Sources of Technical Efficiency: The Roles of Modernization and Information

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Discussion Paper 36 April 1974

ABSTRACT

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A major goal of agricultural policy in many developing nations is the improvement of farm management. Economists have treated aspects of this issue in the literature on technical and allocative efficiency, but much of the work has focused almost entirely on devising techniques for quantifying efficiency differentials. This paper takes the next logical step and attempts to identify sources of such differentials. A simple model is presented relating technical efficiency to general modernization and agricultural information. All three variables are measured among a sample of cotton farmers in Tanzania. Correlation analysis and estimates of modified Cobb-Douglas production functions seem to indicate that general modernization is the more important causal factor and that its impact is primarily labor-augmenting.

The note appended to this paper demonstrates that when management is omitted from a Cobb-Douglas production function the direction of bias in estimated returns to scale depends on the manner in which management enters the "true" function. Griliches' [1957] seminal article on this topic implicitely assumes a particular specification that leads to negative bias, whereas alternate, perhaps more appealing, specifications may yield opposite results.

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[1]An earlier version of this paper was presented at the Annual Meetings of the Econometric Society, December, 1973, New York.

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April 1974

1. Introduction

Leibenstein (1966) has suggested that losses from X- or technical inefficiency may be far more important than losses from allocative inefficiency. Several recent studies have attempted to measure the magnitude of these former losses while Timmer (1970) and Muller (1973) have noted that invocation of the term "technical efficiency" may imply an admission of the analyst's incomplete understanding of the production process. Improved specification of the model (as, for example, in Muller, 1973) may relate interfirm productivity variability to input variability rather than to the somewhat enigmatic technical efficiency.

This improved specification may be extremely helpful to policy-makers in developing nations, where the list of proposed programs often includes many that aim at improving management. For example, in the area of agricultural development there are frequent proposals related to extension services, farmer training centers, model farmer programs, best farmer awards, field days, mass media programs, and the like. The specific content of such programs may vary considerably: teaching specific farm skills; teaching general skills such as literacy and arithmetic; exhorting farmers to work harder; stimulating demand for cash goods; and attempting to develop a generally more modern, change-oriented outlook. If policy-makers know why some farmers are better managers (i.e., why there are technical efficiency differentials) they might have firmer grounds for choosing among such an array of programs. For example, the choice among extension, general education and mass media programs might hinge on whether technical efficiency was most closely associated with knowledge of specific farming techniques, or literacy, or a modern outlook.

Policy-makers would not be the only beneficiaries of improved specification. Econometricians attempting to improve our understanding of production processes would also benefit. Failure to adequately specify a management-related variable leads to problems of simultaneous equation bias and inconsistency (see Mundlak and Hoch, 1965), and specification bias (see Griliches, 1957).[1] Furthermore, a continual effort to improve economic models follows naturally from adherence to the notion that "...the distinctive aim of the scientific enterprise is to provide systematic and responsibly supported explanations"[2] (Nagel, 1961, p. 15).

This paper addresses the issue of improved specification by analyzing the roles of information and modernization in the production process on cotton farms in Tanzania. Muller (1973) has provided a theoretical and empirical analysis of the role of information on California dairy farms. The role of modernization has been discussed primarily in the sociology literature and a theoretical economic analysis would require a separate paper. Suffice it to say that such a discussion must consider not only adoption of innovations (a common sociological theme), but also possible reshaping of indifference curves.

The two following sections outline the conceptual issues upon which this paper focuses, and the remaining sections present results of an empirical investigation of those issues.

2. The Conceptual Problem

Consider a sample of firms (in one industry) whose production activities give rise to the scatter of points in Figure 1. Some firms are on the technically efficient frontier isoquant[3] while others lie varying distances

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[1] See Appendix.

[2] Emphasis added.

[3] See Farrell (1957).

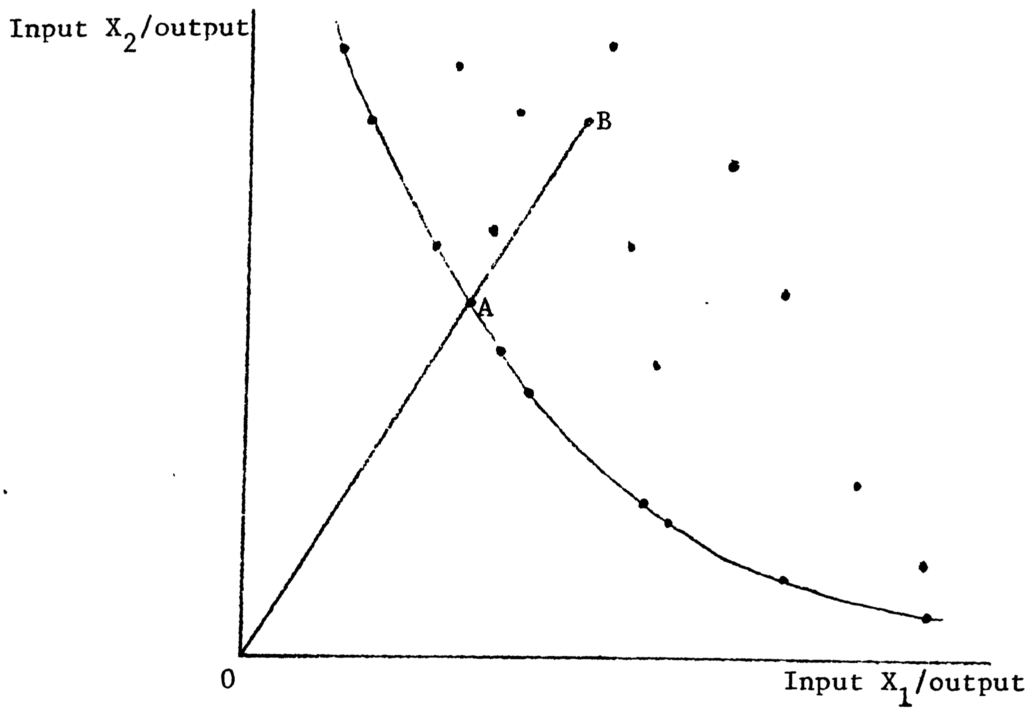

Figure 1

away from it. One explanation of this pattern is that firms actually face different technologies. If this were true, there would be no basis for analyzing technical efficiency since that concept refers to exploitation of a common technology. An alternative explanation is that the pattern does not represent real differences in technology but rather arises from random disturbances. This is a common assumption underlying regression estimation of a unique production function. Again, we have no reason to speak of technical efficiency.

