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ABSTRACT

Measures of capital services are used in studies of production and to inform policies related to growth and development. A variety of methods have been used to measure capital stocks and service flows. In this study we review methods commonly used to measure capital service flows, and outline important assumptions used in constructing such measures. We examine two recently constructed data sets that measure capital inputs in U.S. agriculture. Substantial differences in the measures appear to have been caused by the use of a fixed real interest rate versus a variable real market interest rate to calculate capital services.

Key words: capital measures, U.S. agriculture, state-level panel data

Capital Service Flows: Concepts and Comparisons of Alternative Measures in U.S. Agriculture

"The capital time series is one that will really drive a purist mad."

Robert Solow (1957, p. 314)

1. Introduction

An accurate measure of the annual flow of capital inputs is valuable for policy makers and researchers who are interested in production and productivity. However, data limitations and a myriad of assumptions required to construct estimates of capital stocks and service flows make them difficult to calculate and vulnerable to significant measurement errors. Estimates of the flow of capital services are especially sensitive to underlying assumptions. Information about the implications of the alternatives can provide a basis for making better-informed choices about the appropriate approaches and assumptions to apply when measuring capital stocks and flows. Few, if any, sectors in the U.S. economy have production data as detailed as those available for agriculture, and so it is to this sector we turn, using national and state-specific estimates to examine the empirical implications of alternative data measurement choices when quantifying stocks and flows of capital services.

This paper begins with a review of methods used commonly to measure capital stocks and service flows, making explicit a number of important assumptions required to construct such measures. Next, we examine and compare the measures of capital inputs in U.S. agriculture from two contemporary state-specific panel data sets. We compare the methods used to construct the capital series and we reveal and discuss some important differences in data sources, the types of data used to construct the capital measures, and the resulting estimates. We also outline some assumptions about depreciation, service lives, interest rates, aggregation methods, and the scope of goods included in each of the capital series for each data set.

Both sets of estimates are based on the use of modern index number procedures and appropriate economic theory. Even so, our examination of the estimates of capital service flows reveals dramatic differences between the two data sets in the majority of the 48-contiguous states. These results demonstrate how methods of measurement can have significant consequences for measures of capital service flows, resulting in differences that are likely to have very substantial implications for findings from studies that treat the measures simply as data.

In his Waugh lecture to the American Agricultural Economics Association, Bruce Gardner (1992) discussed the importance of both the activity of creating data and of the point that data users should know how the data they use were created.

> "Agricultural economists and other social scientists tend to take data as facts. . . . The problem is the data are not facts. Facts are what is really there. Data are quantitative representation of facts, which statistical workers and economists concoct."   (Gardner 1992, p. 1074)
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> "I call the study of how primary statistical information is made into economic data "factology." The neglect of factology risks scientific ruin." (p. 1067)

Gardner drew specific attention to the measurement of agricultural inputs (especially capital), outputs, and productivity as instances where a lot of effort and judgment goes into the creation of the "data," such that the data themselves are very much transformed from the raw material used to make them, and consequently areas where factology matters more than most. Our findings reinforce Gardner's point that it is incumbent on researchers who use "data" on capital from any source to know how the measures were made and what is implied for the measures and estimates based on them.

2. Calculating Indexes of Capital Input

The measurement of capital inputs is problematic for two general reasons. First, capital is purchased in one time period but the amount of the initial investment used in each subsequent time period is not directly observable. Assumptions about physical depreciation, obsolescence, replacement, and durability are required to define the accumulated stock of capital as well as the flow of services from the stock, which is the relevant measure to be used in studies of production or productivity. Second, the consumer of capital services is also often the supplier, such that the entire transaction occurs within the internal accounts of the economic unit making the investment (Griliches and Jorgenson 1966). Consequently, scant data are available on the rental rates and the ex-post usage of most capital assets in U.S. agriculture. Additionally, the heterogeneity of capital on farms—which includes assets of different types, different service flow profiles, and different vintages—further compounds the problem of forming estimates of the aggregate stock of capital and the quantity of capital services flowing annually into U.S. agriculture.[1]

A measure of the stock of capital can be constructed either (a) directly, from current data on the stock of capital goods, measured in physical units, or (b) indirectly, from a long time-series of data on investment in capital goods. The first approach, based on counts of purchased or in-place assets, is called the physical inventory method; it is often infeasible because of limitations of data and other resources. The second approach, based on investment data, is called the perpetual inventory method, and is used more often. When a long historical series on capital investment is not available some studies apply a mixed approach in which a benchmark measure of the capital stock (such as a census knot) is combined with a series on capital investment thereafter, along with an assumption of a geometric rate of depreciation for the capital stock.

[1] OECD (2001) and Diewert (2003) examined the measurement of capital in detail.

The actual (or latent) flow of capital services is unobservable to the researcher because the data are typically not available. Instead, a measure of the service flow usually must be inferred from a measure of the capital stock and information used to construct it (see, for example, Andersen, Alston and Pardey 2007). Consider the example of agricultural machinery. Ideally, we would have data on the number of machine hours used in production each period for each class of machinery, and an hourly rental rate for each class. An index of the quantity of machine services could then be calculated for the different classes of machines with the hourly rental rates as weights. However, since such data are not typically (if ever) available, a measure of the stock of machinery is often substituted in the indexing procedure under the assumption that the flow of machine services is proportional to the stock of machines (with each additional machine providing a fixed number of machine hours per period). If the proportionality assumption is correct, then the observable stock can be used in the indexing procedure as an accurate proxy for the latent quantity of capital services.

The perpetual inventory method is commonly used to estimate a stock of capital each period using a time series on investment in real dollars, I. Denoting the service life of an asset, L, and the annual rate of capital deterioration, δ, the current stock of capital can be defined by the following capital accumulation equation:

$$K_t = I_t + (1-\delta)I_{t-1} + (1-\delta)^2 I_{t-2} + ... + (1-\delta)^L I_{t-L} \quad (1)$$

Equation (1) is the moving sum of the depreciated value of current and past investments truncated at the assumed service life of the asset. In this manner, annual estimates of the stock of capital for each class can be estimated.

The rental rate for each class of asset is a function of the price of a new unit of the asset, P_t, its (assumed) constant rate of depreciation, δ, and the real interest rate, r_t.

$$\rho_t = f(P_t, r_t, \delta) \tag{2}$$

The estimates of rental rates serve as weights in the calculation of the index of capital services. These weights are intended to represent the relative marginal products of the different classes of capital. Many different functional forms have been used to compute rental rates. Coen (1975) generalized the rental rate expression to incorporate a range of depreciation patterns. The simplest form for the rental rate calculation assumes a constant interest rate and a constant geometric rate of depreciation (many other models of depreciation exist and the appropriate method to use in practice is the topic of an extensive literature, as discussed in section 3):

$$\rho_t = P_t\left(r + \delta\right) \tag{3}$$

The first term in this expression, $P_t r$, represents the opportunity cost of the invested funds. The second term, $P_t\delta$, represents the cost of physical wear and tear, and any other sources of economic depreciation of the asset as it ages.

The rate of “depreciation” in equation (3) may differ from the rate of “deterioration” in equation (1) if other forms of economic depreciation are important. In practice, both in general and specifically in the work reported in this paper, the two concepts are treated as though they are equivalent such that the rate of economic depreciation used in equations for rental rates is identical to the rate of deterioration used in equations for capital stocks.

