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Supply Response in Agriculture
A Review of Methodologies

An ICRISAT-NCAER Collaborative Study
Funded by the Ford Foundation

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Preface

This paper is part of an ICRISAT-NCAER collaborative study on "Changes in Cropping Patterns and Resource Use Efficiency in the Semi-Arid Tropic of India: the Role of Price and Non-price Factors". We are grateful to the Ford Foundation for funding this study and for presenting an opportunity to work collaboratively with ICRISAT. The NCAER team is lead by Dr. Ashok Gulati, while Dr. T.G. Kelley is the project leader at ICRISAT. The author has worked under the guidance of both team leaders.

This paper reviews methodologies that have been in vogue for some decades in studies concerning supply response in agriculture. In supply response studies, one has to view output supply and factor demand functions (and perhaps, institutional constraints) in a simultaneous equations framework. It is in this context that different models that are generally used in such studies are evaluated. These include models using different functional forms such as the Nerlovian model, i.e. an adaptive expectations-partial adjustment framework, the multinomial logit model, the time series-cross section model, the profit function model, and the frontier production function model.

Both, the limitations and pleasing features of each model are brought out, especially the non-availability of cost and other data for some and the parsimonious data requirements of others. The author does not chase quantitative model-building unmindful of the ground realities. She is well aware of the diverse socio-economic realities operating at the household, village, and district levels. Accordingly, she sounds self-cautioning notes throughout the paper. Finally, for each model, problems connectd with estimation and interpretation are also discussed. The summary chart presented in the concluding section attempts to educate those who wish to be initiated to respective 'price response' and 'non-price response' nuances.

New Delhi
May, 1996

Rakesh Mohan
Director-General

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This paper is part of an ICRISAT-NCAER collaborative study - "Changes in Cropping Patterns and Resource Use Efficiency in the Semi-Arid Tropic of India: the Role of Price and Non-price Factors"- funded by the Ford Foundation. On the 11th of August, 1995, some preliminary thoughts were presented before a workshop at NCAER. Valuable comments were received from Dr. G.K. Chadha, Dr. Mruthunjaya, Dr. R. Radhakrishna, and other eminent economists participating in the workshop. The author also had the opportunity to interact with and obtain constructive suggestions from Dr. Ashok Gulati, Dr. T.G. Kelley, Dr. A.K. Sharma, Dr. K.N. Murthy, and Mr. Parthasarthy Rao. The author would like to specially thank Dr. G.K. Chadha and Dr. P. Kumar for their critical comments. She is also extremely grateful to the Ford Foundation for sponsoring this study.

Deepali Singhal Kohli

I. Introduction

Production of a particular crop can be raised by increasing the area under and/or by augmenting the crop's productivity. Yield increases can be obtained through improvements in technical and/or allocative efficiencies. Thus, there are several different approaches to supply response studies. Each method focuses on a particular channel (increase in area, higher technical efficiency, or more allocative efficiency) of achieving greater production. Each alternative supply response model has its own particular merits and limitations. The approach adopted in a supply response study depends largely on the policy implications the researchers wish to extract. The choice of the model could also be dictated by certain pragmatic considerations such as data, personnel, and time as well as computing facilities available for the study.

When the aim of the study is comparatively short-run forecasting of the supply of some subset of products, simple one-stage econometric procedures, such as the Nerlovian model and some time series-cross section models, can be employed to directly estimate functions using market level time series data. Similar procedures can also be applied for longer term forecasting of output of supplementary enterprises. For long-term forecasting of crop acreage response, a single independent equation may yield misleading projections. The multinomial logit transformation of these models (i.e. the Nerlovian type models) can be more appropriate for long-term crop acreage projections. However, when the central concern of the study is to derive sector-wide agricultural policy impact analysis, perhaps relatively comprehensive approaches to supply response, such as the profit function methodology, are more suitable since these approaches consider the simultaneity between output supply and factor demand decisions. While, the Nerlovian and the profit function models, measure the responsiveness of output supply to both price and non-price factors, the frontier production function models evaluate the responsiveness of output supply to non-price factors alone. These models are based on the premise that it is technical inefficiency rather than allocative inefficiency which constrains the supply of output.

The supply response models have evolved over time—better computational facilities have led to the evolution of more sophisticated models. This paper discusses the merits and demerits of some of the supply response models, namely the Nerlovian model, the multinomial logit model, time series-cross section models, the profit function model, and the frontier production function model. Section II presents models that identify both price and non-price factors determining supply responsiveness, while Section III examines those models which attribute supply response to just non-price factors. Section IV summarizes the basic features of these models in a comparative framework. This section also provides some concluding remarks on the choice of methodology(ies).

II. Models Assessing the Supply Response to Both Price and Non-price Factors

II.1 The Nerlovian Model

The Nerlovian model is frequently employed in supply response and area allocation studies. It is a dynamic partial adjustment model based on the concept of adaptive expectations. The partial adjustment mechanism reflects the inertia arising from investment adjustment costs and technical constraints which spread the response to any change in economic stimuli over a number of time periods. According to Lahari and Roy (1986), the Nerlovian model evolves from an expected utility maximization problem. This model can be represented by the following set of equations:

$$A_t^D = a_0 + a_1 P_t^e + a_2 z_t + u_t$$

$$P_t^e = P_{t-1}^e + B(P_{t-1} - P_{t-1}^e)$$

$$A_t = A_{t-1} + r(A_t^D - A_{t-1})$$

where

A_t = Actual area under cultivation at time t.

A_t^D = Desired area to be put under cultivation at time t.

P_t = Actual price of output at time t.

P_t^e = Expected price of output at time t.

z_t = Other exogenous factors affecting supply at time t.

u_t = Random disturbances or error in period t.

B and r are termed the expectation and adjustment coefficients respectively. Although the model presented above is an acreage response model, a Nerlovian output supply response framework can be constructed in a similar fashion.

This model assumes that farmers continuously adjust the crop area (output supply) over time and base this land allocation to crop decision (output supply decision) on their expectations of the future price of the crop. This expected future price is a weighted moving average of past prices with greater weights attached to more recent observations. The two alternative specifications of the expected future price generally used are *(i)* the current year's price is expected to depend solely on the last year's price, and *(ii)* the current year's price is expected to be some weighted average of previous years' prices. Koyck's distributed lag method can be used to determine the lag structure. Bapna, Binswanger, and Quizon (1981) found that the elicited lag structure only used information from the two immediately preceding years.

II.1a Advantages of the Nerlovian Approach

Some of the factors in favour of the Nerlovian model are:

(1) It operates directly upon the aggregate supply data which may be the central object of interest for projection purposes in many studies.

(2) It permits flexibility in developing dynamic specifications.

(3) It is the simplest procedure both in terms of estimation methods and data requirements.

(4) As it entails fewer computational steps to generate supply response coefficients, it minimizes the specification errors that accumulate over successive estimation stages.

(5) Unlike the systems approach, this framework does not impose a similar structure on dissimilar products. For instance, there may be little competitive interaction between poultry farming and mango orchards.

