CHAPTER I

THE ANALYTICAL MODEL

In the earlier chapter, we have already defined the scope of our study as dealing with only one aspect of the problems of resources management, viz. the allocation of the existing resources in agriculture, over various crops (Product-Product relationship). A brief review of the existing literature on resource allocation in agriculture would be helpful for choosing the appropriate analytical model and corresponding method of measuring the relevant variables and collecting the data required. The present chapter is devoted to this end. This describes various techniques used for analysing resource allocation and their relative suitability vis-a-vis the objectives of the present study.

I Approaches to the Study of Resource Allocation in Agriculture

Agricultural economists who have studied the problem of resource allocation can be broadly grouped into three categories, namely: (i) those using production function approach, (ii) those using farm Budgeting approach, and (iii) those using Programming techniques.

The production function approach: It consists of the following. A relation between output and the various inputs used in production is fitted to the given set of observations.
Marginal products of various inputs are estimated and compared. The equality between the marginal products is considered as a condition of optimum allocation of resources. A departure from this equality is then examined to determine the direction in which the various inputs should be changed for an improved allocation of resources. Several research workers in India and abroad have made use of this method for studying resource allocation in agriculture.

**FARM BUDGETING APPROACH:** Farm Budget is an expression of a farm plan of the crops to be grown, practices to be adopted...

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1. The most popular production function fitted to farm data is the Cobb-Douglas type production function. For reasons of its popularity, see Tintner [295], Head [112], Head and Dillon [118, pp. 24-25], Head, Johnson and Hardin (ed) [117, Chap. I]. Other functions are: linear functions, Spillman Function, Quadratic Function, Hyperbolic Function etc. See Head and Dillon [118, Ch. 1]. Also see Head, Johnson and Hardin (ed) [117, Chap. I]. Also see I.C.S.S.R. [129, pp. 26-7].

2. Some of the research workers using production function approach for studying resource allocation in Indian agriculture are Sahota [236], Naik [196], Santhavan and Sirohi [240], Chennareddy [40], Acharya [1], Raj Krishna [216], Raj [225], Nag and Singh [195], Crow and Nagdeva [48], Desai [55], Chowdhari and Tripathi [43, 52, 53], Saini [237], Desai and Doshi [59], Khuero [153], Melello and Desai [227], Kahlon and Karan Singh [142], Jai Krishna [134], Radha Krishna [211], Driver and Desai [57], Singh and Pandey [270], Koppe [124], Ram Saran [217], Chowdhari and Desai [42]. Also see Ministry of Food and Agriculture, Government of India [88]. Also see Soni [280], Desai and Husumdar [60].

3. For a review of the progressive application of this technique to farm data in various countries, see Head and Dillon [118, Ch. I]. Some of recent studies using production function approach, conducted by research workers outside India are those of Rasmussen [226], Hum [126], Tyner and Twe installed [296], Delworth and Fulbrom [53], Hayami [109], Sadan [235], Totopoulou and Lau [309], Torgason and Spears [309].
in their production, total inputs to be used, other activities to be undertaken, etc. in monetary terms. It estimates 'the receipts, expenses and net income' from a given farm plan. John and Kapur, 1972, p. 212. By preparing alternative farm plans and estimating the receipts and expenditure pertaining to each plan, one can arrive at the best plan.

Farm budgeting is of two types: partial budgeting or enterprise budgeting and complete budgeting. Partial budgeting, relates to estimation of return from different plans concerning one or two activities on a farm e.g. regarding the production of one single crop. Complete budgeting considers the farm as a whole -- all the resources and activities being simultaneously considered. Thus, partial budgeting, is useful for knowing the effects of only small changes in the farm plan. A big change in one activity is likely to disturb the other parts of the total farm plan since the resources at the disposal of the farmer are limited and the various crops on a farm are either complementary, supplementary or competitive. One has thus to move on to the complete budgeting if the full effects of the reframed farm plan have to be estimated. Only a few research workers have used it in India for studying resource allocation.

Linear Programming: This approach is quite popular with the farm economists for studying allocation of resources. It is a systematic method of determining the optimum combination of activities or inputs so as to maximise the income or minimise

the cost within the limits of available resources.\footnote{This technique was evolved by Dantzig during the second world war out of a necessity to specify ship routes for (a) quickest movement, and (b) least cost of distribution of supplies on various war fronts. Since then the technique has found a large number of applications. Many texts have been written on Linear programming. Some of these are: Adams \[37\], Dalclembo and Bell \[48\], Dorfman, Samuelson and Solow \[65\], Driebeek \[66\], Gass \[62\], Gale \[72\], Kim \[74\], Spivey \[28\], Heady and Candler \[116\], Hadley \[103\], Dantzig \[50\], Arrow \[6\], Boulding and Spivey \[29\].}

In mathematical terms, we can set the problem to be solved by linear programming method as follows (assuming we are faced with a maximising problem):

\[
\begin{align*}
\text{Max } & \quad Z = c^T x \\
\text{Subject to } & \quad Ax \leq b \quad \text{and} \\
& \quad x \geq 0
\end{align*}
\]

Where \( c \) is column vector representing coefficients of the objective function; \( x \) is the column vector representing the activities; \( A \) is the technical coefficient matrix and \( b \) is the constraint column vector.