Assuming i = 1, 2, …, N capital classes, annual time series of the rental rate can be combined with annual time series of the stock for each class of capital (which serves as a proxy for the latent annual service flows under the assumption of proportional service flows) to form an index of the quantity of capital services. Commonly, a discrete approximation to a Divisia index, such as a Fisher Ideal index, is used for aggregation. The Fisher Ideal index of the quantity of capital services in year t, qk_t for i =1, … , N classes of capital is computed using:

$$\frac{qk_t}{qk_{t-1}} = \left(\frac{\sum_{i=1}^{N} \rho_{i,t-1} K_{i,t}}{\sum_{i=1}^{N} \rho_{i,t-1} K_{i,t-1}} \right)^{\frac{1}{2}} \left(\frac{\sum_{i=1}^{N} \rho_{i,t} K_{i,t}}{\sum_{i=1}^{N} \rho_{i,t} K_{i,t-1}} \right)^{\frac{1}{2}} \tag{4}$$

where $\rho_{i,t}$ is the rental rate of capital class *i* in period *t*, and $K_{i,t}$ is the stock of capital of class *i* in period *t*. The aggregate rental rate is then calculated as an implicit price index, by dividing the total rental value each period, $\sum_{i=1}^{N} \rho_{i,t} K_{i,t}$, by the quantity index of service flows for that period.

3. Depreciation Patterns in Agricultural Capital

An accurate measure of how capital depreciates over time is one of the necessary components for constructing a time series of capital service flows. Hulten and Wykoff (1981 and 1996) and Jorgenson (1996) provide an extensive treatment of the issues surrounding the measurement of depreciation. These studies examine changes in the market value of assets over time to infer rates and patterns of depreciation.

The change in the market value of an asset over time measured in current dollars can be attributed to two main sources, depreciation and re-valuation (capital gains and losses). Depreciation is the loss in the value of an asset over time measured in constant dollars. Some assets would depreciate to some extent without any use while some depreciation reflects physical deterioration associated with use. Commonly, it is assumed that an asset loses value over its life either by a constant proportion each period (geometric depreciation), by a constant amount each period (straight-line depreciation), or not at all until the end of its useful life, at which time 100 percent depreciation applies (a one-hoss-shay pattern).

The only components of depreciation that are of interest for measuring the loss in the productive capability of capital assets are those that affect the marginal productivity of capital, namely physical deterioration and possibly obsolescence (i.e., physical as opposed to other forms of economic depreciation). The physical deterioration of an asset is sometimes assumed to follow a hyperbolic pattern over time.

Limited empirical research has been done on depreciation patterns for the different classes of agricultural capital; however, a few studies provide the following findings. First, depreciation in the market value of agricultural machinery follows a geometric pattern. Blue book data on used tractors or combines are typically provided as evidence that prices follow a geometric pattern over time. Second, the evidence on the physical deterioration of assets is mixed. For some mechanical assets (including tractors used in U.S. agriculture) physical capability appears to decline following a hyperbolic pattern in which an asset deteriorates at an increasing rate over its life.[2]

One possible reason why many empirical studies find that the value of capital declines geometrically is because exhaustion and obsolescence are strongly convex. Theoretically, the combination of these effects could be enough to offset a concave physical deterioration pattern. Alternatively, all three of the depreciation components might be convex. The empirical evidence suggests that the value of most durable assets declines geometrically, a view that is widely supported in the literature. However, geometric decay in the value of an asset could be consistent with a hyperbolic, linear, or geometric deterioration in its physical capabilities.[3]

[2] Penson, Hughes and Nelson (1977) examined expenditures on maintenance and repairs for tractors in the United States and found that the loss in productive capacity of a tractor is low during the early years of its life, and increases rapidly as it approaches the end of its useful service. Romain, Penson and Lambert (1987) examined a model of investment behavior for tractors in Canada and found that a hyperbolic depreciation pattern best reflected actual investment decisions. However, using price data LeRoy and Lee (1990) found a geometric pattern for the physical deterioration of agricultural machinery. Finally, Cross and Perry (1995) found large variations in depreciation rates and depreciation patterns for different classes of agricultural machinery, but found that the decline in value of used equipment generally follows a geometric pattern.

[3] In the presence of a positive discount rate the value of an asset can decline geometrically, even when the physical deterioration follows a hyperbolic pattern. Yotopoulos (1967) provides more details on depreciation patterns for flows of capital services.

Hence, while the evidence supports assuming a geometric pattern of economic depreciation, less information is available on on the patterns of the physical deterioration of assets that are relevant when measuring capital for empirical studies of production and productivity. Perhaps this is one reason why there is little consensus in the literature on the appropriate pattern of deterioration to employ when measuring capital. Part of the disagreement relates to the distinction between the decline in efficiency of an individual asset and the decline in efficiency of the stock of a heterogenous group of assets. Berndt (1990, p. 155), wrote: "…because of varying vintage composition over time, the average efficiency (deterioration) function of an entire cohort can be quite different from the individual efficiency functions; while each asset in a stock might, for example, follow the one-hoss-shay form, the cohort as a whole can follow a rather different age-efficiency (deterioration) pattern." Jorgenson (1995, p. 218) argued that the ". . . available empirical evidence supports the use of geometric decline in efficiency as a useful approximation to replacement requirements and depreciation."

The assumption of a constant geometric rate of depreciation, δ, is widely used in the literature on capital measurement because it is simple to apply and provides a good approximation to physical deterioration when working with measures of the aggregate stock of assets. Also, the assumption of geometric depreciation provides an internal consistency between estimates of the productive stocks of assets and their rental rates, as the same δ is used in the calculation of both the stocks (and flows) and the rental rates.

In constructing their measures of productivity the BEA (1997) and the BLS (1998) assumed geometric deterioration of nonresidential assets, and used estimated depreciation rates from a highly cited study by Hulten and Wykoff (1981). Dean and Harper (1998, p. 22) wrote: "The available evidence was evaluated by Barbara Fraumeni [1997] and used by Arnold Katz and Shelby Herman [1997] to recalculate the BEA capital stocks. Rather than assume straight-line depreciation, BEA now assumes geometric depreciation of most asset types in computing its net stocks." Additionally, Hulten (1990, p. 142) wrote: "The studies of Fraumeni and Jorgenson (1986), Jorgenson, Gollop, and Fraumeni (1987), Boskin, Robinson, and Huber (1989), and Boskin, Robinson, and Roberts (1989) use the Hulten-Wykoff estimates of δ more or less directly. These studies accept the best geometric approximation and use the self-dual property of geometric depreciation to calculate stocks and user costs using the same δ."

4. State-Specific Capital Measures in U.S. Agriculture

The rest of this paper draws on the work of two teams of economists who have compiled state-level measures of inputs, outputs, and productivity in U.S agriculture. In the 1980s a group of researchers at the University of Minnesota led by Philip Pardey and Barbara Craig began compiling production accounts data at the state level in U.S. agriculture. Craig and Pardey (1996) used state-specific data on prices and quantities to construct Tornqvist-Theil indexes of outputs, inputs, and productivity for the 48-contiguous states for 1949-91. They included 54 commodities in their output index, as well as 11 classes of purchased inputs, 32 classes of labor, 12 classes of capital, and three classes of land in their input indexes. These data were subsequently revised by Acquaye, Alston, and Pardey (2003) who performed additional quality adjustments to the data and calculated Fisher Ideal indexes of inputs, outputs, and productivity. Finally, the aforementioned production accounts were recently revised and updated again to the year 2002 by Andersen (2005). The database now includes 74 categories of outputs and 58 categories of inputs. The indexes, some of the underlying production data, and an extensive documentation of data sources and specific measurement issues are available through the

International Science and Technology Practice and Policy Center (InSTePP) at the University of Minnesota.[4] This data set is referred to here as the InSTePP data.

