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Describing Agricultural Technology - Bridging the Gap from Specific Processes to General Production Functions

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DESCRIBING AGRICULTURAL TECHNOLOGY -- BRIDGING THE GAP FROM SPECIFIC PROCESSES TO GENERAL PRODUCTION FUNCTIONS.

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FOREWORD

The Food and Agriculture Program at IIASA focuses its research activities on understanding the nature and dimension of the world's food problems, on exploring possible alternative policies that can help alleviate current problems and prevent future ones.

As a part of the research activities investigations of alternative paths of technological transformation in agriculture in the context of resource limitations and long term environmental consequences are being investigated. The purpose is to identify production plans strategies which are sustainable. The general approach and methodology developed at IIASA for this investigation is being applied in several case studies on the regional level in different countries with the help of collaborating institutions.

Before we can explore these alternatives, we needed to describe quantitatively agricultural technology. The large number of operations involved in agriucltural work and its specificity to particular agroclimatic situations tend to make agricultural technology data banks very large. This paper presents some ways to efficiently describe and store information on agricultural technology.

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1. INTRODUCTION: THE PROBLEM

Quantitative descriptions of technological alternatives available to produce a particular product or service follow one of two paths, depending on disciplinary bias as well as on the problem at hand. Thus engineers and technologists who are usually concerned with decisions at the field or factory level prefer descriptions which refer to specific machines used in particular processes. Economists concerned with decisions at the industry or the economy level, on the other hand, prefer a production function in which only an aggregate measure of machinery and equipment – eg., dollars worth of capital – is used. It is difficult to identify specific technical processes that correspond to a particular point on the production function, though in principle such a correspondence does exist. Many times aggregate production functions are estimated econometrically from financial data at the industry level that do not provide even qualitative information on the processes involved. Thus even when the raw data behind the estimated production functions are available, it is not easy to relate specific techniques to points on the production functions.

On the other hand, the technologist's description is so detailed and specific to particular situations of the field or factory that it is difficult to use the data for industry- or region-level decisions. When such data are collected from a large number of cases, the resulting data set becomes so large and diverse that the information contained in the data gets drowned in the mass of numbers. Such technological descriptions are thus not easy to use for analytical purposes and system-level optimization.

These two approaches should be reconciled. Because of the limited variability of aggregate data, estimated production functions would remain highly unsatisfactory for many useful analytical purposes unless the technological knowledge of the engineer can be brought to bear on the economist's estimates of production functions. This would also benefit the engineer, as it could help him to perceive patterns and universality of parts of his technological data and thus to avoid much duplication in data collection.

The dichotomy between the description of field-level techniques and sector-level production function is particularly severe for agriculture, where the soil and climate characteristics seem to make each field a separate and non-reproducible observation. This poses a formidable difficulty in exploring at a regional level optimum strategies for agricultural development in a way that satisfactorily deals with the interactions between agricultural technology, cultivation and management practices, the environmental consequences of these, and their impact on soil and water resource quality.

A desirable scheme for description of technological options should as far as possible meet the following requirements:

(a) It should relate specific micro-level processes and operations to a relatively aggregated production function.

(b) It should facilitate a representation of technological options that can be used in analysis for system-level optimization. This means that the resulting analytical model should be computationally manageable. For example, if the model is a linear programming one, the size of LP that is generated should be reasonable.

(c) It should account for technological progress in a way that could be useful for projecting such progress.

(d) It should identify the elements of technology which are site and situation specific and those which provide a universal description of technology which is applicable to other situations, so that with every case study the data bank grows in a meaningful way.

I have outlined below a scheme that, I think, meets these needs. In Section 2 the proposed scheme for technology description is outlined along with the components of the data bank that would embody such a description of technology. The main research problem is identified in this process. The assumptions behind the scheme are further elaborated in Section 3. Finally, the feasibility of the scheme and the possibility of successfully carrying out the research needed are demonstrated by an illustrative example in Section 4.

