MEASURING THE PRODUCTIVITY OF CAPITAL IN UNITED STATES AGRICULTURE

Cole R. Gustafson

Abstract

The agricultural sector has operated in a period of high real interest rates for over half a decade. Some are concerned that this has limited capital availability and stagnated the historic capital for labor substitution occurring in the sector. This study proposes new procedures for estimating the aggregate production function of United States agriculture. Improvements include incorporation of total returns and revised measures of both durable and nondurable capital inputs. Results indicate increasing capital productivity has occurred, but encouraging further capital substitution may not benefit agricultural producers.

Key words: productivity, accounting, capital-labor substitution, agricultural finance, interest rates.

One of the cornerstones of economic theory is the concept of the production function. Once a production function is identified and prices of inputs and outputs known, the economic agent can logically deduce an optimum level of inputs to use and the level output to produce. Further, the law of substitution modifies this optimum mix, over time, as the relative prices of inputs change. One would expect the economic agent to respond by using less of the relatively higher-priced good and more of the relatively cheaper good.

The induced innovation hypothesis (Hicks) extends the law of substitution and presents the concept that differences in the level of relative factor prices influences the direction of innovative activity and, hence, of technical progress. An increased use of capital can then be expected as the capital-labor price ratio falls. A long-standing trend in the farm sector has been and continues to be the substitution of capital inputs for labor.

Since the end of World War II, agricultural output has increased by more than 60 percent. In nominal terms, agriculture's contribution to the United States gross national product has risen from $20 billion in 1950 to $80.2 billion in 1984. Domestic agricultural exports over this period have risen from $3.4 billion in 1950 to $38.3 billion in 1984. When adjusted for inflation, the value of exports has still increased over 2.5 times. Agriculture is an important part of the United States economy.

Recently, the United States and other countries have experienced a period of high real interest rates. They have remained persistently high for over half a decade despite generally lower inflation. Production practices in the United States are relatively more capital intensive than those of many foreign countries. Concern has arisen whether adoption of new technology in United States agriculture will abate as increasing capital costs reduce the competitive position of United States agriculture and lead other countries to underprice the United States in export markets. Most affected is new technology that is capital using. High capital prices relative to labor may misallocate resources and reduce the physically efficient mix of inputs and outputs.

An opposing view is that the high price of capital should be taken in stride as it is only a temporary phenomena that will be offset by technological progress. Griliches, among others, argues that the real concern should

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Cole R. Gustafson is an Assistant Professor of Agricultural Economics, North Dakota State University, Fargo, North Dakota.

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be the apparent lack of new resources (funds allocated to research) that are available to develop more productive inputs (1986). Past developments have included hybrid seeds, artificial fertilizers, and a proliferation of pesticides. Difficulties are recognized concerning the sources of new developments and possible interactions that may evolve and limit the usefulness of past developments, such as toxicity to or new tolerance of plants to chemicals, for example. If these problems can eventually be overcome, high interest rates would even be a logical consequence as firms bid up the price of capital in order to acquire new technologies. Of course, this depends on the relative importance and linkages between agriculture and other sectors of the economy.

Various measures have been taken in this country to ensure that agricultural producers have greater access to debt capital. Examples include establishment of the Farm Credit System, the Farmer's Home Administration, state operated beginning farmer programs, and various other special banking and commercial laws designed to provide farmers with low-cost sources of debt capital.

In order to evaluate the relationship between capital costs and productivity, one needs to analyze the underlying aggregate production function of United States agriculture. This is not a new approach as voluminous writings on the subject appear in the literature (USDA, ESCS). However, there is reason to believe that the component of capital has been misspecified in the past and important relationships have been omitted.

There are two purposes of this study: to estimate an aggregate production function of agriculture and to ascertain whether the current period of high capital costs has changed the productivity of capital. The next sections present a brief review of past research and outline a new theoretical approach. Following is an empirical test of the model using aggregate USDA time series data.