Beginning in the 1990s, a group of researchers at the United States Department of Agriculture's Economic Research Service (USDA-ERS) also began constructing state-level production accounts data. Eldon Ball took the lead in developing the USDA's state-level production data.[5] Many of the details about these data can be found in Ball, Butault, and Nehring (2001). They constructed Fisher Ideal indexes of inputs, outputs, and productivity for the 48 contiguous states for the period 1960-96. These data—from here on referred to as the USDA data—have recently been updated to 2004 (USDA 2009). = Estimates of the stock of each asset in both the InSTePP and USDA data sets are state-specific. A primary difference between the USDA data and the InSTePP data is that the USDA used the perpetual inventory method to calculate the capital stocks and InSTePP used a physical inventory method (except in the case of buildings, which is based on a value series). Consequently, the USDA stocks are measured in real dollars while the InSTePP stocks are measured in physical units. The USDA and InSTePP estimates of stocks also differ in their treatment of depreciation and the retirement of capital assets, as well as in the sources and categories of data used.

The USDA used investment data from *Fixed Reproducible Tangible Wealth in the United States, 1925-1994* (U.S. Department of Commerce, Bureau of Economic Analysis 1999) to construct estimates of capital stocks using the perpetual inventory method. National data on investment were partitioned among states using state-specific data from the Census of

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[4] These data and their documentation will be posted at www.instepp.umn.edu in Fall 2009. Pardey et al. (2009) provide more complete details for the InSTePP capital series.

[5] Huffman and Evenson (1993) developed a set of state-level input, output and productivity accounts wherein they ". . . estimated the nominal service flow from these [automobiles, trucks, tractors and other equipment] capital items as depreciation plus a fixed percentage (.04) of their current value at replacement cost" (p. 361). In later published work, Huffman and Evenson abandoned this earlier series in favor of the USDA data (e.g., Huffman and Evenson 2006).

Agriculture.[6] InSTePP used a variety of data sources including both publicly available and unpublished data to estimate capital stocks in physical units using a combination of inventory data and investment data. The main data sources for the InSTePP stock measures are the National Agricultural Statistics Service (NASS) Census of Agriculture, the USDA–ERS, and unpublished data on machinery sales from the Association of Equipment Manufacturers.[7] The machinery sales data allowed InSTePP to incorporate vintage and size (i.e., quality or compositional) effects in their stock estimates. Both groups of researchers used national asset price deflators from the BLS. The InSTePP researchers used the BLS Producer Price Index (PPI) for "Farm Machinery and Equipment Manufacturing."[8]

The USDA method of calculating stocks began with national data on investment. The perpetual inventory method was used to construct estimates of national capital stocks that were subsequently partitioned among states using additional state data from the Census of Agriculture; a 'top-down' approach to constructing the state-level estimates that is consistent with national income accounting in other sectors of the economy. In contrast, InSTePP started with state-specific data on physical inventories and physical counts of different assets to construct their state (and ultimately national) stock estimates; a 'bottom-up' approach. The choice of method is driven by the purpose for which the estimates are being constructed and at, least in part, by the

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[6] The procedure the USDA researchers used to partition the national data among states is not reported in Ball, Butault, and Nehring (2001) or in the more recent on-line documentation: http://www.ers.usda.gov/data/agproductivity/methods.htm.

[7] The authors are grateful for assistance provided by John Smylie and the Association of Equipment Manufacturers in making data available. Details of all data sources used to construct the InSTePP series are in Pardey et al. (2009).

[8] BLS (2009) PPI data are available on line at http://www.bls.gov/data/#prices.

availability of data. In turn, each method carries with it implications for the choice and use of data, and differences in the resulting measures of state-specific capital stocks and service flows.[9]

A summary of the composition of assets and the assumed service life and deterioration pattern for each capital aggregate is provided in Table 1. The InSTePP researchers calculated values for twelve separate classes of capital with asset-specific estimates of stocks and rental rates, and the USDA researchers calculated values for six classes of capital with asset-specific estimates of stocks and rental rates. For purposes of comparison, we classified these capital classes into three main categories, machinery, inventories/biological capital, and service structures.

[*Table 1: Composition of the Capital Aggregates and Service Life Assumptions*]

Table 1 indicates that the InSTePP capital measure has a more disaggregated basis, for example, including five separate classes of biological capital, whereas the USDA measure included all livestock and crop inventories in a single class. Furthermore, the InSTePP researchers included mowers, combines, and pickers/balers as separate classes of machinery, whereas the USDA researchers included these in a single class labeled ‘other machinery,’ the exact content of which is unknown to us. The InSTePP researchers also compiled disaggregated counts of tractors and combines of different sizes and types at the state level to explicitly address changes in the quality or composition of these machines over time. Finally, the InSTePP researchers used unpublished data on machinery sales provided by the Association of Equipment Manufacturers to help reduce errors related to aggregating tractors and combines of different vintages. For these reasons, the composition of the assets included differs substantially between the two capital aggregates.

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[9] Any statements concerning the construction of the USDA and InSTePP data are the authors’ interpretation of the methods based on the published data documentation.

The USDA researchers assumed a hyperbolic depreciation pattern for capital assets, which implies an increasing rate of depreciation over an asset's life (a concave pattern of depreciation over the service life of an asset). In contrast, the InSTePP researchers assumed a geometric depreciation pattern for durable assets, which implies that assets deteriorate rapidly in the early years of life and more slowly in later years (a convex pattern). Although the choice of depreciation pattern differs, each of the methods used to depreciate the capital stocks has been widely used and accepted in the literature on the measurement of capital. The USDA expressed the decline in the productive efficiency of an asset *t* years old using the hyperbolic function,

$$d_t = (L-t)/(L-\beta t), \quad 0 \le t \le L \tag{5}$$

and $d_t = 0$, $L < t$, where L is the assumed service life of the asset, and β is known as the decay parameter. The decay parameter can take on different values depending on the asset. The USDA researchers set $\beta = 0.5$ for equipment, $\beta = 0.75$ for buildings, and $\beta = 1.0$ for inventories (a one-hoss-shay pattern). The InSTePP researchers assumed a constant geometric rate of depreciation of durable assets, δ, with different rates for the different types of assets (see Table 1). The different assumptions concerning the depreciation of assets imply differences in the estimates of stocks and rental rates in the InSTePP and USDA data sets; however, it is difficult to say how much this aspect may have contributed to the observed differences in the InSTePP and USDA indexes of capital input, considering the numerous other differences between these measures.

The age of retirement of assets also differs significantly between the two data sets. In the case of a geometric decline in efficiency, it is typically assumed that an asset will be retired when its productive efficiency falls below a threshold. The threshold and the assumed constant rate of depreciation, δ, jointly determine the service life of the asset. For example, the InSTePP researchers set the threshold at 10 percent, and calculated service lives using the expression, $(1-\delta)^L = 0.10$. The USDA used estimates of service lives from a 2003 Bureau of Economic Analysis (BEA) publication titled, *Fixed Assets and Consumer Durable Goods, 1925-97*.

Table 1 shows that the USDA estimates of service lives are shorter than the InSTePP estimates for all assets. In general, the choice of service lives can have a substantial impact on the resulting estimates of stocks and rental rates. In Figure 1, we have graphed the assumed depreciation patterns for tractors, trucks, service structures, and other machinery for a single unit of capital over the corresponding assumed service life. Under the hyperbolic depreciation assumption, in the early years of its service life capital deteriorates less rapidly than under the geometric assumption. While we did not test the sensitivity of the capital measures to changes in service lives, this is another important difference in the construction of the InSTePP and USDA capital series and another potential source of discrepancy between the measures. Recall, as discussed above, the literature in this area indicates that, although the hyperbolic pattern might be more representative of the depreciation pattern for a homogeneous class of capital (same type and vintage), the geometric pattern is more representative of depreciation in a heterogeneous class of capital (different types and vintages).[10]

[*Figure 1: Hyperbolic (USDA) and Geometric (InSTePP) Depreciation Patterns*]

The rental rate of capital is typically a function of the price of a new unit of capital, the real interest rate, the rate of depreciation and the service life of the asset. The simplest form for the rental rate calculation assumes a constant geometric rate of depreciation, a constant interest

[10] A heterogeneous class of capital means we are aggregating different types of capital within a given category. For example, constructing an index of tractor services requires aggregating over tractors of different vintages and different horsepower.

rate, and, implicitly, an infinite service life: i.e., $\rho_t = P_t\left(r+\delta\right)$.[11] In constructing the quantity indexes, the rental-rate estimates are used as proxies for the relative marginal products of the different classes of capital. If the rental rates do indeed reflect the relative marginal products, they will be the appropriate weights to use when calculating the aggregate index of capital services.

