ESTIMATION OF FARM SUPPLY RESPONSE AND ACREAGE ALLOCATION: A Case Study of Indian Agriculture

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PREFACE

Understanding the nature and dimension of the food problem and the policies available to alleviate it has been the focal point of the Food and Agriculture Program at the International Institute for Applied Systems Analysis (IIASA) since the program began in 1977.

The national food systems are highly interdependent, and yet the major policy options exist at the national level. To explore these policy options, therefore, it is necessary both to develop policy models for national economies and to link them by trade and by capital transfers. For greater realism, the models in this scheme of analysis are being kept descriptive rather than normative. The final result will link models of 20 countries, which together account for nearly 80 percent of such important agricultural attributes as area, production, population, exports, and imports.

This report presents the results of work on farm supply response in India; it is part of the work devoted to building an agricultural policy model for that country. As understanding farmers' behavior in response to various possible policy instruments is a critical part of much of agricultural policy analysis, this work is a significant element of the IIASA agricultural policy model for India.

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SUMMARY

Some of the most important decisions in agricultural production, such as what crops to grow and on how much land to grow them, must be made without certain knowledge of future rainfall, yields, and prices. In this report we model the land allocation decisions of Indian farmers as a significant first step in developing a model for Indian agricultural policy. The approach that we have adopted is consistent with the premise that farmers behave rationally and react to circumstances in a way that maximizes their utility in the context of opportunities, uncertainties, and risks as perceived by them.

After a brief review of the approaches available for estimating farm supply response, we summarize a few relevant studies, which are constructed largely after the traditional Nerlovian model, based on adaptive expectations and adjustment schemes. Significantly, however, the model seems to involve a serious error of specification with respect to the formulation of the price expectation function. Nerlovian specification does not separate past, actually realized prices into "stationary" (expected) and random components, and it attaches the same weights to the two components for predicting expected prices.

The model described in this report deviates from the traditional Nerlovian model in two principal respects:

- *We estimated acreage response for different crops by using expected revenue instead of expected prices as a proxy for expected profits.*
- *We formulated an appropriate revenue (or price, as the case may be) expectation function for each crop by clearly identifying the "stationary" and random components involved in past values of the variable and by attaching suitable weights to these components for prediction purposes. We postulated an autoregressive integrated moving average (ARIMA) model for this purpose and used Box--Jenkins methodology in estimating these functions.*

In our study we considered nearly all crops grown in India. On the basis of sowing and harvesting periods in different states, we drew up an overall substitution pattern among

crops at the national level. This pattern permitted us to classify the crops into ten groups; the crops in different groups are usually grown in different soils, seasons, or both. The essential data for estimating the acreage response consist of area, production, yield, irrigation, prices, and rainfall.

We then inserted into the Nerlovian model the estimated revenue expectation functions for different crops and estimated the acreage response equations. Later we formulated an area allocation scheme so that the individually estimated areas of different crops would add up to the exogenously specified total gross cropped area in the country. Finally, we subjected all of the estimated equations to a validation exercise to judge the model's performance, particularly its ability to predict turning points.

1 THE PROBLEM AND ITS IMPORTANCE

Any analysis of agricultural policy needs to deal with the problem of affecting the supply of agricultural outputs. For policy purposes, not only the levels, but also the composition, of outputs are relevant. Agricultural supply, however, is the result of the decisions of a large number of farmers. How do farmers decide what and how much to produce? What policy instruments and other factors affect their decisions? We must understand these questions if we hope to devise a successful policy.

An important characteristic of agricultural production is the time lag that it involves: outputs are obtained months after planting operations are begun. After planting has been completed, farmers have comparatively little control over output.

The most important decisions – what crops to grow and on how much land – must be made without certain knowledge of future rainfall or harvest prices. How do farmers form their expectations about these factors? How do their expectations affect their crucial decisions about land allocation?

In this report we investigate these issues in India. Modeling the land allocation decisions of Indian farmers is an important first step in developing a model for Indian agricultural policy. K.S. Parikh (1977) has described the framework of the full model, which is a computable, general equilibrium model.

We start with the premise that farmers behave rationally and that rational farmers should react in a way that maximizes their utility within the context of the opportunities, uncertainties, and risks that they perceive. Our approach is consistent with this premise. We have estimated our model econometrically, using Indian data covering the period from 1950 to 1974. The model states that farmers' desired allocation of their land among competing crops depends on rainfall and on the relative revenue that they expect to derive from different crops. Moreover, various constraints may restrict the rate at which the farmers can adapt to a desired new cropping pattern.

We have used expected revenue rather than expected prices, not only because expected revenue is theoretically more satisfactory (farmers must observe that in good years prices fall), but also because a great deal of uncertainty is associated with yields. Expected revenue is used as a proxy for expected profits because adequate data for crop-specific costs and profits are not available, and for farmers who operate with a fixed amount of total available inputs (an amount that is less than the profit-maximizing input level), maximizing profits and maximizing revenue give nearly the same results.

The model may be used as part of a year-by-year, simulation-type, price-endogenous, computable, general equilibrium model. We have carried out validation exercises to test its performance in simulating the area allocation system developed.

In the next section we discuss certain methodological issues. A review of literature follows in Section 3. In Section 4 we describe our experience with the estimation of the Nerlovian model on acreage responses, the estimation of crop revenue expectation functions based on the Box–Jenkins methodology, and the modified acreage response model. In Section 5 we describe the validation exercises. A discussion of policy implications and conclusions follows in Sections 6 and 7.

2 POSSIBLE APPROACHES TO MODELING SUPPLY RESPONSE

We have followed a two-stage approach to modeling supply response. In the first stage, which is described in this report, farmers allocate their land to different crops. This is followed by a second stage in which, given the areas, yields are determined. The first-stage model is econometric. The second-stage model may be a programming one in which farmers allocate the inputs and factors other than land to different crops in order to maximize profits. Alternately, yields in the second stage may be estimated econometrically as a function of inputs and rainfall.

Why have we followed a two-stage procedure instead of one in which all allocation decisions (of land, as well as of other factors and inputs) are made simultaneously? In a one-stage procedure, two broad approaches are possible. One is to develop a programming model in which area allocation is internal; the other is to have an econometric estimate of the output levels themselves as supply functions.

Each alternative has limitations. A programming approach leads to a corner solution, in which land is allocated to one crop, unless the area allocations are constrained either explicitly or through production functions in which there are diminishing returns to area devoted to one crop. A corner solution may also be avoided by introducing measures of uncertainty regarding the output of various crops. It is sometimes suggested that explicit constraints on areas prescribed exogenously are acceptable or even desirable, particularly when farmers consume a large amount of their output themselves. This argument, however, implicitly assumes either that farmers' allocation decisions are so complex that they cannot be modeled or that farmers have so little choice in allocating land to different crops that the arbitrariness of explicit area constraints is tolerable. These assumptions are questionable and need to be tested empirically, for even farmers growing food largely for self-consumption should not be insensitive to changing prices and profitabilities. In self-consumption, where the farmer essentially sells to and buys from himself, the trade margin on that amount accrues to the farmer himself. Taking this into account, a rational farmer should want to maximize expected profits, including margin on trade for self-consumption. Similarly, the perverse relationship of marketable surplus to prices (marketable surplus going down as prices rise; see Krishnan 1965) can also be consistent with conventional economic theory. As higher prices for his products make him richer, the farmer might want to consume more of his own product. These arguments suggest that one should consider modeling farmers' land allocation decisions before one adopts arbitrary constraints.

An alternative method of avoiding corner solutions in a programming model is to introduce diminishing returns to size of area devoted to a crop. Empirical estimates of such production functions are not easy to make and are not generally available. Moreover, the data required to make such estimates are not plentiful. This is therefore a hard procedure to follow. The difficulty of introducing in a programming model uncertainties regarding various crops is essentially that of identifying separately the variations in yield levels resulting from input levels and weather.

Estimating an econometric output supply function is unsatisfactory for a policy simulation model because only the final outcome of a number of decisions is estimated. The estimation thus provides less flexibility in changing certain parameters in the model. For example, the impact of new high-yield varieties might be hard to assess in such a framework. We have therefore followed a two-stage model.

3 A BRIEF REVIEW OF LITERATURE ON SUPPLY RESPONSE

Most empirical research on estimating farmers' acreage response is based on direct application, minor modification, or extension of the celebrated work of Nerlove (1958). Nerlove distinguishes three types of output changes: "(1) in response to changes in current prices which do not affect the level of expected future prices, (2) in immediate response to a change in the level of expected future prices, and (3) in response to a change in the expected and actual level of prices after sufficient time has elapsed to make full adjustment possible."

Of these, output changes of the first type may be limited for two reasons. First, a sudden change in output based on sudden changes in input–output prices may be difficult to achieve. Second, if the change (increase or decrease) is only a short-term phenomenon, such quick and frequent output changes may be quite costly. Hence we ignore output changes of the first type and are left with the three essential ideas of the Nerlovian model: (1) over time, farmers keep adjusting their output toward a desired (or equilibrium) level of output in the long run, based on expected future prices; (2) current prices affect output only to the extent that they alter expected future prices; and (3) short-term adjustments in output, which are made keeping the long-term desired level of output in mind, may not fully reach the long-term desired level because constraints on the speed of acreage adjustment may exist.

Nerlove's model is as follows:

$$X_t^* = a_0 + a_1 P_t^* + a_2 Z_t + U_t \tag{1}$$

$$P_t^* = \beta P_{t-1} + (1 - \beta) P_{t-1}^* \qquad 0 < \beta \leqslant 1 \tag{2}$$

$$X_t = (1 - \gamma) X_{t-1} + \gamma X_t^* \qquad 0 < \gamma \leqslant 1 \tag{3}$$

where

X_t^* is the long-term desired (equilibrium) acreage of the crop in period t

X_t is the actual acreage

P_t^* is the expected "normal" price

P_t is the actual price

Z_t is any other relevant variable (say, rainfall)

U_t is a random residual

β is the price expectation coefficient

γ is the acreage adjustment coefficient

Given that $0 < \beta \leqslant 1$, eq. (2) implies that the current expected price P_t^* falls somewhere between the previous year's actual price P_{t-1} and the previous year's expected price P_{t-1}^*. That is, the current year's expected price is revised in proportion to the difference between actual and expected prices in the previous year. If $\beta = 0$, the expectation pattern is independent of the actual prices, and only one expected price for all time periods exists. If $\beta = 1$, the current year's expected price is always equal to the previous year's actual price.

The restriction $0 < \beta \leqslant 1$ is an essential one. The value of β indicates the nature of the movement of price expectations over time as actual prices are observed. If $\beta < 0$ or $\beta > 2$, the price expectation pattern represents a movement away from the actual price movement. Moreover, when $\beta > 1$, the weight for P_{t-1}^* becomes negative, which does not seem aesthetically appealing. Some researchers, such as Cummings (1975), have presented empirical results that do not satisfy the condition $0 < \beta \leqslant 1$.

Equation (3) also implies a similar process of acreage adjustment. Farmers adjust their acreage in proportion to the difference between the desired or long-term equilibrium level and the actual acreage level during the previous period. Again, a meaningful interpretation requires that $0 < \gamma \leqslant 1$, for $\gamma < 0$ implies that a farmer allocates less area in time t than that in time $t - 1$, while in fact he desires to have more area (assuming that $X_t^* > X_{t-1}$) and $\gamma > 1$ implies overadjustment.

