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Factor Gains and Losses in the Indian Semi-Arid Tropics: A Didactic Approach to Modeling the Agricultural Sector

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INTRODUCTION

The principal purpose of this paper is to empirically implement a model, first developed in Quizon and Binswanger (1983) (henceforth, Q-B), which attempts to determine the impact of technical change and exogenous shifts in output and input supplies and demands on the equilibrium prices and quantities of the same outputs and inputs in agriculture. This paper develops the simplest closed economy version of the Q-B model using actual data for the Indian semi-arid tropics (henceforth, SAT). It explains the operational features and demonstrates the capabilities of the Q-B model in a step-by-step fashion. Thus, this paper should be considered as both a guide and an initial exercise. It is useful as a guide to future modeling efforts and as an initial benchmark with respect to which findings from future expanded models may be compared.

There are of course certain limitations that accompany this first exercise. First, although the paper puts together a number of econometrically estimated output and input elasticities, estimates of certain elasticities are assumed. Second, the estimated producer supply elasticities are for the SAT alone, but the counterpart output demand elasticities used in this exercise are averages for all of India. Third, the model developed is a closed economy version of the rural SAT. Therefore, except for labor migration into and from the SAT, no attempt is made to endogenously account for output and factor mobility to and from the SAT. Finally, producers and consumers are not distinguished by socio-economic groupings. Thus, the model is unable to properly account for differences in production and consumption behavior across the spectrum of rural SAT households.

The first section of this paper outlines, in brief, the basic Q-B model. A second section describes the various data sources and elasticity estimates that are used to operationalize this basic model. Finally, a fourth section discusses proposed avenues for later simulation. Appendices explain in detail how some equations in the model are derived.

I. The Model

Producer behavior is represented by a system of output supply and factor demand equations called the producer core. Analytically the producer core is derived from a variable profit function $\Pi^* = \Pi^*(V,Z,\tau)$, where Π^* is maximized variable profits, $V = [\underline{P}, \underline{W}]$ is the vector of prices of outputs $\underline{P}$ and variable inputs $\underline{W}$. Z is a vector of fixed inputs and τ is a technology index. The output supply and factor demand curves are derived from Π^* via Shepards lemma i.e. the vector of outputs and (negative) variable inputs is written as $Q = [\underline{Y}, -\underline{X}] = \frac{\partial \Pi^*}{\partial V}$.

For a case with one region, one agricultural output (Y), two variable inputs (L = labor and K = capital) and one fixed input (Z = land), the producer core can be written in rates of changes as:

(1.1) Output supply equations $\quad Y' = \beta_{YY} P' + \beta_{YL} W' + \beta_{YK} R' + \beta_{YZ} Z^* + E_Y'$

Input demand equations $\quad L' = \beta_{LY} P' + \beta_{LL} W' + \beta_{LK} R' + \beta_{LZ} Z^* + E_L'$

$$K' = \beta_{KY} P' + \beta_{KL} W' + \beta_{KK} R' + \beta_{KZ} Z^* + E_K'$$

where W = wage rate, R = capital rental rate, P = output price. Except for the E variables the primes refer to rates of growth of the endogenous variables while the asterisks refer to rates of growth of exogenous (shifter) variables or to the exogenous components of the rate of change of an endogenous variable. The βs are elasticities of the first subscript with respect to the price of the second subscript. The E's are exogenous technology shifters of the output supply and variable factor demand curves.1/ (For a discussion of conceptual and measurement issues see Binswanger 1973).

1/ When there is only one output, Quizon and Binswanger (1983) show how Hicks neutral and biased technical change may be modelled into (1.1) by following the cost function approach rather than the profit function approach hitherto described.

The first equation of (1.1) is the output supply equation. When there are n ($n>1$) agricultural outputs, n equations appear here and the β_{YY} and P' elements in each of these n equations are expanded into ($1xn$) and ($nx1$) vectors respectively. The second and third equations are the input demand equations, which can again be expanded as more inputs are added.

Given initial equilibrium in the output and variable input markets, output demand and input supply equations are used to close the model. In these, prices and quantities are also expressed in terms of rates of growth and price coefficients in terms of elasticities.[1/] For the case described by (1.1), we close the output market with the following demand equation:

(1.2) Output demand equation (a) $Y' = \alpha_P P' + \alpha_m m' + y^* + N'$

Equation (1.2) is the aggregate output demand equation. N' is the rate of change in the consuming population. The parameter α_P is the compensated output demand elasticity with respect to the output price P, α_m is the elasticity of output demand with respect to real income m and y^* are exogenous changes in per capita output demands. Again, when there are n($n>1$) agricultural outputs, n equations appear here and the parameters α and P' in each of these equations become ($1 \times n$) and ($n \times 1$) vectors respectively. We now turn to the derivation of the population and labor supply equations.

1/ As in the producer core system, this consumer core system can be derived from an indirect utility function with neo-classical properties, the consumer's counterpart of the producer's profit function.

We assume that the rural population $\bar{N}$ grows at a rate arising from a variety of exogenous influences which are not modeled. But in addition it grows via immigration or is diminished via emigration, a process which is responsive to the real wage rate w. Differentiating totally and converting to rates of changes:

(1.3) $N' = \varepsilon_m w' + N^*$

where ε_m is the migration elasticity to be discussed below and w' is the real wage rate, which can be expressed as follows as $w' = W' - \bar{P}'$, where $\bar{P}'$ is the rate of change in the consumer price index. Thus we rewrite:

(1.4) $N' = \varepsilon_m (W' - \bar{P}') + N^*$

Because the resident population (NRES) may respond differently in terms of migration than populations elsewhere, who supply the migrants (NMIG), the migration elasticities must be further decomposed. Let total population be defined as

(1.5) $N = NRES + NMIG$

Differentiating with respect to real wages and normalizing with respect to the total population ε_m decomposes into

(1.6) $\varepsilon_m = \frac{\partial NRES}{\partial w} \frac{w}{N} + \frac{\partial NMIG}{\partial w} \frac{w}{N}$

In Appendix I, we show how this elasticity can be computed from Dhar's (1980) econometric study of migration behavior. Agricultural labor supply is a function of the labor effort per person in the population ℓ. In terms of traditional labor supply concepts $\ell = re$, where r is the agricultural labor participation rate and e is effort per person

(1.7) $L = reN = \ell N$

As we do not know the participation rate and the effort supply rate separately for the resident population and the immigrants, we assume them to be the same.

Differentiating totally and converting to rates of changes, we find

$$(1.8) \qquad L' = \varepsilon_{\ell} w' + \ell^* + N' = \varepsilon_{\ell} (W' - \bar{P}') + \ell^* + N'$$

The labor supply change is thus decomposed into a response of total effort ℓ to the real wage rate ε_{ℓ}, an exogenous change in total effort supplied to agriculture ℓ^*, and the total rate of change in population.

The supply of capital services is as follows

$$(1.9) \qquad K' = \varepsilon_K R' + K^*$$

Where ε_K is the supply elasticity of capital services with respect to the rental rate and K^* is an exogenous rate of growth of capital.

We derive the rate of change in land rents S' residually from variable profits by making use of the fact that variable profits must be equal to the total land rent, i.e.,

$$(1.10) \qquad \Pi = SZ = \sum_i V_i Q_i$$

Differentiating (1.10) with respect to time t leads to

$$(1.11) \qquad \sum_i V_i \frac{dQ_i}{dt} + \sum Q_i \frac{dQ_i}{dt} .$$

Solving for S', we obtain

$$(1.11) \qquad S' = \sum_i \phi_i V_i' + \sum_i \phi_i Q_i' - Z^*$$

where ϕ_i are profit shares, S', V', and Q' are the rates of change over time of the rental rate, variable prices and variable quantities respectively.[1]

The change in the consumer price level $\bar{P}$ can be related to the changes in the endogenous agricultural prices as follows:

$$(1.12) \quad \bar{P}' = \sum_{i \varepsilon 0} \mu_i P_i' + \mu_{NA} P_{NA}^*$$

where μ_i are shares of consumer expenditure on commodity i, and μ_{NA} and P_{NA}^* are the share and change in the price index of nonagricultural commodities. The per capita income equation is derived as follows: Let M stand for total nominal income and be expressed as

$$(1.13) \quad M = WL + RK + SZ + W(LNA) + MN$$

where LNA is rural labor used for nonagricultural purposes, here assumed to be exogenous and MN is other nonagricultural income, while agricultural income is the sum of factor incomes. Then real per capita income is defined as

$$(1.14) \quad m = \frac{M}{\bar{P}N}$$

The total rate of change of m therefore becomes

$$(1.15) \quad M' = \delta_L(W' + L') + \delta_K(R' + K') + \delta_Z(S' + Z^*) + \delta_{LNA}W' + \delta_{MN}MN^* - \bar{P}' - N'$$

1/ See Appendix II.

Table 1: The Model in G-Matrix Form

Variable in column	P'	W'	R'	Y'	L'	N'	K'	S'	$\bar{P}'$	m'			
Output supply	$-\beta_{YY}$	$-\beta_{YL}$	$-\beta_{YK}$	1	0	0	0	0	0	0	P'		$Z^* + E_Y'$
Labor demand	$-\beta_{LY}$	$-\beta_{LL}$	$-\beta_{LK}$	0	1	0	0	0	0	0	W'		$Z^* + E_L'$
Capital demand	$-\beta_{KY}$	$-\beta_{KL}$	$-\beta_{KK}$	0	0	0	1	0	0	0	R'		$Z^* + E_K'$
Output demand	$-\alpha_P$	0	0	1	0	-1	0	0	0	$-\alpha_m$	Y'		y^*
Labor supply	0	$-\varepsilon_\ell$	0	0	1	-1	0	0	ε_ℓ	0	L'	=	ℓ^*
Population	0	$-\varepsilon_m$	0	0	0	1	0	0	ε_ℓ	0	N'		N^*
Capital supply	0	0	$-\varepsilon_K$	0	0	0	1	0	0	0	K'		K^*
Land rent	$-\phi_Y$	$-\phi_L$	$-\phi_K$	$-\phi_Y$	$-\phi_L$	0	$-\phi_K$	1	0	0	S'		$-Z^*$
Price level	$-\mu$	0	0	0	0	0	0	0	1	0	$\bar{P}'$		$\mu_{NA}\bar{P}^*_{NA}$
Real per capita income	0	$-(\delta_L + \delta_{LNA})$	$-\delta_K$	0	$-(\delta_L + \delta_{LNA})$	1	$-\delta_K$	$-\delta_Z$	1	1	m'		$\delta_Z Z^* + \delta_{MN} N^*$

Note: $\phi_Y = \frac{1}{s_Z}$, $\phi_L = -\frac{s_L}{s_Z}$, $\phi_K = -\frac{s_K}{s_Z}$

where δ_i is equal to the share of income from source i in total income. Thus the change in total per capita income is the sum of the rate of change in the reward of each factor and the endogenous changes in their supply, less the endogenous rate of change of the price index, less the endogenous rate change in population, including the migration component. If there is an exogenous change in income, it is captured by MN*.

