DEPRECIATION OF DURABLE ASSETS: A RECONCILIATION BETWEEN HYPOTHESES

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Studies measuring the total capital stock and its implied service flows are numerous in the economic literature [Jorgensen]. An accurate measurement of the aggregate capital stock is often essential in analyses of investment, consumption, and productivity at both regional and national levels. Growth in the capital stock is considered by many economists and policy makers as an important indicator of the general health of the economy.

Measurement of the capital stock is difficult, owing to the hetero- geneous nature of capital and how it is used. A related problem, however, is measuring how the capital stock depreciates in capacity as it ages. The importance of depreciation at the macroeconomic level cannot be overstated. In 1986, for example, replacement of depreciated capital represented 12 percent of GNP and 68 percent of all fixed private domestic investment [U.S. Department of Commerce].

The manner in which durable assets depreciate is also important at the firm level. Firms frequently obtain loans to gain the necessary financial capital needed to purchase a durable asset. Because the asset is often used as collateral, lenders typically structure retirement of loan principal to ensure that current asset value is and will always remain greater than outstanding principal. Larger than expected declines in asset values can jeopardize the security of these loans. In addition, the rate of economic depreciation can be important in replacement decisions [see, for example, Reid and Bradford, 1983; 1987].

Despite its importance and the amount of research conducted on depreciation, no clear consensus exists about the depreciation patterns followed by different types of capital goods. Jorgensen and his associates have advocated the use of a geometric depreciation pattern in studies of investment behavior. In addition, several analyses of market data for used capital assets appear to support the geometric pattern,

A number of articles have been written challenging the constant rate assumption as both implausible and misleading. Feldstein and Rothschild, for example, point to the unrealistic requirements for asset replacement or asset decay that are necessary for a geometric pattern. Penson, Hughes, and Nelson suggest that the rapid decline in productive capacity immediately after purchase is inconsistent with actual capacity depreciation for individual capital assets. These authors and others [e.g., Taubman and Rasche] also have produced empirical evidence supporting their arguments. Although evidence on both sides is convincing, it does not seem plausible that both can be right.

In this paper we attempt to explain why both arguments can be supported empirically. We suggest that many individual assets within a cohort can exhibit a decidedly non-geometric pattern but that, as an aggregate, will depreciate at a more constant rate. This phenomenon is the result of a) in asset quality and in patterns of usage and care given to these assets, and b) changes in these patterns for an individual

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asset during its life. In the next section we explain in greater detail the implications of geometric versus other depreciation patterns and suggest why usage and care are important (but often overlooked) factors in depreciation. The second half of the paper is devoted to empirical analysis that supports some of the points we make about aggregation usage and care.

Depreciation Patterns

The value of a durable capital good represents the discounted value of all net services derived from the good over its expected life. Although this definition of value is not universally accepted [see, for example, Young and Musgrave] it is the most common definition in use. Economic depreciation represents the change in value occurring during a specified period of time and is important in issues related to durable asset values, taxes, and national income accounts [Hulten and Wykoff, 1981b].

Productive capacity generally represents the total quantity of services that can be derived from a durable capital good over its life. This definition reflects an assumption that input levels do not vary across an asset cohort or across time. Capacity deterioration is a change in the remaining amount of services available during a particular time period. An accurate measure of capacity deterioration is needed, of course, if one is to determine what remaining services are available from aging capital. The ability of asset owners to change input usage can offset declines in productive capacity.

Hall [1967] and others [Arrow; Jorgensen, 1974] have argued that capacity and economic depreciation have a dual relationship. Feldstein and Rothschild counter that this dual relationship exists only if capacity deterioration accounts for obsolescence, changes in the level of inputs required as a result of capital deterioration (or input decay), and the level of output achieved (or output decay). Whether or not productive capacity should reflect input decay and obsolescence depends on the purpose for which productive capacity is being estimated.

Hall [1967] demonstrated that economic depreciation can be expressed as a function of ex ante real discount rates, the price of new capital, and capacity deterioration. When capacity deterioration occurs at a constant rate, however, economic depreciation is solely a function of changes in capacity and is also geometric.

Most researchers express both capital value and current productive capacity relative to their respective values when new. Thus the ratio of current productive capacity to initial capacity (CPC) for a geometric pattern is

(1) $$CPC = e^{-\delta a}$$

where a is the age of the asset and d is a constant that determines the depreciation rate.

A countervailing belief about productive capacity is that it exhibits a hyperbolic relationship of the form

(2) $$CPC = \frac{A - a}{A - \beta a}$$

where A is the age of the asset when scrapped and β is a constant that determines the depreciation pattern. Special cases of the hyperbolic are the one-hoss shay ($\beta = 1$) and the linear ($\beta = 0$). A characteristic of the

[1] Hulten and Wykoff were among the first to argue that heterogeneity of assets plays a major role in depreciation patterns. This paper both supports and builds upon their argument by considering additional aspects of heterogeneity and other factors important in depreciation.

hyperbolic function is that it causes the economic depreciation rate to accelerate over time when $\beta \geq 0$. Should capacity deterioration exhibit a nongeometric form, calculation of aggregate capital stock depreciation and deterioration requires estimates of deterioration by vintage, and some knowledge of the vintage mix in the overall aggregate. In short, a nongeometric function greatly increases the complexity of calculating aggregate depreciation.

The empirical evidence has been somewhat inconclusive. Most studies of automobile depreciation suggest a geometric pattern is appropriate, although some have found that depreciation rates actually decline for automobiles [Wykoff, 1970; 1987; Ackerman]. Whether building depreciation is geometric or hyperbolic is more open to question. Hulten and Wykoff maintain a geometric pattern is correct with Taubman and Rasche, as well as Coen, presenting evidence suggesting a one-hoss shay pattern is more appropriate. Consensus on farm tractors is also not unanimous with Griliches suggesting a geometric pattern and Penson concluding that a near one-hoss shay pattern ($\beta = 0.9$) was more appropriate [Penson, Hughes and Nelson; Penson, Romain, and Hughes].

The focus of this paper is on depreciation of farm tractors. Tractors are probably the single most important durable capital good used in agriculture. As such, estimates of tractor depreciation are important if one is to accurately access productive capacity and value of capital assets in this sector of the economy. Many of the points made, however, are equally applicable to other types of capital.

Individual versus Aggregate Depreciation

The aggregate stock of farm tractors in agriculture is nothing more than the sum of tractors held by all farmers and ranchers. Although all tractors are similar in appearance and function, the aggregate is quite heterogeneous in productive capacity and value. Aside from the obvious differences of size, model type, and manufacturer that exist between tractors, notable differences exist for seemingly identical tractors. For example, although two tractor models may be manufactured on the same day at the same plant, the materials used and small differences in manufacturing technique may result in one later being labeled a "lemon", while the other provides many years of dependable service to one or more farmers.

Of greater importance is what is done with these two "identical" tractors after they leave the manufacturer. Different firms may buy the same model of tractor to perform the same job, but one firm may use the equipment more often than the other. Different rates of use will result in different rates of wear. A heavier rate of use will presumably cause faster depreciation and a shorter life than will occur with tractors subjected to lower use levels.

The usage decision was embodied in Keynes definition of the user cost of capital, in that "... an entrepreneur has to exercise a choice between using up his equipment now or preserving it to be used later on" [Keynes, pp. 69-70]. Keynes also suggested that capital usage will decline with age because factor (or input) costs become too high. In the case of tractors there are additional reasons for a decline in usage. Newer tractors represent more advanced technology and will have a higher degree of reliability. As Oi suggests, older capital tends to be sold to smaller firms, where it is used less intensively and reliability costs are lower. If use does result in faster consumption of capital, tractors with high use should sell for less than lower use tractors, ceteris paribus. Consequently, a decline in use over time will extend the tractor life and slow depreciation.