A HISTORICAL PERSPECTIVE

Numerous production functions have been estimated at the micro level in order to help farmers determine the optimal usage of inputs (Heady and Dillon). Production functions have also been estimated at the aggregate level. Examples of early techniques used can be found in the writings of Griliches and Hayami and Ruttan, and Ruttan. Each utilized a Cobb-Douglas model with independent variables consisting of labor, land, livestock, fertilizer, machinery, and various measures of human capital. The Cobb-Douglas functional relationship has been a favorite of agricultural economists because it exhibits constant returns to scale if the exponents sum to one, is everywhere increasing and continuous, and demonstrates diminishing marginal productivity.

Tyner and Tweeten ((a) and (b)) observed the developing problem of highly correlated independent variables. If more than two or three independent variables are used, questions arise regarding the *"structural validity and usefulness of the parameter estimates."* Later, Doll established a theoretical basis and stated, *"users of the Cobb-Douglas model who are dismayed to find multicollinearity among the independent variables should be pleased because of the presence of multicollinearity serves as a verification of their economic model."*

The approach used by Tyner and Tweeten ((a) and (b)) to solve the problem utilized the concept of factor shares where $\alpha_{1,t}$, $\alpha_{ndk,t}$ and $\alpha_{dk,t}$ are defined to be the ratio of an expenditure on factors labor (L), nondurable capital (K_{nd}), and durable capital (K_d) in period t to the value of output (Y) with prices P_1, P_{ndk}, P_{dk}, and P_y, respectively, where:

(1) $\alpha_{1,t} = P_1L/P_yY$,

(2) $\alpha_{ndk,t} = P_{ndk}K_{nd}/P_yY$, and

(3) $\alpha_{dk,t} = P_{dk}K_d/P_yY$.

A unique property of $\alpha_{1,t}$, $\alpha_{ndk,t}$, and $\alpha_{dk,t}$ is that they are equal to the production elasticities and provide a convenient method of estimating:[1]

(4) $Y = \alpha_0 L^{\alpha_{1,t}} K_{nd}^{\alpha_{ndk,t}} K_d^{\alpha_{dk,t}}$.

Tyner and Tweeten ((a) and (b)) were concerned that the assumption of economic equilibrium may not hold when shares are estimated and they utilized a Nerlove partial adjustment model. In a later article by Rosine and Helmberger, actual factor shares were estimated directly, implying instantaneous adjustment. Shumway, Talpaz, and Beattie

[1]From the first order conditions of a model in equilibrium and reflecting perfect competition, $MPP_i = P_i/P_y$. Multiplying by X and dividing by Y implies:

$e_i = MPP_i\, X_i/Y = P_iX_i/P_yY = \alpha_{i,t}$.

compared these two studies and stated, *"the least-cost research alternative of assuming instantaneous and complete adjustment . . . seems appropriate."* Thus, this method was utilized here.

Other researchers have used these concepts although permitting more flexible functional forms. Lu used a variable elasticity of substitution (VES) production function and found the Cobb-Douglas form to be an appropriate form among those investigated. Binswanger and Weaver rejected the Cobb-Douglas functional form when using translog cost and translog expected profit functions, respectively. The difficulty of specifying aggregate prices limits the empirical usefulness of these more general approaches.

Three contributions to this stream of knowledge are developed in this study: (1) past specifications of output have not included all returns and have thus understated the productivity of inputs, (2) some costs have not been fully reflected in the data used, and (3) insights into the productivity of capital are derived from the economic relationship stating longrun profits are zero.

A REVISED METHOD OF MEASURING PRODUCTIVITY

Information necessary to estimate equations (1) to (3) includes an identifiable number of units of both nondurable and durable capital and labor with appropriate prices and output, again with an appropriate price. Identification of these "units" and "prices" in an aggregate setting is difficult, hence, the use of factor shares. The strict definition of a production function is upheld. One could easily disaggregate capital into the individual components of fertilizer, herbicide, etc. However, the purpose of this study is to analyze the productivity of capital in general and not of each of these specific items.