2. THE PROPOSED SCHEME

The proposed description scheme considers agricultural production to consist of a set of basic operations. Technological options in agriculture arise mainly from the alternative ways of performing these operations and the alternative interactions of inputs that are possible. Based on these alternatives the scheme proposes to estimate production functions for each of these operations. It shows how such operation production functions can be described and estimated to separate site and crop specific characteristics from the more universal mechanical engineering characteristics of technology. The first step is to define basic operations.

2.1. DEFINITION OF OPERATIONS

- An operation that can in principle – i.e., technically as opposed to economically – be carried out by a set of alternative combinations of factors such as men and machines should be considered as a separate type of operation.
- Operations required at different times may be treated as different types of operations for some analytical purposes but would not require separate operation production functions.

- Operations that can be performed only in specific situations by very specific machinery should also be treated as different types of operations.

Having defined operations, the next thing is to define units of measurement.

2.2. UNIT OF MEASUREMENT OF OPERATION

A standard unit of operation should be defined for each operation. Let us take plowing as an example. We can define an SPUW (Standard Plowing Unit of Work) as follows:

SPUW = Amount of plowing work required to plow 1 hectare of standard land for standard crop to a given depth.

Standard land and standard crop can be arbitrarily selected. However, some choices may be naturally more convenient.

2.3. ALTERNATIVE TECHNIQUES FOR OPERATIONS

Each operation can be carried out in different combinations of labor, machines, equipment, and associated energy inputs. Moreover, the machines vary from year to year in quality and also in the type of attachments they can take. Thus, the number of alternatives can be very large. What we need to do is to develop a production function for operations. This can be conceived as follows:

OO_i = output of i-th operation measured in "Standard Operation Unit of Work."

Inputs in the i–th operation are Standard machine $\equiv MS_i$

Standard labor $\equiv LS_i$

Standard equipment $= QS_i$

Associatedenergy $\equiv AE_i$

$$OO_i = O_i(MS_i, LS_i, QS_i, AE_i)$$

where MS_i is stipulated to be a function of

- some physical attribute of the machine (e.g. horsepower of tractor)
- the date of manufacture of the machine, to reflect technical progress.

QS_i is stipulated to be a function of

- some physical attribute of equipment, e.g. width of plow
- the date of manufacture of the equipment

LS_i is stipulated as a function of

- average age of worker
- level of education

and AE_i is in energy equivalent unit, such as ton of oil equivalent.

Note that technical progress is embodied in machines, equipment, and men. Developing

MS_i

QS_i

LS_i

and OO_i would be an important research task in this scheme.

2.4. CROP PRODUCTION TECHNIQUES

Yields are defined simply as a function of input levels of variable inputs such as seed rate, fertilizers, pesticides, and water, and standard units of operation work required for the crop and for the soil.

$$Y^{soil}_{crop} = Y^{c,s} (Fert^{c,s}, seed^{c,s}, water^{c,s}, O_i^{c,s} \ldots, O_n^{c,s})$$

These functions are within the traditional framework of economists and should pose no new difficulties in estimation once the operation output functions, OO_is, are developed.

2.5. THE COMPONENTS OF THE DATA BANK

This will result in a data bank with two components: a crop production activity matrix and operations output activity matrices.

(a) Crop Production Activity Matrix

The structure of the matrix is shown in Figure 1.

		Activities									
		soil 1							soil 2	...	soil s
	Inputs	crop 1						crop c			
		alternatives									
		1	2	3	4	...	m				
A	Main yield	-1	-1	-1	-1						
	Joint yield 1	-	-	-	-						
	Joint yield 2	-	-	-	-						
	Seeds	s_1	s_2	s_3	s_4						
	Fertilizer	f_1	f_2	f_3	f_4						
	Pesticides	p_1	p_2	p_3	p_4						
B	Operation O_1	O_{11}	O_{12}	O_{13}	O_{14}						
	Operation O_2	O_{21}	O_{22}	O_{23}	O_{24}						
	.	.	.	.	.						
	.	.	.	.	.						
	.	.	.	.	.						
	Operation O_n	O_{n1}	O_{n2}	O_{n3}	O_{n4}						

Figure 1. The Crop Production Activity Matrix.