II.1b Limitations of the Nerlovian Model

Theoretical Problems

Among the model's theoretical problems are:

(1) It is the change in profitability of cultivating a crop relative to other crops that drive cropping pattern changes. In the present specification of the model, price is assumed to reflect these changes. However, because yield and costs vary independently, neither relative prices nor independently entering price variables measure profitability. Moreover, profitability may also depend on crop by-product and choice of inter-cropping techniques employed.

(2) In a way, the Nerlovian model is similar to the diffusion models presented by Mansfield (1961), Knudson (1991), and others. These models assume

that the area allocated to a variety of crop (HYV) at time *t* depends on the area already under this crop at time *t-1*. In the Nerlovian framework actual area under a crop at time *t* is also defined as a function of the actual area under the crop at time *t-1*. However, unlike Knudson's diffusion model, the simple structure of the Nerlovian model does not consider the differential effects of changes in input prices on the allocation of land among crops.

(3) Prices are assumed to reflect changes in technology and improvements in infrastructure. Thus, the effect of this factor is not explicitly modeled. However, in developing economies with limited market orientation, visible prices do not take into account such technological changes.

(4) Besides not capturing the effect of technological change, the model as specified above does not incorporate the farmers reaction to risk. Some studies have used yield as an independent variable to capture the effect of technological change. However, yield does not only proxy the effect of technological change. Yield also assesses the effect of incorporating different qualities of land in cultivation and the effect of varying the quantities of inputs such as fertilizers and pesticides. To capture the farmers' reaction to risk, the Nerlovian models can include indicators of risk such as standard deviations of price and yield. The use of the standard deviation of price as a proxy for risk is debatable as it may also capture the effects of general price inflation.

(5) The simplified version of the Nerlovian model assumes that price expectations are based on last

period's price. Suppose after growing steadily, output suddenly increases by a much larger amount than the normal increment. An actual price decline would then be realized. This resulting price decline would be significantly different from the price expectations for the period. Rational farmers would take into account this unexpected decline in price when forming their price expectations for the next period. Thus, farmers' expectations of prices may depend on a number of factors, such as changes in output and any exogenous occurrences that influence prices, other than just last period's prices. Expected output prices need to be evaluated. In contrast, no lags must be imposed on input prices because these prices are usually known when the inputs are committed.

Econometric/ Estimation and Data Quirks

Several econometric problems are encountered when estimating the Nerlovian model. These include:

(1) Farmers respond to relative profits per hectare. However, continuous cost data are seldom available to enable the calculation of relative profits. Consequently, researchers have incorporated price and yield as separate variables among the set of explanatory variables. This procedure fails to capture the true effect of profits on supply response.

(2) The estimated values of expectation and adjustment coefficients are sensitive to omissions of relevant variables.

(3) The Nerlovian model estimates the relationship between prices and crop acreage responses in a

district. Thus, separate equations will have to be assessed for each district. As a result, the number of useable explanatory variables in the estimating equation is limited and the efficiency of the parameter estimates is reduced. Models combining time series and cross sectional data overcome these shortcomings by allowing the evaluation—with greater degrees of freedom—of crop acreage responses across districts.

(4) The output price series employed in the model must be chosen in accordance with the factors that motivate farmers to produce more of that particular crop. If acreage or output is changing to keep the farmers' consumption of the crop the same in the face of rising input cost, then the best price series to employ is the ratio of the prices of the crop to the index of input prices or the difference between crop and input prices. However, if the farmers want to increase the acreage of the production of a crop in order to buy more of other goods or to keep the consumption of the other goods the same in the wake of rising prices, then we can select either crop price deflated by some index of consumer prices or crop price relative to the price(s) of alternative crop(s). If the farmers are encouraged to raise crop acreage and production by a desire to increase their own consumption of the crop, then no price variable will be relevant.

In developing economies, where farmers buy at the most a very select basket of goods, a price variable calculated by deflating by some consumer price index may be dubious. Problems can be encountered when using the relative price of two competing crops as well. For example, if the relative price of chickpea to pigeonpea increases considerably in a period when all other prices are constant, then there may be a large increase in chickpea production. However, if this increase in relative price is accompanied by increases in most other prices, then the chickpea production response may be much lower. This problem can be eliminated by using the ratio of the acreage planted to chickpea to the acreage planted to pigeonpea as the dependent variable. In summary, if we wish to justify the inclusion of any specific price variable, we must know why the farmers want to alter the crop production or the crop acreage.

The choice of the most appropriate price variable could change over time. For instance, in the early stages of development the consumer price index would not be an appropriate deflator; however, in the later stages of development, i.e. as farmers become more prosperous and educated, this deflator could become relevant.

Crop prices that have been deflated by indices of competing crop prices have two limitations. The weights used in constructing such indices are based on the researcher's own subjective assessment. In determining the weights it is important to distinguish and understand the relationship between total and marketed output. Relevant data limitations could hinder such differentiation.

(5) Another issue that needs to be addressed is the probable asymmetric response to changes in prices, i.e. acreage response to a change in relative price will depend on the source of the price change and on the direction of the change in

price—whether the price has increased or decreased. The first of these asymmetric price response problems can be resolved by considering all prices as separate regressors. This asymmetric response to price changes may arise because the low salvage value of assets already invested relative to their acquisition costs tend to restrict the influence of downward price movements.

(6) In the Nerlovian supply response models the choice of the dependent variable is important. Most supply response studies use planted area as a proxy for desired output because farmers have a greater control over crop area than output. Thus planted acreage more effectively gauges how farmers translate their price expectations into production. However, in practice a farmer can respond to price changes by re-allocating land and/or by altering the application of other inputs to improve yield. Another problem confronted when using planted acreage as the dependent variable is that area adjustment is fraught with ambiguities, i.e. if farmers had planted acreage as their goal, they could increase their crop area with sparse planting. This argument re-emphasizes the need to understand the attitudes of the farmers when designing the structure of the model.

(7) Several estimation problems can surface when using the OLS technique for estimating the Nerlovian model. The estimation can be inefficient if the residuals in the estimating equation are serially correlated. The model includes lagged values of the dependent variable on the right-hand side of the estimating equation. This could

cause serial correlation. One method of surmounting this problem of inconsistent parameter estimates is to employ non-linear maximum likelihood estimating techniques.

(8) The OLS estimation of the Nerlovian form of supply response model yields biased and inconsistent estimates because the supply of output is determined simultaneously with input demand equations, i.e. the variable inputs are choice variables and hence endogenous.

(9) The technology variables used—yield or the irrigated area relative to the total area, are not independent of prices. For instance the level of irrigation itself is determined by price incentives. Similarly, yield depends on the quantity of inputs utilised which are in turn influenced by both output and input prices. The simultaneous inclusion of price variables and the proxies for technology introduces multicollinearity. As a result, the estimated elasticities of these technology variables are low.

(10) Multicollinearity will arise if prices, yields, and gross returns are included simultaneously in the regression. Thus, gross returns should be used in lieu of prices and yields in the analysis. Similarly, rainfall and irrigation may be directly related to yield. The presence of multicollinearity results in high standard error of estimates and in parameter estimates that are unstable and very sensitive to possible model misspecification. The effects of multicollinearity can be reduced by employing corrective econometric measures. However, the multiple regression analysis still cannot measure

the true underlying relationship in supply functions. It can merely identify the degree of association revealed by the variations in the time series.