A third explanation argues that all firms have potential access to the same technology but that some are more successful than others in exploiting it. In this case we may compare relative levels of technical efficiency. In figure 1 the ratio of distances $\frac{OA}{OB}$ is a measure of firm B's relative technical efficiency, in that B could reduce its use of inputs X_1 and X_2 to $\frac{OA}{OB}$ of present levels and still maintain the same output if it became as efficient as A.[1] Only those firms on the frontier isoquant have an efficiency rating of 1.00. Most work in this area has focused on developing quantification techniques to facilitate such comparisons. We propose to build on this earlier work and go beyond quantification to identification of the sources of technical efficiency differences.

3. Sources of Differences in Technical Efficiency

We posit a set (T) of physical relationships between inputs and output. This is the full technological set faced by an industry. It includes those relationships represented by the frontier isoquant and also by all other points in Figure 1. The subset T_i^1 ($T_i^1 \subset T$) contains all the relationships available to firm i. This availability is determined, in part, by the amount of information possessed by entrepreneur i. (See

[1]This follows Farrell (1957) and assumes constant returns to scale.

Müller, 1973).

The subset T_i^2 ($T_i^2 \subset T_i^1$) is the group of relationships actually employed by firm i. Traditional economic analysis assumes that this group is the most technically efficient subset (T_i^{2*}) in T_i^1. However, Shapiro (1973) has argued that in developing agriculture various factors may cause T_i^2 to differ from T_i^{2*}. The influence of some of these factors may vary inversely with modernization. Thus, the more modern farmers may be more likely to employ T_i^{2*} (or a very similar subset) than are the less modern farmers.

In sum, we hypothesize that differences in technical efficiency (with regard to T) may arise from interfirm differences in information and modernization, which act as a double filtering system in determining the technological subset T_i^2 that any firm actually employs.

The remainder of this paper is a report on an effort (1) to measure information, modernization and technical efficiency on African cotton farms; (2) to determine the interrelationships among those variables in light of the above hypotheses; and (3) to analyze the roles of information and modernization in the production process. Sections 4 through 7 attempt to provide substantive insights into the variables through discussion of the research site; the sample and the collection of data; specification of physical inputs and output; and specification of information and modernization, for which a new methodology based on factor analysis and Guttman scaling is presented. The next two sections consider the measurement of technical efficiency and the empirical determination of its sources. This determination indicates possible roles for information and modernization. The nature of these roles is analyzed in sections 10, 11 and 12 by introducing those variables into Cobb-Douglas production functions.

4. The Research Site

Data used in the following analysis were collected during a year-long (1970-1971) research program in a 55-square-mile political ward adjacent to the south shore of Lake Victoria in Geita District, Tanzania.[1] Geita is one of the two leading cotton-producing districts in the country, and cotton alternates with coffee as the nation's leading foreign exchange earner. The research site lies about 3,700 feet above sea level and receives about 40 inches of rain per year, concentrated between October and May. There is a variety of fairly fertile, granitic, sandy-loam soils in catenas running down the gentle slopes that characterize the landscape. Population density is about 106 persons per square mile. In general, land is not scarce, but land with the best soils and near main roads is no longer relatively abundant.

A "typical" farm in the area might control[2] about 25 acres, of which 9-1/2 would be allocated to crops as follows: cotton - 3.98; mixtures of cassava, maize (the two main staples), legumes and sweet potatoes - 3.82; old cassava (often a form of fallow) - 1.07; rice - .27; millet and sorghum - .12; others - .27 (Collinson 1964). Cattle and other livestock are widespread. The agricultural technology currently employed is primarily traditional: axes are used for land clearing, hand hoes are used for weeding and for building the ridges on which crops are planted. There is

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[1]The research is reported more fully in Shapiro, 1973. Support for the research was provided mainly by the Foreign Area Fellowship Program and also by the National Science Foundation and Stanford University. In Tanzania the University of Dar es Salaam and the Ministry of Agriculture provided substantial aid. We are grateful to all these organizations.

[2]Tenure is fairly secure on all land worked (including reasonable fallow) by a household, but land may not be legally sold nor rented. All land allocation or reallocation had been under the control of tribal authorities, but is now controlled by the Village Development Council, a local group of elected farmer representatives.

no irrigation and only about 10 per cent of the district's farms use fertilizer or insecticide. The main obstacle to increased cotton yields is insect damage. Average net farm income (subsistence value and cash) has been estimated at sh. 1355/- to sh. 1474/-, of which one-third to one-half is derived from cotton (Collinson, 1964, and Larsen, 1970).

The research site is about a two-hour trip (including a half-hour ferry ride across Smith Sound and attendant wait) from the city of Mwanza, which is the regional capital and has a population of about 34,000. In 1966 Geita District had 132 miles of main roads and 400 miles of minor ones, all unpaved. Most residents get their water from small streams and from Lake Victoria. Marketing facilities in Geita include 105 cooperative primary societies that buy all the cotton and some of the food crops; the latter also being sold at marketplaces in settlements along the roads. The district's leading settlement, Sengerema, is located two miles south of the research site and contains, in addition to an open-air marketplace, about 15 small shops, a bus stop, police station, mission, hospital, post office, primary school, secondary school (under construction in 1971-- the district's first), and a Ministry of Agriculture substation.

5. The Sample and Collection of Data

Seventy-six farms (about 10% of the ward's population) were chosen in a two-stage random sample designed to cluster each group of five farms within a small area. Five farms dropped out because of deaths or moving from the area. Obvious data problems limited the analysis of modernization and information to only 67 farms. Fifty-nine of these grew cotton, the crop on which most of this paper focuses; but additional data problems left only 40 farms in the comparative analysis of efficiency, modernization, and information.

Records of all labor (family and hired), purchased inputs, harvest volumes, and sales were obtained during twice-weekly interviews of each farm for one full year. Acreage planted in each crop was measured with a plane table or tape and compass. Data related to modernization and information were gathered with questionnaires and special interviews. The labor data collected during the twice weekly interviews were spot-checked against hourly records made by an observer who stayed at various farms through several recording periods. A t test revealed no significant differences between various paired totals from the two sets of records.

6. Specification of the Physical Inputs and Output

Labor is specified as the actual number of hours worked on cotton fields. These are raw hours unadjusted for timeliness or age or sex. This specification implies the assumption that an hour worked by any one person yields the same effective labor power as an hour worked by any other person.[1] Undoubtedly, this is not completely accurate. The more strenuous land-preparation tasks probably can be done more quickly by men in their prime than by others. However, if others stop working when they tire, distortions may be minimized. It is important to recall that the labor variable is actual hours worked, not, as is true in some other studies, hours available.