The InSTePP researchers used an annual real interest rate of 4 percent and a constant (asset-class-specific) annual rate of depreciation to estimate asset rental rates. The USDA used an exogenous market interest rate and a rate of depreciation that varies with the age of the asset to estimate asset rental rates. The market interest rate used by the USDA researchers was the annual yield on Moody's BAA corporate bonds, minus the rate of inflation as measured by the rate of growth of the implicit price deflator for Gross Domestic Product—the GDP deflator.[12] The choice of a constant or variable interest rate in the rental rate expression has advantages and disadvantages. For instance, using a variable market rate to represent opportunity costs in the rental rate calculation can result in highly volatile estimates (Harper, Berndt and Wood 1990). A constant real interest rate is easier to implement and has the intuitive appeal of representing an expected average annual rate of return over the entire service life of an asset. One potential drawback of using a constant rate is that it may be an inaccurate measure of opportunity cost during turbulent economic periods or if real interest rates undergo a substantial, enduring shift. Obviously, these differences can (and do) result in different estimates of rental rates and thus different weights in the final step of the indexing procedure. Only limited state-specific data on asset prices in agriculture are available. Hence, the rental rate estimates for the different classes

[11] An income tax rate is sometimes included in the rental rate expression as well.

[12] A detailed description of the methods used to construct this measure is provided in Ball, Butault and Nehring (2001).

of capital are all national estimates except for the five classes of biological capital in the InSTePP data, and the class of inventories in the USDA data, which are state-specific estimates.

One apparent similarity between the InSTePP and USDA indexes of capital services is the use of a Fisher Ideal indexing procedure (see equation 4). However, even this commonality is obscured because of additional treatment of the Fisher indexes by the USDA researchers. Notably, the USDA state-specific indexes are multilateral, meaning they are normalized to one state (Alabama) in one time period (1996). The USDA researchers applied methods developed by Elteto and Koves (1964) and Szulc (1964) to incorporate spatial differences in prices among the states in their indexes. The idea is to incorporate relative price differences among states much in the same manner that standard (chain-linked) quantity indexes incorporate inter-temporal price changes. Given its extensive use of state-specific data, InSTePP's capital series is a conventional set of panel of estimates spanning the 48 contiguous U.S. states for the period 1949-2001; the InSTePP national series was formed by a Divisia aggregation of the state-specific data.

5. Comparisons of the Capital Series

In this section we provide additional comparisons and examine differences in the final estimates of capital service flows from InSTePP and the USDA. We compare the estimated indexes of the quantity of capital services as well as the real value of those services. The value of capital services can be calculated as the rental rate of capital multiplied by the corresponding flow of capital services each period. For instance, given ideal data, we could calculate the number of tractor hours used in production in each year and multiply the number of hours by the estimated hourly rental rate of tractors. Data of such detail are not available; however, constructing indexes of aggregate capital input requires calculating the annual value of the flow of services from each class of capital, which is an estimate of the annual stock multiplied by the rental rate of capital. Furthermore, the InSTePP and USDA estimates of the annual value of services from each class of capital are comparable because they are in the same units, dollars.

To facilitate state-by-state comparisons we standardized the InSTePP and USDA state-specific indexes of capital service flows to a base period of 1960. Divisia type indexes are invariant to choice of base period; however, differences in the specifics of the indexing and other data construction procedures should be kept in mind when examining differences in the resulting estimates. In most of the comparisons that follow, a subset of the InSTePP and USDA data sets is used, representing the years in which the two data sets overlap.[13]

Indexes of the quantity of capital services for each of the 48-contiguous U.S. states are plotted in Figure 2. A visual inspection reveals that the InSTePP capital series are substantially different from the USDA series in the majority of states. Statistical tests indicated that we failed to reject the hypothesis of equality of the means of the state-specific capital series in only 10 of the 48 states.[14] We also performed F-tests of the equality of the standard deviations for each state and we failed to reject the hypothesis of the equality of the variances in only 9 of the 48 states. Not only are the annual averages and variances of the state-specific measures mostly different, the InSTePP measures of capital services indicate far more state-to-state variation than the USDA measures. A common pattern is apparent for most states in the USDA data, which is an upward trend before the early 1980s and a downward trend thereafter. This suggests that the state trends in the USDA measures are driven more by national than state-specific effects.

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[13] The indexes of the quantity of capital service flows overlap for the period 1960-2002; however, we also have national data on the value of capital services for different categories of assets that overlap for the years 1949-1999. Therefore, comparisons of national value data are for the years 1949-1999 where indicated.

[14] We performed two-tailed t-tests for equality of the means (annual average 1960-2002) of the two series under the assumption of unequal variances. In 38 of the 48 states we calculated p-values of less than 0.05, indicating rejection of the null hypothesis of equal means in these states.

[Figure 2: *State-specific Indexes of the Quantity of Capital Service Flows, 1960 = 100*]

Figure 3 shows scatter-plots of the annual averages (1960-2002) of the state-specific estimates of capital services from each database. The farther are the figures away from the indicated 45 degree lines, the larger is the difference in the estimates between the two databases. The plot of the quantity indexes in Figure 3, Panel a reveals that the USDA estimates are slightly greater on average for the majority of states and the nation. Figure 3, Panel b shows that on average the growth rates of the state-specific quantity indexes are similar for the full 1960-2002 period, and both of the national estimates indicate the quantity of capital was slightly decreasing at an annual rate of less than one-half of 1 percent per year. However, the full-sample averages mask large differences in the measures during certain sub-periods. In terms of the real value of capital services, the USDA measures are greater in all of the 48 states as shown in Figure 3, Panel c, and the estimated growth in the services is also greater in most states as shown in Figure 3, Panel d. The USDA estimates of the real value of capital services are greater than the InSTePP estimates in all 48 states primarily because of a large 'bubble' in the USDA series in the 1980s that is not present in the InSTePP data. In the remainder of this section we examine more closely some differences in data construction methods and data sources that might have caused the wide discrepancies in estimates of capital service flows between the two data sets.

[Figure 3: *USDA versus InSTePP Capital Service Flows, 1960-02*]

National estimates of the real value of services (1949-99) from tractors and trucks, other machinery, service structures, and aggregate physical capital from each of the data sets are shown in Figure 4, Panel a.[15] Note the similar pattern in each of the four sets of plots in Figure

[15] In this example, the 'other machinery' category for the InSTePP series represents the sum of the service flows from combines, pickers/balers, mowers, machine hire, and automobiles. In the USDA series it represents their category of 'other machinery' plus automobiles. Nominal values were deflated using the GDP-IPD (base year 1996).

4, Panel a, revealing that the USDA and InSTePP value series diverge in the 1970s and early 1980s and then re-converge in the later 1980s and 1990s. The USDA and InSTePP estimates for the value of truck and tractor services follow relatively similar paths over most of the sample; however, even these series are different for most of the 1980s.

[Figure 4: *The Real Value of Capital Services in U.S. Agriculture, 1949-99*]

In Figure 4, Panel a each of the USDA value series increases sharply from around 1975, peaks around 1982, and then declines sharply. This pattern is consistent with movements in real interest rates during the same period, and we suspect that the pattern is the result of using a variable market interest rate in the calculation of capital services. Figure 4, Panel b shows the annual average growth rates of the value series for different periods. The averages for the full sample (1949-99) indicate little difference between the InSTePP and USDA series; however, substantial differences are apparent in the sub-periods (decades). One notable difference is that the InSTePP measure of the real value of aggregate capital services increased at a rate of 1 percent per year in the 1990s, and the USDA measure decreased by approximately 3 percent per year. These are very different findings about patterns of capital use in agriculture, which have very different implications for understanding what happened and when, for findings from models of agricultural production, and for agricultural policy that is based on such measures of agricultural capital and productive performance.