(11) In the area allocation specification of the Nerlovian model, there is no guarantee that the shares of area under crop in gross cropped area will always be non-negative and less than one and their sum will always equal one. Hence, the single independent crop area response model could give misleading projections. The multinomial logit model should be employed as it ensures that the shares of total area allocated to different crops are non-negative and sum to one.

II.1c Summary

Despite these limitations, this model has been extensively relied on by researchers because it produces reasonably acceptable results. However, caution must be exercised when using the Nerlovian model in studies that are attempting to make projections of cropping pattern changes because the Nerlovian model can yield erroneous results. Thus, for long-term prediction of cropping pattern changes, perhaps the multinomial logit method should be resorted to. As a supply response model, the Nerlovian model ignores the simultaneity between output supply and input demand decisions. The profit function approach deals with this problem by simultaneously estimating the output supply and input demand equations. Besides, when evaluating the impact of a hypothetical policy change upon a number of variables and/or groups of economic factors, the joint estimation of this system of equations is essential.

II.2 Multinomial Logit Model

The "multinomial logit model is a useful approach in the study of the allocation of a fixed resource between alternative uses",[1] such as the allocation of land to the cultivation of various crops. The allocation of the gross cropped area among a number of alternative crops can be represented as a process of allocating shares of gross cropped area to different crops. These shares are limited dependent variables because by definition the sum of the shares equals one.

The actual and estimated or predicted shares must be non-negative and must sum to unity. Thus, these shares behave like probabilities. Although several specifications can ensure that the summation of the shares equals one, the dual problem of adding-up and non-negativity requires a highly non-linear equation system. Theil's (1969) multinomial extension of the linear logit model meets these requirements.

The following example illustrates the need for the multinomial logit approach in area allocation problems. Suppose farmers in a region have a choice between planting rice and sorghum. We are concerned with the determinants of the proportion of the total area planted to rice. As argued above these shares can be interpreted as probabilities and henceforth will be referred to as probabilities.

Now, let P be the probability that the farmers have sown rice and hence $1-P$ the probability that the farmers cultivate sorghum. The following linear model can be specified to identify the determinants of P:

$$P = a + b_1 r_1 + b_2 r_2 + c_1 A_1 + c_2 A_2$$

where r_1 and r_2 are the net revenues from the two competing

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[1] Bewley et. al. (1987)

crops, i.e. the alternative specific characteristics, while A_1 and A_2 are the total irrigated area and the annual rainfall in the region respectively, i.e. the subject (region) specific attributes. The problem with this equation is that the left hand side, probability P, is constraint to the interval from zero to one, whereas the right hand side can take arbitrary values. This problem can be resolved by replacing the left hand side P with a suitable variable. For example the model can be specified as :

$$[P/(1-P)] = e^{\alpha}\Pi_i(r_i)^{\beta i}\Pi_j(A_j)^{\gamma i}$$

or the logarithmic form:

$$ln[P/(1-P)] = \alpha + \Sigma_i \beta_i ln(r_i) + \Sigma_i \gamma_i ln(A_j)$$

The left-hand side variable in this equation resembles the logit function corresponding to the probability that rice is sown.[2] In general farmers have a choice among three or more crops. Therefore, one equation is not sufficient. A system of linear logit functions, i.e. the multinomial logit model, needs to be specified because the probabilities of land allocation to N alternative crops, P_1 , P_2 , ...P_N , i.e. the shares of N alternative crops in total area, must still sum to one.

II.2a Double-log Specification of Area Allocation Versus the Multinomial Logit Approach

Many econometricians have argued that the double-log transformation of the Nerlovian model ensures that the shares of the crop acreage in total cropped area are non-negative. However, the double-log specification is not entirely appro-

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[2] This function is montonically increasing and can vary between $-\infty$ and ∞. It has a convenient property that it is perfectly symmetric in the two alternatives. Thus, the roles of the two alternatives can be interchanged. Each term in the equation remains the same except that it takes on opposite sign. Thus $ln\ [P/(1-P)] = -ln(1-P)/P$.

priate to area allocation studies. The double-log model assumes constant elasticities[3] and violates the adding-up constraint, while the linear logit naturally enforces adding-up and the elasticities evolve over the data period.

The linear logit model can be derived from an ad hoc correction of the double-log model. Consider the following double-log model specification:

$$ln(w_i) = \alpha_i + \Sigma_i \beta_{ij} x_j + u_i \qquad i = 1, 2, 3$$

where w_i denotes the share of gross cropped area allocated to crop i, α_i and β_{ij} are parameters, and u_i is the distribution term. Suppose $f_i = \alpha_i + \Sigma_j \beta_{ij} x_j$, then

$$ln(w_i) = f_i + u_i$$

The predicted shares from this equation can be found by taking antilog of f_i, i.e.

$$w_i = exp(f_i)$$

Because the predicted errors of shares will probably not be zero or will not cancel each other out, the sum of all the estimated shares will not equal one. Thus $w = \Sigma_i w_i = \Sigma_i exp(f_i) \neq 1$, where w is the sum of the estimated shares, for all values of f_i. This problem can be circumvented by normalizing the predicted shares, i.e. $w_i^o = (w_i/w)$. Then $\Sigma_i w_i^o = 1$ and $0 \leq w^o \leq 1$.

Thus,

$$w_i^o = (w_i/w) = exp(f_i + u_i)/\Sigma_k exp(f_k + u_k)$$

This specification is similar to the linear logit model.

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[3] The coefficients in this model have a direct interpretation as constant elasticities.

The linear logit model yields a highly non-linear system because all variables and disturbances affect all equations through the denominator even when restrictions are placed on some of the f_i. This system can be estimated by transforming the model so that each equation shares a common term. Such a transformation, taking the ratio of one equation to another and cancelling the common terms, was proposed by Theil (1969). The log of this ratio produces an equation which is linear in parameters:

$$ln(w_i/w_h) = (\alpha_i-\alpha_h) + \Sigma_j(\beta_{ij}-\beta_{ih})\, x_j + (u_i-u_h)$$

The drawback of this linear logit model is that its regression coefficient cannot be directly interpreted as elasticities. Moreover, as there are only *n-1* equations, the individual β_{ij} coefficients cannot be determined. However the elasticities can be computed.