The complete model is given by equations (1.1), (1.2), (1.4), (1.8), (1.9), (1.11), (1.12) and (1.15).

It can be written in matrix notation as

$$(1.16) \qquad GU' = K^*$$

where G is the expanded matrix with the β, ε, δ, ϕ and α terms, U' is the column vector of endogenous prices, K* is the column vector of policy variables. Indeed, (1.16) can include any number of factors of production and outputs. Table 1 rewrites the complete model in the above matrix form.

The solution to (1.16) is

$$(1.17) \qquad U' = G^{-1}K^*$$

and the effects of changes in the exogenous (starred) variables on input and output prices and quantities can be solved for, given numerical estimates of the inverse of G. The inverse of an expanded G matrix describes what happens to prices and quantities of factor inputs and agricultural outputs when policy decisions shift the starred variables in the model. In the next section, a G matrix is assembled for the semi-arid region of India.

II. THE ELASTICITIES ESTIMATES

In order to construct the expanded G matrix for the semi-arid region of India, empirical estimates of elasticities from three main studies were used. The study of Bapna, Binswanger and Quizon (1981) provided output supply and fertilizer demand elasticities. Consumer demand elasticities come from Binswanger, Quizon and Swamy (1982) while labor demand and bullock power demand elasticities were estimated in Binswanger and Evenson (1980).

Four agricultural outputs were considered, namely rice, wheat, coarse cereals and other crops. These categories of output are exhaustive, i.e., they account for all agricultural crop production in the Indian semi-arid tropics. In instances where elasticity estimates from the above mentioned studies were available at a finer level of disaggregation only, the estimates were combined to form the output and input aggregates listed above. Three variable inputs, namely labor, fertilizer and bullock power were identified. Total land was treated as a fixed factor of production. The inputs were not allocated to individual crops.

The elasticity for labor participation, ε_{ℓ}, is set at the low value of 0.3, based on Rosenzweig's (1980) econometric estimates.1/ The elasticity for migrant labor, ε_m, is computed from Dhar (1980) and is .1083.2/ Finally, no fertilizer or bullock supply elasticities have ever been estimated. The fertilizer supply elasticity is set at 4.0, a high value which reflects opportunities of international trade. The own supply price elasticity for bullock labor is set at .5756, the weighted own supply price elasticity for all crops. We believe that this is appropriate, as bullocks are reproducible

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1/ Rosenzweig estimated both elasticities of participation and elasticities of effort.

2/ Appendix I shows how this is computed.

out of agricultural output.

In the Bapna, Binswanger and Quizon and the Binswanger, Quizon and Swamy studies, all regularity constraints implied in production theory and consumer demand theory were imposed, except for the convexity constraints. Prior to using the elasticity estimates from these studies therefore, the estimated coefficients of these systems of equations had to be made convex. Trial and error procedures were used to obtain convex estimates without violating any other regularity constraint. Not all coefficients in all equations were adjusted. Rather, attempts were made to have the minimum number of adjustments and to concentrate on those estimates that seemed least consistent with a priori expectations. Coefficient estimates were not adjusted by more than one-half their standard errors, except for the price coefficients in the inferior cereals demand equation (in Binswanger, Quizon and Swamy (1982)) where an adjustment of the order of one standard error was needed. These constraints, which do not hold globally, are imposed at base year prices for the simulation (the agricultural year 1973-74). Appendix Tables 1 and 2 compare price elasticity estimates before and after adjustments for the producer core and the consumer demand system respectively. Most of the adjustments are very small.

Table 2 gives the full set of elasticity estimates used in the G matrix in exactly the same format as in Table 1 except that the presence of several commodities now leads to expanded output supply and commodity demand submatrices. Footnotes to this table explain the origin of each element in this matrix. In Table 3, the expanded vector of exogenous shifter variables is shown. This vector is again analogous to the K* vector in Table 1, except that more than one exogenous shifter variable is included in the producer core equations. The rightmost column of Table 3 lists the exogenous supply and demand shifters in the equations they are supposed to

Table 2

Expanded G Matrix in the Equation GU'=K*1/2/ for the SAT Region of India

Endogenous 3/ Variables	Output Prices				Input Prices		
	RICE	WHEAT	CEREALS	CROPS	FERT	LABOR	BULLOCK
PRICE	-.885134	0	0.252479	0.406146	0.046013	0.180468	0
PWHEAT	0	-0.6468	0.663943	0.152453	0.235093	-.404689	0
PCEREALS	0.243964	0.231751	-0.79988	0.131261	-.206332	0.405176	0
PCROPS	0.2171	.0294376	.0726124	-.272281	.0716868	-.119058	0
PFERT	-.182434	-.336709	0.846627	-.531727	0.827872	-.631325	0
PLABOR	-.229832 5/	0.186175 5/	-.534015 5/	0.283655 5/	-.202786 5/	0.496795 5/	-0.062
PBULLOCK	0	0	0	0	0	-0.051	0.496795
QRICE	0.896228	-.319648	0.210655	-.546249	0	0	0
QWHEAT	-.753715	0.720026	-0.01421	-.133154	0	0	0
QCEREALS	0.68359	-.015503	0.402386	-.812642	0	0	0
QCROPS	-.346804	-.035762	-.162818	0.77825	0	0	0
QFERT	0	0	0	0	-4 6/	0	0
QLABOR	0	0	0	0	0	-0.3 7/	0
POPLN	0	0	0	0	0	-.108281 8/	0
QBULLOCK	0	0	0	0	0	0	-.575579
RENT	-.886922	-.263369	-.942395	-1.32293	0.101548	1.44573	0.422571
PBAR	-.119248	-.063094	-0.1839	-.364629	0	0	0
INCOME	0	0	0	0	0	-0.388	-0.108

Endogenous 3/ Variables	Output Quantities				Input Quantities						
	RICE	WHEAT	CEREALS	CROPS	FERT	LABOR	POPLN	BULLOCK	RENT	PBAR	INCOME
PRICE	1	0	0	0	0	0	0	0	0	0	0
PWHEAT	0	1	0	0	0	0	0	0	0	0	0
PCEREALS	0	0	1	0	0	0	0	0	0	0	0
PCROPS	0	0	0	1	0	0	0	0	0	0	0
PFERT	0	0	0	0	1	0	0	0	0	0	0
PLABOR	0	0	0	0	0	1	0	0	0	0	0
PBULLOCK	0	0	0	0	0	0	0	1	0	0	0
QRICE	1	0	0	0	0	0	-1	0	0	0	-.649915
QWHEAT	0	1	0	0	0	0	-1	0	0	0	-.981421
QCEREALS	0	0	1	0	0	0	-1	0	0	0	0.722964
QCROPS	0	0	0	1	0	0	-1	0	0	0	-1.09658
QFERT	0	0	0	0	1	0	0	0	0	0	0
QLABOR	0	0	0	0	0	1	-1	0	0	0.3	0
POPLN	0	0	0	0	0	0	1	0	0	0.108281	0
QBULLOCK	0	0	0	0	0	0	0	1	0	0.575579	0
RENT	-.886922	-.263369	-.942395	-1.32293	0.101548	1.44573	0	0.422571	1	0	0
PBAR	0	0	0	0	0	0	0	0	0	1	0
INCOME	0	0	0	0	0	-0.388	1	-0.108	-.254712	1	1

1/ Unless otherwise indicated, reported output supply and input demand elasticities are from the Wheat SAT and the Rice SAT elasticity estimates (NQ systems) in Bapna, Binswanger and Quizon (1981).

2/ Unless otherwise indicated, reported output demand elasticities are from the translog (or TL) consumer demand system in Binswanger, Quizon and Swamy (1982).

3/ Variable names that start with P refer to prices. Variable names that start with Q refer to quantities.

4/ These figures are the SAT labor and bullock demand NQ elasticity estimates with restricted land in Evenson and Binswanger (1981).

5/ These figures are obtained by first solving for implied labor quantities in the Wheat and the Rice SAT regions using the β_{LY} estimate (Y = aggregate output with price P) from the Evenson and Binswanger (1981) study and the price, quantity and β_{iL} estimates from the Bapna, Binswanger and Quizon (1981) study. Labor quantities were computed by solving for L in the equation $\beta_{LY} = (\Sigma w_i \beta_{iL}) \frac{PY}{WL}$, where w_i is the value share of output i in the total value of output. Total labor in SAT, the sum of labor in the Wheat and the Rice SAT, was then used, given the symmetry constraint $(b_{Li} = b_{iL})$ to solve for the final elasticities reported here. See Binswanger and Quizon (1980) for the relationships between elasticities that arise from the symmetry constraint.

6/ This fertilizer supply elasticity has not been econometrically estimated.

7/ This supply elasticity for resident labor is from Rosenzweig (1978).

8/ This supply elasticity for migrant labor is computed from Dhar (1980) and is an average for all India. Appendix I explains how this estimate was computed.

Table 3: EXPANDED K* MATRIX IN THE EQUATION GU' = K* FOR THE SAT REGION OF INDIA

U' Matrix	K* MATRIX									
Endogeneous Variables 1/	Exogeneous Shifter Variables 2/									Other Shifter Variables 5/
	RAIN	HYV	IRR	ROADS	MKTS	LAND 3/	POPLN*	PBAR*	CAPITAL	
PRICE	0.687257	0.211481	-.186869	0.115553	0.109949	0.1617	0	0	0.0366	SRICE*
PWHEAT	0.3767	-.179526	0.375798	-.261507	0.114913	0.1617	0	0	0.0366	SWHEAT*
PCEREALS	-.033487	-.209493	0.130664	0.334055	-.114789	0.1617	0	0	0.0366	SCEREALS*
PCROPS	.0777054	.0428496	0.426184	0.228845	-.030148	0.1617	0	0	0.0366	SCROPS*
PFERT	.0445969	0.417001	0.452202	1.15181	0.105549	0.1617	0	0	0.0366	DFERT*
PLABOR	.0729671 4/	7.8E-04 4/	.0688566 4/	.0620998 4/	-.001855 4/	0.508	0	0	0.131	DLABOR*
PBULLOCK	.0729671 4/	7.8E-04 4/	.0688566 4/	.0620998 4/	-.001855 4/	1.053	0	0	-0.06	DBULLOCK*
QRICE	0	0	0	0	0	0	0	0	0	DRICE*
QWHEAT	0	0	0	0	0	0	0	0	0	DWHEAT*
QCEREALS	0	0	0	0	0	0	0	0	0	DCEREALS*
QCROPS	0	0	0	0	0	0	0	0	0	DCROPS*
QFERT	0	0	0	0	0	0	0	0	0	SFERT*
QLABOR	0	0	0	0	0	0	0	0	0	SLABOR*
POPLN	0	0	0	0	0	0	1	0	0	
QBULLOCK	0	0	0	0	0	0	0	0	0	SBULLOCK*
RENT	0	0	0	0	0	-1	0	0	0.547315	
PBAR	0	0	0	0	0	0	0	0.269129	0	
INCOME	0	0	0	0	0	0.254712	0	0	0.139407	

1/ Variable names that start with P refer to prices. Variable names that start with Q refer to quantities.