Parks and others [Schmalensee; Kim] suggest that the rate of capital decay is also influenced by maintenance applied by the asset owner during its life. Care will not be provided unless the expected discounted value of additional services obtained from the tractor, plus the additional market value at the expected time of sale (if relevant), exceeds the cost of care. Providing timely and proper care may greatly extend a tractor's life, but will also generate significant costs to the firm. One might expect care expenditures to decline with asset age because of declines in the value of output (a result of obsolescence). Long-term repairs (such as an engine overhaul) may also not be profitable on an older tractor because it's expected life is shortened.

Most empirical studies of economic depreciation have relied on transaction data for used durable assets. These data are appropriate for this kind of analysis, provided they are a representative sample of the aggregate capital stock. A number of factors suggest, however, that most market data are not representative of the aggregate stock. Most obvious is the omission in market data of tractors that have been retired from service. Clearly retirements must be included in any analysis of depreciation since they were part of the original capital stock. Hulten and Wykoff suggest multiplying market data by the probability of survival to correct for this form of bias.

Misrepresentation also occurs when poorer quality tractors (or "lemons") are over-represented in the market data relative to their share of the aggregate stock [Ackerlof]. A related form of bias is that of heterogeneity in usage. Replacement of a more heavily used tractor would occur sooner than replacement of the same tractor used less intensively. Market data would, therefore, be over-represented in early years by tractors that have had above normal usage. Including a variable for usage in the regression would correct for any usage bias. Accounting for usage would also be desirable if the usage patterns for tractors across their lifetime differed between market (or sample) data and the aggregate tractor stock. Care patterns also may differ between segments of the aggregate tractor stock.

Empirical Results

There are several good reasons for focusing on tractors in empirical work on depreciation. Already mentioned was their importance in agricultural production. Like automobiles, there are well developed markets for used tractors. Unlike automobiles, however, relatively little of a tractor's value could be considered consumptive in nature. Rather, a tractor's value is derived from the work it can do and the costs incurred when doing this work. Finally, tractors have been the focus of much research to determine the influence of age and usage on maintenance, repairs, and reliability.

We use two different approaches in generating empirical results. After suggesting a function for calculating tractor price, we use a simulation approach to suggest how that price behaves over time. The advantage in using simulation is that it allows an analysis of depreciation patterns in a controlled environment. Various assumptions can be made about the factors influencing economic and capacity deterioration, with the results demonstrating how important these factors are in determining depreciation. Also, the effect of aggregating across tractors of different lives can be clearly illustrated in a simulation approach.

The second approach utilizes econometrics in a fashion similar to that used in other studies. Estimating the actual depreciation pattern can indicate the relative influences of age, usage, and care on depreciation. Comparisons with the simulation results can then suggest why depreciation studies could exhibit both constant and accelerated depreciation rates.

Simulation Approach

Assume the value (in real dollars) of a tractor can be calculated as

(3) $$V = \int_{t_1}^{T} [(P(t) \cdot C(t) - R(t) - B(t))(1-\alpha) + \alpha D(t)]\, e^{r(t_1-t)}\, dt,$$

where t_1 is the current year, T is the tractor life (in years), P(t) is the value of output in time t, C(t) is the productive capacity in t, R(t) is repair and maintenance cost in t, B(t) is reliability cost in t, a is the marginal tax rate, r is the discount rate, and D(t) is the amount of tax depreciation claimed in t. Dividing both sides by the purchase price yields a remaining value (RV) equation, which is more convenient for analysis. This division requires P(t), R(t), B(t), and D(t) be converted and expressed as proportions of purchase price.

The resulting equation, written in discrete rather than continuous time, is

$$(4) \qquad RV = \sum_{t=t_1}^{T} [(P'(t) \cdot C(t) - R'(t) - B'(t)) (1-\alpha) + \alpha D'(t)] \, e^{r(t_1-t)}$$

Data for R'(t) and B'(t) were based on engineering studies. D'(t) was based on the MACRS depreciation schedule for tractors. A hyperbolic relationship was assumed for C(t), with $\beta=0.9$ (i.e., close to a one-hoss shay). A 30 percent tax rate and four percent real discount rate were also assumed. Greater detail on the data used and sensitivity analyses for these parameters are given in Appendix A.

Initially it was assumed T was equal to 20. Table 1 provides the remaining values for the first 15 years of the tractor's life. Figure 1 graphically depicts the annual depreciation rates generated for this tractor. The economic depreciation pattern exhibited is nearly linear in shape, with the depreciation rate exponentially increasing over time. Repair costs and, to a lesser extent, depreciation rates and productive capacity deterioration were identified in the sensitivity analyses as being the most important factors in creating the near-linear pattern.

Of course, not all tractors manufactured during the last decade or so are expected to last exactly 20 years. Because tractors are put to so many different uses and intensities of use, one would expect a particular vintage of tractors to generate a distribution of lives. Moving from firm level to aggregate depreciation, therefore, requires some knowledge about this survival distribution.

Despite the importance of survival distributions in understanding depreciation patterns, relatively little has been done in recent years to estimate what distributions are appropriate for any durable asset. Average lives and survival distributions currently used by the Internal Revenue Service and BEA are based on work published in 1935 by Winfrey. His analysis, in turn, was based on survivability of assets manufactured up to 50 years before. All farm equipment considered by Winfrey, for example, was horse-drawn.

A better source of information on tractor survival is a survey conducted by the U.S. Department of Agriculture (USDA) in 1960 which estimated disappearance of tractors between 1927 and 1956 [Csorba]. An examination of these data suggested retirements most closely exhibited a Winfrey L-3 distribution, with an average life of just under 17 years. An average life of 20 years was assumed in this study, recognizing that current tractors are better built and probably will not become technologically obsolete as rapidly as did tractors considered in the USDA survey.

A number of studies have used market data to estimate depreciation relationships. As we suggested before, market data neglects tractors that have been consumed or worn out. The aggregate depreciation pattern for only marketable tractors is reported in Table 1, as is the aggregate pattern for both marketable and defunct tractors. Both are weighted using the Winfrey L-3 distribution.

Both patterns exhibit a convex relationship and, as Figure 1 demon- strates, the year-to-year change in depreciation rates is less than that for a tractor with a 20-year life. The yearly rate begins to increase exponentially after year 30 for both aggregate patterns, but by that time remaining value is less than 10 percent of purchase price. Thus, although depreciation is rapid after year 30, the relative cost to society is small. Also, the depreciation rate for marketable tractors fluctuates within a relatively small range (four percent-nine percent) for the first 30 years. Were market data to exhibit this pattern, one might conclude from econometric analysis that depreciation most closely appropriated a geometric pattern.

The age of the USDA data leaves the assumption of an L-3 survival distribution somewhat open to question. Two alternative distributions, an L-1 and a uniform, were also considered. Remaining value for these distributions are given in the table for all tractors, with the depreciation rates indicated in Figure 1.

In both cases, the year-to-year change in depreciation rate was markedly different from that for the L-3 distribution. For the uniform distribution, the rate was within a five percent range during the first 25 years of the data.