Equations (1), (2), and (3) contain the long-term equilibrium and expected variables that are not observable. However, for estimation purposes, a reduced form containing only observable variables may be written (after some algebraic manipulation) as follows:

$$X_t = a_0\beta\gamma + a_1\beta\gamma P_{t-1} + (1 - \beta + 1 - \gamma)X_{t-1} - (1 - \beta)(1 - \gamma)X_{t-2}$$

$$+ a_2\gamma Z_t - a_2(1 - \beta)\gamma Z_{t-1} + \gamma[U_t - (1 - \beta)U_{t-1}] \tag{4}$$

Underlying the reduced form (eq. (4)) are the hypotheses and assumptions described above, although it might be possible to arrive at the same reduced form under a different set of hypotheses and assumptions. Unless the structural parameters are identified and found satisfactory, a good fit for the reduced form is hard to interpret.

Fisher and Temin (1970) give an example of a reduced-form equation (notation changed and trend variable t added here) obtainable by different sets of hypotheses:

$$X_t = a_1 + a_2P_{t-1} + a_3t + a_4X_{t-1} + U_t \tag{5}$$

They say that one may arrive at eq. (5) in at least three different ways. First, eq. (5) can be modified and rewritten to express X_t as a function of past prices, which then means that current acreage is related to past observed prices. Second, farmers may conceive of a desired level of acreage – say, X_t^* – knowing P_{t-1}, but may somehow be unable to achieve that level. If

$$X_t^* = a_1^* + a_2^*P_{t-1} + a_3^*t + U_t^*$$

and

$$X_t - X_{t-1} = \mu(X_t^* - X_t) + W_t \qquad 0 < \mu \leqslant 1$$

it is possible to arrive at eq. (5) after substitution. Third, whatever their adjustment ability may be, farmers may make decisions on the basis of the price that they expect from their observations of actual prices. If

$$X_t = a^* + a_2^* P_{t-1}^* + a_3^* t + V_t$$

and

$$P_t^* - P_{t-1}^* = \mu(P_t - P_{t-1}^*) \qquad 0 < \mu \leqslant 1$$

then again from these two relations X_t can be expressed as a function of past prices.

In the previously mentioned cases, these hypotheses lead to reduced forms that are not distinguishable by observation. The Nerlovian case corresponds to a situation where the last two hypotheses were made together.

Equation (4) involves some estimation problems that we should mention briefly here. Suppposing that there is no Z_t variable in eq. (1), the reduced form becomes

$$X_t = a_0\beta\gamma + a_1\beta\gamma P_{t-1} + (1 - \beta + 1 - \gamma)X_{t-1} - (1 - \beta)(1 - \gamma)X_{t-2}$$
$$+ \gamma[U_t - (1 - \beta)U_{t-1}] \qquad (6)$$

Then $\beta\gamma$ (i.e., the product of β and γ), but not β and γ separately, can be obtained from the quadratic equation formed from the coefficients of X_{t-1} and X_{t-2} of eq. (6). Using the estimate of $\beta\gamma$, however, an estimate of a_1 clearly can be obtained. Hence, even though the adjustment and expectation parameters β and γ are not identified separately, the long-term elasticity with respect to expected price may still be known.

This difficulty of parameter identification cannot be overcome, even by introducing another variable Z_t into the system. As can be seen from eq. (4), such an introduction yields separate, but not unique, estimates of β and γ. However, by postulating a suitable expectation pattern, one might be able to solve this difficulty. In the Nerlovian system, farmers have expectations only about the price variable. Actually, farmers might have simultaneous expectations about such other variables as yield or rainfall. Their area allocation decisions would follow from these expectations.

During the last decade and a half, Nerlove's model has inspired a great deal of empirical research (see Askari and Cummings 1976) in a number of countries, including India, with respect to estimating the acreage response of farmers to price movements. A review of relevant literature, including modifications and extensions of the Nerlovian model and occasional comments about the estimation problems involved, follows.

R. Krishna (1963) made one of the earliest attempts to apply a Nerlovian approach to Indian data. His model, simply an area adjustment supply model, includes irrigation, rainfall, relative price, and yield variables. He does not distinguish between actual and expected prices, which implies that farmers have full knowledge of what prices are going to be.†

† Behrman (1968) gives a critical analysis of this model.

Narain's study (1965) on the impact of price movements on areas under selected Indian crops is not based on a Nerlovian approach but on graphical analysis. As it is not based on econometric analysis, the usual estimation problems disappear in Narain's work, but comparison of his approach and results with those of other researchers is difficult.†

Cummings (1975) writes the reduced form (eq. (4)) in the following way:

$$A_t - (1-\beta)A_{t-1} = a_0\beta\gamma + a_1\beta\gamma P_{t-1} + (1-\gamma)[A_{t-1} - (1-\beta)A_{t-2}]$$
$$+ a_2\gamma[Z_t - (1-\beta)Z_{t-1}] + \gamma[U_t - (1-\beta)U_{t-1}] \tag{7}$$

He estimates eq. (7) for a range of specified values of β and selects that value of β "for which the regression error sum of squares is minimized." Two points should be noted. First, according to Cummings, the price expectation coefficient "can be reasonably assumed to fall within the range of zero to two." No justification is provided for assuming β to be greater than one. Second, to take care of autocorrelation, Cummings employs the Cochrane–Orcutt technique, which uses a first-order autocorrelation scheme on the disturbance terms.

If eq. (7) is estimated, it means that the following is assumed to be true:

$$U_t - (1-\beta)U_{t-1} = \rho[U_{t-1} - (1-\beta)U_{t-2}] + V_t \tag{8}$$

With the usual assumptions for V_t and ρ, eq. (8) implies a second-order scheme of auto-disturbance for U_t, which is the basic disturbance term in eq. (1). Cummings explains neither the second-order autocorrelation scheme of U_t nor the first-order one shown in eq. (8).

Madhavan (1972) pays explicit attention to deriving eq. (1), the first equation of the Nerlovian scheme. He formulates a Lagrangian to maximize farmers' net income:

$$J = \sum_i P_i Y_i - \mu H(Y_1, \ldots, Y_m)$$

where Y_i is the production function for the ith crop and H is the same for the farm as a whole. Setting the partial derivatives to be zero and imposing the marginality conditions

$$\frac{(\partial Y_i/\partial X_i^*)}{(\partial Y_j/\partial X_j^*)} = \frac{P_j^*}{P_i^*} \tag{9}$$

he derives

$$\log X_i^* = a_0 + a_1 \log(P_j^*/P_i^*) + a_2 \log Y_i^* + a_3 \log Y_j^* + a_4 \log X_j^* + U_i \tag{10}$$

where X_i^* is the desired acreage of the ith crop, X_j^* is the desired acreage of the jth crop, and P^* and Y^* are the expected levels of prices and yields. This formulation is interesting because it is a consequence of the maximization procedure. Madhavan also introduces

† Lipton (1966) makes further comments on this study.

competing crops and relative yields. With respect to expectations, however, he assumes current expectations to be the previous year's actual values.

The next step in this field of research was to incorporate the elements of risk and uncertainty. In a case study of four major annual crops in Thailand from 1937 to 1963, Behrman (1968) attempts to capture the influences of variability of prices and yields on supply response functions. Along with such variables as population and the death rate from malaria, he introduces the standard deviations of price and yield in the three previous periods to give an idea of farmers' reactions to risks. However, Nowshirvani (1971) points out that Behrman's analysis was an empirical exercise without an explicit theoretical model. He also contends that Behrman's procedure is somewhat unsatisfactory because "the Nerlovian price expectation model is inconsistent with a changing variance of the subjective probability distribution of prices."

Nowshirvani develops a theoretical model for farmers' decisions on land allocation that accounts for uncertainties in prices and yields. Farmers' decisions follow from maximization of expected utility. Under a set of specific assumptions about farmers' utility functions, Nowshirvani shows that incorporating risk in the analysis of agricultural supply may show a negative area–price response. The natural variability of land also affects the magnitude of this response. As he says, "if the diversification of cropping is not dictated by the physical conditions of production but rather by the desire to reduce risk, stabilization schemes may sometimes be more effective policy instruments than price in bringing about area shifts among crops." He also observes that when prices and yields are negatively correlated, price stabilization leads to income destabilization, which could also lead to reducing the area devoted to the crop under consideration.

Nowshirvani does not distinguish between the prices received by farmers and prices paid for the same product. However, many of his conclusions would be strengthened by making this differentiation.

Two issues often raised are:

- Which is the relevant variable for characterizing farm supply response – acreage or farm output?
- Which price should be used – average, pre-sowing, post-harvest, modal, or another?

Several authors, including Nerlove, R. Krishna, and Narain, used acreage. Different prices have, however, been used in various studies. For example, Nerlove used an average price, while R. Krishna used post-harvest prices. Rao and J. Krishna, who examined this issue in two studies (1965, 1967), attempted to determine the impact of different prices on acreage estimations; they used a total of 21 different combinations or sets of prices in their work. It is thus difficult to conclude that any particular set of prices best explains supply response.

Whatever prices one might use, A. Parikh (1972) questions the validity of the common assumption that farmers react primarily to prices. In a static framework, he argues, prices can be the major determinant of land allocation. In a dynamic setup, however, there are often other factors, such as technological changes, that might equally influence allocation decisions. In time-series analyses, this becomes even more important. Further, when one is dealing with individual crops rather than with aggregate agricultural production, relative profitability determines the extent to which one crop is substituted for another.

A. Parikh uses relative price as well as yield expectations (though not a combined relative revenue expectation) and, in an essentially Nerlovian model, estimates Indian farmers' market responsiveness for commercial crops from data covering the period from 1900 to 1939.

4 ESTIMATIONS

Two points should be noted with respect to estimation. First, while a large number of the studies discussed in Section 3 are based on time-series data, several do not specify whether they allowed for autocorrelation. The exact form of autocorrelation in the ultimate reduced form depends on the assumptions made about the nature of the disturbance terms involved in the original model; sometimes, applying the Cochrane–Orcutt technique may not be sufficient.

Second, some studies accepted the naive expectation model as far as the price expectation functions are concerned, i.e., $P_t^* = P_{t-1}$. This is probably because of the problem of parameter identification. In some studies, P_t^* is written as a distributed lag of past prices, assuming that the lag is known.

We believe that prices cannot adequately explain acreage response and that, for most crops, revenue relative to that of competing crops is a more appropriate variable. After summarizing our experience with the traditional Nerlovian model, we separately estimate the revenue expectation functions for each crop. As we have time-series data, we employ the Box–Jenkins method to estimate these revenue expectation functions. We then use these crop revenue expectation functions in estimating the Nerlovian equations required.

4.1 Indian Crops

Rice, the most widely grown crop in India, accounted for roughly 23 percent of the total gross cropped area in the country in 1974. Wheat has gradually evolved to be the second most important crop, closely followed by jowar and then by bajra. Wheat's total gross cropped area is around 50 percent of that of rice. Other important crops are maize, gram, barley, and ragi among the food grains, and groundnut, rapeseed and mustard, sesamum, and cotton among the nonfood crops. Sugarcane accounted for 1.6 percent of the total area in 1974.