II.2b A Linear Version of the Multinomial Logit Land Allocation Model

Kumar et. al. (1992) developed a model for area allocation based on a linear version of the multinomial logistic function. The share of total crop area allocated to each crop is a function of expected crop revenues per hectare and quasi-fixed inputs:

$$ln(w_i/w^*) = a_i + \Sigma_j b_{ij} ln(r_j) + \Sigma_j c_{il} ln(A_l) + u_i$$

where $ln(w^*) = \Sigma\ \bar{w}_i\, lnw_i$, w_i are individual crop shares, $\bar{w}_i$ is the average share of the *i*th crop, w^* is the weighted geometric mean of the crop area shares, r_j is the *j*th expected net crop revenue[4], and A_l is the *l*th type of total land in the cropping

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[4] According to Dr. P. Kumar as cost of cultivation data are not complete at the district level and. therefore. net crop revenues cannot be obtained. gross crop returns may be substituted.

system (total irrigated area and total rainfed area). The transformed shares of total area allocated to each crop is a function of the normalized expected net crop revenues, total irrigated area, and total rainfed area. The expected net crop revenue of the *n*th crop is used as a deflator to normalize expected net crop revenues. Then the elasticities of the area shares in response to expected net revenue are given by:

$$E^{rj}_{wi} = b_{ij} - \Sigma^{n}_{k=1} \bar{w}_k b_{ik}$$

$$E^{rn}_{wi} = -\Sigma^{n-1}_{j=1} E^{rj}_{wi}$$

$$(i = 1,\ldots\ldots, n;\ j = 1,\ldots\ldots, n-1)$$

The elasticities of area shares with respect to quasi-fixed variables is expressed as:

$$E^{Al}_{wi} = c_{il} - \Sigma^{n}_{k=1} \bar{w}_k c_{ik} \qquad (l = 1,\ldots\ldots,m)$$

These elasticities give the area response equation:

$$\Delta w_i = \Sigma^{n}_{j=1} E^{rj}_{wi} \Delta r_j + \Sigma^{m}_{l=1} E^{Al}_{wi} \Delta A_l$$

where Δ denotes the rate of change. Since $\Delta w_i = \Delta A_i - \Delta A$,

$$\Delta A_i = \Sigma^{n}_{j=1} E^{rj}_{wi} \Delta r_j + \Sigma^{m}_{l=1} E^{Al}_{wi} \Delta A_l + \Delta A$$

Now, $\Delta A = \Sigma \delta_l \Delta A_l$ where δ_l is the share of the *l*th type of land in the total cultivated area. Therefore,

$$\Sigma A_i = {}^{n}_{j=1} E^{rj}_{wi} \Delta r_j + \Sigma^{m}_{l=1} (E^{Al}_{wi} + \delta_l) \Delta A_l.$$

This implies that the area elasticity with respect to expected net revenue and type of land are:

$$E^{rj}_{Ai} = E^{rj}_{wi} \qquad (i,j = 1,\ldots\ldots,n)$$

$$E^{Al}_{Ai} = (E^{Al}_{wi} + \delta_l) \qquad (i=1,\ldots\ldots,n;\ l=1,\ldots\ldots,m)$$

The restricted dynamic linear logit model of area allocation proposed by Bewley et. al. (1987) resembles the Nerlovian model. It incorporates the lagged value of each dependent variable and imposes the restriction that each adjustment coefficient must be identical, i.e.

$$ln(w_i/w^*)_t = a_i + \gamma_i ln(w_i/w^*)_{t-1} + \Sigma_j b_{ij} ln(r_j)_t + \Sigma_j c_{il} ln(A_l)_t + u_{it}$$

The adjustment coefficient across equation (γ_i) can be tested and restricted to be equal. The equilibrium values of the estimated coefficients can be calculated by dividing each coefficient by *$(1-\gamma_i)$*. The short-run and long-run elasticities of area share or area can be evaluated using a similar procedure.

II.2c Limitation of the Multinomial Logit Model

Note that, a major disadvantage of this estimation procedure is that the definition of total area on the basis of which competing crop area shares are evaluated holds only if the following two assumptions are true: *(i)* the same crops compete for this area year after year, and *(ii)* these crops do not compete with any other crops for area. Thus, according to Narain (1965), "unless we can locate crops which simultaneously satisfy both the conditions, we ought not to cast individual crop areas into percentages of a larger whole, because individual crop areas would have been expressed as percentages of an inappropriate total and could yield an erroneous picture". Nonetheless, he believes that for all practical purposes an approximation of the total area can be acceptable as these two conditions may not always be fully realized.

II.3 Time Series-Cross Section Models

Time series-cross section models can be employed in both acreage response and output response studies. Pooling time series and cross section data can enhance the statistical degrees of freedom, improve the efficiency of estimates, and enable the estimation of effects associated with a particular dimension of the data set. Although these models are presented in this section, these models may also be used to estimate the frameworks analysing the effects of only non-price factors on supply response.

Time series-cross section models basically fall under two categories: *(i)* the fixed effects model, and *(ii)* the random effects (error components) model. Each of these models have their specific application. However, both these models attempt to capture the individual cross-sectional unit and/or time period effects on the general behavioural relationship. The fundamental decision that must be taken while choosing any one of these two models, is whether to treat the individual effects as constant parameters or as random variables.

II.3a Fixed Effects Model

The fixed effects model allows the intercept term to vary across the N cross-sectional units and/or across the T time periods. Thus, $(N\text{-}1) + (T\text{-}1)$ dummy variables can be introduced and the ordinary least squares (OLS) estimation technique can be used. This procedure isolates the cross-sectional unit specific and/or the time period specific effects in a behavioural relationship. In general this model is adopted when the data exhaust the population. However, when the economic relationship under investigation is of a dynamic nature, dummy variables are invalid because they imply that cross-sectional and/or time effects are constant parameters. Moreover, if lagged dependent variables are incorporated as regressors in the model, the individual (state) effects may be difficult to separate from the effect induced by the lagged variables and the coefficients of these lagged variables may be too low. Therefore, it may be more appropriate to consider time and cross-sectional effects as random samples from a population of such effects.

II.3b Random Effects Model

The random effects specification includes only one overall intercept term and decomposes the error terms into two or three components: *(i)* A traditional error term which is unique to each observation, *(ii)* an error term representing the extent to which the intercept of the cross-sectional unit differs from the overall intercept, and/or *(iii)* an error term identifying the extent to which the time period's intercept differs from the overall intercept. By decomposing the error term, the random effects model captures the net effects of numerous individually unimportant but collectively significant variables which have been omitted by the model specification. A typical random effects model can be expressed as:

$$y_{it} = x_{1it}\beta_1 + \ldots\ldots + x_{Kit}\beta_K + u_{it}$$

where $i = 1, \ldots., N$ farms observed over $t = 1, \ldots.T$ time periods. The disturbance term u_{it} can be decomposed as follows: $u_{it} = \mu_i + \lambda_t + v_{it}$ where μ_i, λ_t and v_{it} denote the individual specific, time specific, and the observation specific effects (errors) respectively.

These equations can be written in matrix form as:

$$y = X\beta + u$$

where y and u are $TNx1$ vectors, X is a $TNxK$ matrix and β is a $Kx1$ vector.

This model is applied when a sample of observation is drawn from a large population and inferences regarding the population need to be obtained. A major advantage of this model is that it saves considerable degrees of freedom. However, it may yield biased coefficient estimates as it ignores the possibility of a correlation between the random error associated with each cross-sectional unit and other regressors.[5] This model also assumes away the possible correlation between the error components capturing the individual cross section effects.