2/ Unless otherwise indicated, reported elasticities with respect to these shifter variables are from the wheat SAT and the rice SAT estimates in Bapna, Binswanger and Quizon (1981).

3/ Reported elasticities in this column are computed from the NQ equation estimates with restricted land for the SAT in Evenson and Binswanger (1981).

4/ These elasticities are taken to be a third of the output weighted sum of the crop specific elasticities.

5/ Variables that start with an S are exogenous supply shifters. Those that start with a D are exogenous demand shifters.

Table 4

Inverse of the Expanded G Matrix in the Equation GU'=K* for the SAT Region of India

Endogenous 1/ Variables	Output Supply Shifters				Input Demand Shifters			Output Demand Shifters				Input Supply Shifters						
	RICE	WHEAT	CEREALS	CROPS	FERT	LABOR	BULLOCK	RICE	WHEAT	CEREALS	CROPS	FERT	LABOR	POPLN	BULLOCK	RENT	PBAR	INCOME
PRICE	-.924877	-.450357	-.773557	-1.56092	-.053863	0.588668	.0360309	1.76358	0.699408	1.66472	2.81193	-.042164	-.515325	2.71175	-.034672	0.945636	-3.83165	3.71257
PWHEAT	-.599796	-1.22355	-1.13677	-1.81127	-.062593	0.44264	.0280971	1.65223	1.53607	2.25503	3.38108	-.057905	-.350608	3.81514	-.026392	1.18662	-4.95139	4.65866
PCEREALS	-.308513	-.414877	-1.8452	-1.82835	-.044799	0.992462	.0585427	0.796951	0.559918	2.36419	2.55691	-.011124	-0.94975	3.16612	-.057751	0.550712	-2.18676	2.1621
PCROPS	-.462437	-0.38858	-.746532	-2.07848	-.069146	0.434521	.0273243	1.38744	0.663256	1.72939	3.45821	-.036762	-.353632	2.79009	-.025825	1.04293	-4.27572	4.09456
PFERT	-.120552	-.095659	-.024749	-.249376	0.203415	0.171658	.0103136	0.283975	0.144187	0.198394	0.493138	-.222126	-.157367	0.238925	-.010049	0.184259	-.696278	0.723401
PLABOR	-.358973	-.177904	-1.20516	-1.19126	.0186924	1.87148	0.108967	0.68098	0.273523	1.54731	1.67157	-.055561	-1.84332	0.904679	-.108445	0.363061	-.907924	1.42538
PBULLOCK	-.217535	-0.19572	-.473556	-.805142	-.022633	0.324672	0.952077	0.551413	0.294864	0.828316	1.30315	-.015595	-.295475	1.20435	-.95153	0.376445	-.972006	1.47793
QRICE	0.5174	-.099551	0.303006	0.150618	-.021015	-.251645	-.014126	0.66033	0.152327	-0.11416	0.114482	6.7E-04	0.267187	0.293438	.0144139	0.200389	-.906954	0.786728
QWHEAT	-.229545	0.493795	0.12176	-.064198	-.040456	0.278127	.0168117	0.536839	0.597455	0.204754	0.522557	.0052728	-.251255	0.250098	-.016314	0.346472	-1.30256	1.36025
QCEREALS	0.299141	0.164928	0.557414	.0421471	0.035286	-0.23224	-.014084	-.575132	-.246883	0.149332	-.453815	-.003686	0.208105	0.303296	.0136369	-.311179	1.11857	-1.22169
QCROPS	.0808399	.0437899	-.009589	0.835075	-.014395	0.115925	.0067736	-.050888	-.034896	.0414139	0.2096	.0109653	-.113306	-.080658	-.006725	.0337703	-.085986	0.132582
QFERT	-.482208	-.382635	-.098997	-.997505	0.813659	0.686634	.0412544	1.1359	0.576747	0.793576	1.97255	0.111496	-0.62947	0.955701	-.040195	0.737036	-2.78511	2.89361
QLABOR	.0059254	.0698089	-.175419	.0829879	.0255241	0.584821	.0335479	-0.11678	-.102727	.0576309	-.248338	-.012832	0.405485	0.485974	-.033728	-.124988	0.335849	-.490703
POPLN	.0015714	.0185141	-.046523	.0220091	.0067593	0.155102	.0088973	-.030971	-.027244	.0152848	-.065862	-.003403	-.157673	0.863674	-.008945	-.033148	0.089071	-0.13014
QBULLOCK	.0897626	.0881595	0.173797	0.339236	.0121971	-0.06585	0.53257	-.239209	-.132537	-.332591	-0.56215	.0049138	.0527814	-.552174	0.467187	-0.1685	0.436584	-.661532
RENT	-.467866	-1.12131	-.763375	-3.14724	-.375832	-1.81431	-.720382	3.61176	2.05488	4.1039	7.83666	.0158723	0.565945	8.18256	0.301469	3.54472	-11.2199	9.99059
PBAR	-.373487	-.348886	-.775508	-1.39452	-.043824	0.439078	.0267986	0.967009	0.525131	1.40615	2.27982	-.024132	-.387176	2.16368	-.025837	0.669194	-1.73052	2.62726
INCOME	0.101962	-.008795	.0595522	0.090546	-.042646	-0.07531	-.003548	0.236548	0.109315	0.30013	0.414375	0.003888	0.104912	-.333152	.0040968	0.381668	-1.49619	1.49843

1/ Variable names that start with P refer to prices. Variable names that start with Q refer to quantities.

appear and with-coefficients equal to one. In the other columns of Table 3, the variables for rainfall (RAIN), percent of area under high yielding varieties (HYV), percent of area irrigated (IRK), road density (ROADL), market density (MKTS), operated area (LAND), population (POPLN), and value of farm buildings and implements (CAPITAL) are preceded by the coefficients which were, unless otherwise indicated, estimated from the corresponding output supply and factor demand equations referred to in this table. Impact multipliers (or the G^{-1} matrix) have to be multiplied by these coefficients to arrive at the effects of these exogenous shifters on any of the endogenous variables.

III. THE RESULTS

Table 4 provides all the impact multipliers or the G^{-1} matrix. Each row corresponds to one of the endogenous variables: output prices, input prices, output quantities, input quantities, land rent and real income. In general, each element in each row gives the impact of a shift in a supply or a demand curve on the endogenous variable of the row. This interpretation comes from multiplying this inverse matrix with the exogenous supply/demand shifter variables given in the last column of Table 3. Thus, for example, the first element in the first row is -0.925 and tells us that the price of rice would fall by approximately 0.925 percent if the supply curve of rice shifts by one percent, a shift which could come about in various ways, one of which could be from a technical change in rice production in the SAT. The effect of a shift in the wheat supply curve on the rice price is shown in column 2 as -0.450 i.e., a percentage increase in wheat supply would, via its effects on consumers and producers, also lead to a drop in rice prices by 0.450 percent.

A shift in rice demand by one percent (because of decision to export a certain quantity, for example) would lead to an increase in rice prices by 1.764 percent as shown in the frist row by the eight column. Also, a one percent increase in labor supply due to a change in the labor participation rate (column 13) would lead to a sharp drop in wages (row 6) of 1.843 percent and a modest increase in rice supply (row 8) of 0.267 percent. This outcome reflects the inelasticity of labor demand in production, but it also reflects the low labor supply elasticity used for agricultural labor. Other stories can of course be told from these Table 4 figures. In what follows, we proceed more systematically by first considering a more general overview.

Prior to interpreting the figures given in Table 4, it is helpful to consider a cautionary remark. What the figures show are the likely price, quantity and per capita income effects of an initial exogenous percentage increase in a supply or demand variable.

Thus, one has to carefully distinguish how these exogenous positive changes in supplies and demands actually come about. For example, an increase in the supply of rice in the SAT may come via imports. The same may be accomplished by a technical change in rice production. Both these sources of rice supply increases, however, have different initial effects on the variables in our model. Whereas rice imports initially increase the supply of rice,[1/] a technical change initially affects not only the supply of rice but also the returns to factors of production, because production of this increased rice output takes place within the SAT.[2/] Thus, their effects are likely to be different. The effects of a technical change in crop production as against that due to imports will be more thoroughly discussed in later sections.

1/ Note that how imports are financed is not treated in our model. The same is true for technical change. Hence, the question of what factors of production eventually gain or lose cannot be completely addressed by our model.

2/ Our model assumes that factor gains from an increase in rice production due to technical change initially accrue to land, the fixed factor of production.

Table 4 shows the signs of the own equilibrium quantity and price effects of shifts in agricultural input and output supplies and demands conform to *ex ante* expectations. An exogenous increase in any input supply (output demand) decreases (increases) its own price. The same also increases own equilibrium quantities of inputs (outputs).

The signs of the cross price effects of any exogenous shifts in output demands are also as expected. An exogenous increase in the demand for an output increases prices of all other outputs. Input prices also increase. The opposite of the aforementioned cross price effects hold for any increases in the supply of an output. Table 4 also shows that an increase in the supply of an input decreases the prices of all outputs and all other inputs.[1/]

With regard to the equilibrium cross quantity effects of any exogenous shift in an output demand and/or an input supply, the signs of these effects cannot be theoretically anticipated. These signs can be easily read off Table 2, however. For instance, a percentage increase in the demand for rice would lead to an increase in the equilibrium quantity of wheat (0.537%), a decrease in the equilibrium quantities of coarse cereals (-0.575%) and other crops (-0.051%).

