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RESOURCE PRODUCTIVITIES AND PRODUCTION FUNCTIONS

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This paper is mainly intended to provide a vehicle for discussion of recent research in measuring resource productivity using what has come to be known in agricultural economics as the Cobb-Douglas approach. I have attempted to draw together most of the points that have been raised by others together with some comments. The organisation of the discussion has been to give a brief historical background to this type of work and then to consider the economic and statistical difficulties involved in fitting empirical production functions. Finally, the use of the results of such work in assisting policy decisions both by the community and the individual farmer is considered.

1. INTRODUCTION

The early work of Douglas and his associates in obtaining estimates of resource productivity, particularly the labour resource, was used to make inferences about the extent of monopolistic practices in factor markets.[1] In particular, Douglas' finding that the marginal value productivity of labour was equal to the wage rate was taken by him as evidence of lack of monopsonistic practices in the labour market. Since the publication of Douglas' findings, attention has been directed at the reliability of the statistical estimates.

Reder pointed out the distinction between the production function of economic theory, which relates physical output to physical inputs for a given firm, and the function fitted by Douglas which related product (value added) in manufacturing to physical units of labour and the value of plant and equipment (capital).[2] The former Reder called the intra-firm production function and the latter and the inter-firm production function. Reder showed that where the production function differed for each firm the estimates obtained by fitting output to capital and labour could be biassed estimates of the productivity of the inputs. Bronfenbrenner directed attention to the fact that, in certain circumstances, the marginal productivity of input could be the same for all

[1] Charles W. Cobb and Paul H. Douglas, "A Theory of Production", *American Economic Review*, Vol. XVIII, Supplement (March, 1928), pp. 139-165. A more extensive bibliography together with a more detailed discussion of some of the problems raised in this paper is contained in R. M. Parish and J. L. Dillon, "Recent Applications of the Production Function in Farm Management Research", *Review of Marketing and Agricultural Economics*, Vol. 23, No. 4 (December, 1955), pp. 215-236.

[2] M. W. Reder, "An Alternative Interpretation of the Cobb-Douglas Function", *Econometrica*, Vol. 11 (July-October, 1943), pp. 259-264.

firms even with different production functions but under this case the algebraic form of the function fitted by Douglas was inappropriate.[3] Mendershausen showed that where exact collinearity existed between inputs the estimates would be indeterminate.[4]

In more recent years, agricultural economists have taken over the search for estimates of resource productivity and have extended and modified the original techniques of Douglas. The basic form of the production function fitted by Douglas and his co-workers, the so-called Cobb-Douglas function, was

$$P = bL^{k}C^{j}$$

where P is product and L and C are indexes of labour and capital respectively. b, k and j are the parameters to be estimated. Earlier forms of the function were criticised on two grounds:

(*a*) The sum $k + j$ was bound to 1, that is, the restriction of constant returns to scale was imposed.

(*b*) In inter-temporal studies, the effects of changes due to trend were not eliminated.

In subsequent work both these objections were handled by the non-binding of $k + j$ and the restriction of the procedure to cross-section studies for a given year. Agricultural economists have experimented with still further versions of the basic form in both cross-section and time series studies.

The production function has its origin in the static theory of the firm where it is assumed that a firm maximises net revenue subject to the restriction of the technical possibilities embodied in the production function. Here, the production function is envisaged as listing the maximum amounts of physical output that are possible with various levels of physical inputs. For example, consider a farm under perfect competition with two inputs x_1 and x_2 producing an output x_0. The production function may be written as

$$x_0 = f \ (x_1, x_2)$$

and the necessary conditions for profit maximisation may be expressed in the marginal productivity equations

$$\frac{\delta x_0}{\delta x_1} = \frac{\delta p_1}{\delta p_0}, \qquad \frac{x_0}{x_2} = \frac{p_2}{p_0}$$

or the marginal value productivity of x_1 and x_2 must equal their respective prices p_1 and p_2, where p_0 is the price of output. Alternatively, in the case of a firm with a given resource, this resource should be so allocated that its marginal value productivity is the same in each of its alternative uses on the farm.

In the broader context of resource efficiency the marginal value productivity of a resource is a guide to changes in resource allocation between types of farming areas and between the primary and other sectors of the economy. Questions of mobility apart, if it were reliably

[3] M. Bronfenbrenner, "Production Functions: Cobb-Douglas Interfirm, Intrafirm", *Econometrica*, Vol. 12, No. 1 (January, 1944), pp. 35-44.

