Vol XXXIX
No. 2

APRIL-
JUNE
1984

ISSN 0019-5014

INDIAN JOURNAL OF AGRICULTURAL ECONOMICS

INDIAN SOCIETY OF
AGRICULTURAL ECONOMICS,
BOMBAY

ARTICLES

SYSTEMS OF OUTPUT SUPPLY AND FACTOR DEMAND EQUATIONS FOR SEMI-ARID TROPICAL INDIA

Shanti L. Bapna, Hans P. Binswanger and Jaime B. Quizon*

The paper presents six systems of agricultural output supply and factor demand equations for the semi-arid tropical (SAT) parts of the States of Andhra Pradesh, Madhya Pradesh, Karnataka and Tamil Nadu.[1] Three of these systems relate to the entire SAT parts of these States and consider three different levels of commodity aggregation, *i.e.*, seven, four, and two commodity models, including fertilizer. The other three systems are disaggregated (six or seven commodities) and relate to specific sub-zones of the SAT, namely, the rice growing sub-regions, the wheat growing sub-regions and the cotton-groundnut growing sub-regions. The systems are based on flexible functional forms for profit functions. Due to data limitations they are incomplete, *i.e.*, they do not contain an exhaustive list of factors of production.

The first section discusses the theoretical framework, followed by a brief section on econometric procedures. Data sources and the agro-climatic sub-zones are discussed in section III. This is followed by a section on models and commodity aggregations used for the different sub-zones. Section V discusses the results and conculsions.

I

SYSTEMS OF OUTPUT SUPPLY AND FACTOR DEMAND EQUATIONS

Systems of output supply and factor demand equations can be derived from a profit function. The derivation is presented below. In a later section, we test whether this derivation is consistent with the statistical evidence. At this point, however, we note that systems of output supply and factor demand equations can exist, independent of the behavioural mechanism of profit maximization, as long as the behaviour of individual agents is sufficiently stable over time and can be aggregated over farmers. This implies

*Associate Professor, Indian Institute of Management, Ahmedabad; Economist, The World Bank, Washington, D. C.; and Visiting Fellow, Yale University, New Haven, U.S.A., respectively. The project was supported by the International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India with which the first two authors were associated for a number of years. It was also supported by a research grant of USAID to Yale University and by the Economic Growth Center, Yale University. The generous support of these institutions is gratefully acknowledged. The views expressed in this paper, however, do not necessarily reflect those of the sponsoring institutions or the current employers of the authors. All computations in this paper used the programmes "Elasticities" prepared by Sidney Feit. We are also grateful for research assistance received at various stages from M. Pereira, K. Kaboth, P. Kumar, Valasayya and Rajendran. Discussions of the project with J. Behrman, R. E. Evenson and J. G. Ryan were also particularly helpful.

1. In India, ten States contain semi-arid regions. In addition to the above four, these are Maharashtra, Gujarat, Rajasthan, Uttar Pradesh, Haryana and Punjab.

that estimated systems are useful for economic analysis regardless of whether the theoretical restrictions of profit maximization hold. However, if profit maximization does not hold, no inferences can be made from the supply and demand equations about the production function underlying them, since behavioural and technological relationships are then confounded in those equations.

Suppose now that there are n commodities, Y_i, of which the first m are outputs and those indexed m+1,......, n are variable inputs under the control of the individual agent. Define a vector of commodities Y such

$$Y_i \geqslant 0 \text{ for } i=1, \ldots, m \text{ and } Y_i \leqslant 0 \text{ for } i=m+1, \ldots, n. \quad \ldots.(1)$$

Variable inputs are defined as negative quantities, they subtract from revenues of the positive outputs. These commodities have prices $P_i \geqslant 0$ for all i. π is variable profits or return to fixed factors of production and $\pi = Y'P$. There are also k fixed factors of production, Z_k, k=1...K, such as fixed capital or land quality. Let t stand for time or a technology index. If a sufficiently "well-behaved" transformation function[2] exists, g(Y,Z,t) = 0, and agents maximize variable profits π, then a profit function exists which relates maximized profits π^* to the prices of the variable commodities, the fixed factors and time, *i.e.*,

$$\pi^* = \pi^* (P,Z,t) \quad \ldots.(2)$$

The function π^* has the following properties (where π_i^* and π_{ij}^* are derivatives and cross derivatives of the profit function with respect to the prices of the commodities i and j).

(*i*) π^* is monotonically increasing in P_i if i is an output and monotonically decreasing in P_i if i is an input.

(*ii*) The output supply and factor demand curves are derived via Shephard's Lemma:[3]

$$Y_i = \pi_i^* (P,Z,t) \begin{matrix} \geqslant 0 \text{ for } i=1,\ldots m \\ \leqslant 0 \text{ for } i=m+1,\ldots n \end{matrix} \quad \ldots.(3)$$

(*iii*) The cross derivatives of π^* are symmetric, *i.e.*, $\pi_{ij}^* = \pi_{ij}^*$.

(*iv*) π^* is convex, *i.e.*, the(singular) matrix of its cross derivatives π_{ij}^* is *positive semi-definite* or all its characteristic roots are positive or zero.

(*v*) π^* is homogeneous of degree one in P and the supply and demand equations from π^* are homogeneous of degree zero in P. The matrix

$$\left[\eta_{ij}\right] = \left[\frac{\partial Y_i}{\partial P_j} \frac{P_j}{Y_i}\right]$$ defines the factor demand and output supply elasticities

and

$$\sum_{j=1}^{n} \eta_{ij} = 0 \qquad i = 1, \ldots\ldots, n. \quad \ldots.(4)$$

2. For the conditions which must be imposed on the transformation function, see Diewert(1978).
3. See Shephard (1970).

We will consider two alternative functional forms for equation (2) in our empirical work.[4] The first, the Generalized Leontief (GL) due to Diewert (1971), is written as

$$\pi^* = \sum_i \sum_j b_{ij} P_i^{1/2} P_j^{1/2} + \sum_i \sum_k b_{ik} P_i Z_k + \sum_i b_{it} P_i t \qquad \ldots.(5)$$

The corresponding factor demand and output supply system from this profit function is given in panel (*a*) of Table I. All n equations can be estimated jointly but the profit function (6) is not linearly independent since it is the linear combination $\sum_{i=1}^{n} Y_i P_i$ of the individual equations. In this system, the homogeneity constraint is not testable since for each equation η_{ij} estimated residually.