Land is specified as acres of cotton actually planted. There is no adjustment for differences in fertility, drainage, and so forth. No land is irrigated. Data were collected on soil type and rotation, but are not included in the present analysis. All cotton is planted in pure stands

[1] Children under 8 years old were excluded completely.

with rare exceptions of sparse interplanting with quick maturing legumes.

Capital is not included in the analysis for two reasons. First, except for the long-handle hoe and other basic hand tools, there is very little capital (excluding buildings) used in the area. All cotton cultivation is done by hand. Fertilizers and insecticides are used by very few farmers: nine said they used artificial fertilizers, four manure, and eleven insecticide.

The second reason for excluding capital is that among farmers using fertilizer or insecticide, only a very small percentage use them properly. Thus a complex standardization would be necessary. For example, only two of the eleven insecticide users sprayed more than twice. The recommendation is for six applications, and there is reason to believe that two sprayings are worse than none because of damage to the natural enemies of cotton-destroying insects.

Output is specified as the value (Tanzanian cents) of cotton sales. All farmers face the same prices, which are fixed before the planting season by the government purchasing agency. Grade A (clean) seed cotton was worth 52 Tanzanian cents[1] per pound if sold during the first month of the marketing season, and 50 T cents thereafter. Grade B (dirty) cotton was worth only 25 T cents. About 90% of the marketed crop is Grade A.

Inadequate specification is obvious in the above discussion. For example, the use of homogeneous, composite measures of land and labor may hide interfarm variability that may lead to differences in technical efficiency. Two likely sources of such differences are variability in labor timing and in land rotation. While timing and rotation are obvious and measurable, other sources of interfarm differences may not be so

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[1] There are 100 Tanzanian cents to a Tanzanian shilling. In 1969/70 one Tanzanian shilling was worth about 14 U.S. cents.

amenable. To the extent that we have not measured obvious sources of differences and do not have knowledge of still others, the production models can be improved by specifying variables that are thought to give rise to such interfarm variability. Analysis of such variables has the further advantage of possibly shedding light on why some farmers are better managers than others. As discussed above, these considerations have led us to examine the roles of information and modernization in the production process.

7. Specification of Modernization and Information

Data on the amount and type of information possessed by farmers were obtained during a broader investigation of modernization. An individual's relative modernization is operationally defined as some function[1] of the extent to which he has adopted more of the available modern items than have others in the sample and the extent to which he has adopted more of the more modern of those items. (For similar definitions see Rogers, 1969, p. 14 and Moris, 1970, p. 144). A modern item is roughly defined as any possession, practice, opinion, or bit of knowledge that (a) was not part of the traditional culture, (b) has more in common with the (globally) latest version of the item than does its traditional counterpart (if any), and (c) probably was introduced from outside the local culture or was the result of contact with outside cultures. This last feature of modern items helps explain why so much modernization research has been conducted within the framework of communication theory, and also why the investigations of information and modernization are so closely related.

A series of questionnaires and interviews generated data on 85 vari-

[1]Elaborated briefly below and more fully in Shapiro, 1972.

ables that pertain to modern items. Guttman scaling techniques[1] were applied to the adoption patterns of subsets of these items and nine scales were obtained[2] with a total of 45 items. (See Table 1) The scales appear to reflect the following areas or dimensions, respectively: (1) knowledge of cotton-growing recommendations, (2) knowledge of input and output prices, (3) knowledge of local agricultural officials, (4) seeking agricultural information, (5) crops grown, (6) farm inputs employed, (7) farm possessions, (8) household appliances and furnishings, (9) permanent parts of the house and compound. Each farmer received a scale score equal to the number of items (within a scale) that he had adopted. Thus each farmer received nine dimension-specific scores.

The search for appropriate efficiency-related variables focuses on the above information scales (1-4) and also on a measure of composite modernization derived from factor analysis of the dimension-specific scores.[3] Use of factor analysis was stimulated by the hypothesis that, in addition to the nine dimensions of modernization reflected in the scales, there also may be one or more underlying dimensions reflected in common by several or all of the scales. For example, the four information scales might reflect some general information dimension in addition to the specific dimensions indicated. Much prior research has concentrated on identifying a single general modernization dimension that might be underlying all of the scales. (For example, see Kahl, 1968).

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[1]We assume that frequency of adoption is inversely related to the relative modernity of the item. Thus a farmer's Guttman scale score reflects both the quantity and quality (relative modernity) of items adopted by him.

[2]A set of items were judged to form a Guttman scale if the coefficient of reproducibility was $\geq .90$ and if the coefficient of scalability was $\geq .60$.

[3]Each scale was considered as a variable, and farmers' scale scores were considered as observations on the variables. Thus there were nine variables, each with 67 observations.

Table 1--The Guttman Scales

(1) KNOWLEDGE OF COTTON-GROWING RECOMMENDATION

(w = .256, CR = .906, CS = .625)[a]

Level	Item	Number of Adopters
1	Know insecticide recommendation	21
2	Know spacing recommendation	38
3	Know planting date recommendation	49
4	Know thinning recommendation	62

(2) KNOWLEDGE OF INPUT AND OUTPUT PRICES

(w = .273, CR = .944, CS = .610)

Level	Item	Number of Adopters
	Know price of:	
1	Insecticide	1
2	Cassava in 1970	5
3	Fertilizer (either type)	14
4	Insecticide spray pump	20
5	Grade A cotton in 1969	49
6	Grade B cotton in 1970	56
7	Grade A cotton marketed early, 1970	62
8	Grade A cotton in 1970	64

(3) KNOWLEDGE OF LOCAL AGRICULTURAL OFFICIALS

(w = .455, CR = .955, CS = .844)

Level	Item	Number of Adopters
1	Know name of extension agent	12
2	Know village of extension agent	17
3	Know name of cooperative primary society chairman	40
4	Know name of cooperative primary society secretary	46

(4) SEEKING AGRICULTURAL INFORMATION

(w = .288, CR = .918, CS = .677)

Level	Item	Number of Adopters
1	Visited extension agent's home	6
2	Attended Nane Nane Day fair within past three years	19
3	Attended Saba Saba Day fair within past three years	26
4	Attended a cooperative primary society meeting within past three years	50

Table 1--Guttman Scales (continued)

(5) CROPS GROWN
(w = .220, CR = .910, CS = .605)