Note here that neither part A nor B of the matrix is affected by the technical progress that takes place in mechanical equipment development. Part A embodies the information from the genetic and agronomic aspects and varies only when there is genetic technical progress. Part B embodies agronomic aspects relating to soil and remains invariant to technological developments in the machine sector as well as to genetical progress.

(b) Operation Output Activity Matrices
For each operation one matrix will define the alternatives available for producing the output of that operation. The structure of a typical matrix is shown in Figure 2.

Inputs	Activities 1	2	3	m_i
OO_i	-1	-1	-1	
Tractor 1				
Tractor 2				
Tractor .				
Tractor .				
Tractor .				
Tractor t_n				
Equipment 1				
Equipment 2				
Equipment .				
Equipment .				
Equipment .				
Equipment e_n				
Labor 1				
Labor 2				
Labor .				
Labor .				
Labor .				
Labor l_n				
Energy 1				
Energy 2				

Figure 2. A typical Operation Output Activity Matrix

As new machines are developed and new data are available, these matrices have to be augmented by additional rows and columns. But it should be noted that these matrices are largely independent of variations in soil and climate. Thus they are "universal" descriptions of technology.

3. ASSUMPTIONS BEHIND THE SCHEME

What have we assumed and sacrificed in this scheme of technology description can be shown formally by comparing it with conventional descriptions of technology.

Formally a production function can be described as a yield (in quantity/hectare) function for a given soil and a given crop variety where the inputs are the various machines and labor services involved in different operations and other current inputs. Thus

$$\text{Yield}^{\text{soil}}_{\text{crop variety}} = f^{s}_{cv}(M^{o}_{i}, L^{o}_{j}, E^{o}_{k}, \text{Fert, Water, Pesticide, Seeds})$$

where

M_i^o is i-th machine used for o-th operation where $i \in m$, the set of machines

L_j^o is the j-th type of labor used in o-th operation where $j \in s$, the set of labor skills

E_{ik}^o is the k-th type of equipment used in o-th operation where $k \in E$, the set of equipments

Thus if n operations $0 = 1,\ldots,n$ are distinguished, we will have $n \times M \times S \times E$ different possible combinations of factor inputs. In addition one should also consider for a given combination alternative intensity levels of factors. Thus the production function has a very large number of parameters.

Compared to this the scheme suggested introduces certain separability between operations and soils and hypothesizes that operations can be described by production functions. Thus

$$\text{Yield}_{\text{crop variety}}^{\text{soil}} = Y_{cv}^{s}(O_1^s, \ldots, O_n^s, \text{Fert, Water, Pesticide, Seeds})$$

where the output of i-th operation for soil s, O_i^s, is characterized by

$$O_i^s = g(\text{soil}) \cdot O_i(a(M), b(L), c(E))$$

a(M) attributes of machines such as horse power, vintage, etc.

b(L) attributes of labor such as skills, experience, age, etc.

c(E) attributes of equipment such as width, weight, vintage, etc.

4. ESTIMATES OF SOME OPERATIONS OUTPUT FUNCTIONS

To illustrate how this can be done, we have estimated some operations output functions.

Data from experimental stations in Hungary is used to estimate these functions. These stations carry out experiments with different machineries and equipments and report performances in terms of hectares/hour, depth, width, etc. for different soils and different years.

I have used data from Gockler and Lakatos (1977), which gives data from 1965 through 1975. Data with adequate information are available for the operations of ploughing, discing, precultivation, soil preparation, row cultivation and maize harvesting.

To illustrate the nature of the reported data and how I have used it, data for ploughing for a specific soil as given in the book and as reogranized are shown in Table 1. Since the number of observations available for ploughing were large we have used only the average performance. For other operations performance for each year was treated as a seperate observation.

Data on the attributes of equipment used were not available so I have considered just two attributes of tractors, horsepower and vintage, defined here as date of its first use.