When no lagged values of the dependent variable are included in the explanatory variables and the variance-co–variance matrix of the residuals is known the maximum likelihood estimation technique yields consistent, asymptotically normal and efficient estimates. However, when this matrix is unknown, a two-stage estimation procedure proposed by Zellner may be used. In the first stage, using the OLS estimates of the explanatory variables' coefficients and certain suitable restrictions on the form of the variance-covariance matrix, the matrix is estimated. Then, in the second stage, using this estimated variance-covariance matrix of residuals, new estimates of the coefficients of explanatory variables are derived. Note, that when lagged endogenous variables are included among the explanatory variables, the OLS estimates attained in the first stage are no longer consistent.[6] This problem can be resolved by finding estimators of the coefficients which are consistent despite the presence of lagged dependent variables. Alternatively, if the variance-covariance matrix of residuals can be assumed to depend on a single parameter, then the simultaneous maximum likelihood estimation of model parameters can be attempted. This procedure gives coefficient estimates with desirable asymptotic properties and will help determine an asymptotic

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[5] A Hausman test for correlation between the error and the regressors can be conducted to check whether the ramdom effects is appropriate.

[6] This is because the inclusion of lagged dependent variables among explanatory variables introduces serial correlation, i.e. the lagged variables are correlated with the current values of the residuals.

variance-covariance matrix of residuals. Thus lagged endogenous variable models require estimates with large sample properties. One such set of estimates which is asymptotically equivalent to the maximum-likelihood estimates is the Best Asymptotically Normal (BAN) estimates.

Another problem, that can arise in time series-cross section models with lagged dependent variables among the explanatory variables, is the absence of truly exogenous variables apart from the constant term, trend, or shift variables. The lack of truly exogenous variables results in a singular moment matrix of independent variables.

II.3c Summary

Time series-cross section models can be used as tools to estimate the Nerlovian model (both the acreage response and the output response versions) presented above and the frontier production model to be discussed below. By allowing greater degrees of freedom these models help improve the precision with which the model parameters are estimated. These models also enable the most efficient use of a large panel data set. They help isolate the effects associated with particular dimensions of the panel data. However, when forecasting acreage response, these models do not ensure that the acreage shares sum to one. The time series-cross section models also fail to capture the simultaneity between output supply and input demand decisions.

II.4 Profit Function Approach

The profit function approach is commonly employed in supply response studies to estimate simultaneously output supply and factor demand equations. The advantage of the profit function approach over the production function approaches are: *(a)* it allows for a testing of differences in technical, price, and economic efficiencies; *(b)* in estimating production functions (a single equation approach) OLS estimation yields biased and inconsistent estimates because the supply of output is determined simultaneously with input demand equations, i.e. the variable inputs are choice variables and hence endogenously determined; *(c)* the profit function permits the analysis of multiple output supply response while problems with estimating multi-product/multi-input transformations of the production function restrict the applicability of the production function framework to investigations involving a single product; and *(d)* the elasticities generated by the production function are extremely sensitive to the functional form estimated.

The profit function approach expresses the maximized profits of a farmer as a function of the prices of output and variable inputs and the quantities of fixed factors of production. This approach is based on the following assumptions: *(a)* farmers are profit maximizing agents, *(b)* farmers are price takers in both output and variable inputs markets, *(c)* farmers are technically efficient, and *(d)* their production function is concave in variable inputs, i.e. there exists a one-to-one correspondence between the set of concave production functions and the set of convex profit functions. This essentially implies that every concave production function has a dual[7] which is a convex profit function and vice versa. Then, with the help of the duality theorem, a system of output supply and factor demand equations can be derived from the profit function. The profit function and the derived output supply and input demand functions can be explicitly defined as functions of exogenous variables. This system of equations proves to be useful when testing the hypothesis about farmer

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[7] Dual functions all contain the same basic information.

behaviour, when analysing the impact of price policy changes and when evaluating the productivity and/or equity impact of technological changes or policy modifications.

II.4a A Typical Profit Function Supply Response Model

Typically profits are defined as revenue less variable costs, i.e.

$$\Pi(P,w) = [max_{y,x}\ P'y - w'x : (x,y)\ \varepsilon\ \tau]$$

where P is a vector of M output prices, w is a vector of N input prices, y is a vector of M output quantities, x is a vector of N input quantities, and τ is a closed, bounded, smooth, and strictly convex production possibility set. According to the Hotelling Shepherd Lemma, the Marshallian vectors of output supply and input demand [$y(P,w)$ and $x(P,w)$ respectively] can be obtained from $\Pi(P,w)$ by differentiation with respect to P and w.

The multi-output specification of the profit function is preferred to the single output framework because farm units typically produce several outputs and a single output approach does not allow measurement of the interdependencies among output and the differential impact of various outputs on factor demand. The multicrop approach has practical advantages as well. It permits the estimation of supply responses for each output without requiring the knowledge of the allocation of inputs among the crops.

II.4b Estimation Procedure

From the point of view of empirical implementation, the profit function (or alternatively, the supply function) and the factor demand functions should be jointly estimated, since there will be parameters common to both the profit function and the derived demand functions. Thus, the restrictions that the common parameter are equal need to be imposed. Furthermore, as errors in different equations could be correlated, Zellner's Seemingly Unrelated Regression Estimation (SURE) method should be employed.

II.4c Limitations of the Approach

Theoretical Problems

There are several theoretical quirks embedded in the profit function approach. These include:

(1) This framework assumes that fully developed capitalist markets for all inputs and output exist so that farmers only adjust their quantity in response to price changes. In developing countries this assumption is disputable.

(2) This approach also assumes the existence of competitive markets. Once again, in developing economies this is doubtful. Imperfect information, inadequate access to transport and communication facilities, and other local infrastructural shortcomings provide some better endowed agents with varying degrees of monopoly power. Hence, not all agents are price takers.

(3) The model is presented under certainty conditions. In reality agricultural production and input and output prices are subject to a significant amount of uncertainty. Under uncertainty, farmers' decisions may not be governed by expected profit maximization motive. Instead, farmers may be attempting to maximize their expected utility or they may be driven by some safety first principle. Moreover, the duality results which allow the deri-

vation of the profit function break down once the production function is given a stochastic specification, i.e. the theoretical justification for the profit function approach to supply response disintegrates under uncertainty conditions.

(4) Agricultural production is a sequential process. Thus, the timing of inputs application must be explicitly incorporated. This aspect of agricultural production is not captured by the current profit function specification. Therefore, a more dynamic sequential analysis needs to be formulated.

(5) The model as presented is static, i.e. no specific time lags have been introduced to distinguish between short-run and long-run responses, whereas the objective of the study is to determine the factors governing the changes over time. This problem is tackled by developing a more dynamic empirical framework. The model as specified can only be used in a comparative static way.

(6) Imperfect knowledge of relevant technology and prices prevails among farmers. As a result, output at any point in time will deviate from the economic optimum. This is not accommodated by the current specification of the model.

(7) Another drawback of the theoretical model of profit maximizing farmers is that the effects of certain non-price factors such as irrigation, rural market development, and road infrastructure, on the farmers' inputs allocation decisions are not considered.

Problems of Econometric Specification

Several econometric specification problems are encountered when modelling the profit function:

(1) There is no theoretical method of deciding how

many inputs should be included. However, the number of variable inputs in the profit function is restricted by the non-availability of data on prices and quantity of input used. The data may not support the profit maximization theory if enough variable inputs are not specified. Another complicating feature is what variable cost should be subtracted from total revenue because the definitions of 'fixed' and 'variable' inputs lack clarity[8]. For instance, land is treated as a fixed input. However, farmers sometimes have a choice of either leasing out or leasing in land to alter the size of the farm. There is a choice of crop composition, i.e. allocation of land to different crops in the same season. Farmers can also choose how many crops to grow in a year and within a season how much land to leave fallow.