Appendix A provides data on the substitutable crops for most Indian states. Appendix B provides data on the sowing, harvesting, and peak marketing seasons of principal crops in India. (See Government of India 1967.) The inter-crop substitution pattern generally varies from state to state owing to differences in the soils and, at least to some extent, in the customs and habits of the inhabitants in different states. These factors are implicit in the sowing and harvesting periods for different crops, shown in Appendix B. To arrive at a substitution pattern for crops at the national level, the following considerations were taken into account:

- Principal and competing crops in each state
- Relative importance of each crop at the national level
- Relative importance of each state with regard to the crop at the national level
- Sowing and harvesting periods for different crops

Based on these considerations, we formulated the following overall substitution pattern of crops at the national level:

- Rice, ragi, jute, mesta, and sugarcane
- Wheat, gram, barley, and sugarcane
- Jowar, bajra, maize, cotton, oilseeds, and sugarcane
- Groundnut, rapeseed and mustard, sesamum, and other oilseeds
- Fruits, vegetables, condiments, and spices
- Rubber
- Coffee
- Tea
- Tobacco

We then classified the crops into the groups shown in Table 1.

Five points should be noted. First, crops in different groups are usually grown in different soils, seasons, or both. Sugarcane is an exception: it grows in more than one season, and when it is ratooned – that is, when the sugarcane is not planted but is allowed to grow from the stem left in the ground after the first harvest – the crop can cover more than one year.

Second, Appendix A shows that sugarcane (group 9 of Table 1) competes with most of the crops in groups 1, 2, and 3 of Table 1. However, sugarcane may not be the principal competing crop for some of these crops, and we have computed relative revenue for each crop only with respect to its two most important competing crops. Nevertheless, we did investigate the effect of increasing the irrigation facilities for sugarcane (which might increase the yield, and hence the revenue) on the acreage response of each crop in groups 1, 2, and 3.

Third, the oilseeds (group 4) compete with the crops in group 3, but group 4's total area is much smaller than that of group 3. The competition in the reverse direction may thus not be great.

Fourth, except for those mentioned in the two preceding paragraphs, no inter-group substitution possibilities are assumed to be possible at the national level.

Fifth, the residual components in the first four groups contain small millets and pulses. These do not compete to a great extent with the other crops in the respective groups.

4.2 Our Experience with the Nerlovian Model

We began our estimation exercises by applying the Nerlovian model as such. The set of variables in our analysis is as follows:

A_{igt}, P_{igt}, Y_{igt}, R_{igt} are the area, wholesale price index, yield per hectare, and rainfall index, respectively, of the ith crop in group g in period t

t refers to the time period

* refers to the desired or expected values

$\Pi_{igt} = P_{igt}\, Y_{igt}$ is the revenue of the ith crop in group g

Π_{k1gt} and Π_{k2gt} are the revenues of competing crops $k1$ and $k2$

TABLE 1 Crops and groups in the system.

	Group (g)									
Crop (i)	1	2	3	4	5	6	7	8	9	10
1	Rice	Wheat	Maize	Groundnut	Fruits and vegetables	Rubber	Coffee	Tea	Sugarcane	Tobacco
2	Ragi	Gram	Bajra	Sesamum	Condiments and spices					
3	Jute	Barley	Jowar	Rapeseed and mustard						
4	Mesta		Cotton							
Q_g	Residual	Residual	Residual	Residual						
Group total[a]	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}

[a]Sum of area in all groups = total gross cropped area = $A_G = \sum_i A_{ig} + Q_g$.

I_{gt} is the total irrigated area of all crops in group g

I_{Gt} is the total irrigated area in the country

I_{st} is the irrigated area of sugarcane

For the first attempt we used the following equations for the model:

$$A^*_{igt} = a_0 + a_1 \Pi^*_{igt} + a_2 R_{igt} + a_3 \Pi^*_{k1gt} + a_4 \Pi^*_{k2gt} + U_t \tag{11}$$

$$\Pi^*_{igt} - \Pi^*_{ig(t-1)} = \beta(\Pi_{igt-1} - \Pi^*_{igt-1}) \tag{12}$$

$$\Pi^*_{k1gt} - \Pi^*_{k1g(t-1)} = \beta(\Pi_{k1gt-1} - \Pi^*_{k1gt-1}) \tag{13}$$

$$\Pi^*_{k2gt} - \Pi^*_{k2gt-1} = \beta(\Pi_{k2gt-1} - \Pi^*_{k2gt-1}) \tag{14}$$

$$A_{igt} - A_{igt-1} = \gamma(A^*_{igt} - A_{igt-1}) - U_t \tag{15}$$

where $U_t = \rho U_{t-1} + \epsilon_t$ and $0 < |\rho| < 1$.

These give a reduced form

$$\begin{aligned} A_{igt} - (1-\beta)A_{igt-1} &= a_0\beta\gamma + a_1\beta\gamma\Pi_{igt-1} + (1-\gamma)[A_{igt-1} - A_{igt-2}(1-\beta)] \\ &\quad + a_2\gamma[R_{igt} - (1-\beta)R_{igt-1}] + a_3\beta\gamma(\Pi_{k1gt-1}) + a_4\beta\gamma(\Pi_{k2gt-1}) \\ &\quad - [(U_t - \rho\gamma U_{t-1}) - (1-\beta)(U_{t-1} - \rho\gamma U_{t-2})] \end{aligned} \tag{16}$$

We first assumed the price expectation coefficient to be the same for principal and competing crops. We also specified the disturbance term, which serves primarily to facilitate application of readily available techniques to account for autocorrelation. The assumption of the same price expectation coefficient for all competing crops implies that the equations for these crops should be estimated simultaneously, which was our original intention. We did make a separate estimate for each crop to observe the model's behavior, but we encountered difficulties. We estimated eq. (16), the reduced form of eqs. (11) through (15), for a range of specified values of β. We scanned the range $0 < \beta \leqslant 1$ and observed the highest $\bar{R}^2$.

We were somewhat disappointed by the results. We observed that the highest $\bar{R}^2$ was associated with $\beta = 1$ for almost all crops. The values of $\bar{R}^2$ were of course highly attractive in most cases. One could perhaps have accepted such estimates, if β were to be equal to 1.0, in some of the crops, but not in all; our estimates would then become questionable in spite of the high $\bar{R}^2$. This result does not seem to be a quirk of the estimating procedure (such as may result from the likelihood function being monotonic with respect to β) because the estimates obtained in a similar way by Cummings (1975) do not show the same rigid pattern of β always taking a corner value of the possible range.†

†When, to further explore this problem, we extended the range of β to 2.0, we obtained interior estimates of β for a number of crops.

Accepting these estimates would have meant that farmers in India have only naive expectations. However, we did not believe that this could be the case with all farmers. We could not overcome this difficulty, however, even by alternative specifications involving prices, trend variables, and logarithmic values of the variables.

Referring again to the Nerlovian price expectation formulation, we have

$$P_t^* = \beta P_{t-1} + (1 - \beta)P_{t-1}^* \qquad 0 < \beta \leqslant 1 \tag{17}$$

This is a first-order difference equation. The solution of this equation is

$$P_t^* = H(1 - \beta)^t + \sum_{\lambda=0}^{t} \beta(1 - \beta)^{t-\lambda} P_{\lambda-1} \tag{18}$$

where H is a constant. Under certain assumptions made on initial conditions and other factors, this can be rewritten as

$$P_t^* = \sum_{\lambda=0}^{t} \beta(1 - \beta)^{t-\lambda} P_{\lambda-1} \tag{19}$$

That is, the expected "normal" price is a weighted average of past prices. Supposing that the relation between actual and expected prices at period t is $P_t = P_t^* + W_t$, where W_t comprises all random shocks and disturbances,

$$P_t^* = \sum_{\lambda=0}^{t} \beta(1 - \beta)^{t-\lambda}(P_{\lambda-1}^* + W_{\lambda-1}) \tag{20}$$

implies that the weights attached to the expected price value and the random disturbances are the same in each period. This obviously cannot be the case for a meaningful notion of an expectation function.

We clearly needed to formulate the revenue expectation equation differently. The presence of a secular trend in the revenues could lead to a result where β would exceed 1. If expectations reflect secular trends in relative revenues, it seems reasonable to assume that farmers observe the levels of prices and revenues over time and are also aware of any random shocks (which may be of a short-term nature) to which the variables have been subjected. The future expected price or revenue should adequately account for this process of movement and occasional random shocks.

An ARIMA model seemed to be more satisfactory:

$$\begin{aligned} P_t^* = P_t - W_t = \phi_1 P_{t-1} + \phi_2 P_{t-2} + \phi_3 P_{t-3} + \cdots + \mu + \theta_1 W_{t-1} \\ + \theta_2 W_{t-2} + \theta_3 W_{t-3} + \cdots + \end{aligned} \tag{21}$$

where P_t^* is the expected price, P_t is the actual price, W_t is the difference between them, and μ is a constant. If we compare eqs. (17) and (21) by expanding eq. (18) as

$$P_t^* = H(1 - \beta)^t + \beta P_{t-1} + \beta(1 - \beta)P_{t-2} + \beta(1 - \beta)^2 P_{t-3} + \cdots + \tag{22}$$

we see that the Nerlovian formulation of the expectation equation is simply a special case of eq. (21) where the values of θ_1, θ_2, and so forth are all set to zero ($\theta_1 = \theta_2 = \cdots = 0$) and the other parameters are restricted to follow a geometric series. While eq. (21) implies that farmers, in formulating expectations for the future, take into account not only past realized prices but also the extent to which their expectations are off the mark, eq. (17) implies that they ignore past differences between their expectations and realizations.

4.3 Estimating Crop Revenue Expectation Functions

In this section we present the estimates of revenue expectation functions based on the Box–Jenkins methodology (see Box and Jenkins 1970). A time series constituting a discrete linear stochastic process of $\{X_t\}$ can be written as

$$X_t = \mu + \psi_0 \epsilon_t + \psi_1 \epsilon_{t-1} + \psi_2 \epsilon_{t-2} + \cdots + \tag{23}$$

where ψ_js are the weights attached to random disturbances of different time periods. μ is a constant that determines the level of the time-series process. If a given time series is stationary, it fluctuates randomly about a constant mean; this means that the stochastic process remains invariant over time. If the time series is not stationary, it does not have a natural mean. If eq. (23) is a convergent sequence, the process is said to be stationary; if it is divergent, it is said to be nonstationary. Some nonstationary time series can be reduced to stationary series (which are then called "homogenously nonstationary," before reduction) by applying an appropriate degree of differencing d to the original series.

∇, the differencing operator, and B, the backward shift operator, are defined as follows:

$$\nabla^d X_t = (1 - B)^d X_t$$

where

$$B^n X_t = X_{t-n}$$

Then a stationary series $\{Y_t\} = \{\nabla^d X_t\}$ can be obtained from a nonstationary series $\{X_t\}$. A "parsimonious" approach toward estimation requires rewriting the sequence (eq. (23)) as an equation containing on the right-hand side only a finite number of lagged dependent variables p and moving average variables q. Box and Jenkins developed a satisfactory econometric methodology to estimate a model to forecast the value of a variable by being able to identify the stationary and random components of each of its past values. Generally, a Box–Jenkins autoregressive integrated moving average (ARIMA) process can be written for a time series $\{\Pi_t\}$ as

$$\Pi_t = \phi_1 \Pi_{t-2} + \phi_2 \Pi_{t-2} + \phi_3 \Pi_{t-3} + \cdots + \mu + \theta_1 w_{t-1} + \theta_2 w_{t-2}$$
$$+ \theta_3 w_{t-3} + \cdots + \tag{24}$$

where w_t is the white noise or random disturbance in period t. Equation (24) is the ultimate equation to be estimated, in which the number of parameters depends on the values of p, q, and the degree of differencing d. Henceforth in this report, we indicate the ARIMA schemes that we estimate by p, q, and d, in that order. For each crop we applied the following ARIMA schemes (using an International Mathematical and Statistical Library (IMSL) computer programming package) to estimate $\Pi_{igt}(=P_{igt}Y_{igt})$ as a function of past revenues and white-noise (random disturbance) values in the form of eq. (24):

(p,q,d): (1,1,0). (1,2,0), (2,1,0), (1,1,1), (1,2,1), (2,1,1)

We selected the best of these six schemes by first, checking the stationary conditions of the estimated series, implying certain restrictions that the estimated parameter values must satisfy (parameter values can be expressed in terms of the autocorrelation function) and second, making a χ^2 test on the residual autocorrelations.