Depreciation rates generated from the simulation model are in real terms. Year-to-year changes in the depreciation rate would be less if nominal remaining values were considered. Changing assumptions about capacity deterioration and repair costs could result in a decreasing depreciation rate for all tractors.

The simulation results provide a number of insights into aggregate depreciation. Use of an average life (such as 20 years) to calculate depreciation may result in a pattern that is much more accelerated than exists when considering all possible lives with their probabilities of occurrence. This point is important because other studies [Coen; Penson, Hughes and Nelson] have assumed a fixed service life when identifying aggregate depreciation patterns. In both studies the results tended to support the hypothesis that capital asset depreciation occurred at an accelerated rate.

Ignoring the influence of retirements on depreciation may lead one to believe depreciation is geometric. Estimates of nominal depreciation may also exhibit a constant rate. Perhaps most significant, the survivability distribution assumed can have significant impact on depreciation patterns.

The simulation result presumes annual usage and care given to the tractor is the same across its entire life and that all tractors of a particular vintage are represented in the market in direct proportion to their ultimate lives. If usage is a significant factor in remaining value for tractors and usage declines over time, one would expect depreciation to mimic a geometric depreciation pattern. A decline in care over time may offset the effect of declining usage, depending on the relative influence of these two variables on economic depreciation. More important, if usage and care patterns in the data are not representative of aggregate patterns, the estimated rates of depreciation could be quite misleading (assuming these variables influence depreciation). In the next section we consider the influence of usage and care on depreciation patterns.

Econometric Results

The simulation approach permits examination of aggregate depreciation patterns under controlled conditions. An econometric analysis of market data for used tractors permits an opportunity to determine what actual economic depreciation patterns are reflected in the market place and what factors influence these patterns. The estimated model was based on Hall's [1967] work suggesting that depreciation is a function of age, interest rates, and price of new capital. The age variable was expanded to include usage and a proxy for care.

A number of economic depreciation studies for tractors have been conducted [Griliches; Reid and Bradford 1983; 1987]. Virtually all of these studies have relied on "blue book" information published by the National Farm and Power Equipment Dealers Association. This data set contains several flaws. The effect of usage or condition on tractor value is not reported. More important, comparisons of depreciation rates suggest geometric depreciation patterns are assumed when calculating resale prices for different years of the same tractor model. Such characteristics rule out use of these data in identifying economic depreciation patterns.

Markets for used tractors can be subdivided into three categories: 1) purchases involving equipment dealers, 2) auction sales, and 3) person-to-person sales (e.g., sales to neighbors, classified ad sales, etc.). Probably the bulk of the market involves equipment dealers, but auction and person-to-person sales are also significant. The disadvantage in using transactions by equipment dealers is that many are not "arms length" transactions, but involve warranties, financing options, and trade-in considerations (much like the automobile market). Similar factors may be present in person-to-person transactions. Prices from auction data, however, would reflect the perceived productive value of different tractors over their remaining lives.

Auction prices for farm equipment have been published monthly since 1984 by Hot Line, Inc. The data are reported by auctioneers and include the tractor model, sale price, age, an estimate of condition, and some general descriptive information. Although several thousand transactions were available in the original data set (covering the period January 1984-June 1988), most were not included because hours of use were not reported. The remaining data set contained 869 observations.

Several types of auctions were included in the data set. Auctions for farmers who were retiring from farming were most prevalent and represented almost 60 percent of the data. Bankruptcy auctions accounted for another 30 percent of the observations. Consignment sales and other types accounted for the remaining 10 percent. Based on this mix, one can conclude that any lemon bias in the data is probably minimal, since retirement or bankruptcy auctions normally would not be expected to have disproportionate numbers of "lemons" for sale.

Numerous technological advances in tractors occurred during the 1950s and 1960s. Among these advances were development of large, diesel-powered tractors, four wheel drive systems, enclosed cabs, and greater number of transmission speeds. The technological advances of the 1970s and 1980s have been modest in comparison. To avoid having to model two different technological eras, only tractors manufactured since 1970 were included in the data set.

Many econometric studies of equipment depreciation have used the ratio of sales price to list price as a dependent variable. The advantage with this approach is that it allows for aggregation of different sizes of tractors into one data set, thereby increasing the number of observations used in econometric analysis. There are some disadvantages in using list price, however. Although list price is used as proxy for sale price, it is generally agreed that there are consistent biases in list price that will alter any regression results. Adjusting the list price for changes in the price level between the current period and year of manufacture is another potential problem.

An alternative for tractors is to use price per unit of horsepower (PPH) produced. Horsepower is a good measure of a tractor's productive capacity. Because a tractor's value is largely derived from its ability to do work (versus the comfort and status factors in automobiles), aggregating across different types and sizes of tractor was not a major problem. To ensure greater uniformity among the tractors considered, the sample was reduced to include tractors of 90 to 165 horsepower. This reduction eliminated smaller tractors used for utility purposes (and in high demand by hobby farmers) and larger, four wheel drive tractors. The remaining tractors in the data set were homogeneous in the sense that they would generally be used for major field work on commercial farms.

Although it is not possible to fully identify the original quality and technology embodied in each tractor being sold, one might presume that farmers have some expectations about quality and technology based on who manufactured the tractor. A similar approach was used by Parks in his analysis of automobile durability. Although there were seven major companies producing tractors in the 90-165 horsepower range during the time period, two companies--John Deere and International Harvester (IH)--were predominant. Regression models were estimated for each of these two companies. Because an insufficient number of observations were available for the remaining five companies (Allis-Chalmers, Case, Ford, Massey-Ferguson, and White), they were aggregated back together and constituted the third model estimated.

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[2] One would expect major options, such as an air-conditioned cab, to have a significant impact on price. Preliminary models in which a dummy ariable was included for tractors with cabs resulted in an insignificant t-statistic for this variable. Closer examination of the data suggests there is apparently some inconsistency on the part of auctioneers in reporting what options are present on each tractor they sell. Cabs, for example, are often not reported for tractors on which they are usually standard equipment. This inconsistency was probably responsible for the insignificance of the cab dummy. It was presumed all other options also were not of statistical importance.

Hulten and Wykoff [1981a] suggested adjusting market data to account for retired capital. The adjustment price (PPH^*) is calculated as

(5) $$PPH^* = \theta_t PPH_o + (1-\theta_t)\,PPH_s$$

where θ_t is the probability of the capital being operational when it is of age t (as calculated using the Winfrey survival distribution), PPH_o is the value of an operational tractor, and PPH_s is the salvage value. The L-3 Winfrey curve was used to derive probabilities of survival, assuming a 20-year average life. Consistent with the simulation model, as well as the Hulten and Wykoff approach, salvage was initially assumed to be zero.

Verification with a local "junkyard" for tractors suggested scrap value is not zero. Scrap tractors of the size and age included in our study are worth \$800-\$3,500 or more, depending on age, condition, and demand for used parts. Unfortunately, we were not aware of any studies that estimated value of tractors sold for scrap. An extensive search of the auction data resulted in identification of 22 transactions where descriptive information suggested the tractor involved was being sold for scrap. These data were used to estimate a simple function for salvage value as a function of age. The estimated function is

(6) $$PPH_s = \text{Exp}\,[\underset{(0.3198)}{4.2754} - \underset{(0.0159)}{0.0697}AGE] \qquad R^2 = 0.517$$

This function generates scrap values consistent with the information provided by the local junkyard. A second set of estimates were made for each company using these scrap values to calculate PPH^* as shown in (5).