Level	Item	Number of Adopters
1	Cabbage	9
2	Pineapple	11
3	Onion	15
4	Rice	34
5	Cotton	59

(6) FARM INPUTS EMPLOYED
(w = .531, CR = .940, CS = .615)

Level	Item	Number of Adopters
1	Hiring transport to carry food crops to market	3
2	Hiring year-round workers	6
3	Manuring or fertilizing food crops	8
4	Obtaining maize or vegetable seed from agricultural officers	10
5	Hiring temporary workers	25

(7) FARM POSSESSIONS
(w = .421, CR = .940, CS = .630)

Level	Item	Number of Adopters
1	Wheelbarrow	6
2	Insecticide spray pump	9
3	Shovel	21
4	Bush hook	50
5	Axe	66

(8) HOUSEHOLD APPLIANCES AND FURNISHINGS
(w = .405, CR = .952, CS = .754)

Level	Item	Number of Adopters
1	Watch of Clock	9
2	Radio	10
3	Table	33
4	Chair	59
5	Metal Bucket	62

Table 1--Guttman Scales (continued)

(9) PERMANENT PARTS OF THE HOUSE AND COMPOUND

(w = .367, CR = .940, CS = .623)

Level	Item	Number of Adopters
1	Cement covered walls	5
2	Cement floor	7
3	Latrine	8
4	Metal Roof	13
5	Hinged Door	47

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a/ CR is the Coefficient of Reproducibility; CS is the Coefficient of Scalability; w = Weight given the scale (square of the factor loading).

The first factor in the unrotated solution explains more of the communal variation within the sample (of 67 scores on each of 9 scales) than does any other factor in any other solution. We assume that this factor is the best reflection of a general modernization dimension underlying all nine scales. The extent to which any one scale reflects general modernization may then be determined by the percentage of the variation in its scores that is explained by the first factor. That percentage is the square of the factor loading. Thus a farmer's general modernization score is a weighted sum of his individual scale scores, where the weights attached to each of the scales are the squares of their factor loadings. These weights are shown as "w" in Table 1 above.

In addition to the unrotated solution we also obtained several rotated ones in the search for a common information dimension. We found no factor clearly reflecting such a dimension. Thus the candidates for efficiency-related variables are farmers' general modernization scores and farmers' scores on each of the four information scales. The choice among these candidates rests primarily on their correlation with farmers' technical efficiency scores.

8. Measuring Technical Efficiency

The measure of technical efficiency employed here descends ultimately from Farrell's (1957) notion of a frontier function, but more recently from Timmer's (1970) technique of using linear programming to derive an outer-bound Cobb-Douglas production function.[1] The function so obtained for the present sample, after allowance for possible outliers, is

$$\hat{y}_j = 5.3430 + .8025\, \ell_j + .05048\, k_j \qquad (1)$$

[1] See also Aigner and Chu, 1968.

where, for farm j:

$\hat{y}_j$ = log of predicted cotton earnings (T cents);

ℓ_j = log of manhours labor used in cotton field-work;

k_j = log of acres planted to cotton.

A farmer's actual output (Y_j), given his actual input levels, would equal predicted output ($\hat{Y}_j$) only if he operated on the outer-bound function. Otherwise actual would be less than predicted output. Each farmer was assigned a technical efficiency score equal to the ratio of his actual to predicted output ($Y_j/\hat{Y}_j$).

9. Identifying Sources of Technical Efficiency

Table 2 displays the correlations between farmers' technical efficiency scores on the one hand, and farmers' general modernization and Guttman scale scores on the other. All correlations are significant at $p \leq .10$ except for the one with the scale reflecting the seeking of agricultural information. The highest correlations with technical efficiency are for general modernization (.566), knowledge of local agricultural officials (.493), household appliances and furnishings (.446), knowledge of input and output prices (.429), and permanent parts of the house and household (.396). All these are significant at $p \leq .01$. Two of the lowest correlations are with the scales for seeking agricultural information (.108) and for knowledge of cotton-growing recommendations (.226).

Choice of appropriate efficiency-related variables should rest on logical grounds as well as on the above correlations. Such logic might consist of a causal model explaining how the variable could lead to better management or more efficient use of some or all of the inputs. A model for general modernization would call for lengthy discussion and might well lead

Table 2

Correlations Between Farmers' Technical Efficiency Scores and Their General Modernization and Guttman Scale Scores[a/] [b/]

	Technical Efficiency
General Modernization	.566[c/]
Guttman Scales	
(1) Knowledge of Cotton-Growing Recommendations	.226[d/]
(2) Knowledge of Input and Output Prices	.429[c/]
(3) Knowledge of Local Agricultural Officials	.493[c/]
(4) Seeking Agricultural Information	.108
(5) Crops Grown	.223[d/]
(6) Farm Inputs Employed	.307[d/]
(7) Farm Possessions	.313[d/]
(8) Household Appliances and Furnishings	.446[c/]
(9) Permanent Parts of the House and Compound	.396[c/]

[a/] Pearson zero-order, product moment correlations for the sample of 40 farms studied in the following regression analysis.

[b/] Coefficients without footnotes are not significant at $p \leq .20$.

[c/] Significant at $p \leq .01$.

[d/] Significant at $p \leq .10$.

to certain "non-Schultzian" (see T. W. Schultz, 1964) arguments. Hence it is deferred to another forum. However, it is important to note here that the modernization index is influenced only very slightly by activities directly related to cotton production. The index is much broader and hence the observed correlation stems from a link between <u>general</u> modernization and technical efficiency. We consider general modernization as one source of technical efficiency.

Muller (1972, 1973) has developed a theoretical basis for using information as an input in the production process. However, the above correlations do not reveal any information scale that unambiguously fits the model. *A priori* we might have expected that the scale reflecting knowledge of cotton-growing recommendations would be very closely related to technical efficiency in cotton farming. On the contrary, the correlation between the two sets of scores is only .226, the third from lowest in the whole group. Two general explanations may be offered for these results: the recommendations are no good, and/or the knowledge is not translated into action for some reason. The former probably is not true for three of the items in the scale, but the spacing recommendation may not be optimal under average conditions (see Saylor, 1970). The latter explanation (not translating knowledge into action) is not valid for the thinning recommendation, but may be for the other three. A labor constraint may prevent timely planting and (more likely) a capital constraint may prevent proper insecticide application. The spacing recommendation is rarely followed because most farmers believe it is not optimal.

Two information scales are relatively closely correlated with technical efficiency, but the possible causes of these relationships are not immediately obvious. The scale reflecting knowledge of input and output prices seems to relate more to allocative than to technical efficiency. Differential knowledge of different prices for different grades of cotton and for selling at different times in the selling season might have influenced cotton earnings, but probably only in a minor way.