(2) The degree of product and input disaggregation that the profit function can conveniently handle is limited because greater disaggregation reduces the statistical degrees of freedom by increasing the number of parameters to be estimated. Theoretical restrictions need to be imposed in order to generate acceptable results. Most studies using this methodology have tested the validity of the restrictions through an F-test and found only a weak support for the hypothesis that farmers decisions are governed by profit maximization.

(3) There are problems of choosing an appropriate functional form. Economic theory imposes several

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[8] The treatment of a factor as fixed or as variable also implicitly determines the time frame of the computed supply response.

restrictions on the specification of the profit and input demand system of equations. These restrictions hold both within an equation and across equations. They include homogeneity in all prices, consistency of the input demand equations with the profit function, sign restrictions, symmetry, and constant returns to scale.[9]

Each functional form has its own advantages and limitations. For example, the Cobb Douglas production function lends computational ease. However, it is a very restrictive production formulation. Thus, it implicitly accords several restrictions on the profit function. These restrictions include:

(i) The absolute value of the own price input demand elasticity is greater than one.

(ii) All inputs are complementary because the Cobb Douglas production function embodies the restriction of unitary substitution elasticity between pairs of inputs.

(iii) Symmetry of cross price elasticities.

(iv) The effect of an increase in fixed input is the same on all variable inputs.

(v) Price elasticity of input demand with respect to output price is greater than one.

A more general translog profit function resolves these problems. However, an estimable translog

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[9] Note that if the production relationship exhibited increasing returns to scale, the model would break down because no profit maximum exists. Also, the symmetry constraints can be imposed only where price and quantity variables for both factors in any given factor pair.

profit function cannot be derived from a translog production function. Instead, a translog profit function can be postulated and the implicit input demand functions can be attained by assuming that the parameters of this function satisfy certain conditions on the production set. The translog profit function entails large computational costs and programming requirements. Nonetheless, this formulation leads to substantial gains in the degrees of freedom as it uses a time series and cross section data set at as disaggregated a level as possible.

This enormous data set requirement limits the applicability of this version of profit function. When the data set is incomplete, the translog profit function cannot be used. The normalized quadratic specification[10] solves the incomplete data set problem. However, this functional form suffers from the same limitation as the Cobb Douglas formulation—the symmetric impact of exogenous variables across input demand functions.

Problems of Data

Time series and cross sectional studies of profit functions require fairly detailed data on quantities and prices of outputs and inputs. As a result, many data problems surface.

(1) Problems in measurement of variables are frequently encountered. For example, in measuring fixed inputs like land, it is difficult to allow for quality

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[10] **This formulation involves the deflation of all price variables in the profit function by the output price. Consequently, the product price term on the right hand side collapses into the intercept term. Hence, the normalization procedure saves one degree of freedom.**

differences[11]. Similarly, problems are faced when measuring input prices especially labour, operator and hired labour are not substitutes. Operator labour performs mainly administrative and entrepreneurial activities, while hired labour is almost exclusively oriented to simpler manual work. Thus, operator and hired labour should be considered as separate inputs in the profit function. If there are by-products in production, profits cannot be clearly defined.

(2) When separate price index for some of the variables are not available, evaluating profits becomes difficult and the profit function cannot be estimated directly. When the data set is incomplete, we cannot use the translog formulation of the profit function. Also the homogeneity constraints are not testable. The equations for the missing factors have to be left out of the system. Symmetry constraints cannot be imposed as they require both price and quantity variables.

Missing quantity variables alone do not cause biases or inconsistencies in the set of coefficient estimates for the remaining equations. However, they make these estimates less efficient than those achievable in a full systems context. On the other hand, missing prices could introduce omitted variable problems. For instance, suppose the bullock labour prices are not available. Then, if the missing bullock labour price is correlated with any of the other prices included in the model, the coefficient estimates on these prices would be biased.

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[11] Orazem and Miranowski (1994) incorporate land quality differences when studying farmers' acreage allocation decisions.

Missing price data is especially a problem for the generalized Leontief formulation because own price elasticities are computed residually from all price coefficients in an equation. Thus, even if no missing variable bias arises for the included price coefficients, own elasticities may still be effected because the residual computation omits the possible non-zero coefficient of the missing price. If prices of competitive (complementary) outputs are not available, then the own price elasticity of output will be biased upwards (downwards). Similarly, if the prices of substitute (complement) inputs are missing, then the absolute value of the own price elasticity of the input will be biased upwards (downwards). If instead the output (input) price is omitted, then the direction of the bias in the own price elasticity of input (output) is indeterminate.

II.4d Application of the Profit Function Approach

Junankar (1980) believes that the profit maximization model does not explain the behaviour of farmers in developing countries because "it ignores the socio-political matrix within which they act and react", i.e. farmers in these countries are not price taking agents in competitive markets. Thus, Junankar suggests the use of an alternative framework which allows for concepts of class, power interlinkages and the role of social and institutional factors. His argument does not imply that farmers are irrational and do not pursue profits but perhaps it parallels Binswanger's (1980) view that farmers, especially in the semi-arid tropics, are risk averse and, therefore, their decisions are driven by utility maximization objectives rather than profit maximization motives. Nevertheless, the application of the profit function approach should be attempted—its results may at the least indicate whether farmers are governed largely by the profit maximization in their decision making.

A fundamental problem with this approach is that it approximates a farmer's behaviour. If all farmers are assumed to be alike, then aggregation to the district, state, or regional level is possible. However, in reality farmers are not homogenous. For instance, large and small farmers (or owner and tenant farmers) could differ in technical efficiency and/or price efficiency. As a result, their profit functions would differ.

The approach and the model specification must be chosen keeping in perspective the purpose of the study. If the objective of the study is to determine the causes for the observed cropping pattern changes and to forecast the possible changes in cropping patterns brought about by policy changes, then the profit function approach may not be applicable.

Most studies using the profit function approach treat land as a quasi-fixed input. Hence, they do not evaluate the elasticities of area allocation, i.e. the elasticity of demand for land in production. The typical profit function model can be represented as:

$$Max_{y,X}\ \Pi = \Sigma^{n}_{j=1} P_j y_j - \Sigma^{K}_{k=2} w_k X_k \qquad \ldots (1)$$

$$\text{subject to } y_j = f_j(X_{1j}, X_{2j}, \ldots, X_{kj}) \qquad j=1,\ldots\ldots,n \qquad \ldots(2)$$

$$\text{and } X_k = \Sigma^{n}_{j=1} X_{kj} \qquad k = 1,\ldots\ldots,K$$

where $\Sigma^{n}_{j=1} P_j y_j$ is the total revenue from all the crops produced and $\Sigma^{K}_{k=2} w_k X_k$ is the total variable costs of production, y_j denotes the output of crop j, X_k is the total quantity of input k used in the production of all crops, X_1 is the fixed input, i.e. land, P_j is the price of output j, while w_k is the price of variable input k.