Table 5 summarizes the effects of shifts in other Z (fixed factor) variables on prices and quantities of agricultural inputs and outputs. These results come from multiplying the G^{-1} matrix in Table 4 with the K* matrix in

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1/ In Binswanger and Quizon (1980), it is shown that increases in the supply of a variable factor input will lead to a decline in the output price for the two variable input, one fixed input, one output case. This seems contrary to the results in Table 2. However, in that theoretical version of the model, not only are the number of outputs and factors of production different from the Table 2 case, but the land rent and per capita income equations are also omitted. Hence, the output demand effects via incomes were ignored.

Table 3 (except the last column). Thus, from Table 5, for example, a percentage increase in irrigation (IRK), would lower nominal wages by 0.520 percent (row 6, column 3) but also decrease all output prices by more than this amount, i.e., by between 0.744 percent and 1.264 percent (rows 1 to 4 of column 3). These price effects lead to higher real wages for agricultural laborers who normally spend most of their incomes on food. Agricultural laborers further gain because their employment increases by 0.092 percent (row 13, column 3). Landowners lose substantially (row 16, column 3) and their loss implies that overall real per capita income declines, though negligibly (row 18, column 3). There are, of course, other interesting stories that can be told by reading off results straight-forwardly from this table. Rather than do this, however, we turn instead to combining the effects from having two or more exogenous shifters simultaneously. This would then depict more realistic scenarios. This is done in Table 6 where the results from various simulation exercises are summarized.

Table 6 most clearly illustrates the analytical capabilities of the model hitherto described. The first column of Table 6 lists the endogenous variables and their correspondence with the endogenous variables listed in Table 5. The remaining columns of Table 6 describe a variety of simulations which we have designed with a time frame of one decade in mind.[1/] Thus, for example, simulation 1.1 corresponds to a slowdown in the population and labor force growth of 10 percent over a decade or to a decline of the population and labor force growth by somewhat less than 1 percent per year. The effects shown in Table 6 are the cumulative (over a decade) changes in the endogenous variables with respect to the _ceteris paribus_ development path which remains unknown and

1/ The exception is simulation 6.1 which basically describes a short-run phenomena.

Table 5

The $G^{-1}K^*$ Matrix in the Equation $U' = G^{-1}K^*$ for the SAT Region of India

Endogenous Variables	$G^{-1}K^*$ Matrix: Effects of Exogenous Shifter Variables								
	RAIN	HYK	IRK	ROADS	MKTS	LAND	POPLN*	PBAR*	CAPITAL
PRICE	-.857486	-.041548	-.744071	-.627968	-0.02443	-.271586	2.71175	-1.03121	0.972327
PWHEAT	-.944248	0.227612	-1.26408	-.586447	-.028934	-.527205	3.81514	-1.33256	1.17828
PCEREALS	-.373904	0.299587	-1.06647	-.948299	0.178657	-.152413	3.16612	-.588521	0.566757
PCROPS	-.570085	.0108209	-1.04244	-.727815	.0447038	-.356084	2.79009	-1.15072	1.05984
PFERT	-.115084	.0711438	-0.01842	0.191344	.0072449	.0516677	0.238925	-.187389	0.213062
PLABOR	-.220593	0.166789	-.520123	-.525647	0.112641	0.594161	0.904679	-.244349	0.529368
PBULLOCK	-.177785	.0453966	-.360238	-.263184	.0274674	0.890222	1.20435	-.261595	0.334721
QRICE	0.299313	.0612981	-.058117	0.1808	.0044002	-.005191	0.293438	-.244088	0.21836
QWHEAT	.0389068	-.182092	0.219025	-.157955	0.014647	0.204487	0.250098	-.350558	0.424982
QCEREALS	0.235924	-.066792	.0958714	0.212635	-.009232	.0448862	0.303296	0.301039	-.329983
QCROPS	0.145575	.0411192	0.357932	0.17683	-.011902	0.217329	-.080658	-.023141	.0859932
QFERT	-.460338	0.284575	-.073682	0.765376	.0289796	0.206671	0.955701	-.749555	0.852249
QLABOR	.0889511	.0401514	.0916948	.0106203	.0278549	0.333843	0.485974	.0903867	-.061894
POPLN	.0235908	.0106487	.0243184	.0028165	.0073875	.0885392	0.863674	.0239716	-.016415
QBULLOCK	0.15004	-.013267	0.221295	0.16604	-.009756	0.641044	-.552174	0.117497	-0.19929
RENT	-1.16465	-.031277	-2.11949	-1.32636	-.032751	-3.63032	8.18256	-3.0196	2.92334
PBAR	-.438461	.0684461	-.744711	-0.55166	.0444165	-.223517	2.16368	-.465733	0.680964
INCOME	0.064147	-.003299	-7.0E-04	6.8E-04	-.003721	-.009553	-.333152	-.402668	0.415475

unmodeled at present. Thus, for example, simulation 1.1 shows that a 10 percent decline in the population and the labor force growth over the decade results in a 3.13 percent increase in the growth rate of real per capita income over the same period.

Table 6

RESULTS FROM VARIOUS SIMULATIONS, SAT REGION OF INDIA

SIMULATIONS

	Slower Population Growth (-10%)	Increased Urban Income (+10%)	Accelerated Irrigation (+10%)	Accelerated Roads Mktg. and Other Capital Investments (+10%)	Combination of (3.1)(+10%) and (3.2) (+5%)	Increased Rice Yields (+20%)	Increased Wheat Yields (+20%)	Increased Coarse Cereal Yields (+20%)	Increased Other Crops Yields (+20%)	Increased Yields of All Crops (+10%)	Rice Imports (+10%)	Decline in Rainfall (-20%)
Endogenous Variables*	1.1	2.1	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	5.1	6.1
Prices of:												
Rice (PRICE)	-27.12	9.16	-7.44	3.20	-5.84	-21.81	-12.88	-7.73	32.71	-37.57	-17.64	17.15
Wheat (PWHEAT)	-38.15	11.50	-12.64	5.63	-9.82	-7.40	-36.03	-13.23	37.68	-47.17	-16.52	18.89
Coarse Cereals (PCEREALS)	-31.66	5.34	-10.66	-2.03	-11.68	9.71	-8.03	-45.34	-44.01	-43.84	-7.97	7.48
Other Crops (PCROPS)	-27.90	10.11	-10.42	3.77	-8.54	-3.02	-10.20	-10.55	-49.19	-36.48	-13.87	11.40
GNP Deflator (PBAR)	-21.64	6.48	-7.45	1.74	-6.58	-2.38	-9.01	-13.94	-32.31	-28.82	-9.67	8.77
Real Per Capita Income (INCOME)	3.33	1.23	-0.01	4.12	2.06	2.66	-0.63	1.53	1.32	2.44	-2.37	-1.28
Real Land Rents (RENT - PBAR)	-60.19	18.17	-13.75	13.91	-6.80	-7.58	-18.31	-4.73	-32.26	-31.44	-26.45	14.52
Real Wage Rate (PLABOR - PBAR)	12.59	-2.97	2.25	-0.57	1.96	8.57	2.59	-3.87	-1.80	2.75	2.86	-4.36
Labor Employment (QLABOR)	-4.86	-1.21	0.92	-0.23	0.80	3.50	1.06	-1.58	-0.74	1.12	1.17	-1.78
Real Wage Bill (PLABOR - PBAR + QLABOR)	7.73	-4.18	3.16	-0.81	2.76	12.07	3.65	-5.44	-2.54	3.87	4.03	-6.14
Quantities of:												
Rice (QRICE)	-2.93	1.94	-0.58	4.04	1.44	16.14	-3.98	7.07	0.34	9.79	3.40	-5.99
Wheat (QWHEAT)	-2.50	3.36	2.19	2.82	3.60	-7.84	14.43	2.73	-3.60	2.86	-5.37	-0.78
Coarse Cereals (QCEREALS)	-3.03	-3.02	0.96	-1.27	0.33	7.44	3.93	13.23	-1.63	11.48	5.75	-4.72
Other Crops (QOTHER)	0.80	0.33	3.58	2.51	4.83	-0.05	0.47	-1.07	19.67	9.51	0.51	-2.91
Aggregate Output Quantities1/	-1.48	0.06	1.67	1.89	2.61	5.62	1.34	5.28	6.98	9.61	2.25	-4.04
Per Capita Cereal Consumption2/	5.73	0.02	0.43	1.23	1.04	6.71	2.88	9.83	-1.13	9.15	2.75	-4.45

* All endogenous variables refer to the rural SAT only.

1/ These are value weighted sums of the crop specific quantity effects. Value weights in production are used here and refer to 1973-73 prices and quantities.

2/ These refer to rural consumption only. They are computed as value weighted sums of the cereal (rice, wheat and coarse cereals) quantity effects. Value weights in consumption are used here and refer to 1973-74 prices and quantities.

Demographic and Urban Growth Scenarios

In demographic scenario 1.1, the rural population and hence the labor force growth are reduced by 10% over a decade. In the model, the effects of this exogenous shock are obtained from multiplying the POPLN* column in Table 5 by a 10. This, of course, is the same as multiplying the POPLN* column (of the K* matrix) in Table 3 by -10 and subsequently multiplying the G^{-1} matrix in Table 4 with this new column.

Results show that the increased scarcity of labor leads to a decline in labor employment (-4.86%) and to sharply higher agricultural real wages (+12.59%). The decreased demands for agricultural products dramatically lower all output prices (between -27.1% and -38.2%) and decrease the supplies of the same outputs (between -2.5% and 3.03%), except for the other crops aggregate (+0.81%). These reduced demands and lower agricultural prices lead to a substantial decline in land rents of 60.2%. Thus, in this sceanrio, rural laborers gain at the expense of landowners. Aggregate real per capita increases (+3.3%) and so does the rural per capita cereal consumption (5.7%).

Simulation 2.1 assumes that urban incomes increase by 10%. In the model, this is captured by allowing the demands for rice, wheat, and other crops (or DRICE*, DWHEAT* and DCROPS* in Table 3) to exogenously increase by 1.6%, 2.4% and 2.71%, respectively, and that for coarse cereals (or DCEREALS* in Table 3), an inferior commodity, to decrease by 1.8%. These are the initial changes in the demands for agricultural commodities in the SAT that correspond to the 10% increase in region's urban incomes. By multiplying the G^{-1} matrix in Table 4 with these crop specific exogenous demand changes and summing results across all crops, we obtain the results of simulation 2.1 listed in Table 6.