[4] H. Mendershausen, "On the Significance of Professor Douglas' Production Function", *Econometrica*, Vol. 6, No. 2 (April, 1938), pp. 143-153.

shown that the marginal returns to a given resource were greater in either an alternative type of farming or in a non-farming sector then the economic criteria for resource efficiency would suggest a reallocation of the resource.

Allied to questions of efficiency in agriculture are questions of income levels. For example, there is an obvious connection between low levels of income and mis-allocation of resources on individual farms. The mis-allocation, where it is associated with low resource productivities, may result in policies aimed at transferring income from one group in society to another. Apart from theoretical interest, the estimation of the parameters of the production function has particular importance as a guide in policy formation both for individual firms and society as a whole. If accurate estimates of farm resource productivity could be obtained the value of such estimates in specific and general policy in agriculture shows the importance of the economic and statistical questions involved in obtaining them.

In the quest for resource productivities the empirical counterparts of production functions have been derived in a number of countries using various models and estimation procedures. The work of Heady and others[5] in the U.S.A. in assessing resource productivities in particular farming areas has been expanded into comparisons between types of farming areas and then into international comparisons of resource productivities. In the United Kingdom, Antill,[6] using weighted regression as as estimation technique and confluence analysis as a guide to the choice of the model, has derived resource productivities for dairying. In Australia, the work of Parish and Dillon,[7] and Mauldon and Schapper,[8] and Penny and Jarrett[9] has also extended the areas in which resource productivities have been estimated using variants of the basic Cobb-Douglas procedure. In Canada, Clarke has also used statistical procedures in arriving at resource productivities.[10]

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[5] Earl O. Heady, "Production Functions from a Random Sample of Farms", *Journal of Farm Economics,* Vol. XXVIII, No. 4 (November, 1946), pp. 989-1004.

———— and Russel Shaw, "Resource Returns and Productivity Coefficients in Selected Farming Areas", *Journal of Farm Economics,* Vol. XXXVI, No. 2 (May, 1954), pp. 243-257.

————and Schalk du Toit, "Marginal Resource Productivity for Agriculture in Selected Areas of South Africa and the United States", *Journal of Political Economy,* Vol. LXII, No. 6 (December, 1954), pp. 494-505.

[6] A. G. Antill, "Toward a Production Function for Dairy Farms", *The Farm Economist,* Vol. VIII, No. 1 (1955), pp. 1-11. See also: J. Clark and J. E. Bessell, "Profits from Dairy Farming", *Imperial Chemical Industries Bulletin,* No. 7 (September, 1956).

[7] R. M. Parish and J. L. Dillon, "Marginal Resource Productivity for Agriculture in Selected Areas of Australia", (Unpublished).

J. L. Dillon, "Marginal Productivities of Resources in Two Farming Areas of N.S.W.", *Economic Monograph,* No. 188, Economic Society of Australia and New Zealand, New South Wales Branch (May, 1956).

[8] R. G. Mauldon and H. P. Schapper, "A Production Function from Farms in the Whole-Milk Region of Western Australia", (Unpublished).

[9] F. G. Jarrett and D. H. Penny, "Resource Productivity in the Murray Swamps Dairying Area", (Unpublished).

[10] J. W. Clarke, "The Production Function in Farm Management Research", *Canadian Journal of Agricultural Economics,* Vol. II, No. 2 (Spring, 1954), pp. 36-41.

The wide use of the production function method of estimating resource productivity means that a discussion of its advantages and disadvantages should be well worthwhile. For the purposes of this discussion I will assume that the basic data for assessing farm productivity have been collected from a cross-section study of a randomly selected sample of farms. Obviously, if the sample is non-random estimates of the parameters of the production function will be biased.

The major advantages claimed for the statistical fitting of production functions are:

(*a*) To the extent that the estimates are reliable, the production function assesses actual resource productivities. In contrast, a commoner procedure in estimating resource productivity is that of using a residual quantity, usually returns to labour and management or returns to capital, in arriving at productivity estimates of these resources. The practice usually adopted is to use net farm income (gross farm income less cash and certain non-cash costs) as a starting point and use market prices to impute returns to all inputs but one. To obtain a return on capital, a return is imputed to labour and management, and the residual quantity after the return to labour and management is deducted from net farm income is the amount available as a reward to capital. To obtain a labour and management return, a return is imputed to capital and the residual quantity goes to labour and management. Clearly, if the imputed productivity is wide of actual productivity then the residual quantity will also be in error. For example, to use a rate of 5 per cent on capital, the actual return on which is 2 per cent lowers the productivity of labour and management. One could well imagine in agriculture cases where non-monetary factors are so important that an imputed rate of return to capital of 2 per cent would be more appropriate than a market rate of, say, 5 per cent.