The second functional form is derived from the Normalized Quadratic (NQ) profit function. A normalized profit function is derived by stating the initial profit maximizing problem in terms of normalized prices $q_i = \frac{P_i}{P_n}$ where all prices and profits are divided by the price of the nth commodity. Normalized profits are:

$$\bar{\pi} = \frac{\pi}{P_n} = \sum_{i=1}^{n-1} Y_i q_i + Y_n \qquad \ldots.(6)$$

Shephard's Lemma then reads that $\frac{\partial \bar{\pi}}{\partial q_i} = Y_i$. The normalized quadratic profit function (NQ) is written as

$$\bar{\pi} = a_o + \sum_{i=1}^{n-1} a_i q_i + \tfrac{1}{2} \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} b_{ij} q_i q_j + \sum_{i=1}^{n-1} \sum_k b_{ik} q_i Z_k + \sum_{i=1}^{n-1} b_{ik} q_i \ldots.(7)$$

The output supply and factor demand curves for the first (n—1) output and factors are given in panel (*b*) of Table I. Homogeneity of degree zero in all prices is imposed on all the equations and cannot be tested. The symmetry constraint can be tested and imposed. The equation for the nth commodity has to be derived residually: from equation (6) we can compute

$$Y_n = \bar{\pi} - \sum_{i=1}^{n-1} Y_i q_i. \qquad \ldots.(8)$$

By substituting into this expression (7) for $\bar{\pi}$ and the commodity equations for Y_i from Table I, we obtain

$$Y_n = a_o - \tfrac{1}{2} \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} b_{ij} q_i q_j \qquad \ldots.(9)$$

4. Data limitations prevent us from using the translog function.

The derivatives of this equation with respect to individual prices are

$$\frac{\partial Y_n}{\partial P_j} = -\sum_{i=1}^{n-1} b_{ij} \frac{P_i}{P_n^2}, \; j < n \qquad \ldots.(10)$$

from which we can compute the elasticities for the nth equation as

$$\eta_{nj} = \frac{\partial Y_n}{\partial P_j} \cdot \frac{P_j}{Y_n} = - \frac{P_j}{P_n^2 Y_n} \sum_{i=1}^{n-1} b_{ij} P_i \qquad \ldots.(11)$$

Finally, η_{nn} can be determined residually via equation (4) as

$$\eta_{nn} = - \sum_{j=1}^{n-1} \eta_{nj} . \qquad \ldots.(12)$$

It should be noted that one could include equation (5) in the estimation process or leave it out and estimate the elasticities of the nth equation residually.

TABLE I—OUTPUT SUPPLY AND FACTOR DEMAND FORMULAE AND RESTRICTIONS

	(a) Generalized Leontief (GL)	(b) Normalized Quadratic (NQ)
Form of factor demand and output supply equations	$Y_i = b_{ii} + \sum_{j \neq i} b_{ij} \left(\frac{P_j}{P_i}\right)^{1/2} + \sum_k b_{ik} Z_k + b_{it}\, t$ for $i = 1, \ldots n$.	$Y_i = a_i + \sum_{j=1}^{n-1} b_{ij} \frac{P_j}{P_n} + \sum_k b_{ik} Z_k + b_{it}\, t$ for $i = 1, \ldots, n-1$; $Y_n = a_o - \frac{1}{2} \sum_{i=1}^{n-1} \sum_{j=1}^{n-1} b_{ij} \frac{P_i}{P_n} \frac{P_j}{P_n}$
Homogeneity constraint	Imposed not testable	Imposed not testable
Symmetry constraint	$b_{ij} = b_{ji}$ $i \neq j$	$b_{ij} = b_{ji}$ $i, j \neq n$ and including the b_{ij} of equation n.
Elasticities		
Cross price	$\eta_{ij} = \frac{b_{ij}}{2Y_i} \left(\frac{P_j}{P_i}\right)^{1/2}$	$\eta_{ij} = b_{ij} \frac{P_j}{Y_i P_n}$ $i \neq n$; $\eta_{nj} = \frac{P_j}{P_n^2 Y_n} \sum_{i=1}^{n-1} b_{ij} P_i$ $j = 1, \ldots, n-1$
Own price	$\eta_{ii} = \sum_{j \neq i} \frac{b_{ij}}{2Y_i} \left(\frac{P_j}{P_i}\right)^{1/2}$	$\eta_{ii} = b_{ii} \frac{P_i}{Y_i P_n}$ $i \neq j, n$; $\eta_{nn} = - \sum_{j=1}^{n-1} \eta_{nj}$

Incomplete Systems: The data base to be discussed below is incomplete in that data on labour service flows, bullock service flows, and bullock prices are not available. Wage rate data, however, are available and have been used.[5] Missing data implies that profits cannot be measured and the profit function cannot be estimated directly. Therefore, the translog profit function cannot be used since its derived demand equations have profit shares as dependent variables. Futhermore, the equations for the missing factors have to be left out of the system. For the normalized quadratic case, the left out factor is the nth factor.

Missing quantity variables alone introduce no biases or inconsistencies into the set of coefficient estimates for the remaining equations, but make them less efficient than would be achievable in a full systems context. But missing prices may lead to left out variable problems. If the missing bullock price is correlated with any of the other prices, the coefficient estimates on these included prices would be biased. We do not *a priori* expect relative bullock prices to be highly correlated with any of the other relative prices and simply neglect the problem. (Absolute prices are correlated because of inflation.) A further problem arises for the Generalized Leontief form. Own elasticities are computed residually from all price coefficients in an equation (see Table I). Even if no left out variable bias arises for the included price coefficients, the residual computation omits the possible non-zero coefficients of a missing price and this can lead to biased own elasticities. Despite this potential problem, we estimated systems for both forms.

II

ECONOMETRIC PROCEDURES

The systems are estimated with cross-sections of time-series. To take account of the relationships of errors (1) among the time-series in the cross-section and (2) among equations, a stepwise procedure of estimation is used which leads to consistent estimators.[6] The first step performed for each equation separately consists of the estimation of an additive error components model to pool cross-section and time-series data [Wallace (1977)]. The model is as follows: $Y_{irt} = \alpha_i + \beta_i X_{irt} + \mu_{ir} + \nu_{it} + \zeta_{irt}$ ....(13)
where i stands for the ith commodity, r for agricultural sub-regions and t for time, and where μ_{ir} is the regional error component, ν_{it} is the time error component and ζ_{irt} is the residual error component. The components have variances $\sigma^2_{i\mu}$, $\sigma^2_{i\nu}$, and $\sigma^2_{i\zeta}$ respectively which are estimated using a procedure due to Amemiya (1971). The data are first transformed via a cova-

5. Labour and bullock demand equations based on farm management data are reported in Evenson and Binswanger (1981).

6. Maximum likelihood (ML) procedures could have been used. The research reported here is, however, a small fraction of similar estimations for other agro-climatic zones and other crop breakdowns. Given the large amounts of data and the many systems estimated, the cost of using ML procedures would have been prohibitive.

riance transformation from which a consistent set of β_i coefficients is estimated. These β_is are then applied to the original data to estimate residuals from which the variance components are estimated. The original data are then transformed (a second time) using the estimated variance components. The third step in the estimation procedure consists of applying Zellner's (1962) joint estimation technique to transformed data from the second step and this procedure takes account of error interdependence across equations. Restrictions across equations are tested and imposed in this third step.

III

DATA SOURCES AND AGRO-CLIMATIC SUB-ZONES

Data were assembled for 93 districts from the four States of Tamil Nadu (Madras), Karnataka (Mysore), Andhra Pradesh and Madhya Pradesh for the years of 1955-56 to 1973-74.[7] Data were gathered from published Seasons and Crops Reports and/or Statistical Handbooks of each State or else were collected directly from the statistical offices in each State. The crops covered and numbered accordingly are:

Two superior cereals:	(1) Rice, (2) Wheat,
Six coarse cereals:	(1) Sorghum (or jowar), (2) Pearl millet (or bajra), (3) Maize, (4) Finger millet (or *ragi*), (5) *Kodon, Kutki* (or *Kodo* and Barnyard millets), (6) Other minor millets.
Six pulses:	(1) Chickpea (or Bengal gram), (2) Pigeonpea (or *tur* or Red gram), (3) Green gram (*mung*), (4) Black gram (or *urad*), (5) Horsegram (*Kulthi*), (6) Other pulses.
Four oilseeds:	(1) Groundnut, (2) Sesamum, (3) Castor bean, (4) Linseed,
Four other crops:	(1) Sugarcane, (2) Cotton, (3) Tobacco, (4) Chillies.

