{1/2} * 100 \qquad \textit{(weighted average)}\ (4)$$

Diewert, expanding upon the work of Fisher, has devised 22 tests to determine which indices have the least biases from a purely statistical point of view (see tests in Capalbo et al., 1991, pp. 17-18). For example, both the Laspeyres and Paasche indices violate the time-, price-, and quantity-reversal tests (Capalbo et al., p. 48).[6] From an economic point of view, both the Laspeyres and Paasche indices have interpretive shortcomings (in

[5] Price indices can be obtained for these indices by interchanging the P's for the X's, leaving the subscripts unchanged.

[6] Statistically, one does not obtain the same growth rates when reversing some of these parameters, indicating bias. Diewert favors the use of the Fisher-ideal index because it fails the fewest number of the statistical tests. However, the AAEA Task Force rejected the use of the Fisher-ideal index, arguing that it simply averages two oppositely biased indices (Laspeyres and Paasche) and doesn't necessarily accurately measure technical change (USDA, 1980, p. 7). Ruttan (1954) demonstrated that the Laspeyres and Paasche indices represent the lower and upper bias boundaries of technological change, respectively.

addition to implicit production function assumption shortcomings, discussed latter). For example, if there is a movement along an isoquant due to a relative change in input prices (shift in the budget constraint; that is, no technological change), the Laspeyres (base period price) index will suggest technological regression (same output, *more* input), whereas the Paasche (current period price) index will suggest technological progression (same output, *less* input).

Richter attempted to address these kinds of interpretative shortcomings with indices by explicitly defining the properties of the Invariance Axiom (Richter, 1966). The Invariance Axiom states in essence that an accurate index does not change when there is only a movement along a production transformation surface or an isoquant. Richter showed that the Divisia index is a unique index that satisfies all of the tests of the Invariance Axiom.[7] As a continuous time index, it has been approximated in many different ways. In continuous time, the Divisia index is

$$MFP_T = MFP_0 * [\exp \int \frac{P * \Delta X}{P * X} dt] \qquad (5)$$

The commonly used Tornqvist-Theil discrete approximation of the Divisia index (recommended by Jorgenson-Griliches, for example, [Brookings, 1972]) for two consecutive periods is,

$$MFP = Y - X = \ln (\frac{MFP_T}{MFP_0})$$

$$= [\frac{1}{2} \sum (R_T + R_0) * \ln (\frac{Y_T}{Y_0})] - [\frac{1}{2} \sum (S_T + S_0) * \ln (\frac{X_T}{X_0})] \qquad (6)$$

[7] Hulten corrected Richter over the issue of whether the Divisia index is both path invariant *and* independent. Richter argued that it was not, but Hulten demonstrated the conditions under which it was (Hulten, 1973).

where R_i and S_i represent revenue and cost shares, respectively.

A nice feature of the Tornqvist-Theil index is that it is a chained index; that is, it measures year-to-year changes. This is in contrast to the Laspeyres index (for example), which measures current year changes against a base period. The more time that is between the current period and the base period in the Laspeyres index, the more likely the measurement biases are to be.[8] In practice, calculating the Laspeyres weights relatively frequently yields similar results as the Tornqvist-Theil index.[9] For these reasons, the AAEA Task Force strongly recommended that ERS use Divisia (Tornqvist-Theil) indices, or at the very least, change its Laspeyres weights more frequently.

Diewert has shown that many of the indices implicitly relate to production function forms (Diewert, 1976). Diewert called indices that are consistent with specific production functions "exact," while he called indices that are consistent with "flexible" production functions "superlative." The Laspeyres and Paasche indices were shown to be consistent with linear or fixed-coefficient (Leontiff) production functions that have elasticities of substitution that are infinite (perfect substitution possibilities) or that are zero (no substitution possibilities). These production functional forms and their elasticities of substitution were considered inflexible, and hence undesirable.[10] The Tornqvist-Theil index was shown to be "exact" for a homogenous translog production function, which is a second-order approximation to any production function. Since the

[8] Ruttan (1956) has shown that if the base period is not in competitive industry equilibrium, the indices will be biased in the first place. The AAEA Task Force demonstrated how awkward "splicing" the weights can be between 2 periods when the weights have changed considerably (see USDA, 1980, pp. 7-8).

[9] We are grateful to Michael Denny for emphasizing the point that in practice, having frequently updated weights is much more important than using a particular index. However, this can be expensive to government agencies that collect the data.

[10] Despite these advances in production theory, it wasn't until 1991 that ERS finally switched from Laspeyres to Tornqvist-Theil indices (USDA, 1991). It appears that the reluctance to change the weighting system was a budgetary matter (Teigen et al., 1982).

translog production function is considered a flexible production function, Diewert called the Tornqvist-Theil index a "superlative" index.