(*b*) The production function procedure yields marginal resource productivities rather than the average productivities of the residual quantity method outlined above. Since most economic theory on resource allocations runs in terms of marginal quantities it is the empirical counterparts of these marginal quantities that are required for policy formation, especially in the short run. Farmers also tend to think in terms of marginal quantities in making some production decisions. For example, "would feeding additional hay be worthwhile?"

(*c*) In principle, the nature of economies of scale can also be obtained from the production function. If $k + j$ is > 1, then there are increasing returns to scale. That is, for example, a doubling of inputs will more than double output, and conclusions as to the returns to scale can also be drawn for $k + j < 1$ and $k + j = 1$. This piece of information has obvious economic implications for policies affecting the scale of operations in agriculture, for instance, on the question of family farms versus some form of corporate farming.

2. SPECIFICATION BIAS (ECONOMIC)

The particular difficulties raised by Reder, Bronfenbrenner and Mendershausen are part of a more general problem in the fitting of production functions to farm data. This more general problem is that of specification in econometric models. An incorrect specification introduces what is known as specification bias. For purposes of convenience it is suitable to divide this specification problem into two parts, the economic specification and the statistical specification. The two aspects are obviously inter-related but it facilitates exposition to separate them in discussion.

In cross-section studies the research worker usually collects data from a randomly selected group of farms and then attempts to construct a model explaining how these data were generated. In practice, of course, he possesses *a priori* ideas as to what data are relevant. In fact, there may be considerable benefits in research in production economics from constructing more refined and detailed models as to how farm decisions are made. However, few explicit theoretical formulations of farm decision making have been developed.[11] These formulations would be specific guides as to the type of data to be collected. The important point is that the observed data that are collected have already been produced as a result of farmers' decisions and are not produced as a result of decisions by the investigator. Most work along the lines of Cobb-Douglas has its theoretical origin in the production function of the individual firm, that is, the technical relationship between physical inputs and output. An example of such a relationship is that between the observed response of some growth characteristic and the level of fertiliser. Experimentally, the level of fertiliser is subject to the control of the experimenter. He decides beforehand the various levels and observes changes in the response variable.

The production economist has no such control over the data he collects. In general, with economic data they have been produced by the mutual interaction of a number of forces and this mutual inter-dependence must be recognised in constructing a model purporting to explain observed variations in the level of inputs and output between farms. That is, if the appropriate model consists of a number of equations, then selecting one equation only, the production relationship, to the neglect of other relationships will involve one form of specification bias. This is the simultaneous equations problem. Marschak and Andrews, in a model consisting of a number of equations, one of which is the production function, have shown the nature of this single equation bias.[12] The first of the problems in the economic specification is an explanation of how the data collected in the sample were produced.

Part of the problem of model formation is the selection of relevant variables. In the choice of variables the investigator has sources in economic theory pertaining to production, the knowledge of existing production conditions on the farms under consideration and in the experience of people who are close to farmers and farm decision making. Even with these sources, however, specification bias would be introduced through the omission of variables that should have been included

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[11] One attempt at developing a theoretical model of farm decision making may be found in Clifford Hildreth and F. G. Jarrett, *A Statisical Study of Livestock Production and Marketing* (New York: John Wiley and Sons, 1955), pp. 90-106.

[12] Jacob Marschak and William H. Andrews, Jr., "Random Simultaneous Equations and the Theory of Production", *Econometrica,* Vol. 12, Nos. 3 and 4 (July-October, 1944), pp. 143-202.

and vice versa. Some omission of variables may be hard to avoid where observed data are not available. This may be particularly so where account has to be taken of farmers' expectations.