The USDA estimates of the value of capital services in the 1980s are quite volatile—and we suspect they are so because the USDA used the same (national) market interest rate to calculate rental rates for each class of capital. Recall that the USDA calculated real interest rates as the annual yield on Moody's BAA corporate bonds, minus the rate of inflation measured as the rate of growth of the GDP deflator. We constructed a comparable measure of real interest rates using publicly available data and the results are presented in Figure 5 along with the USDA estimate of the aggregate U.S. value of agricultural capital services.[16]

[Figure 5: *The Real Interest Rate and the Real Value of USDA Capital Services, 1960-02*]

The use of a real market interest rate in the calculation of the capital series has a pervasive effect, and appears to account for most of the variation of the USDA capital series. Recall that InSTePP used a constant real interest rate of 4 percent per annum, which is slightly higher on average than the market rate before 1980 and lower than the market rate thereafter. Apparently, the interest rate has a substantial impact on the estimated aggregate value of capital services. In Figure 3, Panel a the USDA estimate of the aggregate value of capital services is roughly consistent with the InSTePP estimate, except for the volatile economic period from 1975 to 1990 when market interest rates were abnormally high. The effect was also transmitted into the state-specific indexes of the quantity of capital input, which exhibit a similar pattern for almost all of the 48 contiguous states in the USDA data.

Real interest rates are likely to be important as a determinant of current investment; but short-run changes in real interest rates probably do not have a major influence on the use of existing capital on farms, which represents the bulk of capital in U.S. agriculture. Unless farmers change the rate at which they utilize their existing stock of capital substantially in response to changes in current interest rates, it would be more sensible to use a less-volatile average market rate when constructing indexes of capital services, and thus reduce the odds of introducing spurious volatility into the measures. Finally, our informal analysis indicates that the different treatment of interest rates in the USDA and InSTePP capital series is the predominant

[16] The source of annual yields on Moody's BAA corporate bond is the Federal Reserve Bank of St. Louis. The source of the inflation series is the Bureau of Economic Analysis.

source of the large discrepancies between the final estimates of capital service flows in the databases.

6. Conclusion

Measuring the annual flow of capital services is a complicated task. It requires decisions about the general approach along with a host of specific assumptions, many of which may significantly influence the resulting measures of capital input. Some of these decisions are driven by availability of data and others by the purpose to which the estimates will be put. In this paper we have reviewed common methods used to obtain measures of the annual flow of services from the stock of agricultural capital, and compared estimates from two data sets that measure capital services in U.S agriculture for the 48 contiguous states. Both sets of estimates use modern index number procedures and appropriate economic theory. Even so, the comparison revealed a host of differences between the measures, indicating that the choice of methods used to construct measures of capital input, in conjunction with differences in the underlying data, can have a big influence on the resulting estimates.

We explored various potential sources of differences and found that the measures are particularly sensitive to the treatment of interest rates, which is a likely source of the very substantial differences in the measures. The use of a real market interest rate in the calculation of capital services introduces volatility in the measure that is not likely to be consistent with the actual services that flow from the stock of capital on farms. A fixed annual average real interest rate (like 4 percent) avoids the problem of excess volatility, and is more plausible as a representation of the use of existing capital on farms.

More research is needed to quantify the importance of assumptions related to the treatment of interest rates, depreciation, service lives of assets, and indexing procedures. Once this is accomplished, we can be more confident in the accuracy and interpretation of these difficult-to-construct measures. Meanwhile, those who wish to treat the measures from either the InSTePP series or the USDA series as data for econometric studies of production or productivity should be aware of the nature of these measures.

The USDA capital input data are readily available and have been used in numerous published studies concerning the structure of agricultural production. For example, we identified 10 recently published studies that utilized the USDA capital data in applications including estimations of capital use (e.g., Ball 2000; Ball et al. 2008), productivity growth (e.g., Ball et al. 1999; Ball et al. 2001b), convergence of productivity growth (e.g., Rezitis 2005; McCunn and Huffman 2000), factor demands (e.g., O'Donnell et al. 1999), environmental effects of production (Morrison et al. 2002; Ball et al. 2004), and the benefits from public investments in agricultural R&D (e.g., Huffman and Evenson 2006).[17] The results from those studies that focused on input (especially capital) uses may be especially vulnerable to the measures of capital service flows, but the results from all studies are sensitive to data measurement details to some degree. As suggested by Gardner "The bottom line is, for data producers, that full disclosure of procedures and labeling of data series are essential; and, for data users, be careful and investigate the data before using them . . . (1992, p. 1076)." This dictum seems to apply especially well to the data series on agricultural capital use, and to the interpretation of findings based on these data.

[17] Other recent studies using the USDA capital data include: Ball, Bureau, Nehring, and Agapi (1997); Ball, Bureau, Butault, and Nehring (2001); Ball, Butault, and Mesonada (2004); Ball, Hallahan, and Nehring (2004); and Pope, LaFrance, and Just (2007).

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Table 1: *Composition of Capital Aggregate and Service Life Assumption*

InSTePP				USDA			
Category	*Class*	*L*	δ	*Category*	*Class*	*L*	β
Machinery				Machinery			
	Automobiles*	9	0.23		Automobiles*	na	0.50
	Trucks*	12	0.18		Trucks*	9	0.50
	Tractors*	15	0.14		Tractors*	9	0.50
	Combines*	15	0.14		Other machinery*	14	0.50
	Mowers*	15	0.14				
	Picker/balers*	15	0.14				
Biological Capital				Inventories of			
	Breeding cows*	5	0.00	Crops/Livestock*		1	1.00
	Chickens*	1	0.00				
	Ewes*	6	0.00				
	Milking cows*	5	0.00				
	Sows*	3	0.00				
Service Structures*		45	0.05	Service Structures*		38	0.75