Chavas-Cox use a relatively new variation of the index approach to measuring MFP (Cox-Chavas, 1990). They use a linear programming approach to calculate a year-to-year factor-augmenting technical change index (as suggested by Varian, 1984). Suppose producers maximize the indirect profit functional form,

$$Max\ [py(Y,A) - r'x(X,B)]$$

where A and B are technological change parameters. Expanding this functional form to test for year-to-year changes gives yields,

$$P_t[y_t - A_t - y_s + A_s] - r'[x_t + B_t - x_s - B_s]$$

When $A_s = A_t$ and $B_s = B_t$, then there is no technological change; when $A_s \neq A_t$ and $B_s = B_t$, then there is Hick's neutral technological change; and when $A_s \neq A_t$ and $B_s \neq B_t$, then there is biased technological change. The aggregate MFP index was calculated taking into account these factor-augmenting technological changes with the equation,

$$\frac{A_s - A_{1977}}{y_{1977}} + 1$$

The advantage of this approach is that it allows year-to-year non-neutral input changes that may move in opposite directions at times[11]--unlike the flexible production functional forms that statistically estimate constant (parameterized) biases over the sample period.

[11] For example, Cox-Chavas found family labor to be negative augmenting in 1953 and 1954, but positive augmenting in 1956 and 1960 and neutral at the other times.

Parametric approach

Two of the studies have used the production function approach explicitly, namely with the translog production function. The primal translog production function is given by

$$\ln Y = \ln \alpha_0 + b\,T + \sum \alpha_i \ln X_i + \frac{1}{2} \sum \sum \alpha_{ij} \ln X_i * \ln X_j \qquad (7)$$

This function is flexible, in that it doesn't impose any restrictions *a priori* on the elasticities of substitution (but if α_{ij} are all zero, then this reduces to the Cobb-Douglas production function). Traditionally the α_0 parameter has been interpreted as "technical change" in competitive equilibrium in the primal approach.

The dual (profit, revenue, and cost) translog production functions are more involved theoretically than the primal translog production function. Duality theory is attractive to users because of the fact that if one assumes that producers maximize profits (maximize marginal revenue and minimize marginal costs), then one can conveniently, but indirectly estimate the underlying production structure from observed outputs, prices and costs.

Suppose one is given the single output, multiple input cost function,[12]

$$C = C(Y,W,t)$$

Differentiating this equation with respect to time yields,

$$\frac{d \ln C}{dt} = \sum \frac{\partial \ln C}{\partial \ln W} * \frac{d \ln W}{dt} + \frac{\partial \ln C}{\partial \ln Y} * \frac{d \ln Y}{dt} + \frac{\partial \ln C}{\partial t} \qquad (8)$$

Noting the cost factor share,

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[12] The following section on cost functions borrows from Antle-Capalbo (1988), pp. 35-36.

$$S_i = \frac{\partial C}{\partial W_i}$$

and rearranging equation (8) yields the dual rate of technological change:

$$-\frac{\partial C}{\partial t} = \sum S_i * \frac{d \ln W_i}{dt} + \frac{\partial \ln C}{\partial \ln Y} * \frac{d \ln Y}{dt} - \frac{d \ln C}{dt} \qquad (9)$$

Equation 9 is referred to as the rate of cost diminution in duality theory and takes into account the scale effect. Antle-Capalbo show that the primal and dual rate of technological change are the same if and only if there are constant returns to scale,

$$\frac{\partial \ln C}{\partial \ln Y} = 1$$

Axiomatic and Parametric Approaches Compared

The choice of using the axiomatic approach versus the parametric approach depends on the modeler's purposes. Some of the advantages of using the parametric approach (for example, using the translog production function) include not requiring the assumptions of neutral technical change or constant returns to scale. One can also estimate productivity with confidence intervals. Some of the disadvantages include dealing with general econometric estimation problems, particularly nonrobust estimators and declining degrees of freedom. If one creates subaggregate inputs to address the degrees of freedom issue, then one must make the assumption of input separability. Also, competitive pricing and efficient resource utilization must be assumed. An advantage of the axiomatic approach is that the weights change (in constrast to estimated production function, where the estimators do not change for a specified time period). Since the axiomatic approach is also theoretically consistent with flexible production functions and avoids the problems of production functions, some economists prefer to use indices.[13]

Specification Issues

Specification of the explicit or implicit production function outputs and inputs is a critical aspect of the differences between the studies reviewed in this paper. There are 2 approaches to specifying sectoral production functions: the net (value-added) approach and the gross approach. The net approach has been adopted in order to be consistent with aggregate income accounting procedures, where one is only interested in the value-added originating from within the sector to the economy when aggregating (avoids double counting of output). Others studies have used the gross approach (net of *intra*sectoral transfers), arguing that the value-added approach is valid for income accounting purposes but it is inappropriate for measuring sectoral productivity because one is interested in the total input-output relationship (is the production function shifting?).[14] Of particular importance in this debate is the treatment of intermediate inputs. The U.S. agricultural sector has a unique productivity problem to address and that is that a substantial portion of output (feed grains) is an input to another portion of output (livestock).

The traditional inputs of a production function are capital, labor, and resources (or intermediate inputs). Kendrick and the BLS use the net approach to measure

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[13] We are grateful to Carlos Arnade for pointing out and emphasizing these arguments.