Greater knowledge of local agricultural officials (as reflected in the other closely correlated scale) may mean that some farmers are obtaining additional agricultural advice not reflected in other scales. For example, the officials may visit some farms and provide on-site advice regarding certain problems or potentials. Van Hekken and Van Velzen (1972) cite such information as one reason for the coalition between large farmers and local officials in several villages in southern Tanzania.[1] If our scale does reflect (indirectly) this type of information, Müller's model may apply. Hence we examine these scale scores as well as farmers' general modernization scores in the following regression analysis to determine more precisely how modernization and information enter into the production process.

10. Specification of Modified Cobb-Douglas Production Functions

Modernization and information have been discussed above in relation to technical efficiency. Technical efficiency, in turn, focuses on interfirm differences in the amount of output obtained from given levels of physical

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[1] On the other hand the relation to technical efficiency might not flow from information obtained from the officials, but perhaps from some factor that leads to knowledge of the officials. A common contention is that local officials concentrate their attentions on larger, wealthier farmers. However the evidence available does not offer very strong support for that view. For example, one indication of farm wealth and size might be area newly planted in 1969. This area had a .30 correlation with farmers' knowledge of officials, but had between a .41 to .60 correlation with other scales (6-9) that seem more clearly associated with wealth. Furthermore, those scales almost unanimously show closer correlations among themselves than between the scale reflecting knowledge of officials and any one of them. (See Table 3) Thus even if wealth and size do lead to better management, they do not seem very closely correlated with knowledge of officials and hence do not provide a causal explanation for the correlation between that knowledge and technical efficiency.

Table 3

Correlations Among Farmers' Guttman Scale Scores[a]

	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Knowledge of cotton-growing recommendations	.172[b]	.276	.232	.386	.292	.241	.157	.146
(2) Knowledge of input and output prices		.271	.257	.299	.212	.260	.217	-.010[c]
(3) Knowledge of local agricultural officials			.333	.220	.398	.231	.284	.250
(4) Seeking agricultural information				.340	.466	.314	.196	.145
(5) Crops grown					.246	.364	.243	.154[b]
(6) Farm inputs employed						.436	.466	.540
(7) Farm possessions							.290	.221
(8) Household appliances and furnishings								.475
(9) Permanent parts of the house and compound								

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[a] All correlations are significant at $p \leq .10$, except those noted by b and c.

[b] Significant at $p \leq .20$.

[c] Not significant at $p \leq .20$.

inputs. Hence it seems appropriate to specify a production function in which modernization or information have a direct effect on those physical inputs. Thus we follow Nerlove (1965) and others in specifying these efficiency-related variables either as neutral intercept-shifters or as components in the elasticities of all or some of the physical inputs.[1] Equation (1) shows the variable (information in this case) in all these possible roles.

$$\text{(1)} \quad Y = e^{(b_I I + A)} K^{(b_K + b_{KI} I)} L^{(b_L + b_{LI} I)},$$

where Y = earnings from cotton (Tanzanian cents),

A = constant,

e = 2.718 (base of the natural log system),

I = information (scores on a scale reflecting knowledge of local agricultural officials),[2]

K = cotton area (acres planted),

L = cotton labor (hours devoted to all field tasks).

This general specification was varied by setting some of the b_{iI} coefficients equal to zero, by using general modernization, (M), rather than information, and by including both in the same equation. We hope to learn the extent to which modernization and/or information are labor-augmenting, land-augmenting or neutral in their impact on production.

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[1]This specification, which does not introduce information or modernization as multiplicative variables on the same terms as the physical inputs, may conform to the spirit if not the letter of Samuelson's admonition "that only 'inputs' be explicitely included in the production function and that this term be confined to denote measurable quantitative economic goods or services" (Samuelson, 1965, p. 84).

[2]We also examined regressions with information specified as farmers' scores on the other three information scales. As expected from the correlation analysis, these variables were almost always insignificant.

11. Regression Results

Before discussing the estimates of those production functions which contain management-related variables, it is worthwhile comparing the regression estimate of average function (2) which contains no such variables with the linear programming frontier production function, (1):

$$\hat{y} = 5.343 + .0505k + .803\ell \qquad (1)$$

$$\hat{y} = 5.470 + .291k + .690\ell \qquad (2)$$

where y, k and ℓ represent logarithms of cotton earnings (T. cents), land (acres), and labor (hours), respectively.

Omission of management variables in (2) probably has resulted in positive specification bias in the two elasticities, but not in the intercept. (See Griliches, 1957.) Unbiased estimates in (2) would be expected to show a greater difference between the frontier and average labor elasticities and a smaller difference between their land elasticities. Thus, although a discussion of the significance of differences between coefficients in (1) and (2) might be misleading,[1] it does seem safe to postulate that farmers in this area achieve greater technical efficiency through higher labor elasticities and not through higher land elasticities nor through a neutral shift. That is, management may be primarily labor-augmenting. The regression results presented in Table 4 seem to support this.[2]

Equation (3M) contains the modernization variable in the elasticities of land and labor but not in the intercept. The estimated coefficient for modernization as a component of labor's elasticity is positive and signifi-

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[1] Only the two elasticities of land are significantly different at $p \leq .20$, but unbiased estimates in (2) would increase the probability of only the labor elasticities being significantly different.

[2] We would like to thank Larry A. Herman for computation assistance.

TABLE 4[1] -- Regression Results

Variable:	A	b_K	b_L	b_M	b_{KM}	b_{LM}
Equation						
(3M) $Y=e^{A}K^{(b_K+b_{KM}M)}L^{(b_L+b_{LM}M)}$	6.174	.592 (.230) a	.449 (.131) a		-.047 (.028) a	.023 (.007) a
(4M) $Y=e^{(A+b_MM)}K^{(b_K+b_{KM}M)}L^{(b_L+b_{LM}M)}$	6.413	.620 (.374) a	.412 (.414) b	-.045 (.479) c	-.052 (.056) b	.030 (.073) c
(5M) $Y=e^{(A+b_MM)}K^{(b_K+b_{KM}M)}L^{b_L}$	5.354	.493 (.208) a	.576 (.112) a	.151 (.047) a	-.031 (.024) a	
(6M) $Y=e^{A}K^{(b_K+b_{KM}M)}L^{b_L}$	5.408	.006 (.161) c	.706 (.117) a		.035 (.013) a	
(7M) $Y=e^{(A+b_MM)}K^{b_K}L^{(b_L+b_{LM}M)}$	4.261	.291 (.110) a	.760 (.171) a	.337 (.240) a		-.031 (.031) b
(8M) $Y=e^{A}K^{b_K}L^{(b_L+b_{LM})}$	5.797	.244 (.106) a	.574 (.110) a			.012 (.003) a