The sub-regions and the criteria used to define each of them are listed in the Appendix.[8] Sub-regions 8, 12 and 17 are excluded from the semi-arid tropics because they are irrigated coastal zones. The remaining 14 sub-regions are either fully specialised in rice growing or in wheat growing but none of them produces both of these superior cereals in sufficient quantities to allow the estimation of the wheat-rice crop substitution. The 14 SAT sub-regions are therefore divided into a wheat SAT (7 sub-regions) and a rice SAT (7 sub-regions) which do not overlap. Groundnut and cotton are also not produced in all sub-regions and a system which contains both of these crops is therefore estimated for a cotton-groundnut SAT which

7. The data were assembled by S.L. Bapna with the assistance of Rajendran, M. Pereira, Pavan Kumar and Valasayya, while they were on the staff of the International Crops Research Institute for the Semi-Arid Tropics, Hyderabad.

8. A detailed description of the procedures used to aggregate the raw data into sub-regions and into crop aggregates (for price and quantity indices) is contained in Bapna, Binswanger and Quizon (1981).

contains 7 agricultural sub-regions from both the wheat and the rice SAT. While the wheat and rice SAT zones are mutually exclusive sets of sub-regions, the cotton-groundnut SAT overlaps both of them. The allocation of sub-regions to these three SAT zones is also indicated in the Appendix.

IV

MODELS AND COMMODITY AGGREGATION

Table III describes the six models. Model A for the entire SAT distinguishes six commodities or aggregates. Wheat and rice are aggregated into superior cereals. Sorghum (jowar) is grown in virtually all sub-regions and treated as a separate commodity. The other coarse cereals are less pervasive and aggregated into "other coarse cereals" (same treatment for models C, D and E). Model A treats all oilseeds as an aggregate and all pulses as an aggregate. Finally, sugarcane, cotton, tobacco and chillies form an aggregate called "other crops A". Fertilizers are measured in tons of nutrients of N, P_2O_5, K_2O. Reliable labour and bullock flow data do not exist. All the systems reported here therefore leave the labour and bullock demand equations unspecified.[9] However, wage rate data have been systematically reported for each district in Agricultural Wages in India (various issues) and all equations therefore include a wage rate variable which is a daily male wage rate standardised on an eight-hour basis. Bullock prices, however, are not available.

Variables which are not under the control of the farmers are listed and defined in panel III of Table II as rainfall (RAIN), extent of use of high-yielding varieties of rice, wheat, sorghum, pearl millet and maize (HYK), road density (ROADL), regulated market density (MKTS), and extent of irrigation (IRK). Some States contain both regulated and unregulated markets and the regulated market density measures government assistance to the marketing process rather than market access. Market access is probably better measured by road density.

Systems B and F are also estimated for the entire SAT. In system B, all coarse cereals are aggregated into a single equation. Oilseeds, pulses and other crops A are aggregated into a single aggregate called "other crops B." System F is aimed at estimating an aggregate agricultural supply equation for the SAT with one equation for "All Crops" and another equation for fertilizer demand.

Systems C, D and E are aimed at estimating supply functions for individual commodities which cannot be handled for the SAT as a whole because not all 13 sub-regions produce the commodity to a sufficient degree. System C for the wheat SAT estimates individual equations for wheat, sorghum and chickpeas, the major pulse in the wheat SAT. Coarse cereals other than sorghum form a fourth equation. The aggregate of "other crops C" includes everything not treated in separate equations.

9. Labour demand and bullock demand equations have been estimated from farm managemen studies in a separate study [Evenson and Binswanger (1980)].

TABLE II—VARIABLE DEFINITIONS, UNITS OF MEASUREMENT AND MEAN VALUES BY SUB-REGIONS

Variable definition	Abbreviation	Dimension Units	Means			
			All 13 SAT sub-regions	Wheat SAT sub-regions	Rice SAT sub-regions	Cotton-ground-nut SAT sub-regions
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I. Quantities						
1. Rice	QRICE	1000 tons[1]	439·83	127·54	1047·17 D[2]	591·46
2. Wheat	QWHEAT	1000 tons[1]	160·33	296·71 C[2]	11·30	58·75
3. Jowar (sorghum)	QJOWAR	1000 tons[1]	344·85 AB[2]	374·19 C	268·41 D	444·63 E[2]
4. Bengal gram (chickpea)	QBGM	1000 tons[1]	70·73	127·03 C	12·04	25·30
5. Groundnut	QGNUT	1000 tons[1]	173·29	105·90	218·20 D	299·67 E
6. Cotton	QCOTN	1000 tons[1]	17·64	20·00	12·80	30·39 E
7. All crops	ALL CROPQ	1956-57 (Rs. 10,000)	74043·35 F	56054·99	102778·13	95290·02
8. Superior cereals	SUPCERQ	1956-57 (Rs. 10,000)	29492·04 AB	19585·53	53924·95	32797·08 E
9. Coarse cereals	CRSCERQ	,,	19914·59 B	17301·90	20566·77	26900·57
10. Other coarse cereals	OCRSCERQ	,,	7761·94 A	4017·32 C	11206·02 D	11250·09 E
11. Pulses	PULSESQ	,,	4551·95 A	6738·18	2672·00	3130·12
12. Oilseeds	OILSEEDQ	,,	8706·12 A	5669·76	10965·34	13957·97
13. Other crops A[3]	OCROPSAQ	,,	10396·50 A	6241·77	13177·51	17301·72
14. Other crops B	OCROPSEQ	,,	24084·36 B	18948·62	27366·72	35006·58
15. Other crops C	OCROPSCQ	,,	44309·26	20783·99 C	81072·11	64441·31
16. Other crops D	OCROPSDQ	,,	23462·75	27383·82	18105·28 D	24577·06
17. Other crops E1	OCROPEIQ	1956-57 Rs.	12593·79	9967·16	14909·71	15121·70 E
18. Fertilizer	FERTQ	1000 tons	3114·51 ABF	1276·62 C	4865·89 D	4510·59 E

(Contd.)