Table 2 shows the selected schemes, the results of the estimates, and the χ^2 values based on the residual autocorrelations. The numbers representing the ARIMA scheme are written in the order p, q, d, where p is the number of autoregressives, q is the number of moving averages, and d is the degree of differencing applied to make the original "homogenously nonstationary" series stationary.

Each of these estimated equations shows a stationary process of a variable for sequential values over time. The estimations provide the appropriate weights to be given for past values of the stationary and random components of a variable. Dropping the subscripts for crops, we write the farmers' expected normal revenue as

$$\Pi_t^* = \Pi_t - w_t = \phi_1 \Pi_{t-1} + \phi_2 \Pi_{t-2} + \phi_3 \Pi_{t-3} + \cdots + \mu + \theta_1 w_{t-1} + \theta_2 w_{t-2} + \theta_3 w_{t-3} + \cdots + \tag{25}$$

In the next section the estimated values of Π_t^* from eq. (25), subsequently referred to as $\hat{\Pi}_t$, are used in reestimating the Nerlovian model.

4.4 Estimating the Acreage Response Model

While reestimating the model, we made additional modifications to the equations presented in Section 4.2.

First, instead of treating the revenues of the principal and competing crops as separate variables, we introduced only one variable Z_{igt}, defined as follows:

$$Z_{igt} = \hat{\Pi}_{igt} / (\hat{\Pi}_{k1gt} \hat{\Pi}_{k2gt})^{1/2} \tag{26}$$

or

$$Z_{igt} = \hat{\Pi}_{igt} / \frac{1}{2} (\hat{\Pi}_{k1gt} + \hat{\Pi}_{k2gt})$$

where

$$\Pi_{igt} = P_{igt} Y_{igt}$$

TABLE 2 Box–Jenkins ARIMA process schemes and results of expectation function estimations.

Variable (π_t)	ARIMA scheme	ϕ_1	ϕ_2	ϕ_3	μ	θ_1	θ_2	ω_{1972}	ω_{1973}	ω_{1974}	χ^{2a}
Bajra price	110	0.9364			8.0810	0.7367		31.65	49.58	13.00	6.99
Bajra yield	120	0.8473			0.0547	−0.1092	−0.5128	0.452	0.332	0.540	8.21
Barley revenue	121	1.2735	−0.2735			−0.9288	1.4495	16.604	74.763	0.00	4.31
Sugarcane revenue	111	0.4641	0.5359			0.8154		284.605	−14.462	0.00	7.45
Cotton revenue	121	0.5718	0.4282			−0.4374	0.7503	−4.444	18.277	0.00	6.29
Groundnut revenue	211	0.0613	−0.0497	0.9884		0.2528		−14.014	153.892	0.00	3.77
Gram revenue	121	0.7787	0.2213			−0.2960	0.6019	71.154	−5.263	0.00	6.39
Jute revenue	121	0.6927	0.3074			0.1676	−0.3014	13.143	−68.96	0.00	5.98
Jowar revenue	121	1.6994	−0.6994			−0.3521	0.7676	36.258	44.130	0.00	5.76
Mesta revenue	120	0.8447			65.7772	−0.2742	−0.0349	89.186	10.514	105.782	9.30
Maize revenue	111	0.6019	0.3981			0.2145		61.995	123.436	0.00	5.77
Maize price	121	1.7914	−0.7914			−0.3660	0.6225	49.023	65.896	0.00	5.71
Maize yield	120	0.9719			0.0264	−0.9729	1.2282	−0.018	−0.048	−0.041	8.97
Rice revenue	111	0.8705	0.1296			0.9236		65.422	9.374	0.00	7.87
Ragi revenue	111	0.4856	0.5144			1.4122		55.297	36.927	0.00	5.02
Rapeseed and mustard revenue	211	0.0069	0.2066	0.7866		0.4297		27.818	39.435	0.00	9.12
Sesamum revenue	211	0.5887	−0.4238	0.8351		0.4254		6.685	17.001	0.00	6.67
Tobacco revenue	121	0.2405	0.7595			1.2292	0.9618	8.465	32.876	0.00	5.72
Wheat revenue	211	0.2497	0.4024	0.3480		0.7508		8.749	234.803	0.00	3.06

NOTES: $\pi_t = \phi_1\pi_{t-1} + \phi_2\pi_{t-2} + \phi_3\pi_{t-3} + \mu + \theta_1\omega_{t-1} + \theta_2\omega_{t-2} + \omega_t$.
μ = a constant equal to the mean of the series if $d = 0$.
ω_t = white noise in time t.
Degrees of freedom = number of observations (21) − number of parameters.
[a]Based on the residual autocorrelations.

Z_{igt} gives the revenue of crop i relative to competing crops $k1$ and $k2$ computed on the basis of either geometric or arithmetic average, and ($\hat{}$) denotes the estimated value obtained from the Box–Jenkins exercise.

Second, we introduced three irrigation variables: I_{Gt}, to catch the impact of further irrigation in the country; I_{gt}/I_{Gt}, to capture the effect of the share of the gth group of crops in the total irrigated area; and I_{st}/I_{Gt}, to account for the irrigated area devoted to sugarcane and thus not available for the crop being considered.

Third, we constructed the rainfall index for the crop by taking a weighted average of monthly rainfall in different states for the months critical to a crop. We used the production levels of the crops in various states as weights (see Ray 1977).

Fourth, we specified the model in a multiplicative way as follows:

$$A^*_{igt} = a_0 (Z^*_{igt})^{a_1} (R_{igt})^{a_2} (I_{gt}/I_{Gt})^{a_3} (I_{st}/I_{Gt})^{a_4} (I_{Gt})^{a_5} V_t \tag{27}$$

$$Z^*_{igt} = Z_{igt} \tag{28}$$

which is defined in eq. (26) as

$$A_{igt} = (A^*_{igt})^{\gamma} (A_{igt-1})^{1-\gamma} \tag{29}$$

Substitution after taking logarithms yields the following reduced form equation:

$$\log A_{igt} = a_0\gamma + (1-\gamma)\log A_{igt-1} + a_1\gamma \log Z_{igt} + a_2\gamma \log R_{igt}$$

$$+ a_3\gamma \log (I_{gt}/I_{Gt}) + a_4\gamma \log (I_{st}/I_{Gt}) + a_5\gamma \log (I_{Gt}) + \gamma \log V_t \tag{30}$$

where $U_t = \log V_t$ is normally distributed as $N(0,\sigma^2)$.

In estimating eq. (30), several essential points should be kept in mind (see Johnston 1972).

First, as the data used represent a time series, autocorrelation is possible. In such a case, applying the ordinary least-squares (OLS) estimator would give unbiased estimates, but the sampling variances might be underestimated.

Second, the presence of the lagged dependent variable on the right-hand side (in the absence of autocorrelation) leads to estimates that are consistent but that can be biased in small samples. However, if OLS is applied in the presence of autocorrelation, the combination does not even yield consistent estimates.

Third, if the disturbance term and the dependent variable in eq. (30) are correlated, the disturbance term is also correlated with at least one explanatory variable, especially under autocorrelation (which, again, gives biased estimates in small samples).

Fourth, under such circumstances we cannot rely on the conventional Durbin–Watson test for autocorrelation. Though the presence on the right-hand side of three or four exogenous variables (such as rainfall, relative revenue, or irrigation) other than the lagged dependent variable helps to reduce the asymptotic biases of the estimates in such cases (see Malinvaud 1970), we decided to allow for autocorrelation, and we assumed a first-order autocorrelation scheme. We initially used the Cochrane–Orcutt technique in estimation.

However, we suspected that, at least in some cases, this technique might yield only a local optimum; this had been our experience in several other exercises. Hence we preferred a scanning technique to the Cochrane–Orcutt technique for estimating the autocorrelation parameter ρ in $U_t = \rho U_{t-1} + \epsilon_t$. We estimated eq. (30) for 40 values of ρ for each crop, over a range of $-1.00 \leqslant \rho \leqslant 1.0$ with a step size of 0.05, and observed the highest $\overline{R}^2$. Interestingly, however, for many crops the estimate of ρ turned out to be zero, implying that U_t and U_{t-1} are not correlated. In this case the previously mentioned problem of correlation between the disturbance term and an explanatory variable might not exist because the estimated revenue term, rather than the actual revenue term, might be one of the explanatory variables on the right-hand side.

We took most of our data from *Estimates of Area and Production of Principal Crops in India* (Government of India 1970–1976). These volumes, published yearly, cover data on area, production, yield, and irrigation area. We collected price data from the Office of the Economic Adviser, Ministry of Industrial Development and obtained rainfall data corresponding to each crop from Ray (1977). All these data cover the period from 1953 to 1974; there are thus 21 observations on each variable.

We estimated eq. (30) for some selected crops in the groups, using Norman (1977) for estimation purposes. We obtained acceptable results for rice, wheat, groundnut, sugarcane, and tobacco initially. We adopted three criteria for acceptability of results:

1. Proper signs of the various estimates
2. Levels of significance for the computed "*t* coefficients"
3. A high $\overline{R}^2$

For ragi, jute, mesta, gram, barley, and sesamum, the results were considered acceptable only for the areas of these crops relative to the areas of some other crops in the group. Thus we estimated the areas under ragi/rice, jute/ragi, mesta/ragi, gram/wheat, barley/wheat, sesamum/groundnut, and rapeseed and mustard/sesamum instead of the areas under ragi, jute, mesta, gram, barley, sesamum, and rapeseed and mustard. In these cases, A_{igt} in eq. (30) represents such relative areas (i.e., A_{igt} is replaced by A_{igt}/A_{jgt}, meaning the area of the *i*th crop relative to that of the *j*th crop in group *g*).

Tables 3a–c show the results of area estimation. For all the above-mentioned crops (i.e., jowar, bajra, maize, and cotton excepted), the coefficients of the revenue terms are positive. These are significant at the 5 percent level for jute, mesta, wheat, barley, rapeseed and mustard, sugarcane, and tobacco. This significance varies between 10 and 20 percent for rice, ragi, cotton, and sesamum. However, these coefficients for gram and groundnut were not significant, even at the 20 percent level. That groundnut acreage response to revenue was insignificant is somewhat perplexing, especially because it is a commercial crop.

The coefficients of the A_{igt-1} term, i.e., $1 - \gamma$ where γ is the adjustment parameter, can be explained as follows:

1. If $1 - \gamma$ is significantly different from zero, then γ is significantly different from one
2. If $1 - \gamma$ is not significantly different from zero, then γ is not significantly different from one

TABLE 3a Results of area estimation.