I have also pooled the data from three different soils. Here again adequate information on the properties of soils were not available to me and I have used dummy variables for the different soils.

A general model is postulated for all the operations.

$$\begin{bmatrix}\text{hectares}\\ \text{operated}\\ \text{per hour}\end{bmatrix} = e^{(\sigma_0 + \sigma_1 s_1 + \sigma_2 s_2)} \begin{bmatrix}\text{intensity}\\ \text{of}\\ \text{operation}\end{bmatrix}^{\gamma} \left[e^{\beta t} H_t\right]^{\alpha}$$

where

s_1 and s_2 are dummy variables for soil type 1 and 2;

intensity of operation refers to

depth in cms for ploughing and discing

width in cms between rows for cultivation

yield of grains in tons/hectares

H_t is the horse power of the tractor first introduced in year t

t is vintage year (t = 66 for 1966, etc.)

Both α and β are expected to be positive, whereas γ is expected to be less than zero. When γ is insignificant it would imply that the hectares operated per hour do not depend on the intensity of operation, which is possible for some operations.

The intensity variables are taken at the mean values of the indicated ranges. For example, depth of ploughing shown as 16 to 18 cms would be taken as 17 cms. For the case of maize harvesting, the data on yields of the fields were not available, and I had to use the data on national yields for Hungary as an approximation. The results of the various regressions are given in Table 2.

The regression results are remarkably good. The t statistics are mostly highly significant and the signs of coefficients are in general right. The $\bar{R}^2$ are also quite good considering that I have used, excepting for ploughing operations, raw data of individual observations and not grouped data.

The only insignificant intensity coefficient is of discing operation implying that depth of discing does not affect performance in terms of hectares per hour, which is conceivable. The vintage coefficients for precultivation, row cultivation and maize harvesting are also insignificant indicating that technical progress in tractors do not affect performance in these operations. The only coefficient with wrong sign is that of intensity (depth in this case) of precultivation operation. Were information on equipment attributes or other special features of tractors to be incorporated into the model, its explanatory power could have been increased further. Also one could try alternative, more elaborate models. For example for ploughing operation. I had also tried:

$$\begin{bmatrix}\text{hectares}\\ \text{ploughed}\\ \text{per hour}\end{bmatrix} = e^{(\sigma_0 + \sigma_1 s_1 + \sigma_2 s_2)} \left[\text{depth}\right]^{(\gamma_0 + \gamma_1 s_1 + \gamma_2 s_2)} \left[e^{\beta t} H_t\right]^{\alpha}$$

which increase the $\bar{R}^2$ to 0.66 with all parameters significant and of expected signs.

Thus the approach suggested here, is very promising and systematic work can be very fruitful.

Table 1a. Ploughing operation in a particular soil -- A sample of data from Gocker and Lakatos (1977)

Field Category I – Ploughing. (depth of ploughing 29-30 cms)

Type of tractors	Horse* power	1965	1966	1967	1968	1969	1970
Zetor S-50	50	0.16	0.20	0.20	0.21	0.23	0.17
T-100M	100	0.39	0.40	0.40	0.40		
D4K-B	50	-	0.37	0.43	0.43	0.46	0.50
MTZ-50	50	0.17	0.19	0.22	0.21	0.23	0.27
DT-75	75		0.41	0.39	0.31	-	-
K-700	120	-	-	-	-	-	-
JD-4020	120	-	-	-	-	-	-
JD-4320	150	-	-	-	-	-	-
IHC-1246	120	-	-	-	-	-	-
IHC-1046/A	150	-	-	-	-	-	-
IHC-1066	175	-	-	-	-	-	-
Steiger	200	-	-	-	-	-	-
Average		0.29	0.32	0.36	0.34	0.38	0.34