TABLE II (*Concld.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
II. Prices						
1. Rice	PRICE	Rs./quintal[1]	85·07	74·31	82.95	87·16
2. Wheat	PWHEAT	Rs./quintal[1]	75·02	74·94	74·58	88·03
3. Jowar (sorghum)	PJOWAR	Rs./quintal[1]	61·82	63·11	59·99	63·56
4. Bengal gram (chickpea)	PBGM	Rs./quintal[1]	74·90	74·30	81·46	86·38
5. Groundnut	PGNUT	Rs./quintal[1]	107·28	104·79	108·49	106·94
6. Cotton	PCOTN	Rs./quintal[1]	480·75	470·66	496·23	479·60
7. All crops	ALLCROPP	S	1·92	1·90	1·86	1·99
8. Superior cereals	SUPCERP	Average price for 1956-57 is equal to one	1·68	1·62	1·63	1·73
9. Coarse cereals	CRSCERP		1·88	1·87	1·89	1·90
10. Other coarse cereals	OCRSCERP		2·07	2·19	2·03	2·04
11. Pulses	PULSESP		2·32	2·27	2·37	2·54
12. Oilseeds	OILSEEDP		2·45	2·44	2·46	2·45
13. Other crops A[3]	OCROPSAP	,,	2·26	2·08	2·37	2·27
14. Other crops B	OCROPSBP	,,	2·30	2·23	2·35	2·32
15. Other crops C	OCROPSCP	,,	1·98	2·03	1·85	2·03
16. Other crops D	OCROPSDP	,,	2·08	1·95	2·30	2·21
17. Other crops E1	OCROPE1P	,,	2·25	2·17	2·31	2·29
18. Fertilizer	FERTP	,,	1·40	1·52	1·36	1·39
19. Labour	WAGE	,,	2·33 ABF	2·27 C	2·29D	2·34 E
III. Other variables						
1. Rainfall	RAIN	mm.	949·07 ABF	990·75 C	959·99 D	809·57 E
2. High-yielding varieties	HYK	Percentage of gross cropped area	2·02 ABF	1·22 C	2·93 D	2·37 E
3. Roads	ROADL	km./10 km[2]	1·77 ABF	1·09 C	2·28 D	1·96 E
4. Markets	MKTS	No./10,000 km[2]	4·87 ABF	5·18 C	4·21 D	5·55 E
5. Irrigation	IRK	Percentage of gross cropped area	14·89 ABF	5·47 C	23·42 D	17·19 E

1. These variables were not used in the regression in their natural units shown here but were transformed such that the average SAT price of each crop was Rs. 1·00 for the year 1956-57. Thus the regression quantities were also measured in 1956-57 Rupees 10,000.
2. The letters indicate the system in which a quantity or a price is included. Labour quantity but the wage rate is included in all systems.
3. See Table III for precise definitions.

TABLE III—SUMMARY OF COMMODITIES, AGGREGATES, MODELS AND REGIONS FOR WHICH ESTIMATED

Crops or aggregates	Abbreviation	All SAT			Wheat SAT	Rice SAT	Cotton-groundnut SAT	Crops included
		A	B	F	C	D	E	
Rice	RICE					x		
Wheat	WHEAT				x			
Jowar (sorghum)	JOWAR	x			x	x	x	
Bengal gram (chickpea)	BGM				x			
Groundnut	GNUT					x	x	
Cotton	COTN						x	
					Aggregates			
All crops	ALLCROP			x				All 22
Superior cereals	SUPCER	x	x				x	1. Rice, 2. Wheat,
Coarse cereals	CRSCER		x					3. Sorghum, 4. Pearl millet, 5. Maize, 6. Finger millet, 7. *Kodon-kutki* (Barnyard and *Kodo* millet) 8. Other minor millets
Other coarse cereals	OCRSCER	x			x	x	x	CRSCER except sorghum
Pulses	PULSES	x						9. Chickpea, 10. Pigeonpea, 11. Green gram, 12. Black gram, 13. Horse gram, 14. Other pulses
Oilseeds	OILSEED	x						15. Groundnut, 16. Sesamum, 17. Castor, 18. Linseed
Other crops A	OCROPSA	x						19. Sugarcane, 20. Cotton, 21. Tobacco, 22. Chillies
Other crops B	OCROPSB		x					OCROPSA + Pulses + Oilseeds
Other crops C	OCROPSC				x			OCROPSA + Rice + Oilseeds +10+11+12+13+14
Other crops D	OCROPSD					x		OCROPSA + Wheat + Pulses + 16+17+18
Other crops EI	OCROPSEI						x	Pulses + 16+17+18+19+21+22
Fertilizer	FERT	x	x	x	x	x	x	N+P+K in nutrient tons
Wage	WAGE	x	x	x	x	x	x	(N+P+K)

x=Crop commodity or crop aggregate is included in the system.

For the rice SAT, separate equations are fitted for rice, sorghum, groundnut, and other coarse cereals. All other crops are aggregated in "other crops D".

The cotton-groundnut SAT contains those sub-regions of the rice SAT and the wheat SAT where both cotton and groundnut are important. Separate equations are fitted for superior cereals, sorghum, other coarse cereals, groundnut, cotton, and an aggregate "other crops E".

The aggregate "other crops" contains widely different crops for the different systems. It is simply the set of crops which complements those crops or crop aggregates for which individual equations have been fitted. Elasticities of other crops are therefore expected to vary across systems.

Lag Structure

No lags are imposed on prices of fertilizer and wages or on any of the Z variables, RAIN, HYK, IRK, ROADL and MKTS. Fertilizer prices and wage rates are largely known when these inputs are committed. However, for all output prices, an expected price was formed with the following lags.[10]

$$P_{it}^{E} = 0.71\ P_i,\ t-1 + 0.29\ P_i\ ,\ t-2$$

V

TEST RESULTS

Table IV presents the summary statistics and test results about the systems. The summary statistics refer to the restricted systems where symmetry constraints are imposed. For the SAT as a whole, the disaggregate system A has the lowest goodness of fit, measured both by weighted mean square and weighted R^2, while the most aggregative system has the best goodness of fit. The highest R^2 value (above 0.5) is achieved by the system C for the wheat SAT.

The symmetry constraint is accepted only for the two relatively aggregated systems B and F in the entire SAT, where only six and one constraints were imposed respectively. For the profit function to be quasiconvex, the (n—1) independent characteristic roots of the Hessian matrix (evaluated at predicted mean price levels in the case of the GL) should all be non-negative. This is only the case for the highly aggregative system F.

Table IV provides virtually no guidance to choose between the two functional forms, since test results are very similar for both forms. We therefore opt in favour of simplicity and concentrate on reporting results from the NQ system.[11]

10. This expected price equation was the final form obtained from a series of lag structure experiments. See Bapna, Binswanger and Quizon (1981) for details.

11. Only in a few instances do the elasticity estimates differ sharply between functional forms.

TABLE IV—SUMMARY STATISTICS AND TESTS OF EQUATION SYSTEMS

Equation system	Normalized Quadratic				Generalized Leontief			
	MSE[1]	$(R^2)^2$	F of symmetry[3]	Negative[4] characteristic roots	MSE[1]	$(R^2)^2$	F of symmetry[3]	Negative[4] characteristic roots
All SAT								
A	1·10 (1386)	·30	3·11* (21)	3 of 7	1·11	·30	3·50*	3 of 7
B	1·06 (798)	·35	1·93 (6)	1 of 4	1·05	·35	1·34	1 of 4
F	1·04 (401)	·45	2·78 (1)	0 of 2	1·04	·45	1·04	0 of 2
Wheat SAT								
C	1·18 (615)	·53	3·26* (15)	2 of 6	1·19	·54	3·71*	2 of 6
Rice SAT								
D	1·15 (615)	·40	1·93* (15)	2 of 6	1·14	·38	1·87*	2 of 6
Cotton-groundnut SAT								
E	1·20 (714)	·41	3·99* (21)	3 of 7	1·18	·41	2·54*	2 of 7

* Significant at 5 per cent or better.
1. Weighted mean squared error. Degrees of freedom in parenthesis.
2. This R^2 corresponds to the approximate F-test on all non-intercept variables in the system.
3. F-value of test of symmetry constraints. Number of constraints in parenthesis.
4. Number of negative characteristic roots of the Hessian matrix evaluated at predicted weighted mean levels.