Since the number of possible variables which may be relevant in production decisions is very large some form of aggregation is necessary. On the output side, farms producing a single product are rare and various outputs are usually aggregated in money terms. Similarly, on the input side aggregation of various inputs into a single index may be necessary. Plaxico has indicated that if inputs within the aggregate combine in a manner different from that specified in the production function fitted then bias will result.[13] If within an aggregate inputs enter linearly then fitting a function in the logarithms of indexes of input will result in bias to the estimates. Where output is on an index basis then a low marginal productivity of a factor may be in part a reflection of a non-optimal combination of products (rates of product transformation equated to ratios of product prices) as much as an indication of an inherently low resource productivity. In using the estimates of resource productivity where output on a given farm is a complex of products a difficulty arises. It is one thing to find that the marginal value productivity of labour is greater than the wage rate but another to suggest which of the particular enterprises making up total farm output should be expanded.

For both inputs and outputs where they are aggregated the problem of quality still remains. There may be grounds for arguing that for agriculture variation in product quality is relatively less than variation in input quality. Where land as an input is measured in acres, even for the same type of farming area there may be wide variations not only in soil types but even variations in fertility within the same soil type. Where such variation exists then the use of acres of land is an inadequate representation of the land input in production.

One other problem in economic specification is that of the algebraic form of the production function. Economic theory has relatively little to say in choosing between various possible forms. The usual criteria which are employed in selecting an apropriate form are :—

(*a*) Statistical manageability both in terms of ease and cost of computation. Algebraic forms which can be handled using conventional least squares procedures have, in general, been employed.[14] The usual choice has been a form either linear in the observed variables or linear in the logarithms of observed variables. More complex polynomials have seldom been used because in cross-section surveys with relatively

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[13] James S. Plaxico, "Problems of Factor-Product Aggregation in Cobb-Douglas Value Productivity Analysis", *Journal of Farm Economics*, Vol. XXXVII, No. 4 (November, 1955), pp. 664-675.

[14] Models involving a number of equations and estimation procedures appropriate for such models have been used in :—

Clifford Hildreth, *Problems in the Estimation of Agriculture Production Functions*, Cowles Commission Discussion Paper: No. 260, University of Chicago.

Earl O. Heady, Dean E. McKee and C. B. Haver, *Farm Size Adjustments in Iowa and Cost Economies in Crop Production for Farms of Different Sizes*, Research Bulletin 428, Agricultural Experiment Station, Iowa State College, Ames, Iowa, 1955.

small sample sizes the fitting of many constants results in a loss of degrees of freedom with consequent decrease in the sensitivity of any statistical tests of hypotheses.

(*b*) A function linear in the observed variables assumes constant marginal productivities. Such an algebraic form does not permit the phenomenon of decreasing returns to inputs. Most economists have a presupposition that the production function for an individual firm should allow diminishing returns to manifest itself. There is of course empirical evidence to suggest that this presupposition may be a correct one.[15] Assuming constant marginal productivities would not be consistent with the belief that the marginal productivity of a factor depends on the level at which the factor is already employed. For these reasons, an algebraic form linear in the logarithms has had preference in most empirical work on production functions. Such a form permits decreasing returns, with marginal productivity of a factor dependent on the level at which the factor is used. However, the parameters are now the elasticities of production showing the percentage change in output associated with a one per cent change in the relevant inputs. These elasticities are assumed constant; which may be a less restrictive assumption than that of constant marginal productivities.

One aspect of equations linear in the logarithms is that for output to be non-zero at least some of every input is essential if any output at all is to be produced. If resources are classified into a large number of highly special inputs, not all inputs may be absolutely essential for the production of some output. That is, with a large number of input categories, some inputs may be omitted but output will nevertheless be forthcoming. On the other hand, if only a small number of input categories are used, it is more likely that some quantity of each of the inputs will be essential for any production to result. In any case, the economic rationale given above for the choice of a particular algebraic form is relevant to the individual firm's production function and the economic arguments on algebraic form may not be pertinent if the production function fitted is of the inter-firm variety.

One other worry in economic specification which is in part a problem of algebraic form has to do with the continuity of the production function. Various algebraic forms have been fitted but to my knowledge all have involved continuous functions which were differentiable at all points on the function. In the real world of agricultural production there may in fact be discontinuities induced by indivisibilities in certain factors. Such indivisibilities may be most important in certain capital items, particularly for some types of farm equipment and buildings. Linear programming procedures are, in part, aimed at handling these discontinuities.

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[15] Einar Jensen *et al.*, *Input-Output Relationships in Milk Production*, U.S. Department of Agriculture, Technical Bulletin 815, 1942.

Aaron G. Nelson, *Relation of Feed Consumed to Food Products Produced by Fattening Cattle*, U.S. Department of Agriculture, Technical Bulletin 900, 1945.