The first order conditions of this maximization problem yield the system of unconditional output supply and factor demand equations:

$$X^*_{kj} = f_{kj}(P_1, P_2, \ldots, P_n, X_1, w_2, \ldots, w_k) \qquad \ldots(3)$$

$$Y^*_j = F_{kj}(P_1, P_2, \ldots, P_n, X_1, w_2, \ldots, w_k) \qquad \ldots(4)$$

where $j = 1, \ldots, n$ and $k = 2, \ldots, K$. Equation (3) is the input or factor demand function while equation (4) expresses the supply function. According to Brorsen and Adesina (1990)[12], if we are investigating acreage allocation decisions, then the relevant subset of equations is represented by expression (3), i.e. expression (3) can be rewritten so that the demand for land, X_1, is a function of prices of output and inputs and the quantity of inputs used in the production of crop j. However, X_1 is the fixed amount of land available for agricultural production. Thus, the problem of allocation of land to individual crops remains unresolved.

The problem of acreage allocation among various crops clearly requires the treatment of land as a variable input, i.e. area under cultivation can be shifted from production of one crop to another crop and, therefore, within crops or within different uses, land is a variable input. If land is incorporated as a variable input in the above maximization problem, then problems of omitted variable arise because appropriate rent on land or price of land data are not easily available. Besides, land cannot be regarded as a purely variable input in this multicrop profit function because unlike the other variable inputs—labour, fertilizer, etc., land cannot be assumed to exhibit a perfectly elastic supply. Perhaps, in a single crop profit function framework, land can be viewed as a fairly elastic variable input. However, this specification requires

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[12] **Brorsen and Adesina (1990) just use the profit function approach to provide theoretical support to the regressors included in a simple OLS regression of crop acreage.**

the cropwise input use data which is not complete giving rise to greater omitted variable problems. Moreover, as explained earlier, single output profit functions fail to capture the interdependencies among outputs and the differential impact of various outputs on factor demand.

II.4e Summary

In summary, changes in crop output can be attained via changes in yield, i.e. by varying the quantity of variable input used in production, and/or through changes in the area under the crop. The profit function approach measures the change in output supply obtained by altering the intensity of variable input use. This approach is one of the most comprehensive. It reveals the maximum number of policy and efficiency implications. While the Nerlovian model assumes that both the quantity of inputs and their prices are exogenously determined, the profit function recognizes the interdependencies between output supply and input demand and, therefore, endogenizes the quantity of input used in production. As discussed above, the profit function incorporates total cultivated area as a fixed variable. Thus, the elasticity of demand for land cannot be evaluated. As a result, the profit function framework is not applicable in acreage allocation studies.[13]

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[13] Orazem and Miranowski (1994) derive structural equations of farmer's acreage allocation from an underlying dynamic profit maximization model. This model assumes that farmers base their land allocation decisions on their beliefs about the effect of current crop mix on the productivity in the subsequent year. Land is incorporated as a variable input, while soil is considered to behave like capital (a quasi-fixed input) which can depreciate and some investment is required to maintain the stock. Soil capital cannot be observed. However, individual farmers have information in their soil's productivity. The model's structural parameters reveal information on the relative stock of soil capital across regions, the relative effects of different crops on soil capital, and the relative crop-specific productivity of a unit of soil capital. The estimated parameters reflect neithter the individual effects of the variable inputs, such as fertilizers, herbicides, pesticides, etc., used in production nor the impact of input prices on output supply or on acreage allocation. Thus, this specification yields fewer policy implications.

III. Models Attributing Supply Responsiveness to Just Non-price Factors

III.1 Frontier Production Function Approach

The frontier production function approach assesses a firm's performance in terms of technical efficiency. The approach is based on the premise that technical efficiency is one of the two components of economic efficiency—the other being allocative efficiency, i.e. economic efficiency is the product of technical and allocative efficiencies. Thus, a farmer who is both technically as well as allocatively efficient is also economically efficient. Technical efficiency is the ability and the willingness of producers to obtain the maximum output at a given level of conventional inputs and technology. In other words, technical efficiency is a measure of how far below the frontier production function—the maximum possible potential output function—is the agent operating. Allocative efficiency is defined as "the ability to obtain the maximum profits from the application of conventional inputs given a set of firm-specific input and output prices and a given technology."[14] Thus, allocative efficiency measures the movement away from the profit maximization point along the production function.

In less developed countries, it is generally accepted that allocative efficiency drives economic growth, i.e. allocative inefficiencies constrain economic growth. In these countries policy priorities for agricultural development have been oriented towards availability and price of modern factors of

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[14] Shand and Kalirajan (1993).

production and towards the acquisition of new technology. However, in the achievement of high levels of economic efficiency over time, allocative efficiency may not be a major impediment. Shand and Kalirajan (1993) among others have found a unidirectional causality from technical efficiency to allocative efficiency. Gains in technical efficiency are a prerequisite to achieving greater allocative efficiency. Therefore, technical efficiency is of critical importance for increasing production and for economic progress. Moreover, the lack of prospects for productivity augmenting technological breakthroughs rules out the possibility of a substantial outward shift of the production frontier in the near future. This implies that the gains in technical efficiency or the realization of the true potential of the current technology is essential for economic growth.

The frontier production function approach is used to determine the level of technical efficiency. A farm-specific stochastic Cobb Douglas production frontier involving outputs and inputs is defined as

$$y_i^* = f(x_i)exp(v_i)$$

where x_i is a vector of m inputs; v_i is the statistical random error that follows a standard normal distribution with mean zero and variance σ_v^2; y_i^* is the maximum possible potential output for the ith farm which varies over time for the same farm and across farms in the same period.

Farmers do not know the exact value of the parameters of their own frontier production function. This lack of knowledge causes farmers to behave in a technically inefficient manner. Consequently, the actual production function of the ith farm can be expressed as:

$$y_i = y_i^* exp(u_i)$$

where $exp(u_i)$ captures the observed technical efficiency of the ith farm. It is assumed that $u_i \leq 0$. When $u_i = 0$, the ith farm is technically fully efficient and operates on the frontier production function. On the other hand, when $u_i < 0$, the farm is not fully technically efficient and produces less than its potential output.

Now, technical efficiency can be defined as:

$$exp(u_i) = (y_i, \text{ given } u_i)/(y_i^*, \text{ given } u_i = 0)$$

where the denominator must be estimated while the numerator is the observed output level. To obtain the denominator, a functional form representing the technology and a density function for u need to be assumed. The denominator can then be estimated using the maximum likelihood method.

III.1a Limitations of the Approach

The stochastic frontier production function approach has several limitations. These include the following:

(1) Technology is represented by some ad hoc functional form involving outputs and inputs. As a result, this approach is restrictive.

(2) There is no theoretical method for choosing the density function for u_i.

(3) The frontier production function is defined as a neutral shift from the actual production function. A neutral shift implies constant slope and variable intercept of the production frontier. This is not consistent with the definition of technical efficiency which is determined by the input application techniques rather than by the levels of inputs used. Therefore, the slope coefficients will vary from agent to agent.