[1] Standard errors appear in parentheses below the regression coefficients; all regressions have an $R^2 > .84$.

a. Significant at $p \leq .10$

b. Significant at $p \leq .20$

c. Not significant at $p \leq .20$

TABLE 4

Regression Results[1] (continued)

Equation	Variable:	A	b_K	b_L	b_I	b_{KI}	b_{LI}
(3I)	$Y=e^{A}K^{(b_K+b_{KI}I)}L^{(b_L+b_{LI}I)}$	5.946	.293 (.159) a	.590 (.126) a		-.001 (.054) c	.019 (.012) a
(4I)	$Y=e^{(A+b_I I)}K^{(b_K+b_{KI}I)}L^{(b_L+b_{LI}I)}$	6.630	.399 (.192) a	.476 (.171) a	-.604 (.613) b	-.077 (.094) c	.115 (.097) b
(5I)	$Y=e^{(A+b_I I)}K^{(b_K+b_{KI}I)}L^{b_L}$	5.786	.259 (.152) a	.619 (.121) a	.111 (.074) a	.019 (.047) c	
(6I)	$Y=e^{A}K^{(b_K+b_{KI}I)}L^{b_L}$	5.541	.133 (.128) b	.681 (.115) a		.076 (.027) a	
(7I)	$Y=e^{(A+b_I I)}K^{b_K}L^{(b_L+b_{LI}I)}$	6.071	.274 (.115) a	.575 (.120) a	-.195 (.353) c		.045 (.048) b
(8I)	$Y=e^{A}K^{b_K}L^{(b_L+b_{LI}I)}$	5.941	.290 (.111) a	.591 (.115) a			.019 (.006) a

[1] Standard errors appear in parentheses below the regression coefficients ; all regressions have an $R^2 > .84$.

a. Significant at $p \leq .10$
b. Significant at $p \leq .20$
c. Not significant at $p \leq .20$

cant, while as a component of land's elasticity it is negative and barely significant. Approximately the same results hold when information is introduced in the same way in (3I).[1]

Equations 4M and 4I are similar to 3M and 3I except that the former pair have the management-related variables in the intercept as well. This specification introduces such strong multicollinearity[2] that none of the coefficients for M or I are significant at $p \leq .10$ and half are also not significant at $p \leq .20$. However, it is interesting to note that only as a component of labor's elasticity is the coefficient for M or I positive; elsewhere it is negative. Other permutations of these specifications are presented but not discussed because of the aforementioned problems of specification bias and multicollinearity.

12. Conclusions and Speculations

We are not surprised to learn that management is primarily labor-augmenting in this part of Tanzania. Land is still relatively abundant[3] and labor is far more likely to be the binding constraint, especially since the labor calendar shows sharp peaks at times of land preparation, weeding

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[1]The only difference is that b_{KM} is not significant at $p \leq .09$ but is at $p \leq .20$ while b_{KI} is not significant at $p \leq .20$ as well.

[2]See Table 5.

[3]The land in Geita is also fairly fertile. Most of the district was nearly uninhabited until after World War II when tsetse-clearing programs allowed the cattle-raising Sukuma to migrate in from the East. Hence the soil's nutrients have not been drawn upon for very long. Relatively high natural fertility is reflected in relatively low fertilizer responsiveness in experiments carried out by the nearby Ukiriguru Research Center.

TABLE 5

Correlations Among Variables

	I log K	I log L	Log K	Log L
I	.751	.990	.261	.341
I log K		.822	.663	.547
I log L			.341	.419
Log K				.808

	M log K	M log L	Log K	Log L
M	.704	.974	.323	.344
M log K		.813	.840	.661
M log L			.485	.529
Log K				.808

	I
M	.666

and harvesting. Furthermore, the proper timing of various tasks, mainly planting and weeding, is often crucial in determining yields. For example, Figure 2 shows how yields decline rapidly if planting is delayed. The care with which various tasks are done is also quite important. A farmer's performance in all these aspects of labor may be determined by his knowledge about them, but we hypothesize that a more important factor is his willingness to be fully technically efficient -- a willingness that is associated with modernization.[1]

A shift to greater technical efficiency in the application of labor to the cotton enterprise may entail a number of economic and noneconomic costs. For example, proper timing of cotton planting may be at the expense of proper timing for food crops. The outcome of such a trade-off would be determined partly by relative prices but also by subjective valuation of the market's reliability as a source of food, and by the extent to which a farmer is willing to break with the traditional notion that a man should grow his own food. (Perhaps only poor, landless laborers and very small landowners buy staple foodstuffs in the market.) Proper timing may, at times, mean forcing family members to work in bad weather or when they are tired or ill. It may also mean not attending mourning for a neighbor.

Similar noneconomic costs may have to be incurred to insure proper care in certain tasks. Victor Uchendu [1969] has reported that in parts of Uganda farmers said they had switched from using traditional, cooperative work groups to using hired individuals because the work of the latter was easier to control. This might be relevant when a farmer wants to vary a traditional task or simply wants to enforce its ideal form. The shift