The Estimates

Space does not permit us to report the full restricted and unrestricted regression estimates for the two functional forms. Instead we report only the elasticities at sample means for the restricted NQ system. It should be remembered, however, that these elasticities are not constant but depend on sample values of prices and quantities. In economic applications it may therefore be more appropriate to use the original regression equations. These are available in Bapna *et al.* (1981). Below, we discuss the elasticities equation by equation.

Superior Cereals Systems A, B and E

Own supply estimates vary from 0.29** to 0.36*** in the NQ form and are all statistically significant. Small but significant cross elasticities indicating competitiveness were estimated with oilseeds in system A and other crops in system B. The All SAT estimates indicate that all Z variables have a statistically significant positive impact on superior cereals. In the smaller cotton-groundnut region the signs are the same but roads and markets are not significant. Irrigation and rainfall elasticities have the largest values, around 0.3*** for All SAT systems and a maximum of 0.8*** for the cotton-groundnut SAT. Road elasticities have a value around 0.17** while markets and high-yielding varieties have elasticities of less than 0.1***.

Wheat (System C)

The supply elasticity is estimated at 0.33, *i.e.*, the same range as for superior cereals, but is not statistically significant. On the other hand, increases in jowar and fertilizer prices significantly reduce the attractiveness of wheat cultivation while higher labour costs tend to increase it. The cross elasticity with respect to the sorghum price is especially large at —0.35**. Wheat cultivation is very responsive to rainfall (0.51***) and irrigation (0.31**). Its lack of responsiveness to HYV may be because high-yielding wheat varieties have not been very suitable for the unirrigated conditions in the SAT.

Rice (System D)

Rice supply appears to be slightly more responsive to its own price than wheat at 0.47***. It competes significantly with other crops D, which in this case includes primarily the highly input-intensive crops sugarcane, cotton, tobacco and chillies. These crops are often grown on similar land of higher quality as rice. Other cross effects are not significant. Rice cultivation responds primarily to rainfall (0.77***) and to high-yielding varieties (0.53***). The high responsiveness to rainfall arises because SAT rice is either grown under rainfed conditions or grown with small scale irrigation directly dependent on local rainfall which covers much larger areas in high rainfall years than low rainfall years.

Jowar (Sorghum, Systems A, C, D, E)

Jowar is the most pervasive coarse cereal in the four State SAT regions. The supply elasticity is fairly low (0.15) and not significant when estimated in all the SAT. However, when estimated in all three sub-zones, its supply appears highly price responsive with elasticity estimates ranging from 0.38** to 0.77***. As mentioned previously, sorghum production appears to be competitive with wheat in the wheat SAT but complementary with pulses for the SAT as a whole (0.25***). Increases in wage rates tend to reduce sorghum supply substantially (—.32 to —.45**) and the effect is significant in three of the four systems (in the GL form it is significant in all systems). Sorghum production is reduced by RAIN and HYK.[12] The RAIN effect, however, is large and statistically significant only in system A (—.2***). The HYK effect is much smaller (—.03** to —.05***) but significant in three of the four cases. During the sample years, high-yielding sorghum hybrids were not yet widely adopted in the SAT and the estimates reflect the shifts away from sorghum when technology improved in other crops.

Coarse Cereals (System B)

The coarse cereals supply elasticity is estimated at 0.2 but is not significant. Neither is any of its cross price elasticities. With the exception of maize, the coarse cereals are fairly drought resistant crops. High rainfall, therefore, tends to reduce areas planted to these crops and the HYK effect is similar to the case of sorghum. Regulated market density has a small statistically significant positive effect on its supply.

Other Coarse Cereals (Systems A, C, D, E)

Other coarse cereals exclude sorghum and comprise a set of crops, each of which is only important in certain sub-regions of the SAT. Finger millet is largely confined to the low rainfall areas of Karnataka, and *kodon* and *kutki* to the higher rainfall areas of Madhya Pradesh. Pearl millet is important in certain districts of Tamil Nadu. As mentioned before, own elasticities have the wrong sign in two of the three cases. The crops appear to be competitive with all pulses in system A and with Bengal gram in the wheat SAT. Complementary relationships appear to exist with oilseeds in system A, with other crops in system A, C and D, and with cotton in system E. Increased fertilizer price tends to favour these crops, an effect which is significant in systems A and E (0.15**, 0.21**). This may reflect a substitution of these crops which use little fertilizer for other crops. As for jowar, higher wages tend to reduce the supply of these crops, an effect which is significant in system E only. Other coarse cereals respond negatively to rainfall, an effect which is significant in the wheat SAT (—.31). They also respond negatively

12. After a certain level of rainfall, higher rainfall causes waterlogging and the crop is damaged. This was also observed in a study [Bapna (1973)] in Kota district of Rajasthan where introduction of canal water led to decline in *kharif* jowar because of waterlogging and the fields were kept fallow. Therefore, the coefficient of rain is consistent with other observations.

TABLE V—PRICE ELASTICITIES FOR THE NORMALIZED QUADRATIC SYSTEMS[1]

System	SUPCERP	JOWARP	OCRSCERP	PULSESP	OILSEEDP	OCROPSAP	FERTP	LABOUR
System A				All SAT				
SUPCERQ ..	·36***	0	−·09	·01	−·13**	−·07	·05	−·13
JOWARQ ..	·01	·15	·01	·25***	−·04	−·06	·03	−·36***
OCRSCERQ ..	−·27	·02	−·13	−·16	·24**	·25***	·15**	−·10
PULSESQ ..	·06	·45***	−·22*	·43**	·10	−·08	−·34***	−·39***
OILSEEDQ ..	−·31**	−·04	·18**	·05	−·01	·08	−·06	·10
OCROPSAQ ..	−·12	−·04	·15***	−·03	·06	·06	−·03	−·04
FERTQ	−·45	−·14	−·49**	·79***	·24	·18	−·28	·14
System B		CRSCERP				OCROPSBP		
SUPCERQ ..	·29**	−·10				−·16*	·03	−·06
CRSCERQ ..	−·13	·08				·11	·06	−·11
OCROPSBQ ..	−·14*	·07				·22**	−·10***	−·05
FERTQ	−·34	−·45				1·10***	−·47	·17
System F	ALLCROPP							
ALLCROPQ ..	·09						−·00	−·09
FERTQ	·14						−·65**	·51
				Wheat SAT				
System C	WHEATP	JOWARP		BGMP		OCROPSCP		
WHEATQ ..	·33	−·35**	−·05	·03		−·12	−·12***	·29*
JOWARQ ..	−·39**	·77***	·06	0		−·26	·14**	−·32
OCRSCERQ ..	−·14	·16	·23	−·48***		·41	·07	−·26
BGMQ	·08	0	−·41***	·46		−·14	·09	−·08
OCROPSCQ ..	−·07	−·13	·08	−·03		·25	−·03	−·08
FERTQ ..	1·48***	−1·46**	−·30	−·46		·64	·03	·08

(Contd.)

TABLE V (Concld.)