L. Jay Atkinson, *Feed Consumption and Marketing Weight of Hogs*, U.S. Department of Agriculture, Technical Bulletin 894, 1945.

3. SPECIFICATION BIAS (STATISTICAL)

In discussing the problems of statistical specification it may be helpful to review briefly the assumptions underlying classical least squares as an estimation procedure since this method of estimation has almost invariably been used on production functions of a Cobb-Douglas form. Consider the simple linear model

$$1.\ Y_i = \alpha + \beta X_i + \varepsilon_i \qquad i = 1, \ldots\ldots n.$$

Under certain conditions least squares will yield best linear unbiassed estimates of α and β. [16]These conditions may be briefly summarised as

$$E(\varepsilon_i) = 0; \quad E(\varepsilon_i \varepsilon_j) = 0, i \neq j; \quad E(\varepsilon_i^2) = \sigma^2; \quad E(X_i \varepsilon_i) = 0$$

where the operator E refers to expected value. Y is the dependent variable which has the random term ε, an error term, associated with it. The error term has a mean 0 and a constant variance σ^2. X is the independent variable regarded as a fixed variate measured without error and is independent of ε. Graphically, we may represent the situation as in Figure 1.

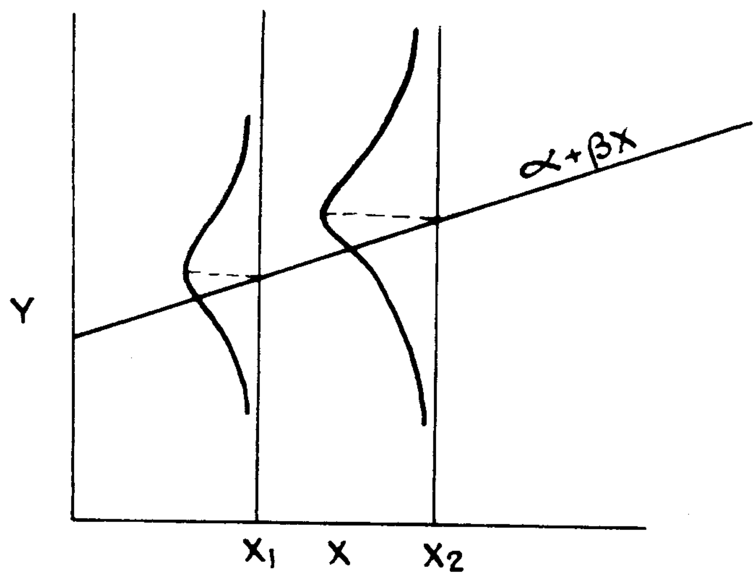

Figure 1.

For any given value of X, say X_i, Y is distributed about a mean $\alpha + \beta X_i$ with a constant variance σ^2 For estimation of α and β it is not necessary to specify the probability distribution of ε. However, for testing hypotheses such a specification, normally distributed for example, is necessary. In cross section studies, with random sampling, the error terms are more likely to be independent than in time series studies where such a specification may be unrealistic since the disturbances ε_i may be auto-correlated. That is, the value of the disturbance at time t may not be independent of the disturbance at time t-j. Auto-correlation of disturbances creates serious problems in time series studies but consideration of these problems is beyond the scope of the present discussion.

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[16] F. N. David and J. Neyman, "Extension of the Markoff Theorem on Least Squares". *Statistical Research Memoirs*, Vol. 2 (1938).

Failure to meet any of the specifications given above will, in general, result in bias to the estimates of α and β and correspond ngly, in any marginal productivity derived from the estimate of β. For simplicity I have confined the discussion to a linear model with one independent variable. In principle the discussion could be similarly extended to a model linear in the logarithms and with more independent variables. It will be noticed that the assumptions underlying the use of east squares are most nearly met in work involving experimental design. The estimation procedure has been taken over in economics and is sometimes used in situations in which the conditions necessary to give best linear unbiassed estimates may not be met.

Suppose that the model given in equation 1 has been applied to data collected from a random sample of farms in a given time period and that only one output Y and one input X are involved. The question arises as to which of the assumptions on which classical least squares is based may not be met in practice. The first condition unlikely to be satisfied is that X is a fixed variate taking on the same value in repeated samples. If, in fact, the appropriate model consists of a number of equations then X may appear in other equations which exhibit a random component. Certain types of farm inputs may be regarded as given; family labour input may be the only labour input and may be determined by family size which may be reasonably regarded as exogenous. Other farm inputs are jointly determined with output. For example, in dairying, the quantity of bought hay fed and output of butterfat may be determined jointly so that to "explain" the quantity of bought hay fed requires an additional stochastic equation in the model, apart from the production relation.