(4) Technical efficiency is considered as a lump-sum increase in output.

Statistical tests can be conducted to validate the selection of functional forms and the distributional assumptions for u_i, while, a modified random coefficients model can be used to accommodate non-neutral shift of the frontier from the actual production function. The GLS technique can be employed for estimation.

The modified random coefficients model assumes that technical efficiency is achieved via best practice techniques which require efficient use of inputs rather than an increase in the levels of inputs. Technical efficiency stems from two sources: *(i)* from the efficient use of each input—the contribution of each input to technical efficiency is captured by the magnitudes of the variable slope coefficients, and *(ii)* from the combined effects of all efficiently employed inputs over and above their individual contribution. This is measured by the variable intercept term.

The highest magnitude of each response coefficient and the intercept form the production coefficients of the potential frontier production function. This modified approach also enables the estimation of input-specific efficiency.

III.1b Summary

The frontier production function approach generates several policy implications. By enabling the measurement of the level of technical efficiency, it helps policy-makers decide what policy changes are required to raise the production to the maximum possible potential with a given technology and limited inputs. However, this approach alone cannot portray the true supply response picture as the supply of output is determined simultaneously with input demand equations.

Although technical efficiency may be a greater constraint to economic growth, full technical efficiency by itself cannot ensure the potential economic growth. Farmers may be operating on the production frontier, but unless the scarce resources are efficiently allocated potential economic growth cannot be realized. Allocative efficiency is directly measured by the profit function approach. However, on the other extreme, this approach considers farmers to be technically efficient.

IV. Conclusion

As summarized by the chart, each model caters to the specific requirements of individual investigations. If the objective of the analysis is only short-term forecasting perhaps the Nerlovian model is the most appropriate as it lends significant computational ease. For long-term prediction of cropping pattern changes, the multinomial logit framework is perhaps the best approach to employ because it not only ensures non-negative crop acreage shares but it also forces these shares to sum to one. To separate individual cross-sectional unit effects, the time series-cross section models can be used.

When the purpose of the study stretches beyond merely forecasting to analysing policy effects, the Nerlovian model, the frontier production function methodology or the profit function approach can be applied. Although the Nerlovian model assesses overall economic efficiency, its major drawback is that it assumes that both the quantity of inputs and their prices are exogenously determined, when, in actuality, output supply and input demand decisions are made simultaneously. This characteristic restricts the number of policy implications that can be drawn from the analysis.

Each of the later two models—the profit function and the frontier production function frameworks, isolates a different component of economic efficiency. The frontier production function approach assumes that the technical efficiency component constraints economic growth. Thus, by providing a measure of currently prevailing technical efficiency, the analysis helps advocate policy reforms (such as measures to enhance farmers' knowledge of the technology) to improve technical efficiency and, hence, supply response. The profit function approach, on the other hand, assumes full technical efficiency and considers allocative inefficiency to be the major barrier to economic growth. This approach recognizes the interdependencies between output supply and input demand. Therefore, the policy lessons drawn from this analysis concentrate on achieving higher level of allocative efficiency (through incentive structures devised to encourage the allocation of the economy's resources in the most efficient manner). As both allocative and technical efficiencies compose economic efficiency, a complete comprehensive analysis can only be conducted by employing both these models.

Summary Chart

Model	*Application*	*Assumptions*	*Estimation Procedure*	*Major Merits*	*Limitations*	*Policy Implications Revealed*
Nerlovian	(a) Acreage allocation (b) Output response. Measures supply response to both price and non-price factors	• Quantity and price of input are exogenously determined. • Farmers continuously adjust the crop area over time. • Farmers base their land allocation and output supply decisions on their expectations of future crop prices.	OLS or SURE	• Simple direct parameter estimation. • Little data requirements and computational ease.	(a) Nature of estimated elasticities such that forecasted shares of crop acreage will not sum to one (b) Ignores simultaneity between output supply and input demand decisions.	• Short-term forecasting of changes in: (a) crop acreage, (b) output supply. • Longer-term prediction in case of supplementary enterprises. • Economic efficiency implications.

Model	*Application*	*Assumptions*	*Estimation Procedure*	*Major Merits*	*Limitations*	*Policy Implications Revealed*
Multinomial logit	(a) Acreage allocation. Can determine acreage response to both price and non-price factors.	• Allocation of gross cropped area among a number of alternative crops can be represented as a process of allocating shares of gross cropped area to different crops. • The same crop compete for area year after year. • These crops do not compete with any other crops for area.	Maximum. Likelihood methods. Zellner's SURE method.	Ensures that shares of crop acreage in total area sum to one.	Definition of total area on the basis of which crop shares are evaluated holds only under certain restrictive conditions.	Long-term forecasting of changes in crop acreage shares.

Model	*Application*	*Assumptions*	*Estimation Procedure*	*Major Merits*	*Limitations*	*Policy Implications Revealed*
Time series-cross section • Fixed effects. • Random effects/ error components model.	(a) Acreage allocation. (b) Output response. May be applied to both types of models, i.e. models attributing supply responsiveness to non-price factors and models ascribing the supply response to price as well.	• Fixed effects model: economic relationship of a non-dynamic nature. • Random effects model: random error associated with each cross sectional unit independent of not only one another but also uncorrelated with other regressors.	• Fixed effects model: OLS estimation. • Random effects model: MLE method used if variance co-variance matrix of residuals known otherwise Zellner's two-stage estimation technique.	• Enhances the degrees of freedom improves precision of estimates. • Enables the estimation of effects associated with a particular dimension of data set.	• Fixed effect model: treats individual cross-sectional unit and time effects as constant parameter which is not true in models of dynamic nature. • Random effects model: ignore the possibility of correlation among the error components and their correlation with the other regressors. • Both types of models do not guarantee that crop acreage shares sum to one; they also ignore the simultaneity between ouput supply and factor demand decisions.	Used for forecasting purposes.

Model	*Application*	*Assumptions*	*Estimation Procedure*	*Major Merits*	*Limitations*	*Policy Implications Revealed*
Profit Function	Output response. Measures the supply response to both price and non-price factors.	• Farmers are profit maximizing agents. • Farmers are price takers in both output and variable inputs markets. • Markets are fully developed. • Farmers are technically efficient. • Farmers' production function is concave in variable inputs.	Zellner's SURE method	Considers the simultaneity between output supply and input demand decisions.	• Ignores technical efficiency. • Highly disaggregate data set required.	• Analysing farmer behaviour. • Evaluating the productivity and/or equity impact of technological changes or policy modifications. • Impact of price policy changes.

Model	*Application*	*Assumptions*	*Estimation Procedure*	*Major Merits*	*Limitations*	*Policy Implications Revealed*
Frontier Production Function	Output response. Measures the supply response to non-price factors alone	• Economic efficiency is a product of technical and allocative efficiencies. • There is a unidirectional causality from technical to allocative efficiency. • Technical efficiency stems from two sources: the efficient use of each input and the combined effect of all efficiently used inputs. • Farmers are allocatively efficient.	GLS	Provides a measure for technical efficiency	Ignores simultaneity between output supply and input demand decisions.	Determines policy changes required to raise production to the maximum possible potential with current levels of inputs and given technology.

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