Agriculture is characterized by producers investing in assets for both current and long-term returns (capital gains). During the later 1970's, one could not justify paying the high prices quoted for land based only on realized current returns (Harrington). Opportunity costs for interest on investment were often far greater than average rental rates. Even though presently in an *ex post* sense one might say investments were made where expectations of investors were unrealized, a rational investor at the time would have been led to believe land values would continue to increase.

When measuring the factor share of land, is it not appropriate to include long-term returns along with current returns? In previous studies, the annual factor share of land was obtained by applying a nominal farm mortgage rate to the current value of farm real estate (Ball; Binswanger; Lu; Rosine and Helmberger; Shumway, Talpaz, and Beattie; Tyner and Tweeten). The only returns included have been the value of current farm marketings and inventory changes.[2] This would tend to understate the productive value of capital because not all returns are included. This is particularly true in agriculture where land is one of the largest residual claimants of capital returns. If the goal is to measure productivity accurately, either long-term gains must be added or only the capital costs necessary to realize current returns should be included.

Another return neglected in previous studies has been the income received from participation in government programs. Various price support, diversion, and conservation payments assist producers in offsetting the ownership costs of various capital items. For instance, in a land diversion program, the only return a producer receives is a rental payment which is used to offset the annual cost of holding the assets. Again, including the capital cost of these inputs and not acknowledging the returns tends to understate the productivity of the input.

Aggregate time series data have been used in the past to empirically estimate these relationships. Care must be exercised when selecting the proper deflator in order to remove the effect of inflation and obtain comparability across periods. In the past, an index of prices received has typically been used. When using the factor share approach, this tends to negate any return that may occur due to commodity prices rising above the general rate of inflation. A more appropriate deflator is the implicit price deflator for the gross national product.

Depreciation and opportunity interest on equity capital are two inputs that have been misspecified in previous studies. Previous estimates of depreciation have been within permissible provisions of tax policy and have overstated true economic depreciation of durable inputs. This leads to an understatement of capital productivity. Ball and Penson et al. have pointed out that the capital rental

[2]Rosine and Helmberger included rental information in their econometric model, but only as a mover of the elasticity coefficient of land. Land was still valued using a nominal mortgage rate, p. 719.

rate should be used to estimate the cost of depreciable assets.

The cost of funds committed to purchased inputs (interest on capital) has been estimated using only expenditure information. No attempt has been made to value the equity funds of operators. Some type of imputation reflecting the opportunity cost of this capital must be made or the productivity of capital will be overstated. A problem that still remains concerns the method for valuing home-produced inputs such as seed, feeds, etc. The same heroic assumption will be made here as in past studies; that is, the cost of these items is, over time, offset by their value in production.

Finally, given the specified model,

$$\sum_{i=1}^{i=dk} \alpha_{i,t} = 1.$$

Economic theory suggests the sum of the factor shares do bear a relationship to output over time. If agriculture is a near perfect model of competition, the value of output cannot be greater than the sum of factor shares over an extended period of time. New entrants would be encouraged to begin production in marginal areas and raise costs (the sum of the factor shares) until profits are again zero. The reverse argument applies when the value of the output is less than the sum of factor shares. The property whereby the exponents sum to one is commonly referred to as constant returns to scale when a Cobb-Douglas model is estimated. In the past, constant returns to scale have normally been assumed; from above, one would be surprised to find that they do not exist. A value other than one would indicate a misspecified model with too few inputs identified or lack of a component to measure risk.

To illustrate this relationship, what can be said if a new technology substantially raises the productivity of one of the inputs used by farmers? In the absence of an increase in price of the input and assuming the new technology is available to everyone, potential output increases. If the demand curve is fixed, the increased output will be absorbed only if product price declines. This is transmitted back to the farmer and either the marginal resources will be removed from the sector or the value of the factors used in the production process will readjust. In agriculture, it is common for land prices to absorb the shock. In reality, the seller of the more productive input extracts an economic profit and the new technology spreads slowly, mitigating any rapid drop in other factor prices.