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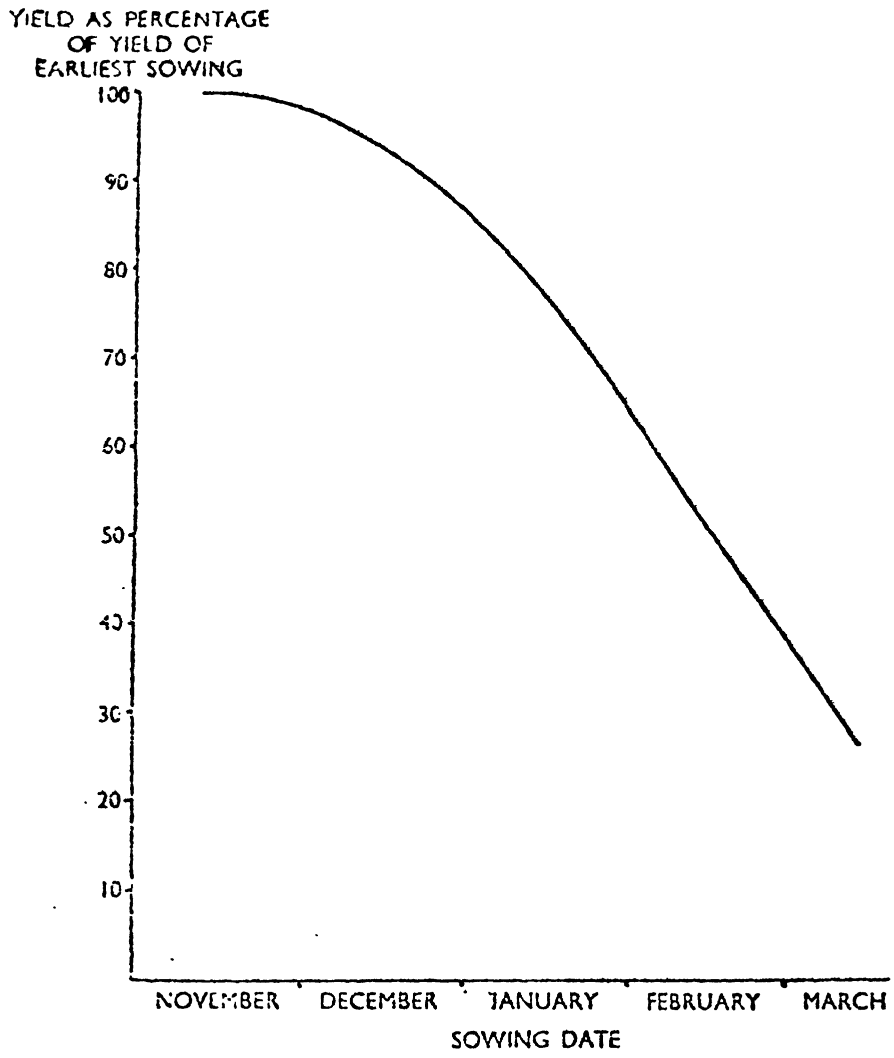
[1]The correlations displayed in Table 2 and the associated discussion seem to indicate a lesser role for information than for modernization.

Figure 2

Relationship Between Cotton Yield and Planting Date*[a]



*Graph from W. Reed. "Problems Posed by Early Sowing of Cotton in Lake Region, Tanganyika." Empire Cotton Growing Review, 1964, p. 256.

[a]Polynomial fitted to results from seven trials over four seasons. $R^2 = 0.74$.

from groups to individual hired workers entails a subtle economic cost to the extent that participation in a group provides a type of insurance policy. The shift also entails noneconomic costs to the extent that nonparticipation may result in, for example, partial social ostracism. Noneconomic costs may also be incurred when a farmer tries to force family members to perform their work in a certain way. All such activities might lead to a farmer being labeled "unsociable" by the area's Sukuma people, who value "sociability."[1]

The above remarks are intended to provide a partial explanation of how general modernization may affect technical efficiency in traditional farming. The modern farmer, who might be marching to a different drummer,[2] may be more willing to incur the aforementioned noneconomic costs, and (to argue along more traditional lines) his risk preferences and his perceptions of the market economy (e.g., the market as a source of food) may lead him to subjectively deflate the aforementioned economic costs. Such factors may make the modern farmer more willing to strive for greater technical efficiency.

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[1]For example, one group of ten households (nyumba ya kumi-kumi) elected as their representative (balozi) to the ward's TANU meetings a farmer whose older brother also lived(in his own compound)in the kumi-kumi. This departure from honoring elders was attributed, by some, to the older brother's lack of sociability. Both brothers were about comparable in wealth and relevant skills such as literacy.

[2]The Thoreau analogy is from Rogers [1969].

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A Note on Management Bias in Estimates of Cobb-Douglas Production Functions

by

Kenneth H. Shapiro

In his famous article on specification bias, Griliches [1, p. 8] proposes to show that, "under 'reasonable' assumptions the omission of managerial inputs from the production function biases the estimate of the elasticity of output with respect to capital upwards, and the estimate of returns to scale downwards." We propose to show that the results regarding returns to scale depend on the manner in which management enters the production function and that the bias may be in different directions for firms with different levels of management.[1] One implication of this indeterminacy is that economists may not explain away findings of decreasing returns merely by noting that management was omitted -- a strategy that Heady and Dillon [2, pp. 225, 230-231] seem to be suggesting and that Yotopoulos [5, p. 182] and others seem to have followed.

To review Griliches' argument, we wish to estimate the parameters in the following "true" relationship between x and y:

$$y = Xa + u \tag{1}$$

but for some reason we estimate the parameters in

$$y = \bar{X}b + v \tag{2}$$

where y is the column vector of values of the dependent variable, X is matrix of the full set of k independent variables, $\bar{X}$ differs from X in lacking one or more columns corresponding to the omitted variables, a

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[1]The results regarding individual coefficients would seem to hold.

is the vector of "true" parameters and b is the vector of extimated parameters. Griliches notes that

$$E(b) = E(\bar{X}'\bar{X})^{-1}\bar{X}'y = E(\bar{X}'\bar{X})^{-1}\bar{X}'(Xa+u) = (\bar{X}'\bar{X})^{-1}\bar{X}'Xa \tag{3}$$

Let $(\bar{X}'\bar{X})^{-1}\bar{X}'X = P$ and write $E(b) = Pa$.

The elements of P may be thought of as estimated parameters in the "auxiliary" regression of each column of X on $\bar{X}$. For example, the k^{th} column of P is composed of the parameters estimated in the "auxiliary" regression of x_k on the h included variables:

$$x_k = \sum_{i=1}^{h} p_{ik}\, x_i + v_k \tag{4}$$

For the case of only one omitted variable, x_k, (i.e. h=k-1) the only non-trivial auxiliary regression is for that variable. For other variables we have, for example,

$$x_1 = 1 \cdot x_1 + \sum_{i=2}^{k-1} 0 \cdot x_i \tag{4a}$$

Hence P may be partitioned into a k-1 by k-1 identity matrix and a k-1 by 1 column vector of the p_{ik} elements from (4). When these results are applied to equation (3) we have, for example,

$$E(b_i) = a_i + p_{ik}a_k \tag{3a}$$

Griliches moves from this general case to the Cobb-Douglas case with an omitted variable -- a variable that Griliches implicitely assumes should have been specified in the function in the same manner as the other multiplicative variables. This unstated assumption and the above preliminary results lead Griliches to write the bias in returns to scale as