It might be expected that an undesirable level of correlation exists between a tractor's age and the total number of hours it has been used. To eliminate this problem, total hours were divided by age to create an hours per year (HPY) variable, which was then used to represent usage. Accurately measuring the care each piece of equipment has received is more difficult. As mentioned before, auctioneers are asked to subjectively evaluate the condition of each machine sold on a scale of 1 to 4 (1=excellent, 4=poor). Condition was used as a proxy for the care variable.

Previously it was suggested that level of care would decline with age and usage. Correlation between care and these two variables potentially could produce undesirable levels of correlation in the data. Simple regressions were estimated for each of the three data subsets. Although age and hours per year were significant, the R^2 statistics for these models were below 0.28. Correlation was, therefore, ruled out as a major potential problem in the estimated models.

No known price index is generated for new tractors in the 90-165 horsepower range. Estimates of average prices paid for new tractors in the 110-129 horsepower range are reported semi-annually by the USDA. These data were used to construct a New Equipment Index (NEI) using 1982 as the base year.

Casual inspection of the regional estimates of new tractor prices suggested that prices were significantly lower in the South and higher in the West than the national average. Unfortunately, regional estimates were discontinued in 1986. To account for these price differences, four regional dummies were created and included in the models. The dummies, designated R_1-R_4, represent the West and Northern Great Plains, the Southern Great Plains, the Eastern Corn Belt and Northeast, and the South. The Western Corn Belt was embodied in the intercept term.

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[3] None of the observations listed usage and all listed conditions as "poor."

Development of an ex ante interest rate is difficult because no satisfactory data exist to represent society's real interest rate expectations. As an alternative, the average nominal rate charged by lenders for farm equipment was used in combination with the GNP Implicit Price Deflator and the estimated average marginal tax rate to arrive at the after-tax real interest rate. The resulting rates, designated as INT in the model, ranged from 4.0 to 7.1.

The functional form used in the estimate can influence the depreciation pattern exhibited by the data, an important point since identification of this pattern is one study objective. Hulten and Wykoff [1981a; 1981b] used a Box-Cox functional form, since it has greater flexibility and in fact can represent most depreciation patterns hypothesized as appropriate for durable goods. We also chose to use the Box-Cox formulation.

The model formulation is

$$P^* = a + bA^* + dH^* + eC^* + fNEI + gINT + d_1R_1 + d_2R_2 + d_3R_3 + d_4R_4$$

where

$$P^* = \frac{PPH^{\lambda}-1}{\gamma}, \quad A^* = \frac{AGE^{\alpha}-1}{\alpha}, \quad H = \frac{HPY^{\delta}-1}{\delta}, \quad C^* = \frac{COND^{\gamma}-1}{\gamma}$$

Because depreciation is influenced by age, usage and care, these three variables were transformed and power transformation parameters estimated for each. All other variables were included without transformations. The models were estimated using the SHAZAM econometrics package.

Table 2 contains the maximum likelihood estimates of the Box-Cox para-meters in the equations for each model. Estimates both with and without salvage value are presented. R^2 estimates were quite good for all six models, given the nature of the data. Virtually all parameters included in the models were statistically significant, particularly those for the three depreciation variables. AGE was, as expected, the single most important variable in all three models (based on the standardized coefficient statistic). The coefficients on prices (NEI) were generally significant and of the proper sign. The estimated coefficients for interest rate (INT) were insignificant, although generally of the proper sign. The regional dummies reflected previously stated observations about new equipment prices, i.e., that prices are generally lower in the South and higher in the West. Tests for homoskedasticity were conducted for all three models with all non-dummy variables. Homoskedasticity generally could not be rejected at the 95 percent level of significance.

The depreciation rate is the change in price during a particular time period, divided by the price at the beginning of the time period. Assuming HPY and COND are constant for a particular time period, the annual rate is

$$\frac{\alpha PPH/\alpha AGE}{PPH} = b\, AGE^{(\alpha-1)}\, PPH^{(-\lambda)} = R^*$$

and R^* is negative when $b < 0$.

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[4] Homoskedasticity was rejected at the 99 percent confidence level for the HPY variable in the Other Model. The presence of the heteroskedasticity was probably the result of combining different companies into a common data set.

The change in the depreciation rate (again assuming no change in HPY and COND) can be calculated as

$$\frac{\alpha R^*}{\alpha AGE} = \epsilon \left[(a-1) - \lambda\left(R^*\frac{AGE}{PPH}\right)\right]$$

where ϵ is the elasticity of PPH with respect to AGE (negative). The rate of depreciation is constant (or follows a geometric pattern) if $\alpha=1$ and $\lambda=0$. If $\lambda>0$ and $\alpha>1$, the rate becomes more negative or accelerates with time. If $\lambda<0$ and $\alpha<1$, the rate moves to zero with time (or deaccelerates). The conditions for an accelerated rate are met for John Deere and IH tractors. The parameters for the Other category fall within the gray area, perhaps suggesting increasing and decreasing rates at different ages.

To better illustrate the patterns for each model, PPH was calculated for years 1-20 with HPY, NEI, and INT set at average values (325., 1.07, and 5.5, respectively) and COND set to 2. The yearly average rates are shown in Figure 2. As suggested by the above derivation, John Deere tractors had a continually increasing depreciation rate over time, increasing from 3.7 percent the first year to 17 percent by year 20. IH tractors had higher initial rates of depreciation, but the year-to-year change in rates was not as dramatic as was the case with John Deere. Other tractors had a much more constant depreciation rate than either John Deere or IH. Noticeably absent from these results is the large initial drop in value from year zero to year one that is commonly observed in other durable asset studies [e.g., Wykoff, 1987]. This absence can be attributed to the lack of transaction prices for new tractors. A casual comparison of the initial PPH values with list prices for new tractors suggest this first year decline is 20 percent-30 percent.

The aggregate depreciation rate for all tractors in the 90-165 horse-power range can be calculated by averaging the weighted PPH values, the weights reflecting the proportion of the aggregate stock represented by each of the tractor companies. These weights were calculated based on the proportion of total observations represented by each company. The weighted depreciation rate is also given in Figure 2.

Perhaps most striking is the similarity between these results and the simulation results in Figure 1. In fact, the depreciation pattern for the aggregate is slightly below that generated using the simulation model and an L-3 Winfrey retirement distribution (Figure 4). Although the degree of similarity is probably coincidental, the simulated rates are not at all inconsistent with those observed in the market data. While this similarity does not prove that all the assumptions made in the simulation model are correct, it does lend some credibility to the simulation approach. Comparisons between the simulation approach and the composite econometric model are appropriate because usage levels and condition are assumed constant in both approaches, salvage value is zero, and the same Winfrey retirement patterns are imposed on both data sets.

The argument that usage and care must be accounted for in depreciation studies has been repeatedly made throughout this paper. To illustrate the importance of these variables, all three models were reestimated without the HPY and COND variables. The estimated parameters are reported in Table 3. The depreciation rates for the three models are illustrated in Figure 3. These patterns are quite different from those in Figure 2, and in fact reflect a near constant rate of depreciation.