The consequences of higher urban incomes differ markedly from that due to slower rural population growth. All agricultural output prices increase so that the GNP deflator rises by some 6.5%. Labor employment declines (-1.2%) since employment is a function of the real wage rate which also drops (-3%). The increased output demands, however, lead to increases in the supplies of all agricultural outputs (from +0.3% to 3.4%) except for coarse cereals (-3%). But since most of these supply increases go to the urban sector, rural per capita cereal consumption increases by only 0.02%. The principal gainers in this scenario are the rural landowners since real land rents increase by 18.2%. Urban consumers, of course, remain net gainers also since the initial increase in their nominal incomes is not overcome by the resultant higher prices this causes.

Investment Scenarios

In simulation 3.1, the percent of area irrigated in rural SAT is assumed to increase by 10% because of investments in irrigation. In the model, this is treated as an increase in IRK in Table 3 by 10%. The final result of this is the same as multiplying the IRK column in Table 5 by a +10.

Because irrigation has a labor using land saving bias, it increases labor employment (0.9%) and the real wage (2.2%) and decreases real land rents (-13.7%). Increased irrigation also leads to higher aggregate agricultural output (+1.7%) and dramatically lowers agricultural output prices. In this scenario, both urban consumers and landless laborers are the likely gainers. Rural per capita cereal consumption increases by 0.4%.

Scenario 3.2 allows for a 10% expansion in rural road and market densities and in capital inputs such as machines, tractors, farm buildings and implements. These are assumed to happen because of infrastructure investments and rural credit expansion in the SAT. The effects of these exogenous shocks are again computed from Table 5, i.e., by multiplying the columns ROADS, MKTS and CAPITAL by 10 and adding these effects up. Results show that except for coarse cereals (-1.3%) all outputs increase, from 2.5% for other crops to 4% for rice. Agricultural prices increase except for coarse cereals. These price increases allow the GNP deflator to increase by 1.7%. Rural laborers lose while landowners gain since real wages and real land rents move in opposing directions. Urban consumers also lose because of the output price increases. Per capita cereal consumption increases by 1.2%.

In simulation 3.3, we assume that the two previous scenarios occur simultaneously except that investments in infrastructure and rural credit programs increase by only 5%. The results of this simulation are obtained by adding the effects reported for scenario 3.1 and one-half of the reported effects shown for scenario 3.2 in Table 6. In general, the effects of increased irrigation dominate this scenario. Landowners continue to lose while landless laborers and urban consumers remain gainers. For output quantities, the combined effects of the scenarios are in most cases a matter in increased magnitudes.

Technical Change Scenario

In agriculture, technical changes are often crop specific and have to do with the introduction of new crop varieties. A new rice variety, for example, would initially increase the rice yields in a particular area of land by a proportion ρ given that all crop-specific inputs are held constant. This means that for a farmer, the initial shock is an increase in his rice supply by the proportion ρ. This is not the only shock that takes place however. Rice production becomes more profitable and the farmer also adjusts to this increased profitability in the same way he would react to an initial increase in rice prices by the same proportion ρ. Using this fact allows us to derive the E_i' shock associated with the initial yield gain and farmer's reaction as follows. Let the subscript $i = 1$ refer to rice, then:

(3.1) $E_i' = \beta_{i1}\rho$ for $i \neq 1$, and

(3.2) $E_1' = (1 + \beta_{11}) \cdot \rho$

Equation (3.1) states that the output supply curves (for commodities other than rice) and the input demand curves shift by an amount which is proportional to the rice yield change and the curve supply (demand) elasticity of that output (input) with respect to the rice price. Equation (3.2) shows that the rice supply curve will, in addition, shift by the initial yield gain ρ.

The final column vector of exogenous shifters that corresponds to a technical change in rice production consists of (3.1) and (3.2). By multiplying the G^{-1} matrix of Table 4 with this column vector of shifter variables, we obtain the effects of a technical change in rice production that increases rice yields by the proportion ρ.

Appendix 3 discusses in more detail the technical change concept used here. This appendix also more thoroughly explains all the above derivations which we have just summarized. Scenarios 4.1 to 4.5 of Table 6 describe the effects of crop specific technical changes that follow from applying these concepts. Simulations 4.1 to 4.4 assume that yields of individual crops or crop aggregates rise by 20%, changes that would correspond to a major varietal shift. Simulation 4.4 considers only a 10% increase in yields although this is assumed to be distributed evenly across all crops.

Table 6 results show in general that technical change in any particular crop reduces aggregate agricultural output prices. The reduction is modest in the case of rice but large for wheat, coarse cereals and especially other crops. The price drops are not unexpected given the closed economy setting of our model where excess supplies have to be consumed locally. Except in the case of wheat, the technical changes lead to higher real per capita incomes. The reason is that the income effects of the technical changes also affect demand, unlike in the theoretical treatment of the Q-B model. Among the individual crops, yield increases in rice result in the highest real per capita income gains (+2.66%), followed by increases in coarse cereals (+1.53%), other crops (+1.32%) and wheat (-0.63%). The real wage effects vary considerably by crop; they increase with yield increases in rice (+8.6%) and wheat (2.6%) but decrease with similar technical changes in inferior cereals (-3.9%) and other crops (-1.8%). Real land rents decline substantially in all cases. Finally, in all technical change scenarios, aggregate output quantities increase. Per capita cereal consumption also increases except when technical change in other crops occurs. This is not surprising since there are no cereals in this crop aggregate.

Scenarios With Food Aid and Rainfall

In simulation 5.1, we consider what happens in the SAT when the supply of rice increases by 10% via imports. Here, we do not yet consider how these imports are financed. Thus, imports are actually treated as a dumping of rice in the SAT as in a food aid scheme.[1/]

1/ In the model, this is not simply accommodated by multiplying SRICE*, the exogenous rice supply shifter, by a +10 and subsequently multiplying the G^{-1} matrix by this shifter. This is because the quantity imported should not affect the residual profit equation (which, as shown in Table 1, depends on changes in outputs). In the model depicted in Table 1 therefore, an extra equation, one that simply adds up domestic rice production (the first equation in Table 1) and rice imports, should be included. Rice imports, of course, remain exogenous. It is in this extra equation (rather than the first equation of Table 1) where total rice supply is equated to total rice demand.

The effects of food aid in rice differ markedly from that arising from increased rice yields due to technical changes. This is because with food aid, the initial increase in the supply of rice takes place outside the SAT whereas when technical change in rice occurs, the initial increased supply of rice takes place within the SAT region itself. With food aid, prices decline dramatically, from -17.6% for rice to -7.8% for coarse cereals. Real wages increase by 2.9% and labor employment by 1.2% and the real wage bill increases by 4%. The latter compares to a larger increase of about 6% in the total wage bill given a 10% increase in rice yields due to technical change. The same technical change would decrease real land rents by some 3.8% as compared to a dramatic decline of -26.5% with food aid. Thus, with food aid, real per capita income declines (-2.4%) whereas with technical change in rice, real per capita incomes increases (2.7%). In the food aid case, agricultural workers gain while their landowning counterparts lose. Aggregate output supplies also increase, though SAT production of rice and wheat declines by 6.6% (computed as the final increase of 3.4% minus the 10% due to the food aid) and 5.4%, respectively. Per capita cereal consumption, however, increases by 2.8%.

Simulation 6.1 of Table 6 traces the effect of a 20% decline in rainfall in the SAT. It therefore depicts a short-run phenomenon. In the model, this is captured by multiplying the RAIN column in Table 3 by -20 and subsequently multiplying the G^{-1} matrix of Table 4 with this column. The results are as expected. All outputs decline considerably except for wheat, a very minor crop in the SAT. Aggregate output decreases by 4.0%. Prices increase from 7.5% for coarse cereals to 18.9% for wheat. Urban consumers lose because of higher food prices and so do rural laborers since real wages and labor employment both decline (-4.4% and -1.8%, respectively). Landowners gain, however, as real land rents rise by a large 14.5%. Overall, per capita cereal consumption declines by 4.5%.

IV. Areas for Future Research

We have to restress the very preliminary nature of the simulations carried out in this paper. Though they demonstrate the capabilities of the model we developed, more has still to be done. We have however described in a step-by-step fashion the operational features and analytical capabilities of the simplest version of a family of models using actual empirical estimates. Future work needs to concentrate on developing more realistic model features.

There are interactions within the agricultural sector of the semi-arid tropics of India. The importance of regional output mobility to and from the SAT, or for any Indian region for that matter, should be allowed for. Also, the formal links between the size and distribution of agricultural incomes and the agricultural output demands need to be explicitly considered. There are important and more specific policy issues that also need to be accommodated when building models along the lines so far described. The output and employment consequences of price policies such as agricultural minimum wages or ceiling prices on government purchases of food crops are an example. The same is true for policies regarding imports and exports of food grains.

In future modeling efforts, therefore, we hope to incorporate two important features:

(a) an open economy setting. The model will then have to consider more than one agroclimatic region of India, plus the rest of the world. The model will have to allow trade in agricultural commodities to take place among regions plus the world. The model will also have to deal with the movement of variable factors of production, particularly labor, among the urban and rural sectors of the regions, given changes in real returns to these factors.

(b) formal links to the distribution of income. The model will have to consider different socio-economic groups of households. Groups, defined for instance as quantities of the income distribution, would have:

(i) different ownership patterns of agricultural factors of production from which they derive income;

(ii) different consumption patterns for agricultural commodities. Modeling these groups individually would highlight the income distribution consequences of our policy simulations. It would also allow us to simulate the effects of other policy in interventions that have to do with asset and/or income transfers across these groups.

Though the general model described in this paper is flexible enough to handle a host of specific policy cases, there are also limits to what it can or cannot be made to accomplish. For one, since later models will be built with only agriculture in mind, the resultant interplay between agriculture and nonagriculture sectors can only be exogenously introduced. Specific programs which have important agricultural output and employment effects, such as rural population control and nutrition programs, can likewise be similarly evaluated only. Despite these limitations, however, what can be accomplished are important building blocks for larger and hopefully more useful modelling efforts. In the meantime, a more thorough understanding of Indian agriculture, an ambitious undertaking in itself, is desired.

Computation of Labor and Migration Elasticities

Equation (1.7) actually decomposes the total labor supply elasticity into an elasticity of participation ε_r, an elasticity of effort supply ε_e and an elasticity of population change via migration ε_m.