Thus, capital is reallocated to its most productive use. If the new input is indeed more productive, it will bid away capital from other factors; it does not necessarily lead to an increase in the productivity of capital. This will occur only if the new technology is labor-saving.

One other set of independent variables has been added to equations (1)-(3) to test another hypothesis. Dummy variables are included to test whether the productivity of any period differs from that of another. It is widely believed that the 1950's and 1960's were the decades of true advancement with respect to the development of new technologies. In contrast, during the 1970's, it is alleged that farmers lived on borrowed resources and were not maintaining their investment levels. One can test the significance of these variables and either accept or refute these hypotheses.

Using factor shares to estimate equation (4) and the hypothesis that these shares sum to one; that is

$$(5)\ 1 = \alpha_{ndk,t} + \alpha_{dk,t} + \alpha_{1,t},$$

the following is derived:

$$(6)\ \alpha_{k,t} = B_1\ (1 - \alpha_{1,t}) + \mu,$$

where $\alpha_{k,t}$ is equal to the sum of $\alpha_{ndk,t} + \alpha_{dk,t}$ and μ is the error vector which is assumed to be distributed N $(0, \sigma^2)$. This will provide a testable null hypothesis that $B_1 \neq 1$.

In order to estimate the value of the elasticities, one can use the following relationship:

$$(7)\ \alpha_i = C_0 + C_1\ (\text{Trend}) + C_2\ (D_j) + \mu$$

where: i = ndk,t; dk,t; and 1,t; "Trend" reflects changes through time; and D_j is a (0,1) dummy variable for decade J. C_0 will provide the underlying value of the production elasticity as modified by the trend and dummy variable effects.

AN EMPIRICAL TEST OF REVISED MODEL

Aggregate time series data for an empirical test are taken from various USDA reports for the years 1940 to 1984 (USDA; USDA-ERS). The measure of output used to estimate the factor shares consists of total farm gross receipts plus an adjustment for the annual change in inventory levels and government payments to farmers. Data are currently reported in a form that excludes household transactions. Thus, items such as net rental of farm dwellings are already excluded and need not be subtracted as in previous studies. Nominal values are deflated to a common period using the implicit price deflator for the gross national product to facilitate intertemporal comparisons (Council of Economic Advisors). Future returns (capital gains) are not included, because the discount rate used to value capital assets is a weighted average of the longrun real after-tax interest rate (external financing) and the expected longrun real after-tax return to equity (internal financing).

The wage share is estimated to be the sum of hired wages and a value imputed to the unpriced labor contributed by the operator and other persons. Hired labor may also be considered as nondurable capital because funds must be expended to acquire it. Thus, a separate equation is estimated where the wage share consists only of owned labor (OL) with the value of hired labor added to nondurable capital.

Capital consists of funds invested in both nondurable and durable factors of production. Nondurable capital equals intermediate production expenses as reported by USDA. The durable capital share consists of real estate, annual cost of depreciable assets, business taxes, and the annual capital invested in nondurable factors. USDA methods for estimating depreciation in their national and state financial summaries of income and balance sheet statistics are not suitable for productivity studies. Depreciation rates are in excess of true economic depreciation. Following Ball and Penson et al., an alternative capital consumption measure was constructed using the concept of a capital rented rate. The most desirable way of obtaining the annual cost of land that excludes any costs of obtaining future gains is to use rental information. Unfortunately, an aggregate rental rate of land devoted to agriculture is unavailable. The alternative is to apply an opportunity interest rate to the aggregate value of farm real estate. An arbitrary real discount rate of 4.4 percent is assumed to reflect the average 20-year current return to farm assets (Hoffman and Gustafson). Tweeten and Melichar have obtained similar estimates of 4.3 and 4.25 percent, respectively. Annual capital invested in nondurable assets reflects both actual interest payments and an opportunity cost for the equity capital of owners.

Trend equals 1 in 1940 and 45 in 1984. D50 to D80 are dummy variables representing decades 1950 to 1980.