[14] Ruttan (1954, pp. 24-28) was the first to demonstrate that it is not appropriate to compare industry or sector level productivity growth rates estimated using the gross approach with economy wide estimates (in which interindustry or sector transfers are netted out). The rate of technical change at the industry or sector level must be equal to or less than the rates of technical change for the economy as a whole when the gross output-input approach in employed.

productivity: output (minus intermediate inputs) is a function of capital and labor.[15] The other studies use the gross approach, where output is a function of capital, labor, and intermediate inputs. Jorgenson et al. use these broad input subaggregates, while most of the other studies decompose these inputs into about 6 to 10 input subcategories.

Database Issues

Teigen et al. have pointed out that the productivity measurement effort by ERS was part of an effort to simultaneously calculate farm income (Teigen et al., 1982, pp. 5-6). Many of the input categories may reflect accounting definitions rather than economic definitions. Most of the studies reviewed in this paper have re-categorized the ERS input components into more meaningful economic definitions, using the ERS database (published annually in the bulletin, Agricultural Production and Efficiency Statistics) as a main source. In fact, ERS itself has very recently re-defined the economic inputs (and re-categorized the input components accordingly) as part of a larger effort to upgrade the way it estimates MFP (see USDA, 1991, pp. 50-51).[16] A complete listing of the input components (using the older categories and weights) are provided in Table 2. ERS

[15] It is not a coincidence that these 2 studies show MFP growth to be a full percentage point higher than the next highest estimates (see footnote 14). The BLS uses output from the National Income and Production Accounting database (U.S. Department of Commerce, Bureau of Economic Analysis), whereas Kendrick uses ERS publications to redefine output (USDL, 1983, p. 35; Kendrick, 1982, p. 59)

[16] In the 1991 Production and Efficiency Statistics report, ERS published its traditional MFP calculations based upon its old input categories (see Table 2) and simultaneously published new MFP calculations based upon some new procedures and input categories (presumably same data, except where noted, but re-categorized). The new input categories included: farm labor; durable equipment; farm real estate; farm inventories; energy; agricultural chemicals; feed, seed, and livestock purchases; and miscellaneous (USDA, 1991: p. 37 vs. p. 53).

collects data on outputs and sub-aggregates the data into 2 output categories (crop and livestock).[17]

Since all of the studies have used the ERS database (most of them with modifications), we will review this database in the following section. Thorough descriptions of ERS' procedures are available in the ERS publication, Handbook of Statistics: Production and Efficiency Statistics (USDA, 1989) and in the AAEA Task Force report. We will highlight the data issues that either point out the shortcomings of the database or highlight the different studies' methodological approaches. The major criticisms of the ERS database by the AAEA Task Force will be touched upon throughout the report. The 8 criticisms include: definition of the agricultural sector, gross vs net productivity issues, quality change problems, stock/flow problems, nonconventional inputs, data gaps, and commodity specific productivity measurement.

Output

There are 4 major issues concerning output: problems with measurement (definition of agricultural sector), treatment of feed output, the crop vs. livestock output problems, and the treatment of deficiency payments. These issues are explained below.

Definition of agricultural sector (establishment vs. product approaches). The establishment approach defines output from the "farm" (which historically is equated with "agricultural" output). The product approach considers "what is produced," not where it is done. Increasingly these neat conceptual boundaries are being blurred. The AAEA Task Force thought that ideally one would like to net out the marketing and processing activities. ERS uses primarily an establishment basis in order to simultaneously calculate

[17] According to the AAEA Task Force report, ERS estimates that it measures about 90 to 95 percent of total agricultural output (USDA, 1980, p. 19).

farm income. The AAEA Task Force thought that either approach was alright, as long as ERS was consistent in its measurements (AAEA thought ERS wasn't consistent) (USDA, 1980, p. 27).

Treatment of feed and seed. Perhaps one of the most important of all issues is the treatment of feed, which goes right to the heart of the gross vs net (value-added) productivity measurement issues (and very much related to the crop vs. livestock issue examined below). Since the U.S. is still such a large grain-fed livestock producer,[18] the issue is critical: should feed grains be excluded from output and treated as an input (as ERS treats it in order to avoid double counting)? Capalbo uses a "fully gross" approach, treating feed and seed as both an output and an input (net zero effect), since this approach is more likely to identify quality changes than the net approach where feed and seed are subtracted from output in the first place as intermediate inputs and are thus invisible (Capalbo, 1988, p. 107; see discussion of this issue in USDA, 1980, p. 28).

Crop vs livestock issues. Generally speaking, these sub-aggregate categories use very different production processes. The AAEA Task Force suggested that it might be more appropriate to calculate 2 different MFP indices for these sub-aggregate categories (representing "upstream" and "downstream" industries). However, it recommended against this, since one of the most common uses of MFPs is to compare the aggregate agricultural sector with other sectors in the economy (USDA, 1980, p. 18). In our judgement, it would be very useful to have annual data on output, input, and productivity for the crop sector, the livestock, and the agricultural sector.[19]

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[18]. According to Ball (1992), approximately 20 percent of feed grains goes to on-farm livestock production today, as compared to slightly over 50 percent back around WWII.