System		SUPCERP	JOWARP	OCRSCERP	PULSESP	OILSEEDP	OCROPSAP	FERTP	LABOUR
					Rice SAT				
System D		RICEP				GNUTP	OCROPSDP		
RICEQ	..	·47***	—·06	—·07		0	—·21***	—·02	—·11
JOWARQ	..	—·31	·46***	·15		—·20	·04	·30**	—·45**
OCRSCERQ	..	—·28	·11	—·00		—·04	·33***	·03	—·13
GNUTQ	..	·02	—·14	—·04		·46**	·12	—·11	—·32
OCROPSDQ	..	—·47***	·02	·19***		·07	—·38***	—·04	·62***
FERTQ	..	·25	—·68**	—·09		·35	·25	—·90***	·82**
					Cotton-groundnut SAT				
System E		SUPERP			COTNP	GNUTP	OCROPEIP		
SUPCERQ	..	·34**	—·05	—·04	—·06	·04	—·08	·02	—·17
JOWARQ	..	—·11	·38**	·12	·06	—·07	·07	—·10	—·35**
OCRSCERQ	..	—·11	·14	—·37**	·34***	·10	·17	·21**	—·48***
COTNQ	..	—·23	·11	·51***	·70***	·10	·12	·05	—1·37***
GNUTQ	..	·07	—·06	·07	·05	0	—·01	—·05	—·08
OCROPEIQ	..	—·12	·06	·11	·06	—·01	—·09	—·19***	·20
FERTQ	..	—·19	·39	—·67**	—·11	·20	·90***	—·62**	·10

1. The corresponding derivatives from which these elasticities are derived are significant at these defined levels.
*** Significant at ·01 level.
** Significant at ·05 level.
* Significant at ·10 level.

TABLE VI—OUTPUT SUPPLY AND INPUT DEMAND ELASTICITIES WITH RESPECT TO THE Z VARIABLES, NORMALIZED QUADRATIC FORM[1]

System		RAIN	HYK	IRK	ROADL	MKTS
System A	SUPCERQ	·3195***	·0675***	·3214***	·1787***	·0710**
	JOWARQ	—·1998***	—·0307***	—·0292	·0413	·0468
	OCRSCERQ	—·0869	—·0606***	·1736	·0810	·1325***
	PULSESQ	·2565***	·0852	·0967	—·1894**	—·0239
	OILSEEDQ	·0715	·0352	·3000**	—·6758***	—·3507***
	OCROPSAQ	·1579	·1665**	·2227	·7473***	—·0765
	FERTQ	·2229	·2411***	·3054	1·0387***	·3669***
System B	SUPCERQ	·3293***	·0589***	·3497***	·1562**	·0762**
	CRSCERQ	—·1778**	—·0497***	·0311	·0113	·0955**
	OCROPSBQ	·0178	·0843***	·1745*	·0629	·0804**
	FERTQ	·2509	·2548***	·2475	1·1261***	·4215***
System F	ALLCROPQ	·0709	·0507***	·1704**	·0655	·0966***
	FERTQ	·1351	·2289***	·2944	·9922***	·4302***
System C	WHEATQ	·5056***	—·0499	·3110**	—·2412	·0985
	JOWARQ	—·0641	—·0498	·2674	·3372*	—·1066
	OCRSCERQ	—·3090*	—·1104***	·5125***	1·4228***	·0097
	BGMQ	·2997***	—·0377	·2722*	—·2203	—·0519
	OCROPSCQ	·0039	—·1079***	·5680***	1·0446***	—·1712*
	FERTQ	·3598	—·0599	1·5297***	4·4378***	·0165
System D ..	RICEQ	·7715***	·0534***	—·1760	·0893	·0586
	JOWARQ	—·0120	—·0507***	—·1810	·0224	—·0605
	OCRSCERQ	·0378	—·0456**	—·0598	·0507	—·1015
	GNUTQ	·1637	—·0050	·4065*	—·8226***	·3379***
	OCROPSDQ	·0888	·2069***	·2770	·1127	—·1388**
	FERTQ	·2204	·2688***	·4514	·9174***	·1326
System E	SUPCERQ	·1519**	·0713***	·8380***	·0960	·0272
	JOWARQ	—·1246	—·0330**	·1454	·1187	—·0274
	OCRSCERQ	—·0636	—·0673***	·4751***	·3120***	·0139
	COTNQ	—·3604**	—·0038	·2380	·3568*	·0346
	GNUTQ	·1021	·0263*	·7624***	—·5562***	·1995***
	OCROPEIQ	—·0147	·1373***	·0077	·5810***	—·1018
	FERTQ	·2014	·1866***	—·1547	1·1478***	·3183***

1. The corresponding derivatives from which these elasticities are derived are significant at these defined levels.
*** Significant at ·01 level.
** Significant at ·05 level.
* Significant at ·10 level.

to increases in HYV acreage, an effect which is always statistically significant and about twice the size as that for sorghum (—.46** to —.11**). Irrigtion tends to increase areas under other coase cereals, as do road length and markets in some cases.

Oilseeds (System A) and Groundnut (Systems D and E)

Oilseeds as a whole cannot be shown to be price responsive for the SAT as a whole. Groundnut supply is elastic in the rice SAT (0.46**) but not in the cotton-groundnut SAT. Results are thus rather contradictory. The only significant cross effects are a competitive relation of oilseeds with superior cereals in system A (—.31**) and a complementary one with other coarse cereals (0.18**). The latter effect is not significant for the GL functional form. Oilseeds as a whole (0.30**) and groundnut in particular (0.41*, system D and 0.76***, system E) respond sharply to increased irrigation levels, which is consistent with *a priori* expectations. In many SAT areas, high yields of groundnut are only achievable under irrigated conditions in the winter season. The sharp negative response in all systems A, D and E to road length is rather unexpected, however. But groundnuts clearly are associated with higher regulated market densities (systems D and E), whereas the same is not true for oilseeds as a whole.

Other crops A: This aggregate contains highly input-intensive crops. Its supply elasticity is not significantly positive.

Other crops E: This aggregate is formed by adding the pulses and three minor oilseeds to OCROPSA, which increases the aggregate only modestly (Table II). The estimates for the cotton-groundnut SAT identify a negative response to increased fertilizer prices (—.19***). Such a negative response was also found for OCROPSA in the GL form, and may reflect the high fertilizer intensity of the most important cash crops forming this aggregate. OCROPSE responds positively to HYK and ROADL (0.14*** and 0.58*** respectively).

Other crops B: This aggregate is the sum of OCROPSE and groundnut. The importance of groundnut as a SAT crop can be seen by noting that for the All SAT case the addition of groundnut nearly doubles the "other crops" aggregate (Table II). A positive output supply elasticity is estimated (0.22**). OCROPSB appears to be competitive with superior cereals (—.14*) but this effect is only significant for the NQ form. On the other hand, with both forms, a significant negative fertilizer price effect is identified, an effect which was discussed already for OCROPSE. The aggregate responds positively to HYK (0.08***), IRK (0.17*), and MKTS (0.08**). The irrigation effect is probably carried into the aggregate via the addition of the groundnuts which have one of the highest irrigation responses.