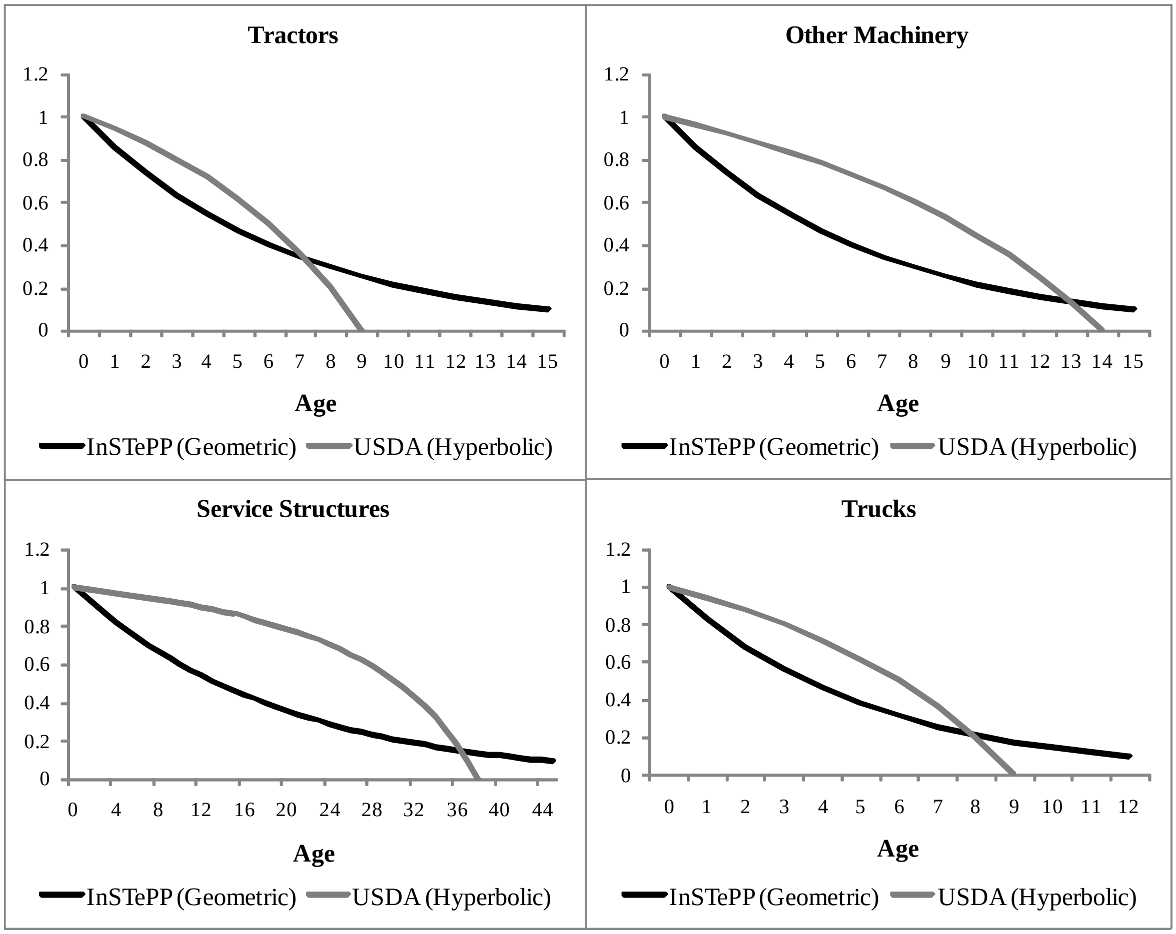
Notes: Asterisks denote *Classes* (or *Categories*) with asset-specific estimates of stocks and rental rates. *L* denotes service life in years; δ is the annual rate of depreciation; and β is a decay factor.

a. Capital *Class* indicates capital with a specific depreciation profile and service life.

b. Capital *Type* indicates distinct items within each class. Combines are distinguished by width of combine head. For 1964-1989 the *Types* of combines include 6 widths ranging from less than 12 feet to 30 or more feet; for 1994-2002 the types include widths or less than 24 feet, 24-30 feet, and 30 or more feet. Tractors *Types* are distinguished according to horsepower. For 1964-1989 there are 16 types of 2WD tractors ranging from less than 20 horsepower to 180 horsepower or more as well as 3 types of 4WD tractors up to 250 horsepower. Data for the same 16 types of 2WD tractors were available for the 1994-2002 period, but there are 4 types of 4WD tractors ranging up to 350 horsepower or more in capacity.

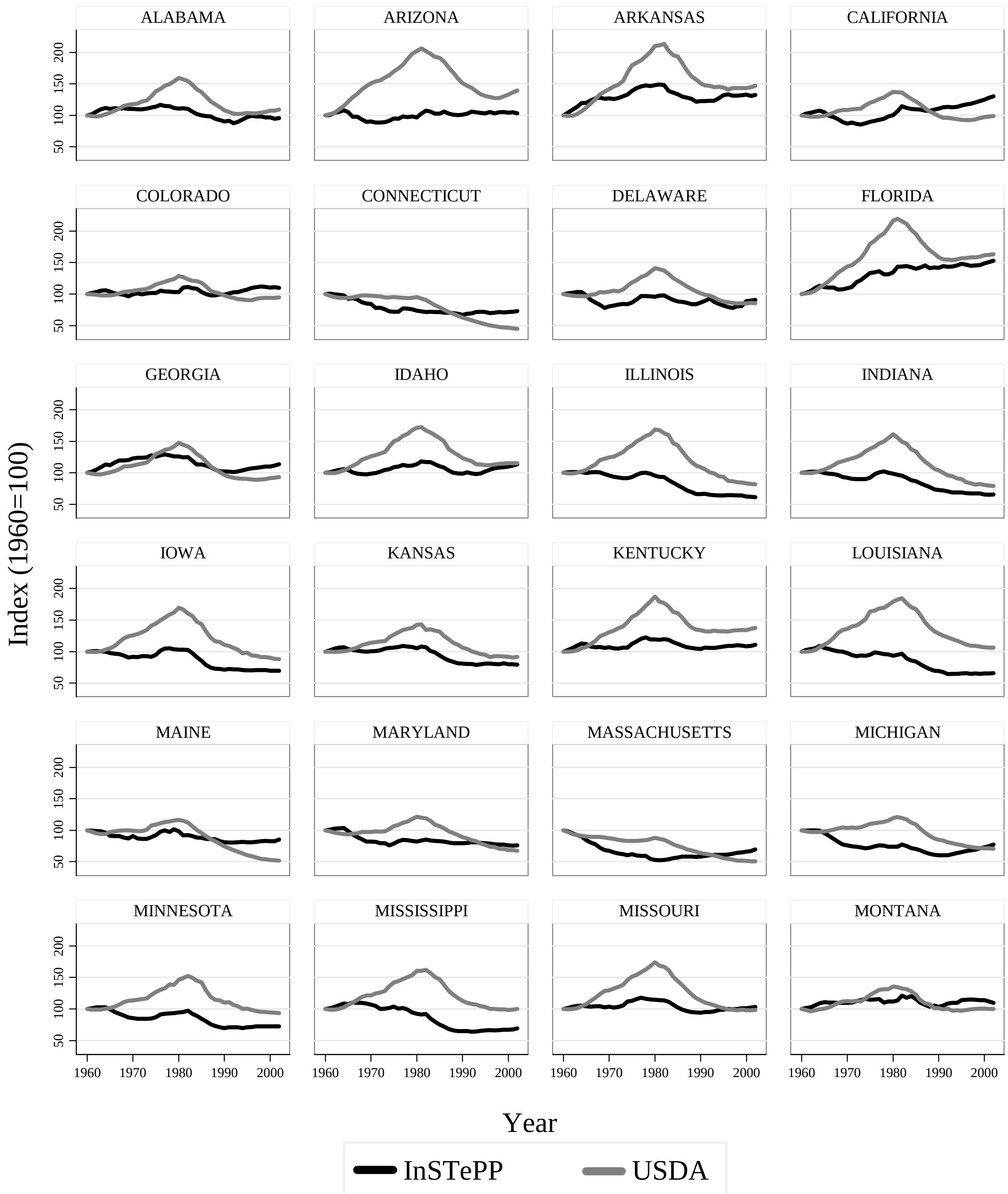
c. Service structures exclude residential buildings.