[19] Many of our reviewers agree with this idea in theory, but have pointed out that there are very substantial difficulties in doing so. In particular, they have pointed out that it is very difficult to break down separate input use for crops vs. livestock use on individual farms, much less create separate aggregate indices. We would still like to see this idea carefully explored by U.S.D.A.'s Economic Research Service USDA.

Deficiency payments. The information on this matter is sketchy, but based upon correspondence between Ruttan and Ball (Ball, 1992), it appears that Capalbo excludes deficiency payments from her definition of output, whereas Ball includes it. BLS explicitly notes that it includes deficiency payments in output (USDL, 1983, p. 37). ERS and presumably other studies include deficiency payments (most studies simply state that output is calculated by multiplying physical quantities by "prices received by farmers").

Inputs

Labor. ERS was criticized for a long time because of its labor database. Prior to 1964, the agricultural labor database relied heavily upon the methodology developed by Ducoff (Ducoff, 1945). ERS then estimated labor inputs based upon a one-time, comprehensive labor input survey in 1964. Thereafter labor activities were estimated based upon this "requirements" approach. These requirements were re-estimated in 1974 based upon budgetary data. Overhead labor was arbitrarily assigned 15 percent and added to the requirements calculations. ERS didn't distinguish between labor by farm operators, family, and hired labor. Griliches argued that treating these groups equally was flawed, since there was substantial evidence that the marginal product of family labor was below the comparable local hired wage rates (Griliches, 1963, p. 337). Griliches also argued that ERS was obscuring important productivity gains due to quality changes (i.e, education levels) and to a lesser degree to demographic changes. Griliches created an education- (quality-) adjusted labor input database and showed that this substantially altered the productivity calculations.

In 1980, the AAEA Task Force recommended that ERS emulate Statistics Canada by directly sampling the labor inputs for farm operators, and hired and family laborers (including overhead costs). In 1987, ERS began using BLS labor data for these 3 labor categories (USDA, 1987, pp. 76-79). However, in 1991, ERS (led by Hauver and Ball) finally joined the other economists (Brown, Ball, Capalbo, and Jorgenson et al.) in using the Gollop-Jorgenson labor database (described below) (USDA, 1991, pp. 50-51).

The Gollop-Jorgenson labor database dates back to Gollop's Ph.D dissertation (Gollop, 1974). This database continues to be updated and played a major role in the recently published book by Jorgenson, Gollop, and Fraumeni, Productivity in the United States, 1948-1980 (Jorgenson et al., 1987). The labor database uses the "RAS bi-proportional" methodology formalized by Bacharach (Bacharach, 1965). Ball, for example, used this methodology to estimate the wage rates for 1,600 cells based upon a matrix cross-classified by sex, 8 age groups, 5 education levels, 2 employment classes, and 10 occupational groups.[20] However, in an apparent step backwards, ERS explains that operator and family labor rates are imputed to be the same as hired labor, which makes Griliches' earlier criticisms again valid (USDA, 1991, p. 51).[21]

Capital. Brown, Kendrick, Ball, Capalbo, and Jorgenson et al. aggregate capital similarly as "tangible capital:" machinery, buildings, and land. Some of the key disagreements occur over how best to measure these productive assets. The disagreements have

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[20] Gollop apparently expanded upon Griliches' earlier work (Griliches, 1960 and 1963). It should be pointed out that Griliches found that demographic factors were not nearly as important as educational levels (1963, p. 340). Another empirical application of this approach also can be found in Chinloy (Chinloy, 1980). We have learned that BLS is the process of adjusting its labor database with this procedure for all of its productivity indicators.

[21] Some of our reviewers have objected to this characterization. They argue that Griliches' arguments are ultimately unprovable, so using the hired wage rate for family labor input is a reasonable procedure.

In addition to this methodological change, Dr. Willard Cochrane noticed questionable labor input growth rates for the 1950's and brought this to the attention to ERS. In the subsequent correspondence, ERS acknowledged an error that led to an upward bias in labor input, which thereby understated MFP (Cochrane, 1992). This error is scheduled to be corrected in the next edition of the Production and Efficiency Statistics bulletin.

centered around stock/flow issues, depreciation methods, and the treatment of capital gains.

Machinery. There are 22 items that comprise the old ERS machinery and mechanical power input, of which the 3 largest components are non-tractor depreciation, fuel and oil, and tractor depreciation (see Table 2).[22] Here depreciation is equated with capital service flows, so the capital stock benchmark measurement and depreciation methods are very important. Griliches has been a long-time critic of ERS' depreciation methods. The depreciation methods and imputed service flows have been subject to much debate ever since, but perhaps the more important point of the deficient stock measurement has not received adequate attention.