Most labor supply studies for India do not distinguish between a participation elasticity and an effort elasticity, i.e., we can only get the sum $\varepsilon_\ell = \varepsilon_r + \varepsilon_e$. Moreover, most estimates are for supply elasticities to the labor market, i.e., they are not the total supply elasticity needed. However, Rosenzweig (1980) estimates supply elasticities for males and females from landless households separately, and we will assume that total labor elasticities are the same for landless and landed households. The own landless male elasticity is estimated at -0.16 and not statistically significant. We will therefore take it as zero. Rosenzweig's elasticity for females is 0.67. A low male labor supply elasticity and a fairly high female elasticity are consistent with labor supply studies from the developed world and with Hanson's work from Egypt. It is also likely that supply elasticity for children is even higher than for females, and we will set it at 1.0. We compute the total labor supply elasticity as the share weighted sum of male, female and child labor supply elasticities, with the shares being the proportion of each group in the total labor force.

It is well known that the 1971 Census of India severely underestimates femal labor participation because of a change in definitions from the 1961 Census of India. In the absence of the 1981 Census of India results, we thus use 1961 census report weights. The percentages of males, females and children in the total agricultural labor force were 59.4%, 32.1% and 8.5% respectively. The resulting resident labor supply elasticities is 0.30.

Migration

To compute the migration elasticity ε_m of equation (1.6), we can rewrite its two components as follows:

$$\frac{\partial NRES}{\partial W}\,\frac{W}{NR} = -\frac{\partial R1U1}{\partial W}\,\frac{W}{R1U1}\,\frac{R1U1}{NR} - \frac{\partial R1U2}{\partial W}\,\frac{W}{R1U2}\,\frac{R1U2}{NR} - \frac{\partial R1R2}{\partial W}\,\frac{W}{R1R2}\,\frac{R1R2}{NR}$$

$$\frac{\partial NMIG}{\partial W}\,\frac{W}{NR} = \frac{\partial U1R1}{\partial W}\,\frac{W}{U1R1}\,\frac{U1R1}{NR} + \frac{\partial U2R1}{\partial W}\,\frac{W}{U2R1}\,\frac{U2R1}{NR} + \frac{\partial R2R1}{\partial W}\,\frac{W}{R2R1}\,\frac{R2R1}{NR}$$

where the notations for the righthand terms are explained in the table below. Note that the weights are ratios of the number of migrants in a particular migrant stream to the total rural population NR.

The total labor migration elasticity for the 0 - 1 year stream is .0182992 (using 0 - 1 year weights) and that for the 1 - 4 year stream (using 1 - 4 year weights) is .0865869. The total labor migration elasticity for the 1 - 4 year stream (using 0 - 4 year weights) is .1082813. This latter elasticity is the value of ε_m used in Table 2A of the text, since we are interested in intermediate run migration effects.

Appendix Table 1.1: Migration Elasticities

Elasticity	Migrant Stream	0-1 Year Elasticity	Source	1-4 Year Elasticity	Source
(1) $\frac{\partial R1U1}{\partial W1} \frac{W1}{R1U1}$	Inside rural to inside urban	-4.8	1/	-7.7	1/
(2) $\frac{\partial R1U2}{\partial W1} \frac{W1}{R1U2}$	Inside rural to outside urban	- .846	Table 3.4	-1.35	Table 3.4
(3) $\frac{\partial R1R2}{\partial W1} \frac{W1}{R1R2}$	Inside rural to outside rural	- .19	Table 3.7	0	Table 3.7 2/
(4) $\frac{\partial U1R1}{\partial W1} \frac{W1}{U1R1}$	Inside urban to inside rural	1.71	Table 5.2	1.34	Table 5.1
(5) $\frac{\partial U2R1}{\partial W1} \frac{W1}{U2R1}$	Outside urban to inside rural	.371	Table 4.6	.050	Table 4.5
(6) $\frac{\partial R2R1}{\partial W1} \frac{W1}{R2R1}$	Outside rural to inside rural	.0925	Table 3.7	0	Table 3.7 2/
Not required	Inside rural to inside rural	.63	Table 5.4	.861	Table 5.3

1/ Not estimated by Dhar (1980). The rural to rural migration elasticity within state (0.63) exceeds the one from outside the state (0.0925) by a factor of 6.8. Similarly, the urban to rural migration elasticity from inside the state (1.71) exceeds the one from outside the state by a factor of 4.5. The average of these factors is 5.7 and we apply this factor to the inside rural to outside urban elasticities to obtain the inside rural to inside urban elasticities shown here.

2/ Dhar's estimate is of the wrong sign, but not significant and we set it to zero.

Computation of the Land Rent Equation

In Quizon and Binswanger (1983), the land rent equation was derived differently in terms of revenue and cost shares s_i:

$$s_i = \frac{Y_i P_i}{\sum_{j\varepsilon 0} Y_j P_j} \qquad i\varepsilon 0 \qquad (1)$$

or

$$s_i = \frac{X_i P_i}{C} \qquad i\varepsilon I \qquad (2)$$

where C is total cost, i.e., $C = \sum_{j\varepsilon VI} X_j P_j + SZ$ and VI is the set of variable inputs. Under competition, total revenue is equal to total cost, i.e., $C = \sum_{j\varepsilon 0} Y_j P_j$.

ϕ_i can thus easily be expressed in terms of s_i:

$$\phi_i = \frac{Q_i V_i}{SZ} = \frac{Y_i P_i}{SZ} = \frac{s_i}{s_Z} \qquad i\varepsilon 0 \qquad (3)$$

$$\phi_i = \frac{X_i W_i}{SZ} = -\frac{s_i}{s_Z} \qquad i\varepsilon VI \qquad (4)$$

Equation (1.11) in the text therefore, is actually

$$S' = \sum_{i\varepsilon 0} \frac{s_i}{s_Z} (P'_i + Y'_i) - \sum_{i\varepsilon VI} \frac{s_i}{s_Z} (W'_i + X'_i) - Z^* \qquad (5)$$

Variable Profit Functions and Definitions of Rates and Biases of Technical Change

The traditional concepts of Hicks rate and bias of technical change are based on either production functions or cost functions of single commodities. In this note I will argue that these concepts are not easily applicable when dealing with multi-product and multi-input cases, and propose conceptually different definitions and procedures to measure them.

The concepts of rate and bias of technical change which are most widely used relate to the production of a single output (Table 1). The production function definition results from a technical maximization problem rarely encountered in economics: How to maximize output for a given bundle of inputs. Technical experiments such as agronomic yield trials generate data with which these concepts can be measured: output levels are compared for different techniques but all conventional inputs are the same. If production functions can be fitted to these data, the rate of technical change can be measured by the shift in the production function between different techniques. The Hicksian bias can be measured as the proportional change in the marginal rate of substitution at constant factor inputs or input ratio.

The cost function approach corresponds to the economic problem of minimizing costs for a given level of output and at given input prices. While this is not usually the maximization problem with which firms are confronted in the short run, competition will force firms to the cost minimization point, which is why this problem is so frequently considered. The rate of technical change is the rate of unit cost reduction (at constant factor prices). The Hicks bias measures the difference in the rate at which individual factor inputs are reduced. In the special two factor case this is most easily done by comparing the factor ratio at a constant factor price ratio. In the many factor case the issue is more complicated. If there are n factors one approach is to consider what happens to the n(n-1)/2 factor ratios, i.e. one may look at biases between land and capital, land and labor, land and energy, etc. A somewhat simpler approach is to consider what happens to each factor share while holding all prices constant. This measures the Hicks bias of a factor with respect to all other factors taken together (Binswanger 1974)[1].

When attempting to measure biases with economic data, the fundamental problem is that input prices change. The observed factor demand or factor ratio changes thus reflect both ordinary factor substitution as well as technical change and any measurement approach has to separate these from each other.

Two approaches exist: The constant time trend approach assumes that rates of biases are constant. Factor demand levels (or factor ratios, or factor shares) are regressed on factor prices and time. The time trends or some transformation thereof is then used to measure the biases. The coefficients of the factor prices, on the other hand, are used to measure factor demand elasticities and, via duali relationships, can be transformed into measures of substitution parameters of the production process. The first study using such an approach was by David and Van de Klundert (1965).

On the other hand, the Residual approach assumes that biases are variable. Provided that the substitution parameters of the production process are known (or what amounts to the same thing, that factor demand elasticities are known) one can partition observed time series of factor input changes (or factor ratio/share changes) into a component explained by ordinary substitution responses to observed factor price changes and a residual factor input change caused by technical change. These residuals, or transformations thereof, measure the biases. The first study using such an approach is by Sato (1970).

A somewhat confusing terminology exists in this area. David and Van de Klundert and Sato specified technical change to be factor augmenting, i.e. the underlying production function is written in the form $Y = f(\alpha_1 X_1, \ldots \alpha_n X_n)$ where X_i are the physical input level and α_i are factor specific efficiency parameters. I later showed (a) that rates of factor augmentation cannot be

1 Weaver (1983) has recently criticized the approach, but his statement is incorrect. The share change of factor i attributable to the technical change does measure the Hicks bias of factor i with respect to the aggregate of all other factors.

interpreted as rates of changes in factor quality: a technical change may become available in the form of a higher quality machine (be <u>embodied</u> in it) yet this normally affects all α_i, not just that of machine capital. Furthermore I showed that, with both the constant time trend approach and the residual approach, the factor demand shifts (or the share changes) can be measured directly, i.e. measurement of rates of factor augmentation is an unnecessary step. And because rates of factor augmentation cannot be interpreted as quality changes, these rates have no straightforward interpretation. The shifts in factor demand curves, on the other hand are readily useable concept. For the cost function case I have called the rate of these shifts "Factoral rates of technical change". For a detailed discussion of all these measurement issues see Binswanger and Ruttan, appendix 5-1, chapter 7, and appendix 7-1.

The cost function problem, however, is not the problem usually confronted by a firm. Instead firms try to maximize profits. <u>In the short run</u>, some of the inputs are fixed and the maximization only involves variable input levels and the output levels. This recognition has led to the development of the profit function literature.

In the profit function framework, we now deal with output supply curves and input demand curves for variable factors only. Technical change will usually result in shifts of both the output supply curves and the variable factor demand curves. Output supply curves will usually shift outwards as technical change makes production more profitable (at constant output and factor prices). Input demand curves may shift backwards or outwards, depending on the factor saving characteristics of the technological change and on its impact on output expansion. For simplicity we will call these changes <u>technology shifters</u>. Clearly the technology shifters of the input demand curves are not the same as those which would be observed in the cost function case (the factoral rates of technical change). In particular, no shift would be observable in the demand for the fixed factors.