Of course, the patterns illustrated in Figure 2 do not correctly reflect aggregate tractor depreciation, because they are based on constant usage and average care for the first 20 years. But the usage and care patterns embodied in the data are probably not representative of the aggregate stock, either. A comparison

[5] The sampling methodology used by USDA was probability proportional to size, meaning that larger farms had a higher probability of being surveyed than smaller farms. One might expect annual tractor use to be higher on large farms because the tractor is more likely to be fully utilized.

between this auction data and a survey of tractor use conducted by the USDA in 1983-84 [Krenz] suggested national average usage is about 613 hours per year or nearly twice that for the auction tractors. Average age is also 40 percent higher for the auction data. Although the USDA data is biased toward larger farms, comparisons with data from tractor advertisements suggest auctioned tractors are (on the average) smaller, older, in better condition, and have less hours when compared to the tractor population as a whole. These characteristics are probably consistent with farmers getting ready to retire. In addition the data set is heavily weighted toward the Midwest, where usage is well below the levels for tractors throughout the southern tier of the U.S.

Average usage tends to decline with age. One must be cautious, however, when examining usage patterns for tractors of different ages bought and sold in the marketplace. A general downward trend in average usage can be expected over time, if only because high use tractors do not survive beyond 8-10 years. Separating the effect of retirements on usage from any conscious decline in usage because of obsolescence and reliability is difficult. If one adopts Keynes' argument, usage would be expected to decline as a tractor ages and with the decline would come a slowing of the depreciation rate.

The addition of an appropriate salvage value to the PPH variable also had significant influence on depreciation patterns. Figure 5 represents annual aggregate depreciation rates for the positive salvage value model along with 75 percent confidence intervals. Average usage was assumed to be 700 hours per year in the first year, thereafter declining by 25 hours per year. Depreciation rates were within a three percent range during the first 15 years. A constant depreciation rate probably would not be rejected if the first two years of data were ignored.

Summary and Conclusions

The objective of this paper has been to suggest some reasons why empirical estimates of depreciation can differ so much from study to study. Beginning with a hyperbolic capacity depreciation pattern for an individual tractor, we demonstrated that aggregation of a tractor stock having different lives will generate a much slower rate of depreciation than is apparent when considering a single, average life tractor. The influence of the distribution for retirements on the depreciation pattern was also illustrated.

Econometric models were then estimated using auction data for tractors. Holding usage and condition constant plus assuming a zero scrap value resulted in a depreciation pattern that was very similar to that generated using the simulation approach. Assuming a decline in usage and condition resulted in a near constant depreciation rate. Accounting for a positive scrap value further stabilizes depreciation at a constant rate. In short, accelerated depreciation patterns for individual assets are not at all inconsistent with geometric patterns for an aggregate capital stock.

A number of additional research topics could be pursued from this point. A better understanding of usage and care patterns for the aggregate capital stock is needed before one can definitely state what depreciation pattern is appropriate for a group of assets. Alternatively, usage and care can be ignored if the data series used to estimate depreciation is representative of the asset class. The sensitivity of the simulation results to the Winfrey survivability distributions underscores the need for an updated analysis of asset survivability. Assuming a zero salvage value is probably inappropriate for most assets, given its effect on the econometric results and depreciation patterns.

The similarity of the simulation results to the depreciation patterns exhibited in the econometric models merits further investigation. The simulation approach is particularly appealing when estimating depreciation patterns for assets that are not commonly traded in used asset markets. Simulation may necessitate more engineering research to identify output deterioration and maintenance costs over the asset life.

References

Ackerlof, G.A. "The Market for 'Lemons': Asymmetrical Information and Market Behavior." Quarterly Journal of Economics 84(1970):488-500.

Ackerman, Susan Rose. "Used Cars as a Depreciating Asset." Western Economic Journal 11(1973):463-474.

American Society of Agricultural Engineers. ASAE Standards, 1985. St. Joseph, Michigan, (1985)

Arrow, Kenneth J. "Optimal Capital Policy, the Cost of Capital and Myopic Decisions Rules." Annals of the Institute of Statistical Mathematics 16(1964):21-30.

Bowers, Wendell and Donnell R. Hunt. "Application of Mathematical Formulas to Repair Cost Data." Transactions of the ASAE 13(1970):806-809.

Coen, Robert M. "Investment Behavior, The Measurement of Depreciation, and Tax Policy." American Economic Review 65(1975):59-74.

Csorba, Julius J. Farm Tractors: Trends in Type, Size, Age, and Use. U.S. Department of Agriculture, Agriculture Information Bulletin No. 231. Washington: U.S. Government Printing Office, (August 1960).

Feldstein, Martin and Michael Rothschild. "Towards an Economic Theory of Replacement Investment." Econometrica 42(1974):393-423.

Griliches, Zvi. "The Demand for a Durable Input: U.S. Farm Tractors, 1921-57" in The Demand for Durable Goods, Arnold Harburger (editor). Chicago: University of Chicago Press. (1960).

Hall, Robert C. "Technical Change and Capital from the Point of View of the Dual." Review of Economic Studies 35(1967):35-46.

Hall, Robert C. "The Measurement of Quality Change from Vintage Price Data" in Price Indexes and Quality Change, Zvi Griliches (editor). Cambridge, Mass.: Harvard University Press. (1971).

Hot Line, Inc. Farm Equipment Guide. Ft. Dodge, Iowa.

Hulten, Charles R. and Frank C. Wykoff. "The Estimation of Economic Depreciation Using Vintage Asset Prices." Journal of Econometrics 15(1981a):367-396.

Hulten, Charles R. and Frank C. Wykoff. "The Measurement of Economic Depreciation" in Depreciation, Inflation, and the Taxation of Income from Capital, Charles R. Hulten (editor). Washington: The Urban Institute Press. (1981b).

Kim, Moshe. "The Structure of Technology with Endogenous Capital Utilization." International Economic Review 29(1988):111-130.

Krenz, Ronald D. Machinery Use in Crop Production in the United States. A.E. No. 8532, Oklahoma State University, Department of Agricultural Economics, (February 1985).

Jorgensen, Dale W. "The Economic Theory of Replacement and Depreciation," Econometrics and Economic Theory: Essays in Honor of Jan Tinberger, W. Sellekaerts (ed.). White Plains, New York: International Arts and Science Press, (1974).

Jorgensen, Dale W. "A Survey of Econometric Investigation of Investment Behavior." Journal of Economic Literature 9(1971):1111-1147.

Keynes, John Maynard. The General Theory of Employment Interest and Money. New York: Harcourt, Brace, and World, Inc. (1935).

McGrann, James M., Kent D. Olson, Timothy A. Powell, and Ted R. Nelson. Microcomputer Budget Management System User Manual. Texas Agricultural Extension Service, Department of Agricultural Economics, College Station. (November 1984)

National Farm and Power Equipment Dealers Association. Official Guide, Tractors and Farm Equipment. Various years.

Oi, Walter Y. "Heterogeneous Firms and the Organization of Production," EconomicInquiry21(1983):147171.

Parks, Richard W. "Durability, Maintenance and the Price of Used Assets," Economic Inquiry 17(1979):197-217.

Penson, John B., Jr., Dean W. Hughes, and Glenn L. Nelson. "Measurement of Capacity Depreciation Based on Engineering Data." American Journal of Agricultural Economics 59(1977):321-329.

Penson, John B., Jr., Robert F.J. Romain, and Dean W. Hughes. "Net Investment in Farm Tractors: An Econometric Analysis." American Journal of Agricultural Economics 63(1981):629-35.

Reid, Donald W. and Garnett L. Bradford. "Machinery Investment Decisions." American Journal of Agricultural Economics 69(1987):64-77.

Reid, Donald W. and Garnett L. Bradford. "On Optimal Replacement of Farm Tractors." American Journal of Agricultural Economics 65(1983):326-31.

Schmalensee, Richard. "Market Structure, Durability and Maintenance Effort," Review of Economic Studies 41(1974):277-287.