According to the AAEA Task Force report, the last ERS machinery stock survey was in 1949 (USDA, 1980, p. 15). Since then, ERS has estimated annual changes to this benchmark with the Agricultural Census and with other sources. The most recent ERS handbook describing the major series' methodologies has nothing to say on this issue, leading one to conclude that this is still the case. The AAEA Task Force made the following comment in its summary recommendations:

> Some of the weakest basic input data relate to the stocks of machinery and equipment. While this situation cannot be corrected immediately and without substantial cost, we believe the improvement of data on stocks of capital equipment, including quality aspects, should be a high priority item in developing future Agricultural Census and other surveys (USDA, 1980, p. 46).

Griliches estimated that the ERS machinery stock was underestimated by as much as 75 percent back in 1957 (Griliches, 1960, p. 1423) (our emphasis). If the stock

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[22] It is worth pointing out that Ball (1985), Capalbo-Vo (1988), Jorgenson et al. (1987), and the latest ERS report (USDA, 1991) all treat energy as its own input. In the earlier ERS database categorization, energy was part of this larger mechanical input. Ball (1985, p. 482) and Jorgenson et. al (1987, p. 150) report using the energy database created by Jack Faucett Associates. Capalbo-Vo do not mention what source they use for energy (Capalbo-Vo, p. 129).

measurement error is truly this large, then the subsequent discussion on depreciation and service flows would seem to be relatively unimportant. It is possible that the underestimation of machinery stock has led to substantial overestimation of productivity growth. In our judgement, more accurate stock estimates should represent a high priority.

The larger issue surrounding depreciation is the stock vs. flow issues.[23] For the labor input, the number of employees can be thought of as "stock" and the number of hours they work as "flows." A similar distinction has to be made with capital: depreciation should approximate the service flows over an asset's useful life.[24] ERS traditionally has used a declining balance ("straight line") depreciation methodology (USDA, 1989, p. 11). The rationale is to approximate resale or "blue book" values.[25] Penson et al. suggested using engineering data for particular machines and models to calculate depreciation rates, but it appears that ERS never adopted this recommendation (Penson et al., 1981). Ball uses a double-declining depreciation method (n/2, where n is the expected lifetime of a capital item), which relative to the straightline method

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[23] The following discussion applies equally well to depreciation on land and buildings.

[24] Exactly what depreciation represents has been subject to much debate (especially between Denison and Griliches-Jorgenson). Brown refers to the confusion between depreciation and replacement by commenting, "Replacement is the amount of investment necessary to restore the productive capacity of the asset. Depreciation represents the decrease in current value of capital stock due to future efficiency declines." (Brown, p. 40). Brown goes on to show that these concepts amount to the same thing: depreciation ($\delta_i P_{it} K_{it-1}$) = replacement ($P_{it} \delta_i K_{it-1}$) (Brown, p. 41). Griliches quotes a USDA definition of depreciation that we think many of us find appealing, "Depreciation is the estimated outlay in current prices which would be required if farmers were to replace exactly the plant and equipment *used up* during the year" (original emphasis) (Griliches, 1960, pp. 1420-1421).

[25] One of Griliches' earliest criticisms was that, given that the declining balance depreciation method reasonably approximates the resale market, the tractor depreciation rate of 18 percent per year was very high (he estimated 11-12 percent was more reasonable). Since ERS was depreciating tractors too rapidly, Griliches argued that the capital stock was underestimated, thus leading to an overestimate in MFP. It is interesting to note that at some point ERS corrected this depreciation rate down to 12 percent (see USDA, 1992, p. 11).

depreciates assets more in the earlier years and less in the later years.[26] Ball cites Treasury Bulletin F as a reference source for basing the capital items' expected lifetime (Ball, 1985, p. 477).

Land and structures. In the ERS database, these 2 items fall under the category, "real estate." Ball and Capalbo break out land separately from structures.[27] There are 4 important issues surrounding land: 1) stock/flow conversion methods; 2) capital gains; 3) measurement of public grazing fees; and 4) treatment of set-aside land.

One of the specific recommendations of the AAEA Task Force report was that ERS change its stock/flow conversion methodology in 3 ways: 1) calculate the service flow of all land consistently, regardless of whether the land is mortgaged or in equity; 2) the preferred calculation should avoid fluctuating nominal long term interest rates (the AAEA Task Force suggested calculating a constant cash rental/land value ratio); and 3) service flows should include property taxes.

Based upon private correspondence between Ruttan and Ball, it appears that one of the biggest differences between Capalbo and Ball is that Capalbo does not include capital gains taxes, while Ball does include it (Ball, 1992). There is little discussion of capital gains by the AAEA Task Force report or by ERS in its procedural handbook (USDA, 1991).

[26] Jorgenson used to use this approach, but has informed us that he no longer does. He now prefers to use the approach by Hulten and Wycoff (1981), in which they assigned individual capital items unique depreciation schedules based upon empirical observations (as opposed to assigning all items one depreciation procedure). Reviewers from the BLS echoed this approach, suggesting that depreciation is simply an empirical issue.