Since under competition long run outcomes are best characterized by Hicks biases, it is important to be able to relate short run profit function biases to the Hicksian concepts. Quizon and Binswanger show that, in the one output case, one can translate the traditional concepts of technical change and Hicks bias into the technology shifters of the profit function, i.e. we establish a one-to-one correspondence between technology shifters (of the profit function) and factoral rates of technical change of the cost function. We have used these correspondences in theoretical models of the consequences of technical change.

When there are many outputs however, such correspondences can only be established for pseudo-one output cases. Diewert (1976) has already shown that the traditional residual measure of the rate of technical change applies to multi output and multi input cases only if the transformation function is separable between inputs and outputs, i.e. if it can be written as $g(\underline{Y}) = f(\underline{X})$ where $\underline{Y}$ denotes a vector of outputs and $\underline{X}$ a vector of inputs. The separability assumption implies that inputs and outputs can be aggregated for measurement into respective indices. Reallocation among inputs which hold the input index constant will not lead to any changes in outputs, and vice versa. Such a formulation is highly restrictive.

The separability assumption is also required to measure Hicksian concepts of biases. Holding the index of outputs constant, what are the relative shifts in demand curves for each of the inputs? In economic data, the proportions of each output in the output index will usually change. If separability were not assumed, measured shifts in input demand curves would reflect both technical changes and the input consequences of a changing output mix, i.e. they could not be used to measure technical change biases.

In a genuine many factor case it is therefore necessary to abandon the traditional definitions of rate and biases of technical change. Diewert (1976) suggests one method. A simpler alternative is instead to define the rate of technical change as some transformation of the change in variable profits, holding output prices, factor prices and fixed factors constant; and to define output and input specific biases simply as the technology shifters in the variable output supply and the variable input demand functions, or as transformations thereof. This approach will be discussed below.

Profit Function Definition of Rates and Bias

Let the profit function be

$$\Pi^* = f(\underline{V}, \underline{Z}) \qquad (1)$$

where Π^* is maximized variable profit, $\underline{V}$ is the vector of output and variable input prices and Z is a fixed input. If S is the rental rate accruing to fixed factor and Q is the vector of positive outputs and negative input quantities, then

$$\Pi^* = Z \quad S = \underline{V}^T\underline{Q} \qquad (2)$$

where superscript T refers to row vectors. Q are optimal variable output and input levels. Change in profits due to technical change alone (here indexed by τ) is

$$\frac{\partial\Pi^*}{\partial\tau}\bigg|_{V,Z} = \underline{Z} \quad [\frac{\partial S}{\partial\tau}] = \underline{V}^T \ [\frac{\partial Q}{\partial\tau}] \qquad (3)$$

$\frac{\partial Q}{\partial\tau}$ are the partial derivatives of the output supply and factor demand equations with respect to a technology index t. Normalizing by $\Pi^* = Z\ S$ and letting X' denote the rate of change over time of variable X leads to the following expression for the "profit rate of technical change"

$$\frac{\partial S}{\partial\tau}\frac{1}{S}\bigg|_{V,Z} = \frac{\partial\Pi^*}{\partial\tau}\frac{1}{\Pi^*}\bigg|_{V,Z} = \Pi' = \sum_i \frac{V_iQ_i}{\Pi^*}\frac{\partial Q_i}{\partial\tau}\frac{1}{Q_i} = \underline{\phi}^T\underline{E}' \qquad (4)$$

where ϕ_i are the positive shares of outputs and the (negative) shares of variable inputs in variable profits and $E_i' = \frac{\partial Q_i}{\partial\tau}\frac{1}{Q_i}\bigg|_{\underline{V},\underline{Z}}$ are the technology shifters of the output supply and factor demand curves. The profit rate of technical change is thus seen to be the rate of change in the rent of the fixed factor attributable to the technical change.

In the special case of a single output and a single fixed factor it is easy to relate the profit rate of technical change to the usual cost or production function rate of technical change T' as follows.

Let Y stand for the output P for its price and X_i for each of the inputs i = 1, . . .I (including Z) and W_i for their price. Let σ_{ij} stand for the Allen partial elasticities of factor substitution of the production function (i.e. of the per unit output factor demand curves); and let s_k stand for shares in total cost.

$$s_i = \frac{X_i W_i}{\sum_{j \varepsilon I} X_j W_j} = \frac{X_i W_i}{PY} \qquad (5)$$

Because we are assuming total competition, total cost equals total revenue, i.e., $\sum_{j \varepsilon I} X_j W_j = PY$.

From formulas shown in Quizon and Binswanger, the E' can then be expressed as follows:

$$E'_Y = A'_Z - \sigma_{ZZ} T'$$

$$E'_i = T' \left(\sigma_{iZ} - \sigma_{ZZ}\right) + A'_Z - A'_i \qquad (6)$$

$$i = 1, \ldots I - 1$$

where the A' are factoral rates of technical change. Note that they are defined as the negative of the input demand shifts (per unit of output) so that positive A'_i correspond to positive rates of technical change. Further note that

$\sum_{i=1}^{I-1} s_i A_i' + s_Z A_Z' = T'$, i.e. the rate of technical change is equal to the share weighted sum of all factoral rates. Substituting the equations (6) into (4), and using the facts that $\sigma_{iZ} = \sigma_{Zi}$ and that $\sum_{i=1}^{I} s_i \sigma_{Zi} = 0$,

we find

$$\Pi' = \frac{1}{s_Z}[A_Z' - \sum_{i=1}^{I-1} s_i (A_Z' - A_i')]. \tag{7}$$

$B_{Zi}^H = A_Z' - A_i'$ is the Hicks bias of technical change between the fixed input and all the variable inputs. When technical change is neutral, $A_Z' = T'$ and all biases are zero. Therefore

$$\Pi' = T'/s_Z \tag{8}$$

i.e. in the neutral technical change case the profit rate of technical change is equal to the usual rate of technical change divided by the share of profits (rents) in total revenue or costs. Note again that this equivalence is only useful in the one output case or in the multi-output case with separability between inputs and outputs.

Profit function biases between outputs i and j are measured as

$$B_{ij}^P = E_i' - E_j' \gtreqless 0 \quad \begin{cases} i\text{-favoring} \\ \text{neutral} \\ j\text{-favoring} \end{cases} \tag{9}$$

Biases between inputs are measured as

$$B_{ij}^P = E_i' - E_j' \lesseqgtr 0 \quad \begin{cases} i\text{-saving} \\ \text{neutral} \\ j\text{-saving} \end{cases} \tag{10}$$

It makes little sense to measure biases between an input and an output.

Only in the one output case is it possible to relate the profit function biases to Hicks biases among inputs. Hicks biases are defined as

$$B_{ij}^{H} = A_i' - A_j' \gtreqless 0 \quad \begin{cases} i\text{-saving} \\ \text{neutral} \\ j\text{-saving} \end{cases} \qquad (11)$$

where the inequalities are reversed relative to (10) because the A_i' are defined to be positive for reductions in the per unit demands.

In the single output case the biases are related as follows. From Quizon and Binswanger we have for inputs $E_i' = T'(n_{iZ} - n_{ZZ})/S_Z + A_Z' - A_i'$

Thus it can be shown that

$$B_{ij}^{P} = -B_{ij}^{H} + T'(\sigma_{iZ} - \sigma_{jZ}) \qquad (12)$$

The profit function bias is the negative of the Hicks bias plus a multiple of the rate of technical change dependent on the difference in the Allen elasticities of substitution between the variable factors on the one hand and the fixed factor on the other. Thus only if the production process is seperable between the fixed inputs on the one hand and the variable inputs on the other hand do the two biases coincide in absolute magnitude.

In the many output case it may be easier to define a single measure of bias for each output, relative to all other outputs combined. Let

$$s_i = \frac{P_i Y_i}{\sum_{j \varepsilon O} P_j Y_j} \qquad i \varepsilon O \qquad (13)$$

i.e. s_i is now the share of output i in total revenue. The change in the revenue share due to technical change (holding fixed the prices of outputs, of inputs and of the quantity of fixed fixed factor).

$$B_i^P = \frac{\partial \log s_i}{\partial \log \tau} = E_i' - \sum_{j \varepsilon O} s_j E_j' = (1 - s_i)E_i' - \sum_{\substack{j \varepsilon O \\ j \neq i}} s_j E_j' \qquad i \varepsilon O \qquad (14)$$

Thus the output i-bias is the technology shifter of output i (weighted by the share of all other outputs) less the revenue share weighted technology shifts of all other outputs.

In the many input case an analogous definition can be used to measure the rate of changes of the share of input i in <u>total</u> costs (including rents). Under competition total cost is equal to total revenue and we can write

$$B_i^P = \frac{\partial \log s_i}{\partial \log \tau} = \frac{\partial \log}{\partial \log \tau}\left(\frac{Y_i P_i}{C}\right) = \frac{\partial \log}{\partial \log \tau}\left(\frac{Y_i P_i}{\sum_{j=1}^{I-1} Y_j P_j + SZ}\right)$$

$$B_i^P = E_i' - \sum_{j=1}^{I-1} s_j E_j' - s_Z \frac{\partial S}{\partial \tau}\frac{1}{S} \qquad (15a)$$

$$B_i^P = (1 - s_i)E_j' - \sum_{\substack{j=1 \\ j\neq 1}}^{I-1} s_j E_j' - s_Z \Pi' \qquad i\varepsilon I \qquad (15b)$$

According to (15a) the factor-i bias is equal to the technology shifter of factor i (weighted by the share of all other factors in total cost) less the share weighted technology shifters of the other variable inputs, less the rate of change in rents (attributable to technical change) weighted by the share of rents in total costs. Since according to equation (6) the rate of change of rents is equal to the profit rate of technical change, equation (15b) follows immediately.

Measurement of profit function technology shifters

Consider the following system of output supply or factor demand equation in rates of changes

$$\underline{Q}' = \underline{\beta}\ \underline{V}' + \delta \underline{Z}' + \underline{E}' \qquad (16)$$

Where β is the vector of output supply and factor demand elasticities and δ are the elasticities of fixed factors on output supplies and input demands. If one is willing to assume a constant rate of technology shifters, equation (16) can be measured by a regression with time trends.

$$\underline{Q}' = \underline{\beta}\ \underline{V}' + \underline{\delta}\ \underline{Z} + \underline{\bar{E}t} + \underline{U} \qquad (17)$$

where $\bar{E}$ is the vector of constant technology shifters and U is an error term. However if β and δ are known or have perviously been estimated, one can estimate variable rates of biases residually from equation (16). The measurement techniques of profit function biases are therefore entirely analogous to the approaches used with cost functions.