Other crops C: This aggregate includes OCROPSA, rice, most pulses and all oilseeds. The major addition compared to OCROPSB therefore is rice, which in the wheat SAT leads to only a modest increase in the aggregate. None of the price effects is significant in the NQ form, probably because of the increasing heterogeneity of the aggregate. IRK and ROADL have significant and large positive effects while HYK and MKTS have smaller negative ones. These estimates now refer to only the wheat SAT, not to all of SAT as OCROPSB.

Other crops D: This aggregate contains OCROPSA, wheat (not important in the rice SAT), all pulses and the oilseeds except for groundnut. It is a quite different aggregate compared to OCROPSB or OCROPSC and very heterogeneous. Own supply response has a statistically significant but negative elasticity. Higher wage rates tend to favour the aggregate, as do higher percentages of HYV and lower market densities.

All crops: The aggregate output supply elasticity is low (0.09) and not significant.[13] All Z variables, however, have the expected sign. Irrigation has the highest elasticity (0.17**), followed by regulated market density (0.10***) and high-yielding varieties (0.05***). The other effects have about the same magnitude but are not significant.

Fertilizer (All Systems): As can be seen from Table II, fertilizer use per agricultural sub-region is about four times as high in the rice or cotton-groundnut sub-regions as in the wheat sub-regions. One might thus expect somewhat different responses to fertilizer according to sub-regions. In the rice SAT and the cotton-groundnut SAT the elasticities are large and significant (—.90***, —.62**). However, in the wheat SAT the fertilizer demand elasticity is not different from zero. Therefore, the fertilizer demand elasticity for the SAT as a whole (systems A and D) are lower than for the sub-regions of intensive use.

The cross elasticity between fertilizer and labour is always positive, indicating that the two factors are substitutes. NQ estimates range from 0.10 for the cotton-groundnut SAT to 0.82** for the rice SAT. Given the importance of both labour and fertilizer in crop cultivation, such strong substitutability is not surprising. For the most aggregative SAT system F, the cross elasticity estimated at 0.51 is not significant.

In the three "All SAT" systems, fertilizer demand responds positively to all Z variables, with remarkably similar elasticities. However, only the effects of HYK, ROADL and MKTS are statistically significant. A remarkable finding is the very high elasticity of fertilizer use to road density (0.99***, system E to 1.13***, system B). Given the uniform price of fertilizer across all railhead points, the road length variable may often capture the largest component of transport cost differences, and stand for an additional dimension of the fertilizer elasticity with respect to the delivered price.

Measured across all the SAT, regulated market density, high-yielding varieties and rainfall all have much lower elasticities (between 0.2 and 0.4). In the rice SAT and the cotton-groundnut SAT these Z variables have substantially similar effects as those for the All SAT. This, however, is not the

13. An earlier study [Bapna (1981)] found an aggregate supply elasticity of 0·20 for the semi-arid district of Ajmer in Rajasthan. While the difference between our elasticity and that of the earlier study may not be significant, one would expect aggregate supply elasticities for groups of districts such as our agro-climatic sub-zones to be lower than for an individual district since factor mobility among individual districts is likely to be higher than among groups of districts.

case for the wheat SAT. ROADL (4.44***) and irrigation (1.53***) have substantially higher elasticities than for the SAT as a whole. Remember that the wheat SAT centres largely on Madhya Pradesh, where irrigation covers only 5.5 per cent of the gross cropped area and road density is much lower than for the rest of the SAT. It is also here that no significant own price effect could be identified for fertilizer demand.

Rainfall Effects

Attempts at measuring rainfall impacts at aggregative levels have been made repeatedly. Our estimates indicate substantial sensitivity of individual crops to as crude a moisture index as average rainfall for the following commodities: rice (0.77***), wheat (0.51***), superior cereals (0.15** to 0.33***), Bengal gram (0.30***). Consistent with these estimates is also the generally positive elasticity of fertilizer use with respect to rainfall, although the effect is never significant. Sorghum, coarse cereals, and cotton, on the other hand, tend to have supplies reduced with higher rainfall. In the case of the coarse cereals, this is probably a substitution effect towards less drought tolerant crops which have higher returns in the high rainfall years. For cotton, it may reflect more intensive pest damage in wet years.

DISCUSSION

(1) Symmetry and convexity constraints on the profit function are only accepted at the most aggregative level (in system F). System B with four commodity equations still accepts symmetry but not convexity. The more disaggregated six and seven equation systems reject both sets of constraints. This holds for both functional forms.

(2) Wherever we can form fairly clear sign expectations (for own elasticities and for many of the Z variables) the estimates conform well with these *a priori* sign expectations. Seven of 32 own elasticities were found to have unexpected signs, but only in two cases, for the aggregates OCROPS and OCRSCER were the elasticities significant. On the other hand, 25 of the 32 own elasticities had the anticipated sign, and 14 were significant. This demonstrates a remarkable extent of price responsiveness of semi-arid tropical farmers, who are generally regarded as working under very adverse climatic conditions where high-yielding technologies have become available only for a restricted set of crops and cropping conditions.

(3) The "best" equations in terms of *a priori* sign expectations are for individual commodities that are fairly widely grown (or used) over the region wherein they are estimated (rice, wheat, sorghum, fertilizer), or for commodity aggregates such as superior cereals or coarse cereals which are also grown in substantial quantities in virtually all agricultural sub-regions. Substantial difficulties are encountered in estimating equations for aggregates such as other coarse cereals or other crops which are heterogeneous and where the individual components are grown in small amounts or in relatively small pockets of the zone for which estimates are sought.

(4) There thus appears to be a trade-off in the levels of commodity aggregation. The higher the level of aggregation, the easier it is to impose constraints but the less we can say about price responsiveness of farmers with respect to individual commodities or well defined sub-aggregates. A second trade-off relates to the size of sub-zones to be formed. Smaller sub-zones enable the estimation of elasticities with respect to individual crops or crop aggregates which are primarily grown in just that sub-zone, *i.e.*, which are not pervasive across vast zones. But if the estimates are to be used for simulation or policy work at the national level, this requires the estimation and later use of many systems for many sub-zones. Furthermore, if one wants to estimate elasticities for fairly location specific crops such as cotton, groundnut or chickpea, one ends up with zones which are not mutually exclusive.

(5) We find a fairly high supply elasticities for sorghum (0.38** to 0.77***), the most pervasive coarse cereal in the four SAT States. The marketed surplus of this crop is a relatively small percentage of the total harvest. Our estimates, therefore, are not consistent with the view that supply of subsistence crops is not responsive to price changes. We also find substantial wage impacts on sorghum supply. Higher cost of labour (or higher opportunity cost of the farmer's own time) appears to make sorghum production less attractive.

(6) The highest supply elasticity (0.70***) is found for cotton, a highly labour intensive commodity. It therefore also appears to be extremely sensitive to wage rate rises with a wage elasticity of —1.37***.

(7) The response of fertilizer to price and price-like variables is also substantial. In the sub-regions D and E where they are widely used, the price elasticities are: —.62** and —.90***, respectively. The elasticity of fertilizer demand relative to road density, a variable which reflects transport costs, was found to be around one, except in the wheat SAT which has the lowest fertilizer use and road density, where that elasticity jumps to a high value of around 4.