[27] Ball wrote, "Estimates of investment in nonresidential structures are obtained from the Bureau of Economic Analysis' capital stock study... To estimate the stock of farmland, Tornqvist-Theil price and implicit quantity indexes are constructed using as prices land values (excluding buildings) per acre. It was assumed that farmland within a state was homogenous in quality; hence, aggregation was at the state level" (Ball, 1985, pp. 476, 478). It is our impression that building stock was based upon an one-time study and may be out of date and inaccurate.

The AAEA Task Force also recommended that public grazing fees be re-evaluated by private shadow-rent prices, presumably since public fees are artificially low. This is a relatively small item that apparently ERS has not adjusted (USDA, 1991, p. 11). It is not clear how much change would occur if ERS were to value these lands at private rental costs.

The treatment of set-aside land is an interesting conceptual issue to discuss. The AAEA Task Force explored this issue in detail and in the end recommended that ERS continue to treat set-aside land as a land input (USDA, 1980, pp. 43-44). The larger conceptual issue is measuring the costs and benefits of maintaining a natural resource base.

Intermediate inputs. The intermediate inputs include feed, seed, livestock, pesticides, fertilizer, and energy. These items are discussed below.

Seed, feed, and livestock. ERS lumps feed, seed, and livestock inputs together that originate from the nonfarm sector as purchased inputs. ERS makes the efforts to estimate only the value-added portion of feed and seed inputs (recall that nonpurchased feed and seed are not counted as either output or input) by subtracting the prices received from the prices paid of these inputs. An important flaw in the ERS database is that the ERS does not collect data on hybrid corn seed prices paid and received, so they are not included in the database. The AAEA Task Force argued that this underestimates productivity; overall, it argued that this part of the database is "sketchy" (USDA, 1980, p. 36). In 1991, ERS added breeding stock to its measurement of livestock input, thereby correcting a previous minor criticism (USDA, 1991, p. 51).[28]

[28] Ball not only added breeding stock, but treated these animals as any other capital inputs, taking note of the different ages of the breeding stock and depreciating them accordingly. Jorgenson considers this a significant improvement and suggests that if ERS really wanted to pursue accuracy to the extreme it could

Agricultural chemicals. There are 2 points that are of interest here: raw nutrient weight measurement problems, and the index problem related to rapidly changing chemical inputs. Griliches was the first to point out that ERS' simple summation of agricultural fertilizers in tonnage terms only (without regard to increased raw nutrient concentration) seriously underestimated fertilizer inputs. ERS has since weighted the major nutrients (nitrogen, potash, and phosphorus) by their 1965 relative prices.[29] It is worth pointing out that the pre-1965 data still remain unweighted (USDA, 1989, p. 12).

The AAEA Task Force used the agricultural chemicals inputs as an example to show some of the problems in aggregating with indices. Some fertilizers and pesticides have become widely used or fallen out of use very rapidly. This can create serious bias problems for indices, especially when the time periods are far apart (USDA, 1980, pp. 29-32).

Other inputs. ERS includes 2 other input categories that don't necessarily fit well under traditional input categories: taxes and miscellaneous. Taxes are considered proxies for intangible inputs, such as education, roads, and research (USDA, 1980, p. 17). The AAEA Task Force suggested that ERS goes too far in measuring taxes (USDA, 1980, p. 34). Miscellaneous items include items such as insurance, irrigation charges, vetinary expenses, telephone, and cotton ginning.

Nontraditional inputs. ERS does not include nontraditional inputs in its productivity calculations. The AAEA Task Force recommended that ERS conduct research in the following areas and include them as inputs as the methodologies become more refined: water, environmental resources, public infrastructure, insurance, and government activity.

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depreciate other nonconventional assets, such as fruit trees and other animal and plant assets.

[29] This assumes that the relative prices haven't shifted.

Summary Evaluation

Before evaluating the studies, we will state the critical features that we consider to be important and the approaches with which we agree. First of all, even though these studies are largely growth accounting studies, we think what is of primary interest is the idea that productivity change should refer to a shift in the production function. Sometimes the concept of a shifting production function gets lost in all of the growth accounting.[30]

We think that both the parametric and index approach are equally capable of measuring productivity; the advantages and disadvantages depend on the researcher's goals. We think it is important that the explicit or implicit production function exhibit "flexible" properties, such as varying elasticities of substitution. By implication, then, we favor use of the Divisia index because it is "exact" for a flexible production function and because it also satisfies the properties of the Invariance Axiom (it measures true technological change). However, we recognize that in practice, the biases of other indices are very small if the weights are updated frequently; thus, we consider frequently updated weights a more important consideration than a particular index form.

As for the specification of the explicit or implicit production function, we favor the gross approach because it is more consistent with the idea of a production function where output is a function of all of the inputs. However, we understand that the net (value-added) approach is widely used for other industries, so we would like to see this methodology continued for the sake of being able to consistently compare the

[30] We think one should bear in mind that ERS collected this data equally, if not more importantly, for the purpose of estimating farm income. One may understand why some of the peculiar data components are collected in this context. The AAEA Task Force was very good at pointing out inconsistencies in ERS' data collection methods.

agricultural sector against other sectors. Along these lines, though, we would like to see separate MFP estimates for the crop and livestock sub-sectors since the production activities in these groups are very different.