Serial number	Crop	Group	A_{igt-1}	Rainfall	Revnrtag	Revnrate	IASO / IARGROSS	$\overline{\text{IACN}}$ / IARGROSS	IARGROSS	Constant	Degrees of freedom	$\bar{R}^2$ / DW	RHO	Competing crops
1	Rice	1	0.9854 (88.89)	0.0708 (3.27)	0.0305 (1.64)		0.0592 (1.76)			−0.000002 (−1.68)	15	95.81 (1.82)	(−0.4)	Ragi Sugarcane
2	Rice	1	0.9823 (77.87)	0.0652 (2.67)	0.0314 (1.57)		0.0685 (1.79)	−0.0236 (−0.75)		−0.000003 (−1.73)	14	95.14 (1.73)	(−0.4)	Ragi Sugarcane
3	Ragi/rice	1	0.1078 (0.42)	0.1348 (0.79)	0.1167 (1.32)		0.2421 (1.05)		−0.2464 (−2.11)	−0.000003 (−0.19)	14	49.00 (2.09)	(−0.15)	Rice Jute
4	Jute/ragi	1	0.3634 (2.08)	0.1717 (1.44)		0.5694 (3.32)	1.5201 (1.60)	−0.3301 (−1.20)	0.9331 (2.18)	−11.8880 (−2.86)	13	57.21 (2.27)	(0.00)	Rice Ragi
5	Jute/ragi	1	0.3636 (2.04)	0.1880 (1.55)	0.5573 (3.20)		1.5485 (1.60)	−0.3287 (−1.17)	0.9489 (2.18)	−11.68 (−2.75)	13	55.78 (2.34)	(0.00)	Rice Ragi
6	Mesta/ragi	1	0.3091 (1.42)	0.0397 (0.27)		0.0874 (2.44)	2.180 (1.76)		1.6926 (2.72)	−17.7745 (−3.06)	14	59.16 (2.33)	(0.00)	Rice Ragi
7	Wheat	2	0.2599 (2.20)	0.0984 (5.77)	0.0678 (2.71)				0.8081 (6.70)	−1.8796 (−2.89)	15	96.36 (2.22)	(0.00)	Gram Barley
8	Wheat	2	0.2568 (2.19)	0.0995 (5.90)		0.078 (2.77)			0.8132 (6.78)	−1.7531 (−3.08)	15	96.43 (2.33)	(0.00)	Gram Barley
9	Gram/wheat	2	0.1627 (0.69)	−0.0911 (−0.82)		0.0678 (0.71)			−1.4081 (−3.50)	14.5845 (3.53)	15	92.97 (2.00)	(0.00)	Wheat Barley

NOTES: All variables are in their logarithmic form.
Figures in parentheses are the corresponding t values.
See Table 1 for the crops belonging to each group.
Revnrtag: revenue of the crop relative to that of competing crops where the revenue of competing crops is computed as a linear average.
Revnrate: revenue of the crop relative to that of competing crops where the revenue of competing crops is computed as a geometric average; see eq. (26).
IASO: irrigated area of the soil to which the group belongs (I_{gt}).
IARGROSS: gross irrigated area of all crops in the country (I_{Gt}).
IACN: irrigated area of sugarcane (I_{st}).
DW: Durbin–Watson statistic.
RHO: autocorrelation parameter in $U_t = \rho U_{t-1} + \epsilon_t$.

TABLE 3b Results of area estimation.

Serial number	Crop	Group	A_{igt-1}	Rainfall	Revnrtag	Revnrate	$\frac{\text{IASO}}{\text{IARGROSS}}$	$\frac{\text{IATOSD}}{\text{IARGROSS}}$	IARGROSS	Constant	Degrees of freedom	$\bar{R}^2$/DW	RHO	Competing crops
10	Barley/wheat	2	0.4320	−0.0399	0.0898				−0.91110	8.7462	15	95.35	(0.00)	Wheat
			(3.09)	(−0.99)	(2.34)				(−3.52)	(3.42)		(2.37)		Gram
11	Barley/wheat	2	0.4388	−0.0388		0.0924			−0.8985	8.56	15	95.35	(0.00)	Wheat
			(3.14)	(−0.96)		(2.34)			(−3.46)	(3.32)		(2.38)		Gram
12	Cotton/maize	3	0.9008	0.0182	0.0654					−0.000051	16	86.90	(0.10)	Jowar
			(9.46)	(1.36)	(1.82)					(−1.84)		(1.63)		Maize
13	Groundnut	4	0.9480	0.0895		0.0465				0.000019	16	78.98	(−0.35)	Sesamum
			(27.79)	(1.24)		(0.91)				(2.53)		(1.88)		
14	Sesamum/ groundnut	4	0.5489	0.0858		0.0737				−0.7785	16	69.16	(0.00)	Groundnut
			(6.37)	(0.90)		(1.54)				(1.76)		(2.15)		Groundnut
15	Rapeseed and mustard/sesamum	4	0.3617	0.0787		0.1336	−0.917[a]	0.1974		0.000011	14	75.29	(−0.6)	Sesamum
			(2.68)	(2.21)		(2.17)	(−1.30)	(2.94)		(−2.11)		(1.70)		Sesamum
16	Sugarcane	8	0.0949	−0.2296	0.1989				0.7230	0.000014	15	68.58	(0.25)	Rice
			(0.42)	(−1.47)	(1.98)				(3.83)	(0.80)		(1.70)		Wheat
17	Sugarcane	8	0.0852	−0.2473		0.2020			0.7233	0.00014	15	69.27	(0.25)	Rice
			(0.38)	(−1.58)		(2.10)			(3.90)	(0.84)		(1.67)		Wheat
18	Tobacco	9	0.1762	0.1559		0.1140				3.7282		75.60		No competing
			(1.45)	(3.39)		(4.58)				(5.55)		(1.85)		crops

NOTES: All variables are in their logarithmic form.
Figures in parentheses are the corresponding t values.
See Table 1 for the crops belonging to each group.
Revnrtag: revenue of the crop relative to that of competing crops where the revenue of competing crops is computed as a linear average.
Revnrate: revenue of the crop relative to that of competing crops where the revenue of competing crops is computed as a geometric average; see eq. (26).
IASO: irrigated area of the soil to which the group belongs (I_{gt}).
IARGROSS: gross irrigated area of all crops in the country (I_{Gt}).
IATOSD: irrigated area of total oilseeds.
DW: Durbin–Watson statistic.
RHO: autocorrelation parameter in $U_t = \rho U_{t-1} + \epsilon_t$.
[a]Proportion of the irrigated area of competing crops other than oilseeds.

TABLE 3c Results of area estimation.

Serial number	Crop	Group	A_{igt-1}	Rainfall	Expected price	Expected yield	$\frac{\text{IASO}}{\text{IARGROSS}}$	IARGROSS	Constant	Degrees of freedom	$\frac{\bar{R}^2}{DW}$	RHO
19	Maize	3	0.0605 (0.25)	0.0158 (0.25)				0.7631 (3.94)	0.000004 (1.20)	16	92.49 (1.70)	(0.65)
20	Maize	3	0.552 (3.59)	0.1107 (1.61)	0.1454 (4.87)	0.1083 (0.78)			2.5942 (2.38)	15	95.73 (2.71)	(0.00)
21	Maize	3	0.4893 (2.90)	0.0882 (1.41)	0.1230 (4.27)			0.2104 (1.10)	1.1541 (1.36)	15	95.90 (2.26)	(0.00)
22	Maize	3	0.13 (0.51)	0.0192 (0.33)		−0.2021 (−1.40)		0.7060 (3.40)	0.000004 (1.38)	15	92.67 (1.77)	(0.80)
23	Bajra	3	0.1371 (0.60)	0.1803 (2.54)			0.7751 (3.72)		8.9726 (3.86)	16	55.08 (1.98)	(0.00)
24	Bajra	3	0.1697 (0.73)	0.0729 (1.19)				0.2818 (3.43)	4.5248 (2.44)	16	51.76 (1.68)	(0.00)
25	Bajra	3	0.1637 (0.73)	0.1545 (2.12)	0.0574 (1.23)	0.4742 (1.49)	0.4742 (1.49)		7.9027 (3.23)	15	56.60 (2.06)	(0.00)
26	Bajra	3	0.2678 (1.17)	0.1213 (1.60)		0.0789 (1.65)	0.5626 (2.39)		7.6335 (3.26)	15	59.74 (2.32)	(0.00)
27	Bajra	3	0.4043 (1.92)	0.0560 (0.87)	0.0773 (2.07)	0.0770 (1.49)			5.0405 (2.72)	15	56.50 (2.29)	(0.00)
28	Jowar/ maize	3	0.3065 (1.42)	0.0341 (0.69)				−0.7492 (−3.38)	8.4956 (3.29)	16	97.51 (0.00)	(0.00)

NOTES: All variables are in their logarithmic form.
Figures in parentheses are the corresponding t values.
See Table 1 for the crops belonging to each group.
IASO: irrigated area of the soil to which the group belongs (I_{gt}).
IARGROSS: gross irrigated area of all crops in the country (I_{Gt}).
DW: Durbin–Watson statistic.
RHO: autocorrelation parameter in $U_t = \rho U_{t-1} + \epsilon_t$.

The first factor implies that farmers could not achieve their desired acreage levels immediately but could adjust their acreage to some extent. The second implies that they could adjust their acreage to the desired levels. For rice, $1 - \gamma$ is significantly* different from zero and almost equal to one, which means that rice farmers could adjust their acreage to the desired levels slowly. As rice is already the most important crop in India, accounting for 23 percent of the total, and as difficulties are involved in bringing more area under cultivation, this is understandable.

Jute, wheat, cotton, groundnut, sesamum, and rapeseed and mustard also exhibit the same phenomenon, but the adjustment parameter γ is not as low as it is for rice. For ragi, mesta, gram, sugarcane, and tobacco, this coefficient is not significant.

Except in the case of sugarcane, gram, and barley, the coefficient of rainfall is always positive. As far as irrigation is concerned, a positive coefficient of I_{gt}/I_{Gt} indicates substitution of the particular crop for the areas of the competing crops in that group, while a negative coefficient indicates that as irrigation facilities for that group increase, other crops are preferred. This argument can be extended with respect to the coefficient of I_{Gt}, which indicates the effects of increasing the total irrigated area in the country on the area devoted to the particular crop. I_{Gt} is included as a variable because many irrigation facilities in India are storage schemes permitting the transfer of water across seasons and regions, i.e., across our groups. Moreover, irrigation schemes in India are designed for extensive rather than intensive irrigation. The fluctuations in irrigation availability due to rainfall fluctuation can be significant. The sign of the coefficient I_{st}/I_{Gt} indicates the substitution trends between the crop under consideration and sugarcane.

Maize, jowar, and bajra were not included in the preceding discussion because a separate analysis, with a different hypothesis, was required for these crops. When the model as presented above was applied to these crops, our estimation results showed consistently negative and significant coefficients for the revenue variable. The $\overline{R}^2$ values were also satisfactory for all the crops; in fact, they were quite high for maize.

We considered this result to be plausible, as these three crops are primarily subsistence crops. If these crops are grown primarily for self-consumption, then farmers need only a fixed output in a given period; they adjust area allocation only to produce that output. If the productivity of the land is increased through technological or other factors, then they need to allocate less area to produce the same output; hence an increase in the yield of these crops should have a negative effect on the acreage response. However, an increase in the price of these grains leads to a positive acreage response because the farmers would then like to grow more for sale. Under these circumstances, the net effect on the revenue per acre, which is price multiplied by yield, may be a negative acreage response.