$$E(\hat{R}-R) = E\left(\sum_{i=1}^{k-1} b_i - \sum_{i=1}^{k} a_i\right)$$

$$= \sum_{i=1}^{k-1} (a_i + p_{ik}a_k) - \sum_{i=1}^{k} a_i$$

$$= \sum_{i=1}^{k-1} p_{ik} a_k - \left(\sum_{i=1}^{k} a_i - \sum_{i=1}^{k-1} a_i \right)$$

$$= a_k \left(\sum_{i=1}^{k-1} p_{ik} - 1 \right) \tag{5}$$

Since a_k is assumed to be greater than zero, the crucial question for Griliches is whether $\sum_{i=1}^{k-1} p_{ik}$ is greater or less than unity. This is determined in the nontrivial regression, which, for the Cobb-Douglas case, is

$$x_k = x_1^{p_{1k}} x_2^{p_{2k}} \ldots x_{k-1}^{p_{k-1,k}} e \tag{6}$$

$$\text{or } \log x_k = p_{1k} \log x_1 + p_{2k} \log x_2 + \ldots + p_{k-1,k} \log x_{k-1} + v. \tag{6a}$$

In this case $\sum_{i=1}^{k-1} p_{ik}$ equals the degree of homogeneity of the "auxiliary" function. If a proportionate increase in all k-1 included variables is associated with a more than proportionate increase in the excluded x_k, then $\sum_{i=1}^{k-1} p_{ik} > 1$ and we would have an overestimate of returns to scale. Griliches [1, p. 13] notes that if x_k is the omitted management variable, the opposite result is far more likely:

> It is probably true, in most of our samples, that a farmer who farms on twice the scale of his neighbor is not twice as good an entrepreneur, nor does he do twice as much managerial work. If this assumption about our samples is right, the sum of the coefficients in the 'auxiliary' equation will add up to less than one and we shall consistently underestimate returns to scale.

The point we wish to make is that these results depend on Griliches' implied assumption that management enters the production function as a multiplicative variable in the same manner as land, labor and capital.

That specification gives rise to the particular form of the auxiliary regression in (6), and the expression for the bias in estimated returns to scale in (5). If management enters the Cobb-Douglas production function in some other manner, equations (5) and (6) will be different and, in some cases, so will the direction of bias in estimated returns to scale. That is, Griliches results are not general but rather apply to a particular specification of management in the production function. Furthermore, that specification may well be less appealing than others that lead to different conclusions about the bias in estimated returns to scale.

Nerlove [3, p. 62] has suggested the following specification:

$$y_f = (a_o m_{of}) \, x_{1f}^{a_1 m_{1f}} \, x_{2f}^{a_2 m_{2f}} \tag{7}$$

where f indexes different firms and the m_{if}, "all represent differences in production functions among firms" [3, p. 62]. These differences stem, in part, from differences in technical efficiency which stem, in part, from differences in management. Shapiro and Müller [4] have estimated the following variant of Nerlove's model:

$$y_f = A \, x_{1f}^{(a_1 + a_{1m} m_{1f})} \, x_{2f}^{(a_2 + a_{2m} m_{2f})} \tag{8}$$

where the m_{if} are measured indices of types of modernization and/or information that are thought to give rise to differences in technical efficiency.

Consider the simple case where management enters only in the elasticity of x_1:

$$y_f = A\, x_{1f}^{(a_1+a_{1m}m_{1f})}\; x_{2f}^{a_2} \tag{9}$$

If we do not estimate (9) but rather estimate

$$y_f = A\, x_{1f}^{b_1}\, x_{2f}^{b_2} \tag{10}$$

The excluded variable is $x_{1f}^{m_{1f}} = z_f$. The auxiliary equation that yields the p_i is then

$$z_f = x_{1f}^{m_{1f}} = x_{1f}^{p_{1z}}\, x_{2f}^{p_{2z}} \tag{11}$$

or

$$\log z_f = m_{1f} \log x_{1f} = p_{1z} \log x_{1f} + p_{2z} \log x_{2f} \tag{11a}$$

Returns to scale in the "true" production function (9) are

$$R = a_1 + a_{1m}m_{1f} + a_2 \tag{12}$$

while in the estimated function (10) they are

$$\hat{R} = b_1 + b_2 \tag{13}$$

The bias in estimated returns to scale is then

$$\begin{aligned} E\,(\hat{R} - R) &= E\left[(b_1 + b_2) - (a_1 + a_{1m}m_{1f} + a_2)\right] \\ &= \left[(a_1 + p_{1z}a_{1m} + a_2 + p_{2z}a_{1m}) - (a_1 + a_{1m}m_{1f} + a_2)\right] \\ &= \left[\sum_{i=1}^{2} p_{iz}\, a_{1m} - a_{1m}\, m_{1f}\right] \\ &= a_{1m}\left(\sum_{i=1}^{2} p_{iz} - m_{1f}\right) \end{aligned} \tag{14}$$

The p_{iz} come from auxiliary regression (11a). Following Griliches' assumption that management (m_1) varies directly (but less than proportionately) with the included variables, an auxiliary equation like (11a) represents a nonlinear relationship of the type shown in figure 1.

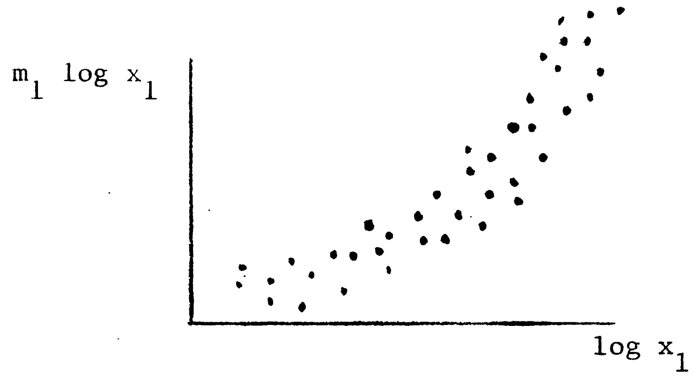

figure 1

A least squares estimate of the p_{iz} will generally yield $\sum_{i=1}^{2} p_{iz} > m_1$ for low levels of m_1 (and x_i), and $\sum_{i=1}^{2} p_{iz} < m_1$ for high levels of m_1 (and x_i).

When these auxiliary regression results are applied to equation (14) we see that there is likely to be an overestimate of returns to scale for farmers with relatively low levels of management and other inputs, and an underestimate for farmers operating at higher levels. This result, like Griliches', is not general but rather depends on the form in which management enters the production function. Thus one general conclusion of this note is that economists should have some notion of the nature of the "true" production function before they venture judgements about the bias in any estimate of returns to scale.

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