Finally, there are a host of data-related issues that are as important as all of the above considerations. On the question of deficiency payments, we believe that they should be included in output, since planting decisions are based upon expected profits where loan rates are known beforehand. On the important issue of feed grains, we agree with ERS' current practice of deducting feed grains from output since this practice avoids double counting. We applaud all of the recent efforts to adjust the labor inputs for education and demographic factors. We think that capital depreciation is an empirical issue; that is, rather than imposing an depreciation methodology upon all assets, we think it possible to observe depreciation rates for each individual asset and implement (approximate) individual depreciation schedules based upon the best method (strightline, double-declining, etc.). The general issue of taxes (capital gains, property, etc.) is one with which we have a problem.[31]

The studies' methodologies and findings are summarized in Table 3. In light of the previous comments, we do not think the Kendrick and BLS studies accurately measure MFP because they use the net productivity approach. Most of the other gross specification studies use similar methodologies that are of good quality that obtain similar results (this is not to say that some of the differences are unimportant). We will review the remaining studies in turn.

[31] It seems to us that one could imagine a farm that produces the same level of output with the same level of inputs in two periods; but if local taxes go up in the second period for some reason, then productivity measurement would go down when in fact this has nothing to do with the production function declining. We don't believe that ERS does a good job at explicitly capturing the "public inputs" for which the taxes go (extension, transportation, etc.).

Brown (1978) was the first "reforming" study to challenge the ERS productivity measurements. His findings were in keeping with later studies, even though his study's time period was shorter. He was the first to use the Gollop-Jorgenson labor database and to create Tornqvist-Theil (Divisia) indices by creating annual shares.

Ball (1984, 1985), an ERS employee, deserves substantial credit for implementing internal changes in the way that ERS calculates MFP. As of this writing, more changes are on the way at ERS under Ball's supervision (see USDA, 1991, pp. 50-51). We applaud most of his methodological changes. We wish that Ball would use the flexible depreciation methodology (described above) rather than using the double-declining depreciation methodology for all assets.

We find the Capalbo-Vo (index) study interesting in the sense that they include feed grains as an output and an input, but we think that this approach is mistaken since it involves double counting. We also consider it a shortcoming that they apparently exclude deficiency payments. Since the same Capalbo-Vo database is used by Capalbo (1988) and Cox-Chavas (1990), the same comments apply there as well. We like the fact that Capalbo (1988) obtained 2 acceptable production function models (one primal, one cost) that have overlapping confidence intervals (1.4 to 1.6 percent per year). At this point, we think that Cox-Chavas provide a novel methodological approach that deserves further and more careful consideration.

Jorgenson (1990) has conducted a very lengthy and thorough study, not just of U.S. agriculture, but of 50 sectors for the entire U.S. economy. Characteristically, he uses the Gollop-Jorgenson labor database. Jorgenson has recently moved away from the double declining capital depreciation methodology to the Hulten-Wycoff flexible methodology. We find the Jorgenson methodology satisfying; the results are also consistent with the other studies.

In conclusion, we believe that the economic theory on MFP has advanced greatly, but the data that has been collected to measure it has not kept pace. We would remind the reader that most of the studies have used the ERS database (with modifications), which still has some serious deficiencies. Three of the more serious problems include the lack of a reliable machinery and equipment stock benchmark, the omission of hybrid seed inputs, and unweighted fertilizer inputs prior to 1965. At this stage, improvement in the database are a much more urgent priority than further refinements in index number and production function estimation methodology.

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Table 2 - 1967-1969 base periods input weights[1]

Item	Million dollars	Percent of total
Farm labor	7,997.0	(20.92)
Hired labor	1,835.3	(4.80)
Operator labor	4,717.4	(12.34)
Unpaid family labor	1,444.3	(3.78)
Farm real estate	8,921.5	(23.34)
Real estate service charges on equity	6,165.8	(16.13)
Interest on real estate mortgages	1,567.4	(4.10)
Depreciation on service buildings	369.0	(0.97)
Accidental damage to service buildings	113.6	(0.30)
Repairs on service buildings	681.2	(1.78)
Grazing fees, total	24.5	(0.06)
Mechanical power and machinery	10,691.9	(27.98)
Automobile depreciation, farm share	402.8	(1.05)
Interest on automobile inventory	118.6	(0.31)
Automobile repairs, parts, and tires	118.2	(0.31)
Automobile licenses, farm share	20.9	(0.05)
Automobile insurance, farm share	77.9	(0.20)
Tractor depreciation	951.0	(2.49)
Interest on tractor inventory	470.7	(1.23)
Tractor repairs, parts, and tires	614.0	(1.61)
Truck depreciation	600.7	(1.57)
Interest on truck inventory	162.9	(0.43)
Truck repairs, parts, and tires	304.9	(0.80)
Truck licenses	74.8	(0.20)
Truck insurance	133.8	(0.35)
Depreciation on other farm machinery	2,215.3	(5.80)
Interest on inventory of other farm machines	920.3	(2.41)
Other farm machines: repairs, parts, and tires	525.2	(1.37)
Fuel and oil (including gasoline)	1,675.6	(4.38)
Electricity, farm share	246.6	(0.65)
Blacksmithing and hardware	94.0	(0.25)
Harness and saddling	12.7	(0.03)
Small hand tools	59.8	(0.16)
Custom work	891.2	(2.33)
Agricultural chemicals	2,637.7	(6.90)
Nitrogen fertilizer	692.2	(1.81)
Superphosphate fertilizer	728.0	(1.90)
Potassium fertilizer	313.4	(0.82)
Limestone	120.4	(0.31)
Pesticides	783.7	(2.05)