Figure 1: *Hyperbolic (USDA) and Geometric (InSTePP) Deterioration Patterns*



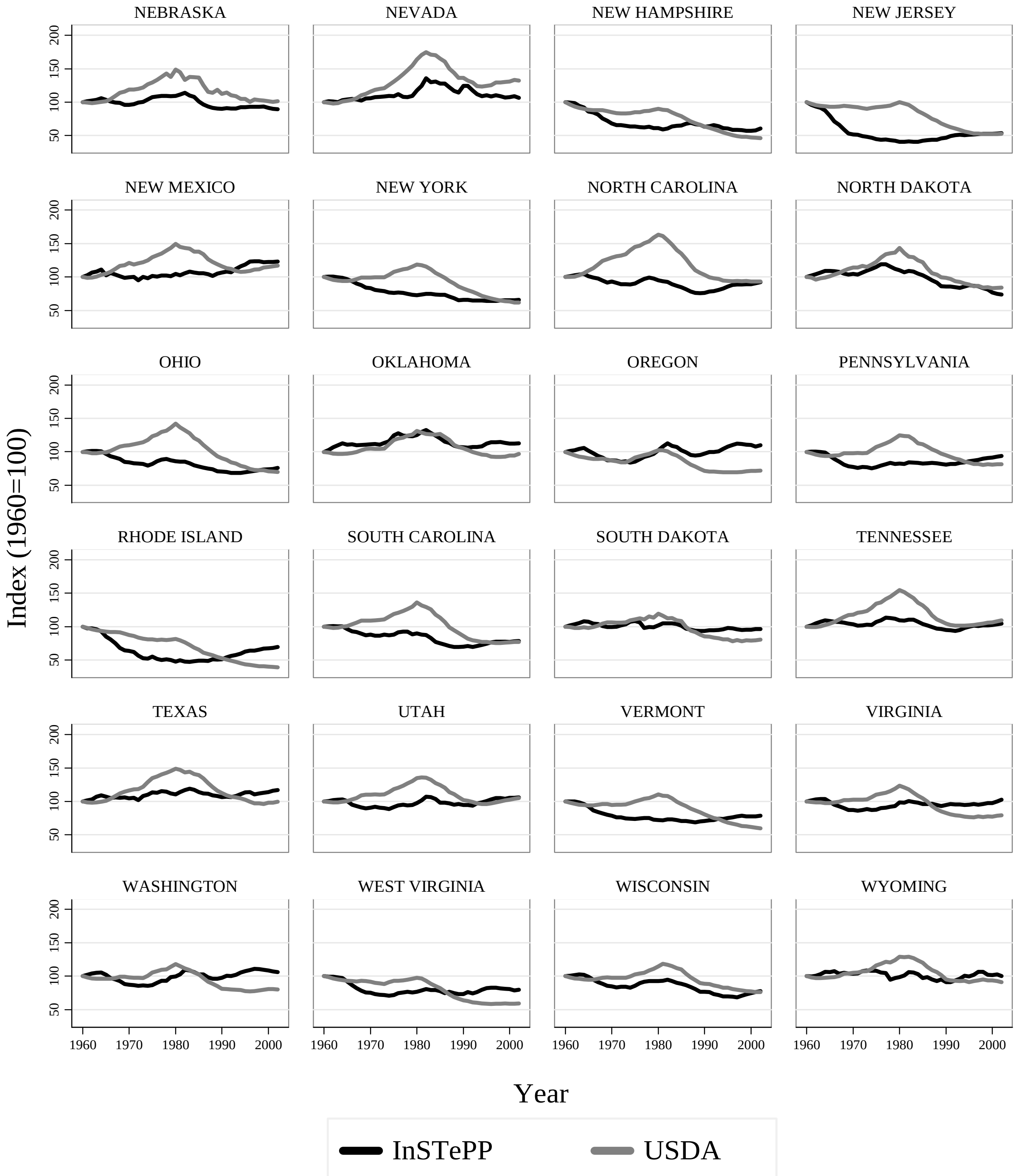
Source and Notes: Calculated by authors. Figures indicate the assumed depreciation patterns of the respective capital series over their service lives from purchase (i.e., age = 0).

Figure 2: *State-specific Indexes of the Quantity of Capital Service Flows,* 1960 = 100



Source: Calculated by authors.

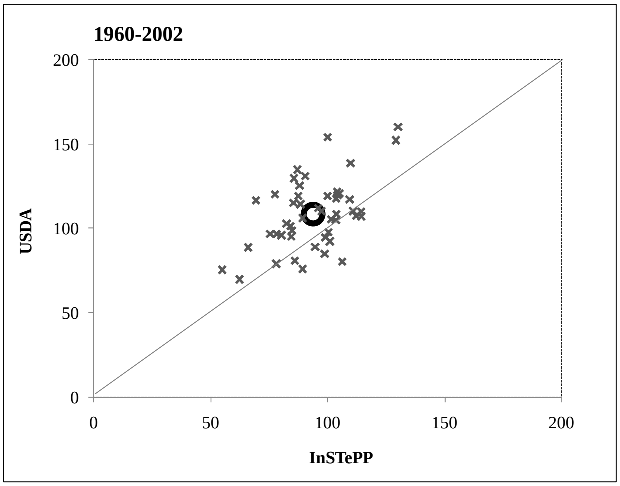
Figure 2 *State-specific Indexes of the Quantity of Capital Service Flows,* 1960 = 100 (contd.)



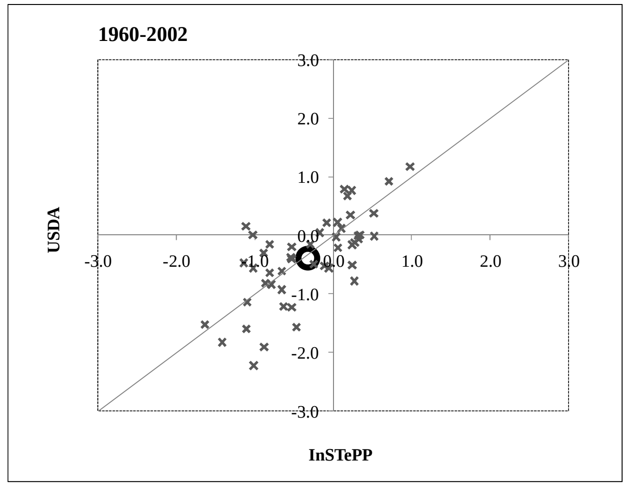
Source: Calculated by authors.

Figure 3: *USDA versus InSTePP Capital Services Flows, 1960-02*

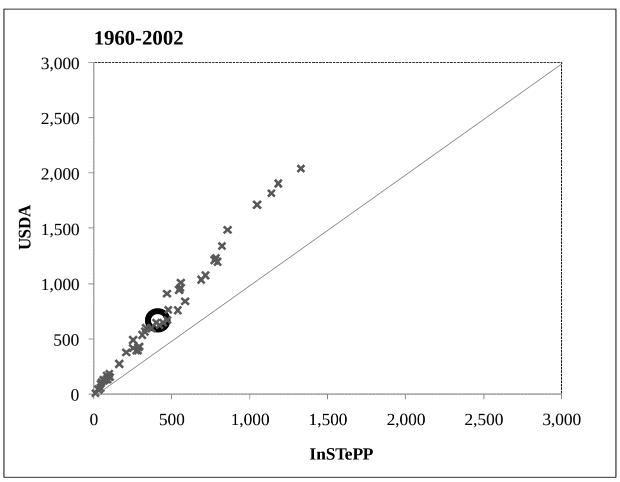
Panel a: Quantity Indexes



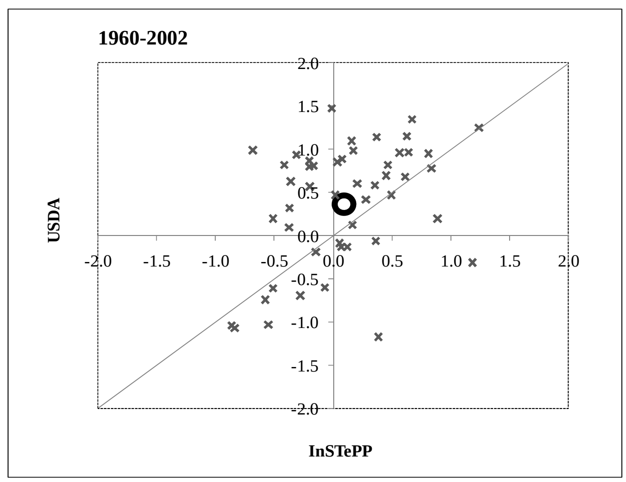
Panel b: Growth Rate of Quantity Indexes



Panel c: Real Value of Services (Millions)