APPENDIX

THE AGRICULTURAL SUB-REGIONS

State	Sub-region	Criteria			Districts	All SAT	Wheat SAT	Rice SAT	Ground-nut-cot-ton SAT
		Rainfall (mm.)	Irri-gated (per cent)	Cropping pattern (per cent)					
Madhya Pradesh	1. Rainfed rice	>950	<30	Rice>40, Wheat<10	Durg, Bastar, Raipur, Bilaspur, Raigarh, Sarguja, Balaghat, Shahdol			x	
	2. Rainfed wheat	>950	<30	Wheat>40	Sagar, Damoh, Sehore, Raisen, Vidisha, Hoshangabad	x	x		
	3. Rainfed wheat-rice	>950	<10	(Rice+Wheat+Chickpea) >40, Rice+Wheat >33	Jabalpur, Seoni, Panna, Rewa, Satna, Sidhi, Mandla	x	x		
	4. High rainfall wheat, sorghum, chickpea	>950	<30	Wheat >15; Sorghum >10 Chickpea >7	Chhindwara, Narsingpur, Betul, Tikhmagarh, Chattarpur	x	x		
	5. Low rainfall, wheat, sorghum, chickpea	<950	<30	Wheat >20, Sorghum >10, Chickpea >10	Gwalior, Shivpuri, Guna, Datia, Morena, Bhind, Indore, Ujjain	x	x		
	6. Cotton-sorghum	>900 $<1{,}200$	<10	Cotton>20, Sorghum >25	Dewas, Khargone (W.N.), Khandwa (E.N.), Shajpur	x	x		x
	7. Low rain, mixed cropping	<950	$\leqslant 10$	Wheat<20, Cotton, Maize, Groundnut, Chickpea >5	Ratlam, Rajgarh, Jhabua, Mandsaur, Dhar	x	x		x

(Contd.)

APPENDIX (*Concld.*)

State	Sub-region	Criteria: Rainfall (mm.)	Criteria: Irrigated (per cent)	Criteria: Cropping pattern (per cent)	Districts	All SAT	Wheat SAT	Rice SAT	Groundnut-cotton SAT
Andhra Pradesh	8. High rain, irrigated coastal rice	>950	>45	Rice >50	Srikakulam, East Godavari, West Godavari, Krishna				
	9. Medium rain, medium irrigation, rice	<950	>30 <45	Rice >30	Visakhapatnam, Guntur, Nellore, Chittoor, Nizamabad	x		x	x
	10. Low rain, low irrigated, mixed cropping	<700	<30	$5<$ Rice <20, Sorghum >15, Groundnut >8	Kurnool, Anantapur, Cuddapah, Mahboobnagar, Nalgonda	x		x	x
	11. Medium rain, low irrigation, mixed cropping	>700 $<1{,}100$	<30	Rice >10, Sorghum >20	Hyderabad, Medak, Warangal, Khammam, Karimnagar, Adilabad	x		x	
Karnataka	12. Humid rice	$>2{,}500$		Rice >90	South Kanara, North Kanara, Coorg				
	13. Transition zone	>680 $<2{,}000$	>18 <50	Rice >25, (Sorghum + *Ragi*) >25	Mandya, Hassan, Shimoga, Chickmagalur	x		x	
	14. Low rainfall *Ragi* zone	>700 <900	<25	Rice >10, *Ragi* >45	Bangalore, Kolar, Tumkur, Mysore	x		x	x
	15. Low rainfall sorghum	>540 <860	<15	Sorghum >25, Groundnut >8, Rice $\leqslant 10$	Chitradurga, Bellary, Dharwar, Belgaum, Bijapur, Bidar, Raichur, Gulbarga	x	x		x
Tamil Nadu	16. Low rain, medium irrigation, mixed cropping	>670 <800	>20 <45	Rice >10	Salem, Coimbatore, Tiruchirapalli, Madurai, Ramanathapuram, Tirunelveli	x		x	x
	17. High rain, irrigated rice	>950	$\geqslant 50$	Rice >40	Chingleput, S. Arcot, N. Arcot, Thanjavur, Kanyakumari				
					Total ..	13	7	7	7

x = Crop commodity or crop aggregate is included in the system.

REFERENCES

1. Y. Amemiya, "The Estimation of the Variances in a Variance Component Model", *International Economic Review*, Vol. 12, No. 1, February 1971, pp. 1-13.

2. S. L. Bapna, "Economic and Social Implications of Green Revolution", Agro-Economic Research Centre, Vallabh Vidyanagar, 1973 (mimeo.).

3. S. L. Bapna: Aggregate Supply Response of Crops in a Developing Region, Sultan Chand and Sons, New Delhi, 1981.

4. Shanti L. Bapna, Hans P. Binswanger and Jaime B. Quizon, "Systems of Output Supply and Factor Demand Equations for Semi-Arid Tropical India", Studies in Employment and Rural Development Paper 73, World Bank, Washington D.C., U.S.A., October 1981.

5. H. P. Binswanger, "Attitudes Toward Risk: Experimental Measurement in Rural India" *American Journal of Agricultural Economics*, Vol. 62, No. 3, August 1980, pp. 395-407.

6. H. P. Binswanger and J. B. Quizon, "Factor and Output Market Effects of Technical Change and Public Investment Policies in Agriculture", Economic Growth Center Discussion Paper 337, Yale University, New Haven, August 1980.

7. W. E. Diewert, "An Application of the Shepherd Quality Theorem : A Generalized Leontief Production Function", *Journal of Political Economy*, Vol. 79, 1981, pp. 481-507.

8. W. E. Diewert, "Duality Approaches to Microeconomic Theory", in K. J. Arrow and M. D. Intrilligator (Eds.): Handbook of Mathematical Economics, North-Holland Publishing Co., Amsterdam, 1978.

9. R. E. Evenson and H. P. Binswanger, "Estimating Labor Demand Functions for Indian Agriculture", Economic Growth Center Discussion Paper 356, Yale University, New Haven, August 1980.

10. Sidney Feit, "Elasticities, A Programming Package for Estimating Linear Demand and Supply Systems with Large Data Sets", Yale University, Economic Growth Center, New Haven, 1980 (mimeo.).

11. Fertiliser Association of India, Fertiliser Statistics, New Delhi, various issues.

12. R. Radhakrishna and K. N. Murty, "Food Demand Model for India", Sardar Patel Institute of Economic and Social Research, Ahmedabad, 1978.

13. R. Radhakrishna, G. V. S. N. Murty and N. C. Shah, "Models of Consumer Behaviour for Indian Economy", Sardar Patel Institute of Economic and Social Research, Ahmedabad, 1979.

14. R. W. Shephard: Cost and Production Functions, Princeton University Press, New Jersey, 1970.

15. G. Swamy and H. P. Binswanger, "Flexible Consumer Demand Systems with Linear Estimation Equations: Food Demand in India", Economic Growth Center Paper No. 339, Yale University, New Naven, March 1980.

16. D. S. Tyagi: Farmer's Response to Agricultural Prices in India, Heritage Publishers, Delhi, 1974.

17. T. D. Wallace, "Methods for Combining Cross-Section and Time-Series Data: Prepared for ICRISAT", ICRISAT, Hyderabad, India (mimeo.).

18. A. Woodland, Personal communication.

19. A. Zellner, "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias", *Journal of the American Statistical Association*, Vol. 57, No. 2, June, 1962, pp. 348-368.