EMPIRICAL RESULTS

Initial regression results for equations (6) and (7) have Durbin-Watson values falling below the lower boundaries and high first-order correlation coefficients among successive disturbances. As a result, the regressions were re-estimated using the Cochrane-Orcutt iterative method (Theil). Further, observations for calendar year 1973 were outliers in all models estimated, but since there are no grounds for questioning the validity of the measurement, the observation was not deleted. In order to estimate B_1 in equation (6), the regression equation was forced through the origin. The R^2 statistic is not shown since it is not reliable and may even be negative when the regression is forced through the origin (Theil). An alternative equation with an intercept was estimated. However, the constant term was insignificant.

Three alternative models of equation (6) were empirically estimated. Model 6a (base) was estimated for comparative purposes using previously developed methodologies, Table 1. Durable assets were valued by applying a nominal interest rate to the value of real estate assets in the sector and the opportunity cost of equity funds provided by owners investing in nondurable inputs was not included. The equation exhibited a good statistical fit of the data but contained autocorrelation with rho = .61. However, the estimates derived are somewhat questionable because the coefficient for labor is statistically different than one. The null hypothesis stating the sum of factor shares does not equal one is not rejected.

The annual cost of durable assets in Model 6b was estimated using the average 20-year current return to farm assets in place of the nominal interest rate as a proxy for the opportunity cost of land, Table 1. Interest on operator's equity funds was also included. The labor coefficient and associated standard error leads to rejection of the null hypothesis ($t_{.01}$, 44 d.f.).

Model 6c assumes hired labor to be a nondurable capital factor and not labor, Table 1. The estimates are similar to those generated in Model 6b. Evidently, equilibrium exists at the margin because the substitution of capital for labor does not change the estimates dramatically.

These results may be questioned because of the problem of circularity originating from the use of residual returns to specify the factor share of durable capital. Indeed, this

TABLE 1. EMPIRICAL ESTIMATES VALIDATING THE FUNCTIONAL FORM OF THE MODEL OF CAPITAL PRODUCTIVITY IN UNITED STATES AGRICULTURE, 1940-1984

Model	Labor coefficient B_1	Standard error	Rho
6a. Base	.769 (22.96)[a]	.034	.61
6b. Revised return on durable capital and opportunity cost of equity capital	1.020 (23.91)	.043	.57
6c. As in 6b but hired labor treated as a nondurable capital factor	1.019 (25.93)	.039	.56

[a]t values are shown in parentheses.

is an empirical problem. At issue, however, is the separation of current and longrun returns. Difficulties specifying capital gains (Plaxico and Kletke, 1979, 1980, and 1981; Dunford; Drynan; and Hodge) and an average nominal interest rate, particularly for seller financing, present far more problems. Aggregate rental rates reflecting the diversity of cash and share arrangements would be ideal, if available. Annual current returns derived from procedures used in this study compared quite favorably with reported rental rates (Doll and Widdows).

The previous discussion attempts to validate the factor share model but does not provide insights into the relative magnitudes of the elasticities or their change over time. To answer these questions, the annual factor shares were regressed with trend and a series of dummy variables using equation (7), tables 2 and 3. Hired labor is treated as a labor factor in Table 2 and as a nondurable capital factor in Table 3.

Elasticity estimates for K_{nd}, K_d, and L of .112, .391, and .440, respectively, were obtained when hired labor was treated as a nondurable capital factor. The elasticities sum to roughly .94. In both formulations the residual difference, as discussed previously, is attributed to a small return to risk. Most of the parameter estimates exhibited very high t values along with excellent fits, as illustrated by the high R^2's received. Autocorrelation problems remained.

The trend variable was found to be significant in all cases with the share of durable capital increasing over time and the share of nondurable capital and labor decreasing. Analyzing the impact of the trend variables during the later periods of observation, the parameter estimates have summed elasticities above one. (The absolute value of the trend variable for durable capital is larger than the sum of nondurable capital and labor.) A value larger than one could be explained by an error in the data, an incorrectly specified functional form of the model, or incorrect combination of independent variables. However, a plausible explanation may be as follows.