Taubman, Paul and Robert Rasche. "Economic and Tax Depreciation of Office Buildings." National Tax Journal 22(1969):534-346.

U.S. Department of Commerce, Bureau of Economic Analysis. Survey of Current Business. Washington: Government Printing Office. (April 1987).

Winfrey, Robley. Statistical of Industrial Property Retirements. Iowa Engineering Experiment Station Bulletin 125, Ames. (1935).

Wykoff, Frank C. "Capital Depreciation in the Postwar Period: Automobiles." Review of Economic Statistics 52(1970):168-172.

Wykoff, Frank C. "The User Cost of Capital from 1978 to 1986: The Case of Business-Leased Automobiles." Paper presented at the Western Economics Association meetings, Vancouver, B.C. (July 8, 1987).

Young, Allan H. and John C. Musgrave. "Estimation of Capital in the United States" in The Measurement of Capital, Dan Usher (editor). Chicago: University of Chicago Press. (1980).

Table 1. Remaining Value Trends for Tractors Based on Simulated Data

Single Tractor-20 yr. life	100	94	89	83	78	73	68	62	57	52	47	42	37	33	31	26
Aggregate Data, L-3 Distribution, marketable tractors	100	93	87	81	75	69	63	58	53	48	44	40	36	34	33	30
Aggregate Data, L-3 Distribution, all tractors	100	93	87	81	74	68	63	57	51	46	41	36	32	27	23	20
Aggregate Data, L-1 Distribution, all tractors	100	93	86	79	73	68	62	57	52	48	44	40	36	33	30	27
Aggregate Data, Uniform Distribution, all tractors	100	91	83	76	70	65	61	56	53	49	46	43	40	37	34	32

Table A1. Sensitivity Results for Simulation Model

	Percent of Purchase Price by Tractor Age															
Scenario	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Base-20 Year Life	100.	94.	89.	84	79.	73.	68.	63.	58.	53.	47.	42.	37.	32.	27.	22.
10-Year Life	100.	87.	76.	64.	54.	43.	33.	24.	15.	7.	0.	0.	0.	0.	0.	0.
8% Discount Rate	100.	96.	92.	88.	83.	79.	75.	70.	65.	61.	56.	51.	45.	40.	34.	29.
ACRS Depreciation	100.	94.	89.	84.	78.	72.	67.	62.	57.	51.	46.	41.	36.	31.	26.	21.
15% Tax Rate One-Hoss Shay	100.	94.	89.	84.	78.	73.	68.	63.	58.	52.	47.	42.	37.	32.	27.	22.
Capacity Depreciation	100.	95.	91.	86.	81.	77.	72.	68.	63.	58.	54.	49.	44.	39.	34.	29.
Repair Function = 1.75	100.	93.	86.	80.	73.	67.	61.	55.	50.	44.	39.	33.	28.	24.	19.	15.
Repair Function = 0.006	100.	95.	90.	86.	81.	76.	71.	66.	61.	56.	51.	46.	40.	35.	30.	25.

Table 2. Box-Cox Parameter Estimates for Full Models

Company	λ	α	δ	γ	a	b	c	d_1	d_2	d_3	d_4	e	f	g	R^2	N	Log Likelihood
A. Zero Salvage Value																	
Deere	0.38	1.23	0.47	1.55	5.6749	-0.3478	-0.0675	0.2268	-0.3514	-0.380	-0.8984	-0.5308	13.327	-0.0503	.808	425	-1891.61
	NA	NA	NA	NA	(1.793)	(0.011)	(0.009)	(0.147)	(0.236)	(0.207)	(0.194)	(0.066)	(1.522)	(0.059)			
IH	0.30	1.07	0.44	0.93	6.0338	-0.3291	-0.0757	-0.2233	0.0333	-0.0421	-0.3542	-.7415	7.6889	-0.0138	.764	260	-1096.42
	NA	NA	NA	NA	(1.817)	(0.016)	(0.011)	(0.142)	(0.245)	(0.185)	(0.191)	(0.095)	(1.505)	(0.059)			
Other Manu-facture	0.25	0.96	0.38	2.39	3.0866	-0.3530	-0.0896	0.3377	-1.2204	-0.1356	-0.405	-0.0812	7.7664	-0.0801	.711	184	-785.08
	NA	NA	NA	NA	(1.92)	(0.023)	(0.019)	(0.153)	(0.487)	(0.162)	(0.236)	(0.036)	(1.596)	(0.061)			
B. Positive Salvage Value																	
Deere	0.35	1.12	0.46	1.52	5.7719	-0.3593	-0.0615	0.1917	0.2986	0.322	-0.7699	-0.4651	11.423	-0.0452	.965	425	-1892.82
	NA	NA	NA	NA	(1.54)	(0.012)	(0.008)	(0.126)	(0.203)	(0.177)	(0.166)	(0.058)	(1.307)	(0.051)			
IH	0.28	0.85	0.44	0.88	5.9497	-0.4898	-0.0688	-0.2009	0.466	0.0372	-0.3310	-0.6897	7.0842	-0.0109	.737	260	-1098.17
	NA	NA	NA	NA	(1.636)	(0.024)	(0.01)	(0.128)	(0.222)	(0.167)	(0.1724)	(0.088)	(1.357)	(0.053)			
Other	0.24	0.70	0.35	2.25	3.5314	-0.5378	-0.0993	0.3289	-1.1572	-0.1143	-0.0216	-0.0816	7.348	-0.0776	.687	184	-786.99
	NA	NA	NA	NA	1.823	0.039	0.021	0.144	0.458	0.152	0.222	0.038	1.504	0.057			

<u>NA - not available when using SHAZAM</u>

Table 3. Box-Cox Parameter Estimates for Models Without Usage and Condition

Coefficient	Deere	IH	Other
λ	0.41	0.24	0.23
α	0.94	0.86	0.86
a	2.3167 (2.45)	-0.9246 (1.647)	1.2083 (1.842)
b	-0.8162 (0.026)	-0.4552 (0.024)	-0.4368 (0.026)
d_1	0.1407 (0.120)	-0.283 (0.141)	0.171 (0.149)
d_2	-1.4879 (0.286)	-0.5268 (0.237)	-1.7201 (0.464)
d_3	-0.3686 (0.286)	0.0198 (0.184)	-0.1439 (0.16)
d_4	-1.3641 (0.266)	-0.4083 (0.186)	-0.1493 (0.233)
f	-16.938 (2.089)	11.021 (1.411)	8.198 (1.565)
g	-0.0120 (0.081)	-0.0772 (0.059)	-0.0177 (0.058)
R^2	0.721	0.609	0.661
Log-Likelihood	-1971.1	-1161.7	-799.7