Item	Million dollars	Percent of total
Feed, seed, and livestock purchases	2,682.9	(7.02)
Total seed input	297.4	(0.78)
Total feed input	1,594.2	(4.17)
Milk hauling	231.3	(0.61)
Livestock marketing	266.0	(0.70)
Baby chickens purchased, broiler type	147.4	(0.39)
Baby chickens purchased, layer type	107.1	(0.28)
Baby turkeys purchased, heavy breeds	35.7	(0.09)
Baby turkeys purchased, light breeds	3.9	(0.01)
Taxes and interest	4,072.5	(10.66)
Taxes: real estate	1,700.4	(4.45)
Taxes: personal property	407.9	(1.07)
Capital charge on inventory of:		
Cattle and calves	1,084.3	(2.84)
Hogs and pigs	112.5	(0.29)
Sheep and lambs	31.9	(0.08)
All chickens	33.2	(0.09)
All turkeys	2.6	(0.01)
Corn	112.7	(0.29)
Oats	11.1	(0.03)
Barley	5.5	(0.01)
Grain sorghum	8.7	(0.02)
Hay	63.0	(0.16)
Forage	21.2	(0.06)
Wheat	24.2	(0.06)
Soybean	27.2	(0.07)
Interest on operating capital	276.6	(0.72)
Interest added by non-real estate debt	149.5	(0.39)
Miscellaneous	1,215.7	(3.18)
Insurance: fire and wind	157.4	(0.41)
Insurance: crop-hail (net)	36.1	(0.09)
Insurance: Federal crop (net)	0.1	(0.00)
Containers	130.1	(0.34)
Binding materials	90.3	(0.24)
Dairy supplies	78.2	(0.20)
Irrigation operating and maintenance charges	136.9	(0.36)
Veterinary	229.9	(0.60)
Telephone (farm share)	143.2	(0.37)
Ginning charges	143.5	(0.38)
TOTAL	38,219.1	(100.00)

Source: USDA, 1980, pp. 50-51.

[1] ERS updated these weights to the 1976-1978 period, and then switched to annual Tornqvist-Theil weights in 1991. The purpose of this table is list all of the components that go into the productivity calculations. Most of the recent studies have re-categorized the components into more meaningful economic subaggregate categories (including ERS in 1991). We have switched the units from thousands to millions and calculated the percentage shares.

Table 3 - Key characteristics of U.S. agricultural sector multifactor productivity (MFP) calculations by study

Item	Axiomatic approach							Parametric approach	
	Brown	Kendrick	Ball	Capalbo-Vo	Cox-Chavas	ERS	BLS	Capalbo	Jorgenson
MFP growth rate	1.42	3.50	1.75	1.22	1.89	1.58	3.06	1.4-1.6	1.61
Time period	1947-1974	1948-79	1948-79	1950-83	1950-83	1948-89	1948-74	1950-83	1948-1989
Index/production form	Divisia	Laspeyres	Divisia	Divisia	Factor aug.	Divisia	Divisia	Translog	Translog
Output concept	Gross	Net	Gross	Gross	Gross	Gross	Net	Gross	Gross
Includes defiency payments?	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes
Feed part of output?	No	Yes	No	Yes	Yes	No	No	No	?
Inputs									
Gollop-Jorgenson labor?	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Depreciation method[2]	DD	DD-SL mix	DD	?	?	SL	Convex	?	W-H
Variables[3]	K,L,F,FSL, E,M	K,L	HL,FL,DE,RE D,E,C,FS,M	HL,FL,A,S O,E,F,P,M	HL,FL,A,S O,E,F,P,M	L,DE,RE,D E,C,FSL,M	K,L	L,RE,K,I; K,L,I	K,L,I

[1] Calculated by the authors from published multifactor indices using formula, $\ln(Y) = \beta_0 + \beta_1(T)$.

[2] Key:

DD = Double-declining
SL = Straight line
WH = Wycoff-Hulten methodology

[3] Key:

A = Land
C = Chemicals
D = Durables, farm
DE = Durable equipment
E = Energy
F = Fertilizer
FL = Family labor
FS = Feed and seed
FSL = Feed, seed, and livestock
HL = Hired labor
I = Intermediate inputs
K = Capital
L = Labor
M = Miscellaneous
O = Other
RE = Real estate
S = Structures