In both formulations, the factor elasticities equaled one around 1960 and have risen since. This tends to coincide with the empirical observation that farming has been unprofitable since then and has resulted in an outward migration of labor from the sector.

TABLE 2. ELASTICITY AND TRENDS OF FACTOR INPUTS TO UNITED STATES AGRICULTURE, 1940-1984 (HIRED LABOR CONSIDERED A LABOR FACTOR)

Factor of production	Constant C_0	Trend C_1	D80 C_2	Adjusted R^2	Rho
Nondurable capital	.112 (9.23)[a]	−.003 (−5.19)	.012 (0.63)	.73	.34
Durable capital	.391 (13.23)	.014 (11.18)	.080 (1.91)	.96	.43
Labor	.440 (33.75)	−0.008 (−15.82)	.039 (1.63)	.95	.09

[a]t values are shown in parentheses.

TABLE 3. ELASTICITY AND TRENDS OF FACTOR INPUTS TO UNITED STATES AGRICULTURE, 1940-1984 (HIRED LABOR CONSIDERED AS NONDURABLE CAPITAL)

Factor of production	Constant C_0	Trend C_1	D80 C_2	Adjusted R^2	Rho
Nondurable capital	.202 (17.70)[a]	−.003 (−6.92)	.014 (0.68)	.80	.19
Durable capital	.391 (13.23)	.014 (11.18)	.080 (1.91)	.96	.43
Labor	.345 (26.20)	−.008 (−14.14)	.036 (1.53)	.95	.17

[a]t values are shown in parentheses.

Schuh hypothesized that it was in this period that the dollar became overpriced and resulted in the "farm problems" that were observed then and exist today. When one evaluates the trend of the labor elasticity, employment in the agricultural sector may not be declining as one would be led to believe by glancing at only the number of farms in 1980 versus 1940. Evidently, there are more workers per farm now or the "price" of labor has increased, resulting in a relatively constant factor share.

The most significant dummy variable was a shifter for capital in the 1980s. Other dummy variable specifications were evaluated, but insignificant results were obtained. In the current decapitalization of the agricultural sector, the positive sign indicated the remaining durable capital has become more productive.

POLICY IMPLICATIONS

The results indicate the historical capital for labor substitution occurring in the United States agricultural sector is continuing at the present despite high capital costs. The unique and stable public funding arrangements of agricultural research may be responsible for this paradox. One would certainly have expected the negative costs of capital to increase the adoption rate of new technologies during the 1970's and the current high costs to reduce adoption rates at the present.

It appears that lowering capital costs for purposes of increasing productivity does not benefit producers given the relationship between productivity and capital or asset values in a competitive environment. If product demand is inelastic, use of more productive capital leads to increased output and reduces value of previously acquired capital. Producers do not increase their demand for capital but merely reallocate capital to more productive inputs. Consumers obviously benefit because of the increased availability of product at lower prices.

CONCLUSION

This study has found the productivity of both durable and nondurable capital rising from 1940 to the present. High capital costs encouraged farmers to acquire more productive capital assets and utilize present forms of capital more efficiently. The bias of failing to include returns from the public sector, an opportunity cost for owner supplied equity, capital gains, economic measures of depreciation, and proper measures of inflation when estimating productivity was demonstrated.

Many questions remain, of which some are basic and empirical. Obviously, the method of using capital rental rates must be investigated as costs of depreciable assets are the single largest component of cost behind land. Methods need to be derived to estimate the annual cost of land and costs of owned funds that are invested in the farm business so various assumptions and proxies need not be used. Progress is being made as primary data are currently being reviewed. The American Agricultural Economics Association has published a task force report suggesting new methods the USDA might consider when estimating labor and capital productivity indices.

Many unanswered questions remain as to the causes of high interest rates and their impact on the farm sector. The model presented in this paper assumed a condition of perfect competition. Such is not the case in the real world even though agriculture more closely approximates this than most industries. Thus, distributional impacts become a concern, particularly the dynamic aspects related to early adoption. These questions must be answered if agricultural economists are to provide decisionmakers (both public and private entreprenuers) with information they require.

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