Figure 1. Simulated Depreciation Rates

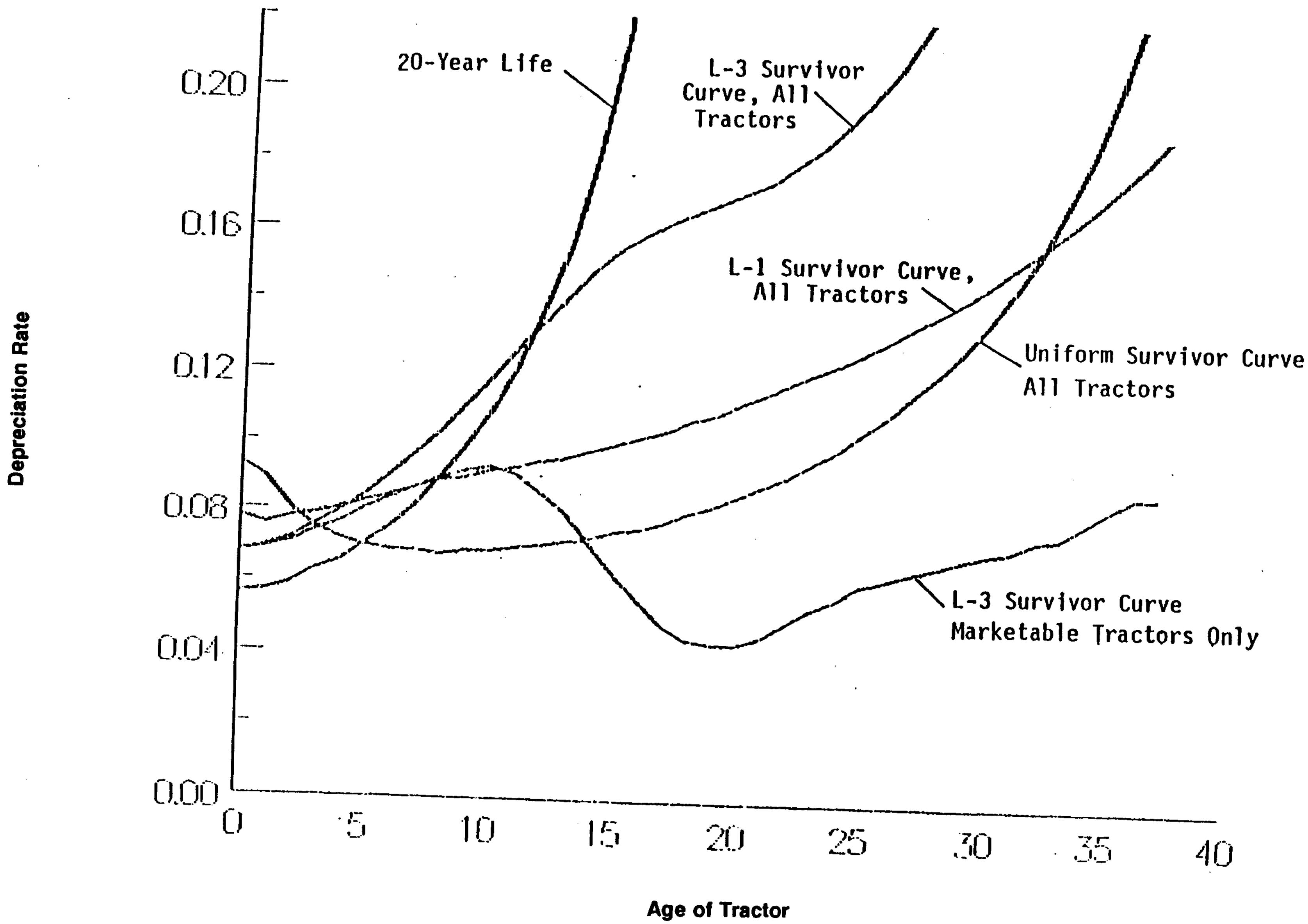


Figure 2. Depreciation Rates by Company

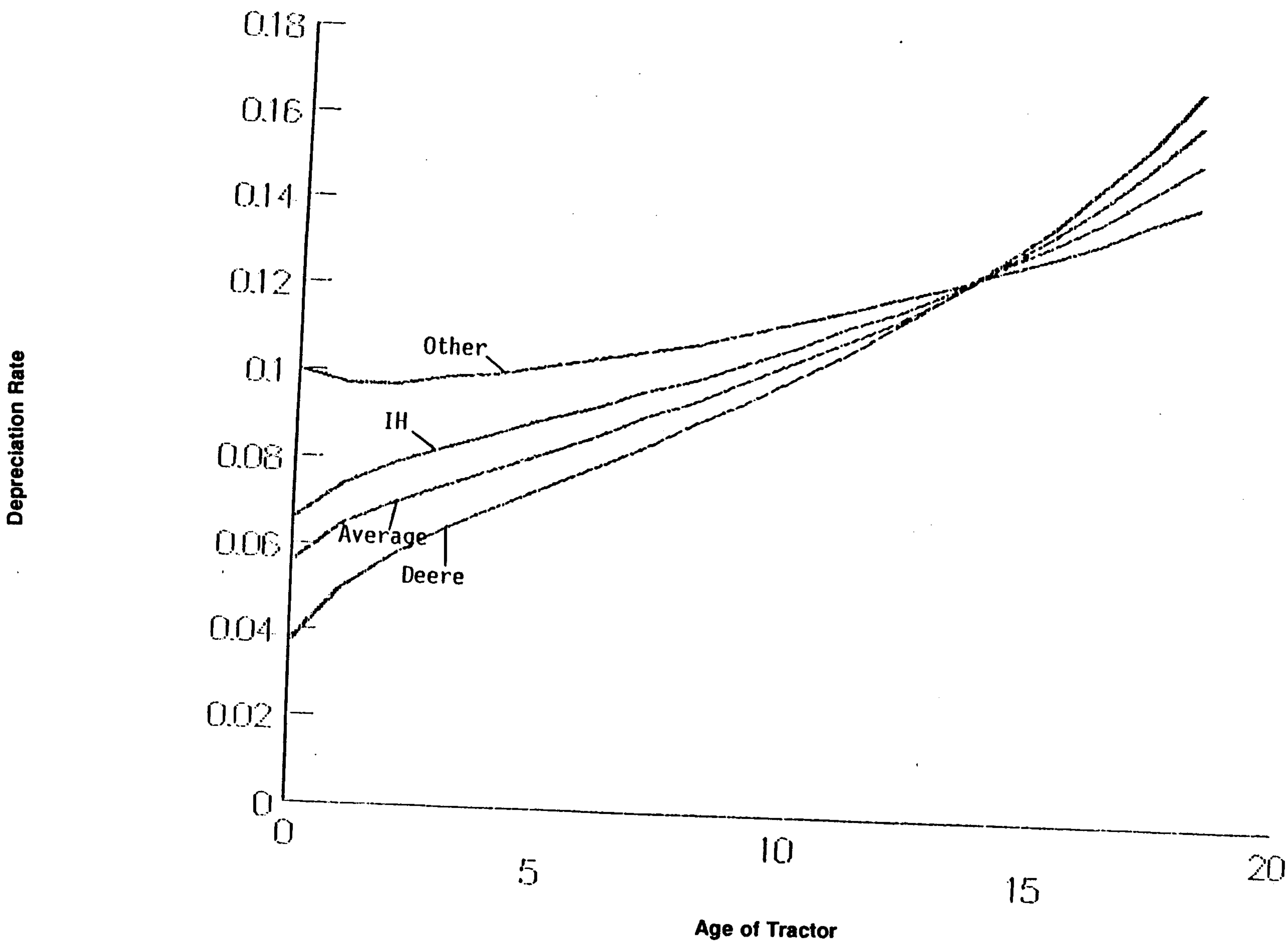


Figure 3. Depreciation Rates When Usage and Condition Excluded