Inferring the technology shifters from experimental data

Consider the case of agriculture, where technical change is often commodity-specific. Let rice have the index 1. A new rice variety may have become available and experiments may have shown that, for a given area of land planted with rice, yields increase by a proportion ϑ_1, holding all other crop-specific inputs constant. If a farmer makes no reallocation of inputs and outputs, but shifts to the new rice variety, his rice supply curve will have shifted by ϑ_1, as an initial shock. However, this is not all. The increased profitability of rice production will lead to an increased rice supply and to changes in input use. The E' must reflect both the initial shock in rice output as well as the changes in output supply and input use which would occur if output prices, variable input prices and the fixed input stayed constant. The farmer's adjustments can be measured as follows: Without loss of generality let rice be the first output and write profits after the technical change as

$$\Pi = (\vartheta_1 Q_1)P_1 + \sum_{i>1} Q_i V_i = Q_1(\vartheta_1 V_1) + \sum_{i>1} Q_i V_i \qquad i\varepsilon O \qquad (18)$$

For farmer behavior a yield increase of ϑ_1 in rice is equivalent to a rice price increase of ϑ_1. He will react to the yield increase in the same way he would to an equivalent price increase. Therefore we can use estimated output supply and factor demand elasticities to compute the E_i'

$$E_i = \beta_{i1}\vartheta_1 \qquad i\neq 1 \qquad (19)$$

$$E_1 = (1 + \beta_{11})\vartheta_1 \qquad (20)$$

where the initial shock on rice outputs is reflected in the factor 1 in equation(20). Suppose now that yield increases of ϑ_i occur in several crops. The corresponding E_i' are the sums of the effects of each of the yield changes, i.e.

$$E_i = (\vartheta_i + \sum_{j \varepsilon O} \beta_{ij}\vartheta_j) \qquad (21)$$

where the index j runs over all outputs. Note that this formula assumes that, within each crop the technical changes are Hicks neutral.

I have not been able to find an equivalent way to deal with commodity specific technical changes which also exhibit input biases. For example, most high yielding varieties tend to be fertilizer-using. The reason why this is not easily dealt with is that the profit function does not contain information on crop specific inputs, i.e. the theory does not provide crop specific technology shifters for inputs. A heuristic way to proceed might be to define the overall technology shifter for a specific input as a weighted sum of crop specific technology shifters with revenue shares s_j as weights:

$$E_i^{\prime} = \sum_{j \varepsilon O} s_j E_j^{\prime} \qquad i \varepsilon I \qquad (22)$$

Suppose it is known that optimal fertilizer levels for a new rice are double those for an old variety. If the share of rice in total revenue were 20%, one would compute a E_i of 0.2. But such an approach is at best a rough approximation.

The Consequences of a crop-specific technical change

A crop specific technical change has three sets of consequences, of which two have been discussed above: First, the adoption of a new seed in crop i leads to an initial shock in output of crop i, given that all input quantities and all other output quantities remain unaltered. Second, an individual farmer confronted with fixed output prices, fixed variable input prices and a given level of fixed inputs will respond to the fact that crop i is now more profitable by reallocating outputs and variable inputs.

The initial shock and the farmer's response are measured in any of three ways; via regression (equation 17), residually (equation 16) or from experimental data (equation 19 and 20).

Third, if all farmers respond in similar ways, market prices of outputs and factors will respond. To measure these market responses a model incorporating both supply and demand of outputs and the variable inputs is required. The profit function represents only one side of each market: Supply for outputs and demand for variable inputs. Quizon and Binswanger's unified approach is such a market model which traces the market responses by feeding the measured technology shifters as "exogenous" variables into the market model.

Table 1: Technical Change Concepts

	Production Function	Cost Function	Profit Function Many Inputs Many Outputs
Economic Problem	Maximization of output	Minimization of cost of all factors	Maximizing profits to variable factors
Fixed Variables	All inputs and input ratios	Output level, input prices	Output prices Variable input prices Fixed input levels
Rate	Increase in output (shift in production function)	Rate of unit cost reduction	Rate of change of variable profits or rents to fixed factors
Bias	<u>Hicks Bias:</u> Change in marginal rates of substitution	<u>Hicks Bias:</u> Change in factor input ratios Relative shifts in factor demands Changes in factor shares	<u>Profit function biases</u> Relative shift in output supplies Relative shift in input demands
Measurement Approaches to Biases	Experimental	Rates of factor augmentation Factoral rates of technical change Rates of factor share changes	Technology shifters

Appendix Table 1: PRODUCER CORE PRICE ELASTICITIES FOR THE SAT[1/]
BEFORE AND AFTER CONVEXITY ADJUSTMENT

	Rice	Wheat	Coarse Cereals	Other Crops	Fertilizer	Labor
			Before Convexity Price Elasticities			
Rice	0.80079	0.00000	-0.25248	-0.40615	-0.04601	-0.18047
Wheat	0.00000	0.55832	-0.66394	-0.15245	-0.23509	0.40469
Coarse Cereals	-0.24396	-0.23175	0.79988	-0.04853	0.24769	-0.40518
Other Crops	-0.21710	-0.02944	-0.02685	0.19218	-0.07169	0.15010
Fertilizer	0.18243	0.33671	-1.01634	0.53173	-0.82787	0.59350
Labor	0.22983	-0.18618	0.53402	-0.35761	0.19064	-0.48606
			After Convexity Price Elasticities			
Rice	0.88513	0.00000	-0.25248	-0.40615	-0.04601	-0.18047
Wheat	-.00000	0.64680	-0.66394	-0.15245	-0.23509	0.40469
Coarse Cereals	-0.24396	-0.23175	0.79988	-0.13126	0.20633	-0.40518
Other Crops	-0.21710	-0.02944	-0.07261	0.27228	-0.07169	0.11906
Fertilizer	0.18243	0.33671	-0.84663	0.53173	-0.82787	0.63133
Labor	0.22983	-0.18618	0.53402	-0.28366	0.20279	-0.49680

1/ Elasticities are computed at base year 1973-74 prices and quantities.

Appendix Table 2: CONSUMER CORE PRICE ELASTICITIES FOR ALL INDIA[1/]
BEFORE AND AFTER CONVEXITY ADJUSTMENT

	Rice	Wheat	Coarse Cereals	Other Crops	Non-Food
			Before Convexity Price Elasticities		
Rice	-0.83323	0.33836	-0.27725	0.53467	0.23807
Wheat	0.80362	-0.67334	-0.08026	0.11292	-0.16232
Coarse Cereals	-1.0398	-0.12674	0.05028	0.85063	0.26625
Other Crops	0.35469	0.03154	0.15046	-0.77257	0.23652
Non-Food	0.21397	-0.06142	0.06380	0.32045	-0.53617
			After Convexity Price Elasticities		
Rice	-0.88563	0.31423	-0.21150	0.53467	0.24886
Wheat	0.74631	-0.72236	0.00493	0.13406	-0.16232
Coarse Cereals	-0.79320	0.00779	-0.34630	0.86610	0.26625
Other Crops	0.35469	0.03744	0.15320	-0.78485	0.24015
Non-Food	0.22366	-0.06142	0.06380	0.32537	-0.55079

1/ Elasticities are computed at base year 1973-74 prices and quantities.

Master List of Symbols for All Theory and Simulation Papers

Variables

$A_i' = \frac{\partial X_i}{\partial \tau} \frac{1}{X_i}$ = Factoral rates of technical change.

Shifts in factor demands per unit of output.

Cost function definition.

$B_{ij}^H = A_i' - A_j'$ = Hicks Bias of technical change

$B_{ij}^P = E_i' - E_j'$ = Profit function biases of technical change

C = Total cost of production, including rents

D* = Final Demand shifters

$E_i' = \frac{\partial Q_i}{\partial \phi} \frac{1}{Q_i}$ = Technology shifters,

Shifts in output supplies and factor demand for given fixed input levels.

Profit function definitions

K = Capital

L = Labor

M = Total nominal income

m = Per capita income, real terms, nominal terms

N = Population with NR = rural population, NU = urban population etc.

M_i = Income from factori

P = Output prices

$\overline{P}$ = Output price indices

$Q = [Y, -X]$: vector of outputs and (negative) variable inputs

R = Capital rental rate

S = Rent to fexed factor, usually land

s_i = Share of output i in total revenue

Share of factor i in total cost C

$T' = \frac{\partial C}{\partial \tau} \frac{1}{C}$ = Rate of technical change

$V = [P, W]$ Vectors of output and variable input prices

W = Wage rate, or vector of variable input prices

X = Variable inputs

Y = Outputs

Z = Quantity of land

Π^* = Variable profits

$\Pi' = \frac{\partial \Pi}{\partial \tau} \frac{1}{\Pi}$ = Profit rate of

Modifiers of variables, unless already defined above

X = level

$\underline{X}$, $\underline{X}^T$ indicates a column and a row vector, respectively of the X variables

$X' = \frac{dX}{dt} \frac{1}{X}$ total rate of change of variable X with respect to time

X^* = exogenous component of the rate of change of an endogenous variable

(except that Π^* stands for maximized variable profits)

τ = technology index

t = time

Indices and Sets of Inputs and Outputs

i = commodities (outputs, inputs)

j = commodities (outputs, inputs)

i and j can vary over different subsets

O = set of outputs number of outputs

I = sets of inputs

VI = set of variable inputs and their total number

r = 1,2 . . . index of regions

k = 1, . . . K income groups and their total number

Parameters

α : Commodity demand elasticities

β : Output supply and factor demand elasticities from the profit function

ε : Factor supply elasticities

η : Factor demand elasticities from the cost function

σ : Elasticity of substitution

Shares and Proportions

Where necessary these shares may also have a region index

δ_{ih} = Share of factor i in the income of income group h

λ_{ih} = Proportion of factor supplied by income group h

Since inputs and outputs are not overlapping we also use

λ_{ih} = Proportion of commodity i consumed by income group k

μ_{ih} = Share of expenditure spent on commodity i by income group k

ν_{ir} = Proportion of commodity i produced by region r

s_i = Share of output i in total revenue (positive) or share of input i in total cost (positive)

ϕ_i = Share of commodity i in total profit (positive for outputs, negative for inputs)

Note that: $\phi_i = \frac{s_i}{s_Z}$ for outputs

$\phi_i = -\frac{s_i}{s_Z}$ for inputs

ν_k = Share of agricultural income received by income group k

Note: We use the term <u>share</u> where value shares are concerned. Where quantities can be used in numerator and denominator, we use the term <u>proportion</u>.

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