More formally, if the calorie content, yield, harvest, and market prices are defined by C, Y, P^{h}, and P^{m}, respectively; and if subscripts c and r refer to coarse grain and to rice, then $\mathrm{d}A/\mathrm{d}y < 0$ and $\mathrm{d}A/\mathrm{d}p > 0$ is possible if three conditions are met:

$$C_{\mathrm{c}} A_{\mathrm{c}} Y_{\mathrm{c}} > C_{\mathrm{r}} A_{\mathrm{r}} Y_{\mathrm{r}}$$

$$P^{\mathrm{m}}_{\mathrm{c}} A_{\mathrm{c}} Y_{\mathrm{c}} > P^{\mathrm{h}}_{\mathrm{r}} A_{\mathrm{r}} Y_{\mathrm{r}}$$

$$P^{\mathrm{h}}_{\mathrm{r}} A_{\mathrm{r}} Y_{\mathrm{r}} > P^{\mathrm{h}}_{\mathrm{c}} A_{\mathrm{c}} Y_{\mathrm{c}}$$

*Hereafter, significance is judged at the 5 percent level.

Imposing the first condition ensures that the farmer gets more calories from his land from coarse grain than from rice; imposing the second, that growing rice for sale to buy coarse grain is uneconomical; and imposing the third, that it is better to grow rice than coarse grain for sale.

We tested this hypothesis by dropping the revenue variable from the model and substituting yield and price variables, both separately and together. For this purpose, we used the Box–Jenkins analysis separately for the yield and price variables of these crops to estimate expected values. Tables 2 and 3a–c show the results.

The results for maize support the plausibility of the hypothesis, and the $\bar{R}^2$ values range from 92 percent to 96 percent. Numbers 21 and 22 in Table 3c indicate that for maize $dA/dp > 0$ when $dA/dy = 0$, and $dA/dy < 0$ when $dA/dp = 0$. However, no. 20 in the same table introduces both price and yield terms; the coefficient for the yield term is not significantly different from zero, which may be due to multicollinearity between price and yield. Thus no. 20 may not be regarded as refutation of the hypothesis. While the analysis of bajra does not seem to support this hypothesis so clearly, the estimations based on price and yield variables were far better than those based on the revenue variable. Hence only these were included and are presented here.

We discovered similar findings for jowar, except that in this case, only relative area with respect to maize gave good results, and including revenue, price, or yield gave no better results than that shown in Tables 3a–c.

As previously mentioned, we did not analyze acreage response for groups 5, 6, 7, and 8, which contain fruits, vegetables, condiments, and spices; rubber; coffee; and tea, respectively. We estimated acreages of these crops merely as a percentage of the country's total gross cropped area, and we do not include estimation results for them in this report.

5 VALIDATION EXERCISES AND RESULTS

To determine the extent to which the estimated equations of crop revenue expectation and acreage response can be relied on for future projections, we decided to carry out simple validation exercises. In this section we give details of these exercises.

5.1 Crop Revenue Expectations

In this part of the exercise we simply compared the estimated values of the expected revenue, price, and yield of different crops obtained in Section 4.3 with the actual past values of these variables. These values for each crop were then plotted separately; Fig. 1 shows the plots, which correspond to the estimated equations presented in Table 2.

From these plots we can see that the estimated expected values (based on the stationary and random components of previous values) closely follow the actual values. In this respect, the performance of the estimated equations seems to be good, especially for bajra (price and yield), maize (revenue, price, and yield), rice, ragi, wheat, and tobacco. The results are also satisfactory for other crops, with the exception of groundnut, jute, and mesta, for which the expected values deviated from actual ones for many observations. This may be because in India international prices affect the prices of these crops to a greater extent than they affect the prices of other crops. It also explains the relatively unsatisfactory result obtained for acreage response for groundnut (see Section 4.4).