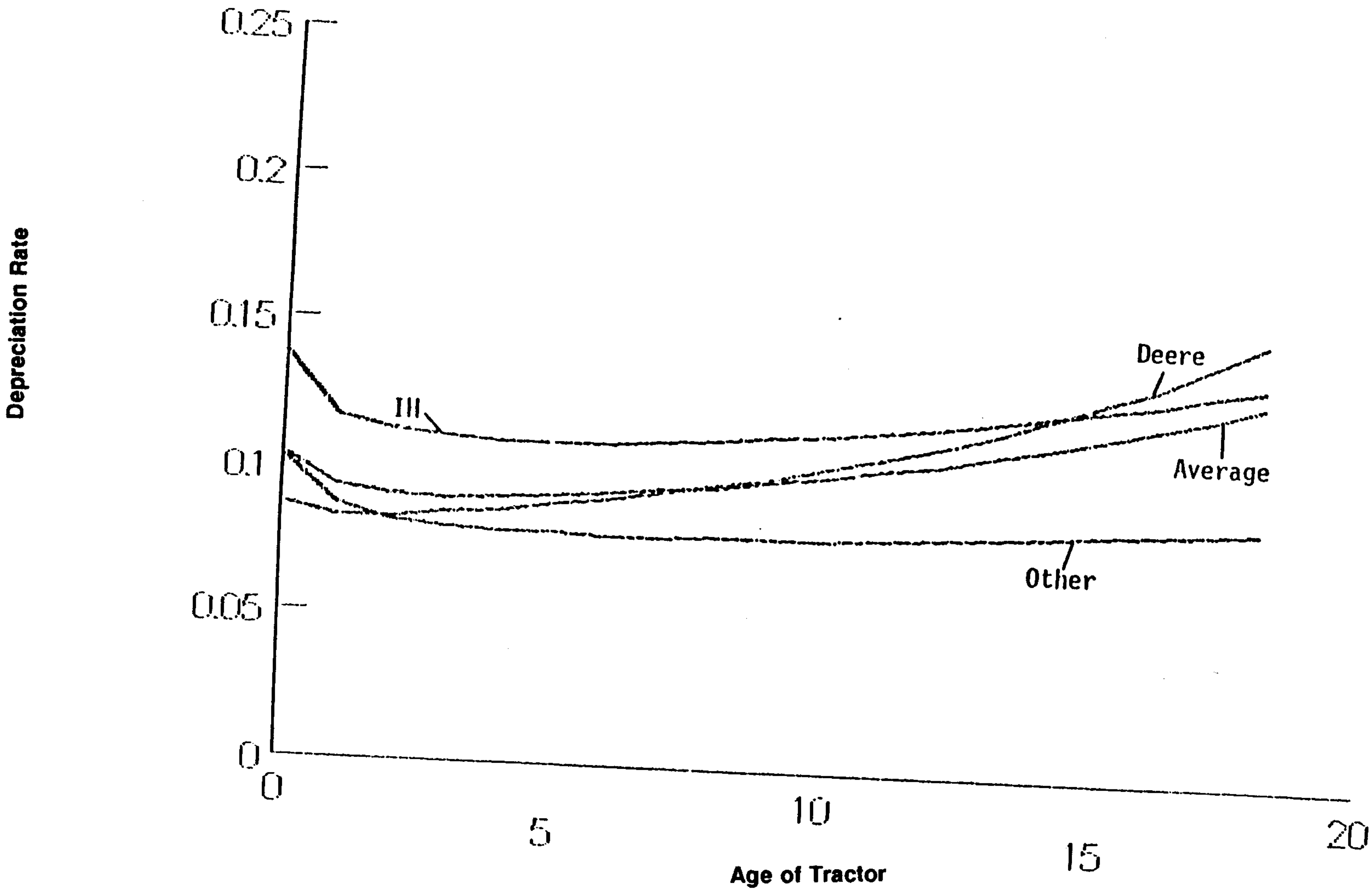
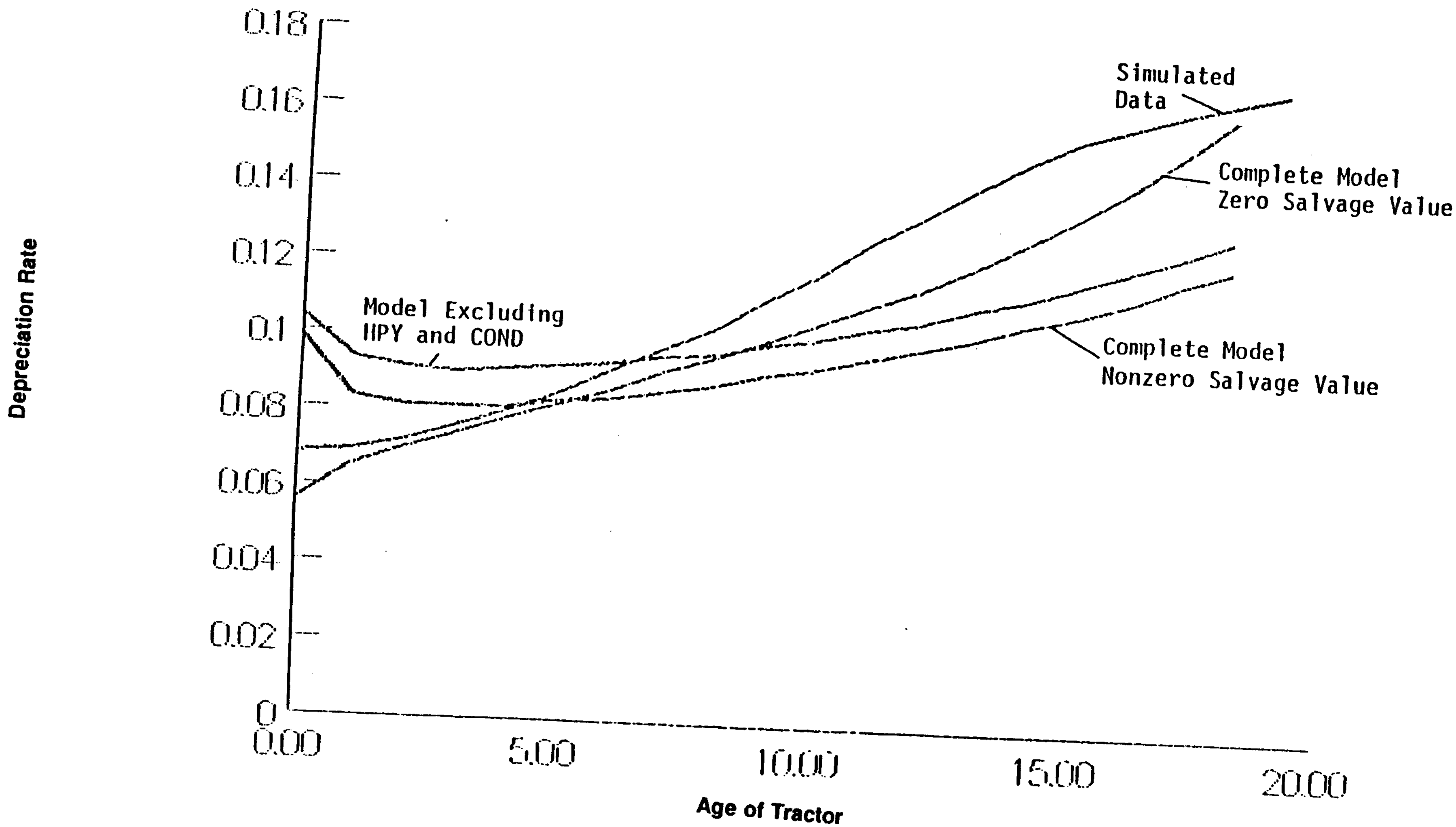


Figure 4. Depreciation Rates for Alternative Methods



Depreciation Rates and Confidence Intervals