Type of tractors	Horse* power	1971	1972	1973	1974	1975	average
Zetor S-50	50	-	-	-	-	-	0.20
T-100M	100	-	-	-	-	-	0.40
D4K-B	50	0.43	0.43	-	-	-	0.44
MTZ-50	50	0.17	0.28	0.28	0.30	0.31	0.26
DT-75	75	0.34	-	-	-	-	0.35
K-700	120	-	-	-	0.43	0.33	0.34
JD-4020	120	-	0.72	0.41	0.39	0.35	0.41
JD-4320	150	-	-	-	0.42	0.20	0.39
IHC-1246	120	-	-	-	0.34	0.37	0.36
IHC-1046/A	150	-	-	-	0.36	0.41	0.39
IHC-1066	175	-	-	0.81	0.79	0.81	0.80
Steiger	200	-	-	-	1.27	1.44	1.35
Average		0.36	0.35	0.44	0.47	0.50	0.37

* Though horse power data is not given, it was easy to obtain from tractor types.

Table 1b. Ploughing operations data as reorganized for regressions

year of first introduction of the tractor type	depth of ploughing in cms	horse power of tractor	average (1965-75) performance (hectares ploughed per hour)
60	30	50	.20
65	30	100	.40
66	30	50	.44
60	30	50	.26
66	30	75	.35
70	30	120	.34
72	30	120	.41
72	30	150	.36
74	30	150	.39
73	30	175	.80
74	30	200	1.35

Notes:

(i) For tractors already available in 1965, the vintage year is taken to be 1960 as I did not have earlier data.

(ii) Since for ploughing operation the number of observations are large, I have taken the average performance over the year 1965 through 1975.

Table 2. Estimated Agricultural Operations Output Functions.

	Coefficent of								
Operation	Constant	Soil 1 dummy	Soil 2 dummy	intensity of operation	vintage* of tractor	tractor horse power		$\bar{R}^2$	F
	σ_0	σ_1	σ_2	γ	β	α	DF		
Ploughing	-2.826	-.103	-.188	-.906	.102	.438		0.60	36.4
	(-5.46)	(-1.47)	(-2.38)	(-8.10)	(5.18)	(4.47)	113		
Discing Operation	-4.892	-.199	-.066	-.017	.079	.561		0.69	70.6
	(-6.37)	(-4.43)	(-1.49)	(-.32)	(3.40)	(10.0)	151		
Precultivation Operations	-4.948	.466	.260	.256	.016	.889		0.64	38.4
	(-4.73)	(5.58)	(2.43)	(2.28)	(.81)	(8.17)	100		
Row Cultivation	-4.156	-.141	0.83	.330	.0056	1.14		0.53	24.0
	(-3.98)	(-1.49)	(-1.47)	(3.03)	(.31)	(6.79)	97		
Maize Harvesting	-6.03		-2.65	-.554	.040	.819		0.42	11.7
	(-4.62)		(-2.30)	(-1.73)	(.92)	(2.23)	55		

* Vintage (years of first introduction of tractor) coefficient β obtained by dividing the estimated coefficient $\beta\alpha$ by α, the coefficient of tractor horse power; the t-values shown under β are t values of ($\beta\alpha$)

Values in ( ) are t-values

5. SOME USES AND IMPLICATION OF THE ESTIMATED FUNCTIONS.

Apart from their value in describing agricultural technologies economically and in reducing the size of programming models, these estimates have important implications for research in agricultural economics.

The significance of estimated vintage coefficients provide strong support for embodied technical progress and for vintage models. The estimates provide guidance on aggregating machinery. Many researchers have used horse power as a measure of machinery in estimating aggregate production functions (see for example, Hayami (1969), Hayami and Ruttan (1970) and Kawague, Hayami and Ruttan (1983)). In the presence of embodied technical progress adding up horsepower of machinery without accounting for vintage would introduce bias in the estimated coefficients. Machinery will be under estimated (as effective horse powers of more recent machinery are not adjusted upwards) and hence its coefficient would be higher. Comparison in changes in factor productivity in different countries based on such estimates would therefore be questionable. Also when data from different countries whose machinery age structures are different are used for cross country regression even the direction of the bias would be unpredicable.

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