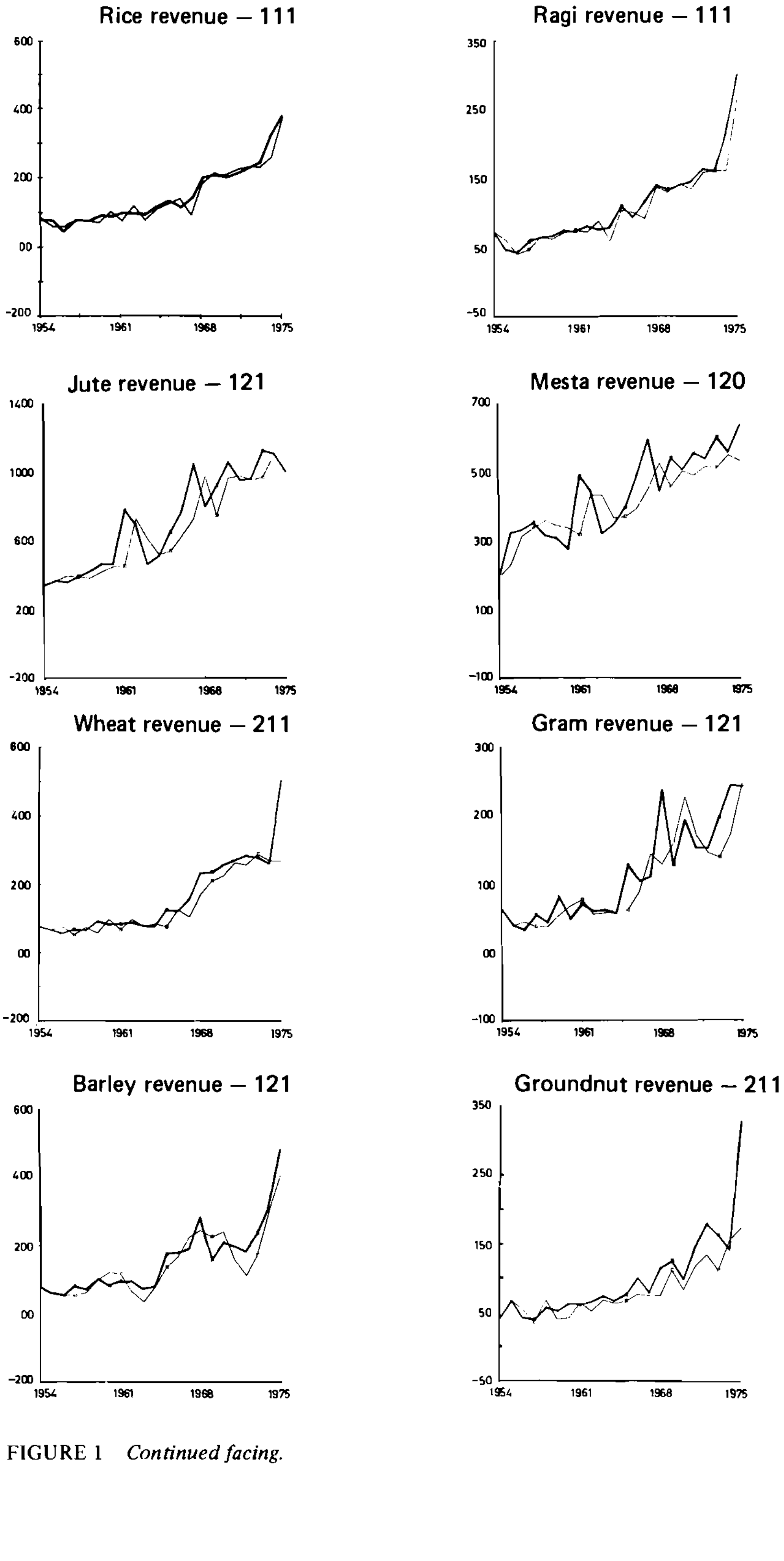

FIGURE 1 *Continued facing.*

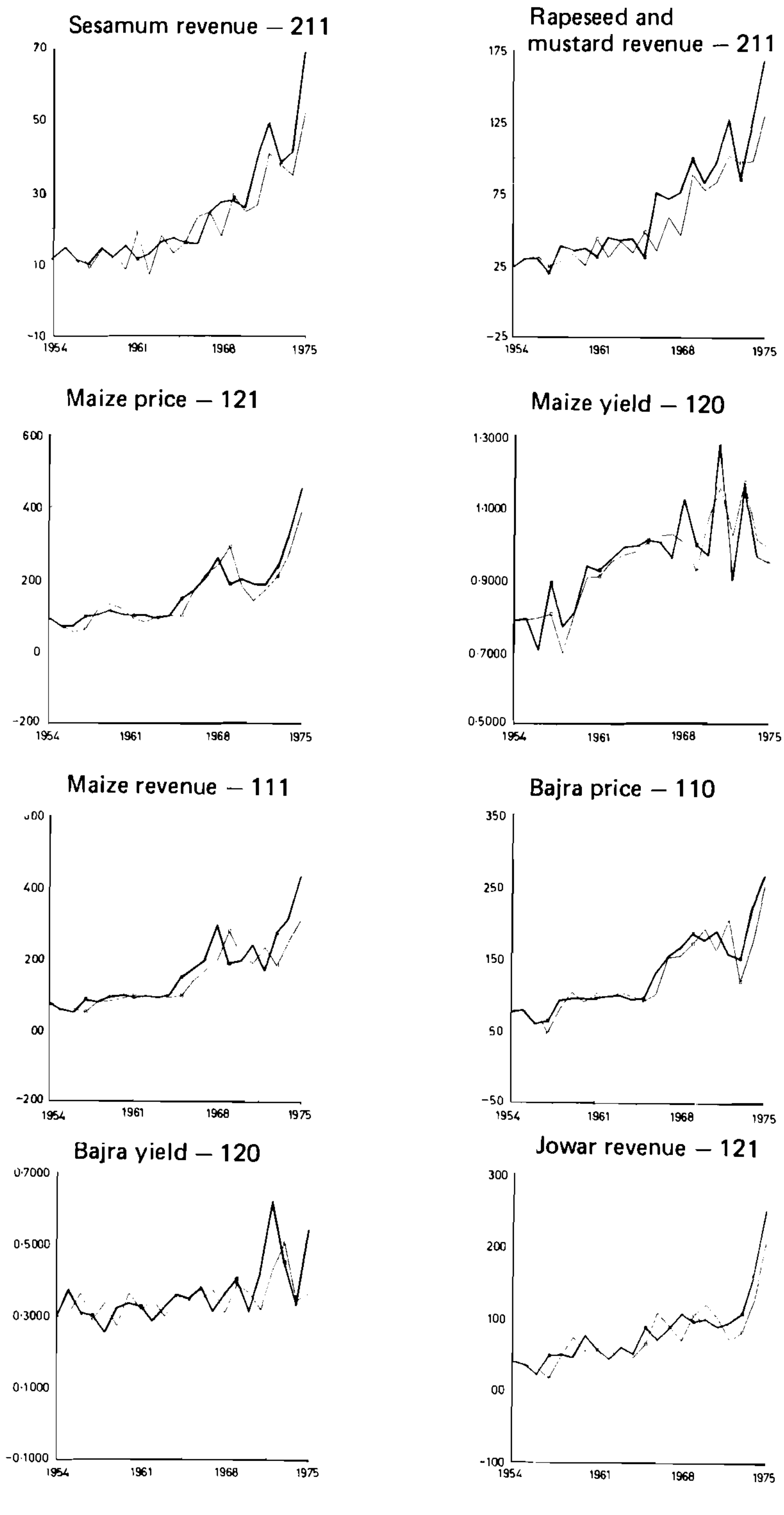

FIGURE 1 *Continued overleaf.*

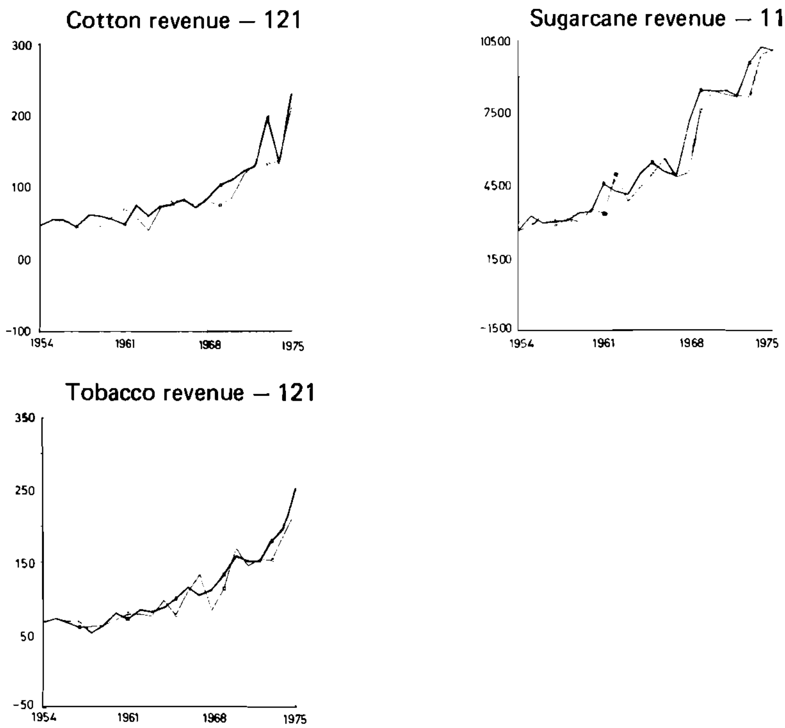

FIGURE 1 Expected (----) and actual (——) values of revenues, prices, and yields. Expected values are obtained from Box–Jenkins estimations. Numbers following crop names refer to the estimated ARIMA scheme represented by p, q, and d (see Section 4.3), where p is the number of autoregressive terms, q is the number of moving-average terms, and d is the degree of differencing. Revenues are products of wholesale price indexes and yields. Prices are wholesale price indexes, with 1961 = 100. Yields are in kg/hectare.

5.2 Acreage Response

As one of our major purposes was to use the allocation model for projection purposes in a year-by-year simulation model, we carried out a validation exercise to observe the model's behavior when it is used for a previous period. A validation exercise carried out over the period of estimation may seem to be just a look at the residuals of individual regressions. In our case, however, area projection for most crops would involve sequential use of a number of equations that were estimated separately. This projection may thus give results different from those indicated by the residuals, and a validation exercise may be required. Moreover, apart from the size of the errors, it is interesting to see to what extent the projections capture turns (ups and downs) in the data.

We estimated eq. (30) for each crop using actual data for all variables except the revenue variable, for which we obtained the numbers from the Box–Jenkins analysis. The right-hand side of eq. (30) contains as one of the variables the proportion I_{gt}/I_{Gt} of irrigated area of group g in the total irrigated area of the country and the proportion I_{st}/I_{Gt} of irrigated area of sugarcane.

Naturally, when this equation is used for future projections, one cannot have the actual values of the variables on the right-hand side, which must first be projected. Then the projected values can be inserted in eq. (30). With respect to revenue, the estimated equations of crop revenue expectation functions obtained in Section 4.3 serve the purpose. As rainfall in India has not been found to be predictable, one can only expect that it would be normal or use a sequence of rainfall, drawn as a random sample from past observations, for the future, i.e., $R_{igt} = \overline{R}_{igt}$ for the crops grown during the rainy season. For crops of the previous monsoon season, rainfall may be considered to be known.

To determine the values of the irrigation variables that appear on the right-hand side, we decided to estimate separately the proportion I_{gt}/I_{Gt} of irrigated area of every group in the country's total irrigated area.

The values obtained from these estimations were used to carry out the validation exercise. While these estimations are carried out, however, the sum total of all these proportions added over different groups in the system should be one. Hence we estimated the following sets of equations simultaneously with a constraint equation toward the additivity:

$$\sum_{g=1}^{6} (I_{gt}/I_{Gt}) + V_{st} = 1 \tag{31}$$

$$I_{gt}/I_{Gt} = a_1 + a_2 R_{gt} + a_3(I_{gt-1}/I_{Gt-1}) + a_4(I_{Gt}) + V_{gt} \qquad g = 1,6 \tag{32}$$

g = 1 for the rice group, 2 for the wheat group, 3 for the jowar group, 4 for oilseeds, 5 for sugarcane, and 6 for all other crops. R_{gt} is the rainfall index for group g (we used the rainfall index of the main crop in that group, namely, the rainfall index of rice for group 1, and so forth). Other variables are as defined in Section 4.2.

Equation (32) expresses the proportion of irrigated area of group g in the total irrigated area as a function of predetermined variables, namely, the previous year's proportion, current year's rainfall, and currently available total irrigated area. Note that I_{Gt} is generally specified from outside the system. Hence use of the scheme behind eq. (32) for projection poses no problem.

We estimated eqs. (31) and (32) simultaneously as a nonlinear least-squares problem, using the computer programming package developed by Günther Fischer at IIASA for estimation purposes; Table 4 shows the results. The estimations correspond to the minimized sum of squares of the composite residual terms $(\Sigma V_{gt} + V_{st})$. A first-order autocorrelation scheme was also imposed on each individual disturbance term V_t.

When inserted in eq. (30), the estimated values obtained for the revenue (and price and yield, as the case may be) and irrigation variables (obtained from the Box–Jenkins equations and eq. (32), respectively), yield the projected values of the acreage response. In the validation exercise we compared these projected values with the actual values. Figure 2 shows the corresponding plots, which correspond exactly to the serial numbers presented in Tables 3a–c. The ultimate results are promising, with the expectation values and actual values falling within a close range. This performance of the estimated equations seems to be especially good for rice, wheat, maize, barley, and gram. Even for the other crops, the estimated equations perform the prediction exercise satisfactorily.

However, for some crops, such as rice and sugarcane, when sudden dips or abnormal rises in actual acreage occur in one year, the expected values for the corresponding year

TABLE 4 Results of estimation of irrigation area by groups.

Irrigation area of the group containing	a_1	$a_2 \times 10^2$	a_3	$a_4 \times 10^4$	ρ
Rice and other crops	−0.0176	0.0534	0.9666	−0.0081	−0.4486
Wheat and other crops	0.0119	−0.0069	0.8949	0.0086	0.0604
Jowar and other crops	0.0541	−0.0201	0.6372	−0.0002	−0.2832
Oilseeds	−0.0092	0.0020	0.5848	0.0049	−0.2507
Sugarcane	0.0355	−0.0083	0.4820	0.0001	0.1953
All other crops	0.0791	−0.0080	0.6066	−0.0064	−0.3498

NOTES: $\sum_{g=1}^{6} (I_{gt}/I_{Gt}) + V_{st} = 1.$

$(I_{gt}/I_{Gt}) = a_1 + a_2 R_{gt} + a_3(I_{gt-1}/I_{Gt-1}) + a_4 I_{Gt} + V_{gt} \qquad g = 1,6.$

$V_{it} = \rho V_{it-1} + \epsilon_t \qquad i = g(1 \text{ to } 6) \text{ and s} \qquad -1 \leq \rho \leq 1.0.$

The estimates correspond to the minimized sum of $(\Sigma V_{gt} + V_{st})^2$.
The following are the estimated values of $\Sigma(I_{gt}/I_{Gt})$ for different time periods: 1.0016, 0.9975, 1.0000, 1.0056, 0.9929, 1.0064, 1.0004, 0.9957, 0.9999, 1.0016, 0.9940, 1.0026, 1.0063, 1.0032, 1.0002, 0.9953, 0.9930, 1.0033, 0.9980, 1.0003, 1.0036, 0.9991, 0.9999.

(as well as the next one or two years) differ widely from the actual values because only the acreage of the previous year is present among the explanatory variables. If there is a sudden dip in the acreage in the previous year, this abnormal value of the acreage, which accounts neither for the general level nor for the possibility of recovery, is given undue weight in predicting the current year's value. If we had considered a weighted average of the acreage of a few previous years, instead of just the previous year's acreage (A_{igt-1}), by appropriately reformulating eq. (29), the acreage adjustment equation, or eq. (8), the ultimate result would have been much better.

6 POLICY IMPLICATIONS

In some planning models, demand projections are obtained by estimating an independent subsystem of demand equations, which does not form an integral part of the entire planning exercise. When the target output levels and demand projections do not match, one assumes that suitable policy measures can be devised to make them consistent. Depending on the circumstances, such measures can include adjusting relative prices of outputs, inputs, or both; adjusting taxes, subsidies, and so forth; expanding irrigation facilities; and imposing quotas on fertilizer availability. There is no guarantee, however, of the availability of a set of reasonable policies that can make the demand or supply targets achievable.

We applied the estimations reported here (see Narayana and Parikh 1979) to identify the agricultural policies implicit in the draft sixth five-year plan of the Planning Commission of India (see Government of India 1978). Based on certain assumptions about irrigation, rainfall, and so forth, we computed for rice, wheat, and their main competing crops implied relative revenues that should prevail if the targeted output levels as specified for 1982–1983 were to be realized. We then compared these implied values with the actual values during the preplan period. We found that maintaining the relative revenue of rice at approximately its present value could lead farmers to produce the targeted levels of rice output. However, we found the relative revenue of wheat that would be consistent with the targeted output