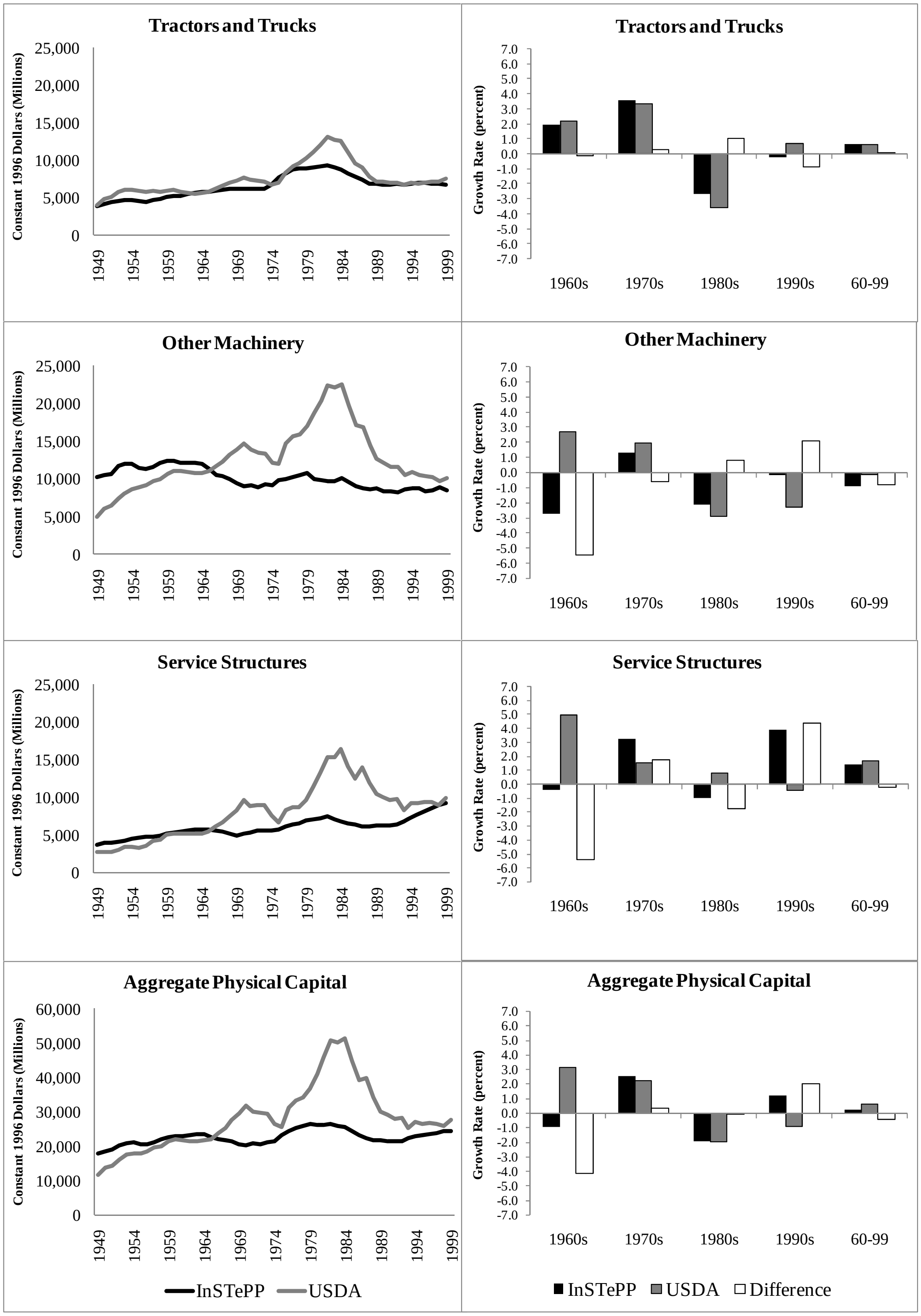
Panel d: Growth Rate of Real Value



Source and Notes: Calculated by authors. Annual averages for given period. Figures for individual states are denoted with an (×), and the large circles represent the 48-state average. Figures deflated using the GDP-IPD (based to equal 1.0 in 1996).

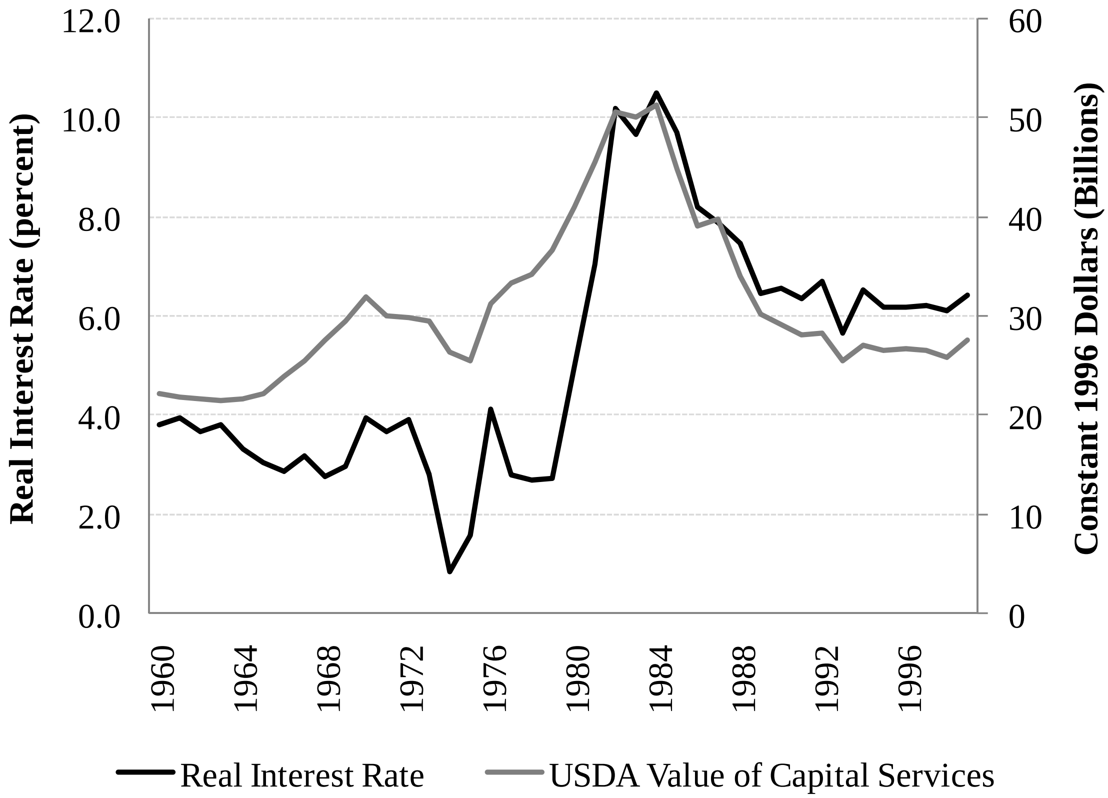
Figure 4: *The Real Value of Capital Services in U.S. Agriculture, 1949-99*

Panel a: Real Value of Services *Panel b: Growth Rate of Real Value*



Source and Notes: Compiled by authors. USDA data provided by Eldon Ball at the ERS. All figures deflated using the GDP Implicit Price Deflator (base year 1996). Growth rates are annual averages for given period. For InSTePP data 'Other Machinery' includes autos, combines, mower/conditioners, picker/balers. For USDA 'Other Machinery' includes autos and unspecified miscellaneous machinery.

Figure 5: *The Real Interest Rate and the Real Value of USDA Capital Services, 1960-99*



Notes: The USDA value series excludes inventories. The value series is deflated using the GDP-IPD (based equal to 1.0 in 1996). The real interest rate is the annual yield on Moody's BAA corporate bonds, minus the rate of inflation as measured by the rate of growth of the GDP deflator.