With economic variables the assumption that the independent variables are measured without error is suspect. Errors of measurement in some of the input variables are likely to be particularly troublesome. For labour input on family farms the variable measured in man-weeks, say, is more likely to be labour available on the farm rather than its theoretical counter-part of labour used in production. Similar difficulties of equating the theoretical concepts of productive inputs with observed variables exist for other factors used in production. This particular problem of errors of measurement in the independent variables has resulted in the employment of weighted regression procedures.[17] It is beyond the intention of this paper to consider in detail the assumptions underlying this procedure. In essence, each of the independent variables is assumed to possess a "systematic" part and an error part. The crux of the estimation procedure consists of using the variance-covariance matrix of these error terms as weights. This variance-covariance matrix must either be assumed known, unlikely in practice, or else estimated in some way. The difficulties involved in actually obtaining the variance-covariance matrix may raise doubts as to whether the use of weighted regression does not raise more problems than it solves. Ideally, one would like an estimation method which would give "good" estimates of

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[17] For a discussion of weighted regression procedures see the following: G. Tintner, *Econometrics* (New York: John Wiley and Sons, 1952), pp. 121-153. L. Klein, *A Textbook of Econometrics* (New York: Row, Petersen and Co., 1953), pp. 293ff. and 305ff.

the parameters and would allow for both errors of measurement in the variables (as in weighted regression) and disturbances in the equation as well, as in classical least squares. So far as I know such a procedure does not exist, except for very simple cases.[18]

The next set of problems likely to arise is that associated with the specification of the ε_i. This is a random variable which is usually a " catch all ", but it may, in part, be taken as giving a distribution of technical and managerial efficiency. That is, two farmers with the same input of X, labour, say, will not both produce the same Y. The one with the greater efficiency will produce the greater Y. From Figure 1, for a given X, ε leads to a distribution of efficiency of farmers. At a level of input X_1, say, the assumption that the $E(\varepsilon_i) = 0$ is equivalent in this context to assuming that, at the level of input X_1, farmers are equal y likely to be above or below average for that level of resource use. This may not be an unreasonable assumption in practice. The specification that $E(\varepsilon_i^2) = \sigma^2$, the assumption of constant variance, may be doubted if the level of resource use and efficiency are related. For example if " better " farmers obtain control of more resources and operate at X_2 in contrast to X_1 then it may be reasonable to state that the variation in efficiency among farmers operating at X_2 is less than the variation among farmers operating at X_1. If this is so the specification of constant variance is violated.

One further difficult problem in specification remains. This is the problem of multicollinearity. This problem was first raised by Frisch.[19] Suppose that we were interested in estimating the parameters of an equation

$$2. \quad \alpha x + \beta y + \gamma Z + \ldots\ldots = 0$$

then Frisch argued that accurate estimation of the parameters may be impossible (or difficult) because other linear relationships also connect the variables in equation 2 either exactly (or approximately). To the extent that the other linear relations are an integral part of the model explaining firms' decisions, integral in the sense that there are in the other relations variables which are simultaneously determined with some of those in equation 2, then treating equation 2 separately raises an aspect of the simultaneous equations problem already mentioned. This type of collinearity is now discussed under the heading of the identification problem in economic models.

Apart from this type of collinearity there is still another one. Suppose that the model consists of the production function only with one dependent (endogenous) and a number of independent (exogenous) variables. Then if an exact linear relationship exists between some of the independent variables the parameters will be indeterminate. If the collinearity is approximate only this will result in large sampling variance in the estimates of the parameters. The method of confluence analysis has been directed at this aspect of collinearity.[20] The bunch

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[18] T. W. Anderson and Leonid Hurwicz, "Errors and Shocks in Economic Relationships", *Econometrica*, Vol. 17, Supplement (July, 1949), pp. 23-25.

[19] R. Frisch, *Statistical Confluence Analysis by Means of Complete Regression Systems* (Oslo: Universitetets Økonomiske Institutt, 1934).