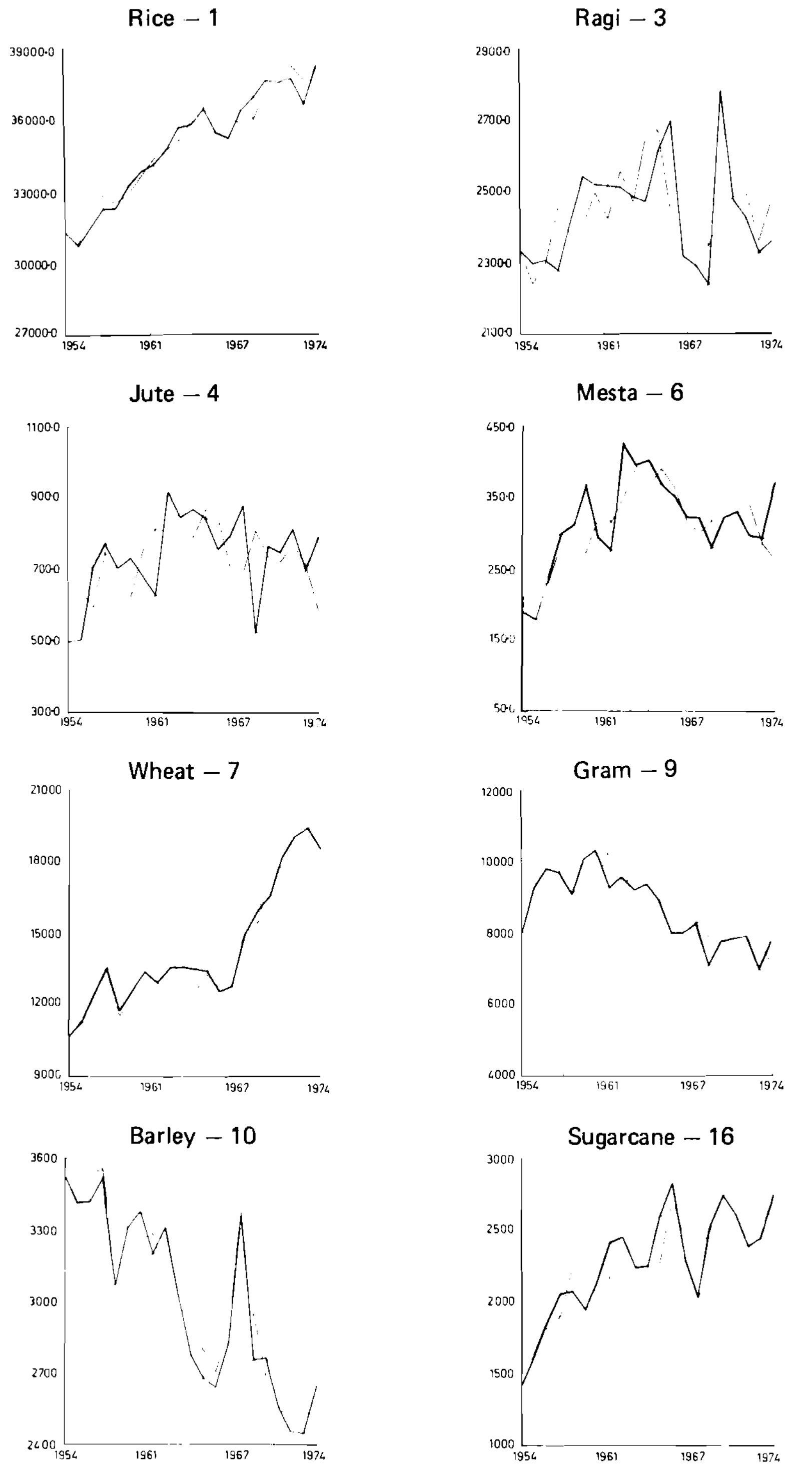

FIGURE 2 *Continued overleaf.*

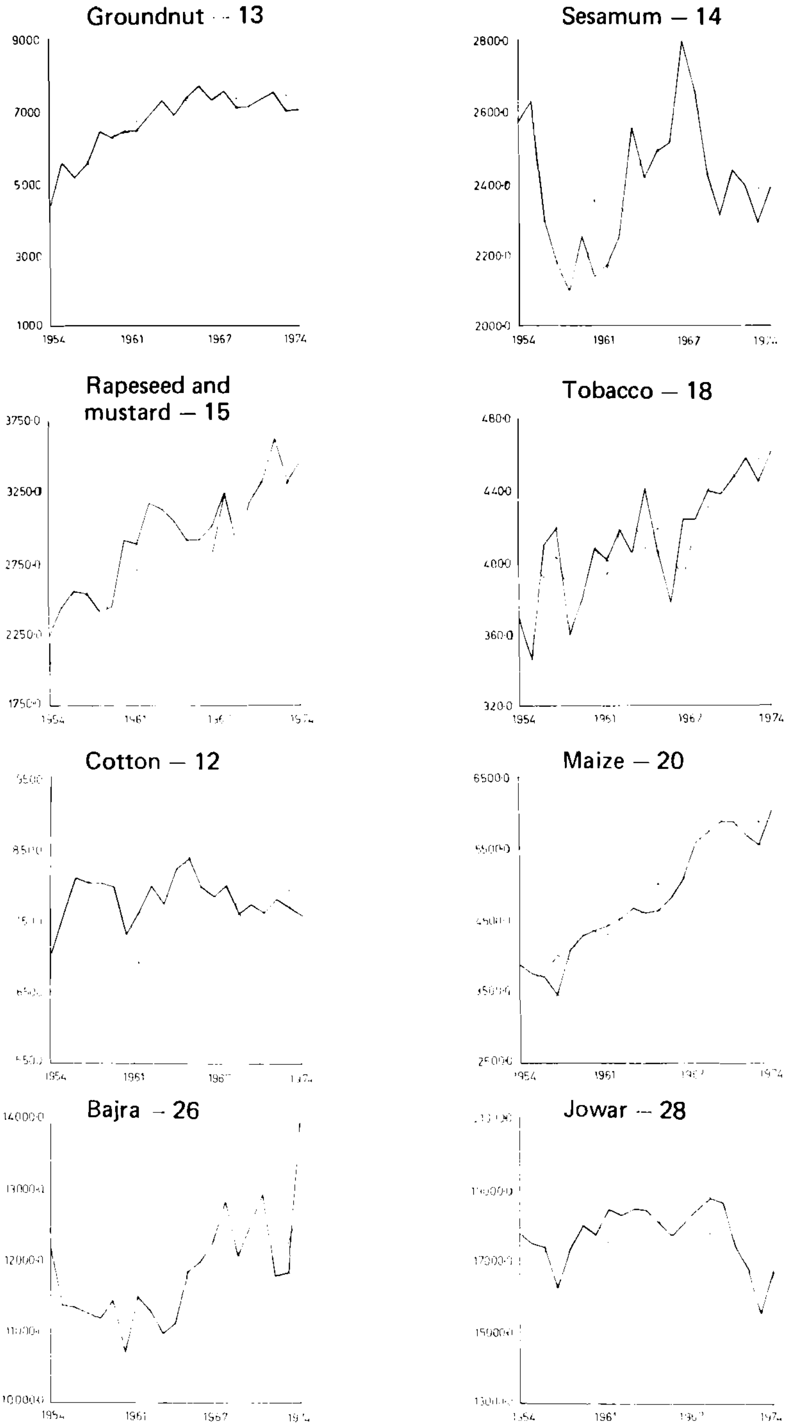

FIGURE 2 Actual (——) and projected (- - -) areas (000 hectares). Projected values are obtained using projected values of predetermined variables in the right-hand side of equations in Tables 3a–c. Numbers following crop names refer to the serial numbers in Tables 3a–c.

of wheat to be an order of magnitude lower than values in the recent past. As such a change in relative revenues may be considered unlikely, this indicates that much more wheat than targeted, and much less gram and other crops that compete with wheat, is likely to be produced.

7 CONCLUSIONS

In this report we sought to model the land allocation decisions of Indian farmers. We believe that rational farmers maximize their utility within the context of opportunities, uncertainties, and risks. They cannot be expected to be insensitive to changing prices and profitabilities. We estimated acreage response for different crops using expected revenue instead of expected prices as a proxy for expected profits.

We reviewed available approaches to estimating acreage response and noted the influence of the Nerlovian model, which is based on adaptive expectations and adjustment schemes. The basic scheme behind the Nerlovian model is quite general and may be applied to the study of acreage response behavior even in developing economies, such as that of India. However, this model seems to involve a serious error of specification with respect to the formulation of the price expectation function.

A better approach to formulating an appropriate revenue (or price, as the case may be) expectation function is to identify clearly the stationary and random components involved in past values of the variable and then to attach appropriate weights to these components while predicting future values. Nerlovian specification of the expectation function cannot identify these components and thus attaches the same significance to them.

The use of Box–Jenkins methodology in estimating the crop revenue expectation functions and the subsequent use of these estimates of expected revenues in the Nerlovian adaptive acreage response model gave satisfactory results. Finally, we subjected the estimated equations to a validation exercise to judge to what extent they might be relied on for incorporation into large-scale system studies.

ACKNOWLEDGMENTS

We are deeply indebted to Michiel Keyzer for having made our "interest" rate in this exercise very high. We greatly benefited from our discussions with him, held anywhere he could be found, although we were not able to incorporate all of his suggestions here.

Klaus Frohberg and Günther Fischer helped us at several stages of this work: in return, we wish that we could blame them for at least some of the errors that may remain, but it is customary to claim that all remaining errors are ours, and we do so. We thank H. L. Chandok for providing us with important data. Sudhir D. Chitale and Frank Latko also helped us in obtaining data and in entering them on computer files. Special thanks are due to the secretaries of the Food and Agriculture Program at IIASA for patiently bearing the strain of typing the manuscript.

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APPENDIX A Substitutable Crops in India

State	Crops
Andhra Pradesh	Rice, ragi, mesta Jowar, maize, bajra Cotton, groundnut, sesamum Wheat, gram
Assam	Rice, jute Moong, gram, urad, cotton, wheat
Bihar	Ragi, rice, jute Wheat, barley, peas, gram, sugarcane
Maharashtra	Linseed, wheat, gram Sugarcane, wheat, gram Jowar, bajra, maize, cotton
Madhya Pradesh	Linseed, wheat, gram Jowar, bajra, maize, cotton
Madras	Rice, ragi, mesta Jowar, maize, bajra Cotton, groundnut, sesamum
Mysore	Rice, ragi Jowar, sugarcane Cotton, groundnut Bajra, maize
Orissa	Rice, ragi, jute
Punjab	Wheat, barley, gram, peas Jowar, bajra, maize, cotton, sugarcane
Rajasthan	Jowar, bajra, maize, pulses Wheat, barley, gram, peas
Uttar Pradesh	Wheat, barley, gram, peas Jowar, bajra, maize, sugarcane
West Bengal	Autumn rice, jute Sugarcane, jute Sugarcane, rice
Delhi	Gram, wheat Wheat, barley Barley, gram
Himachal Pradesh	Wheat, barley Wheat, gram Barley, gram Wheat, mustard Maize, sesamum Maize, pulses
Manipur	Wheat, peas, mustard Maize, soyabean, sugarcane

APPENDIX B Sowing, Harvesting, and Peak Marketing Seasons of Principal Crops in India

Season	Rice (winter)	Rice (autumn)	Rice (summer)	Wheat	Jowar (kharif)	Jowar (rabi)	Bajra
Sowing	June–Oct.	Mar.–Aug.	Nov.–Feb.	Sept.–Dec.	Apr.–Aug.	Sept.–Dec.	June–Aug.
Harvesting	Nov.–Apr.	June–Dec.	Mar.–June	Feb.–May	Sept.–Jan.	Jan.–Apr.	Sept. Dec.
Peak marketing	Dec.–May	Sept.–Dec.	Apr.–July	Apr.–June	Nov.–Jan.	Feb.–Apr.	Nov.–Jan.

Season	Maize (kharif)	Maize (rabi)	Ragi	Barley	Gram	Tur (kharif)	Sugarcane
Sowing	June–Aug.	Oct.–Dec.	May–Nov.	Oct.–Dec.	Sept.–Dec.	May–Aug.	Dec.–May
Harvesting	Aug.–Nov.	Jan.–Apr.	Sept.–Mar.	Feb.–May	Feb.–May	Nov.–Apr.	Oct.–Apr.
Peak marketing	Oct.–Dec.	Mar.–Apr.	Nov.–Mar.	Apr.–June	Apr.–June	Feb.–June	Dec.–Apr.

Season	Tobacco	Groundnut	Castor	Rapeseed and mustard	Linseed	Sesamum
Sowing	July–Dec.	May–Aug.	June–Oct.	Sept.–Nov.	Sept.–Nov.	May–Sept.
Harvesting	Jan.–May	Sept.–Jan.	Oct.–Apr.	Jan.–Apr.	Jan.–May	Aug.–Dec.
Peak marketing	Feb.–June	Nov.–Jan.	Mar.–June	Mar.–May	Mar.–June	Nov.–Feb.

Season	Sesamum (rabi)	Cotton	Jute	Sannhemp	Potato (winter)	Potato (summer)
Sowing	Dec.–Feb.	Mar.–Sept.	Feb.–July	Apr.–Aug.	Aug.–Dec.	Feb.–July
Harvesting	May–Aug.	Sept.–Apr.	July–Nov.	Sept.–Jan.	Jan.–May	May–Dec.
Peak marketing	May–Aug.	Nov.–Mar.	Aug.–Jan.	Dec.–Feb.	Feb.–May	Oct.–Mar.

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