[20] *Ibid.*

map technique used in confluence analysis is essentially a graphical procedure and leaves much to the subjective judgment of the investigator. Tintner has developed a formal statistical test for multi-collinearity which is appropriate under certain circumstances for models involving errors in the variables.[21] These are all interesting statistical problems but are of little interest in a general discussion of Cobb-Douglas production functions. Of more interest to agriculturists is the usefulness of the estimates of resource productivity in both general and specific policy formation in agriculture.

4. RESOURCE PRODUCTIVITY AND AGRICULTURAL POLICY

In general policy, the sum $k + j$ has been used as an indication of returns to scale in agriculture. For $k + j < 1$, this may be taken to indicate that large-scale corporate farming would result in lower per unit costs in the long run. Formally, a method is available to test whether the sum of $k + j$ differs significantly from unity.[22] However, the implications of this test should be treated with caution. If one is prepared to assume that no variables have been omitted then the test may be regarded as a test of returns to scale. Alternatively, if one is prepared to assume constant returns to scale then the test is a test of the importance of omitted variables. Other interpretations of the test may also be possible. The point is that a significant result in testing $k + j$ different from one is not unambiguously a test of the returns to scale in agriculture.

Estimated marginal value productivities which differ from factor prices are not clear-cut guides to decision-making on the individual farm. For a cross section study in a given year, resource productivity may be low or high because of purely climatic factors. The incidence and distribution of rainfall in the area in the period for which the data were collected may markedly affect the values of resource productivity obtained. Only if the rainfall characteristics for the period considered were in some sense "average" would the results be typical of the area and possibly useful guides to changes in resource combination. This is not a difficulty associated with the Cobb-Douglas procedure as such since similar qualifications would have to be made for resource productivities derived in any other way in the same set of circumstances.

The production functions fitted to farm data have been short run in nature. However, few farmers attempt to maximise profits in the short run so that resource productivities which differ from factor prices may be in part a reflection of longer term objectives. For example, farms which are in an early stage of development or on which specific improvements have only recently been undertaken may in a cross section study exhibit resource productivities which are below market prices in the time period considered. An illustration of such a phenomenon would be returns to capital invested in pasture improvement. If the

[21] G. Tintner, "A Note on Rank Multicollinearity and Multiple Regression", *Annals of Mathematical Statistics*, Vol. 16 (1946), pp. 304-308.

[22] *Ibid.*

survey were carried out in the year in which the permanent pasture was first sown then returns from capital invested would be low in that year and it would not be until the pasture was firmly established that the resources devoted to pasture improvement would be compensated. In the same context, the production function approach may provide a useful guide to over-all resource combination in the area considered. However, since the inputs, particularly capital, are measured in general terms the production function does not answer questions related to the profitability of specific farm practices. However, if the production function suggests that the returns to capital, say, are in excess of the interest rate, then I would regard this piece of information as most helpful in planning these specific farm practices which are capital using. In determining which specific farm practices are most profitable linear programming perhaps offers better prospects than the generalised production function.

In a dynamic world the productivities derived from what are essentially static concepts may have restricted usefulness. In farming particularly, the timing of operations is often as important as the resource combinations used and comparisons of marginal productivities and prices may provide little help in assisting farmers in allocating resources where time enters as a variable. Similarly where uncertainty exists, resource productivities less than market prices may indicate a failure of expectations to be realised. Such a failure results in inefficiency in resource allocation but there may be little that an individual farmer can do to remove this inefficiency. In agriculture, with a long production period, an improvement in knowledge of future prices may help to improve resource allocation on farms more than any action that the individual farmer may take.

Farms are also households as well as firms so that farmers may have complex objectives involving both profitability of their farms as businesses and their decisions relative to their farms as places to live. Certainly, any use of resource productivities in extension would have to be conditioned by the household aspect of farms. All that I have said in these paragraphs, in a very brief way, may be applied to most production economics work, Cobb-Douglas resource productivity included.

One may very well feel after seeing the difficulties involved in empirical production functions that only a man prepared to make heroic assumptions would even proceed with such work. However, the investigator must bear in mind the particular qualifications in terms of economics and statistics that apply to such work. Similarly the use of the results in farm advisory work also has its qualifications and I would suggest that the extension officer must bear these in mind. Still attempts at measuring resource productivities are worthwhile and a certain amount of trial and error may be unavoidable. Unless research workers are prepared to make good tries they are most unlikely to obtain good empirical approximations of marginal resource productivity. The estimates of marginal resource productivity are a vital piece of evidence, but only one piece of evidence, in assessing the efficiency of resource allocation.