After the standard algorithm for linear programming was evolved, it began to be progressively used in industry as well as in agriculture. Agriculture actually turned out to be a better field for its application because of its being closer to the model of perfectly competitive industry. This almost ensured single valued expectations for each farmer about the prices of the products as well as of inputs. Multi-product nature of the farm also increased the scope of the application of this method to agriculture.
Heady \(113,7\) appears to be the first agricultural economist to suggest and attempt the application of linear programming to resource management in agriculture. Since then, the method has been progressively applied to see whether the available resources have been optimally utilised on a farm or not. Linear programming has been used by many agricultural economists in India.\(^1\)

All the studies, referred to above, have applied linear programming model to a farm or a group of farms. The difference has been mainly in the nature of resource constraints or activities considered. This method continues to be popular even now for study of misallocation of resources.\(^2\)

During the later half of fifties and after, we find agricultural research workers using the techniques of linear programming technique or suggesting the application of such a technique to agriculture in countries other than India for arriving at an optimum farm plan are those conducted by Heady\(113,7\), Candler \(31, 190\), Miller \(190\), Giaeyer and Seagraves \(85\), Hall \(189\), Swanson \(286, 7\), Vincent \(298\), Candler and Manning \(35\), Finthei Shtein \(74\), Craddock \(45\), Heady and Candler \(116\), Candler and Musgrave \(34\), Chewt \(41\).

\(^1\) Desai \(56, 57, 58\), Aggrawal \(67\), Radha Krishna \(212\), Soni \(277\), Kahlon and Johl \(142, 144\), Kahlon and Sharma \(137\), Johl and Kahlon \(137\), Jai Kishan \(133\), Malviya \(173\), Pant \(204\), Handhava and Heady \(219\), Musumder \(194\), Singh, Verma and Singh \(274\), Raj Krishna \(215\), Oulgani and Sirohi \(104\), Mann, Moore and Johl \(175\), Dhawan and Kahlon \(61, 62\), Dahiya \(49\), Singh and Jha \(273\), Sankhayan and Sidhu \(242\).

\(^2\) Some of the studies applying pure linear programming technique or suggesting the application of such a technique to agriculture in countries other than India for arriving at an optimum farm plan are those conducted by Heady \(113\), Candler \(31\), Miller \(190\), Giaeyer and Seagraves \(85\), Hall \(189\), Swanson \(286\), Vincent \(298\), Candler and Manning \(35\), Finthei Shtein \(74\), Craddock \(45\), Heady and Candler \(116\), Candler and Musgrave \(34\), Chewt \(41\).
programming for some other purposes as well. Some of them, for example, have tried to study the impact of alternative technologies on agricultural production. For this purpose, they have studied the difference between the optimum plans that would emerge when different technologies were used. The optimum plans were obtained with the help of linear programming method. One such study was made by Coffey. The author has assumed four sets of technical coefficients for each of the 9 crops considered: one set reflecting the existing input-output relations in the region, the second set indicating the highest level of efficiency under experimental conditions in the region and the other two representing the intermediate levels between the two. Resource availability for the region as a whole was estimated. The problem dealt with, is rather huge. The author has used 62 restrictions and 150 real activities. Another such study has been conducted by Mann, Morre and Johl for the State of Punjab (India). They divided the state into 10 regions and then in each region selected 5 small farms, 5 medium farms and 5 large farms. Farms in each size group for each region were then synthesised. Linear programming as well as budgeting method was used for each synthesised farm with different technical co-efficient matrices, each representing a different level of technology. They have concluded that the potential contribution of any single improvement in technique towards increase in production and net

1 See also Garg and Singh, Kahlon and Sharma, Singh and Jha.
income of Indian farmers is rather limited. Goodwin, Blase and Colyer have gone a step further. They have used linear programming for developing a methodology which could enable a farm planner to carve out a path of technological change traced through time in the development process. The methodology combines Programme Evaluation and Review Technique (PERT) and coordination technique with linear programming. In their study, they arrange the systems of production on various farms under study into 8 groups in ascending order according to the technique used. The object of their study was to draw up a plan to shift 50 per cent of the farmers to a higher system of production at the end of 5 years and to see the impact of this change on total output.

Another important application of linear programming has been to find out the response of the supply of a particular crop to changes in its price. The process has been to prepare a linear programming model for a region (aggregate or for individual farms — aggregated afterwards) and record the supply for a particular crop at a given price under the optimum plan. Then a step by step change in the price of that particular crop is allowed and new optimum plans determined with changed prices of the particular crop (of course, with the same resource constraints and same technical coefficients). A supply schedule for a particular crop is thus evolved. As the composition of output in the optimum plans obtained from linear

1 See also Eickhorst, Erickson and Scott. Jr. They too, use the linear programming approach for a type of sequential planning.
programming solutions may remain unchanged for a certain range of relative prices; one is likely to find the same amount of supply of the crop in question at more than one level of its price. Because of this feature of the supply response to price change, the supply function obtained through the method of linear programming has been called a 'step supply function'.

Candler [32] used this method in 1957. Since then, many research workers have derived step supply function for agriculture commodities through linear programming technique.

Heady, Hayis and Madsen [119] have extended the application of linear programming technique to yet another problem. They have used linear programming approach (alongwith simulation model technique) for exploring alternative ways of designing price support programme for commercial agriculture.

It is pertinent here to note that linear programming is based on two important assumptions. These are (1) the objective function as well as the input-output relations, for each activity are linear in character; and (2) the expectations are single valued.

Both these assumptions may not be met in practice. The objective function may not be linear; the input-output relation

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1 See Baker, Lancham, and Cowling [127], Knutson and Conchrame [148], Ladd and Basby [159], Moke and Loftgard [182], McPherson and Paris [184], Toussaint [294], Steeval [282], Sheehy and Mc Alexander [264].

2 The other important assumptions are (1) divisibility (2) additivity and (3) finiteness. See Heady and Candler [116], pp. 17-18.
may also bo non-linear. These relations may also be marked by an element of uncertainty. The programming model accordingly needs modification. Efforts in this direction have led to the development of non-linear (Stochastic and non-Stochastic) programming. However, non availability of satisfactory data and computational difficulties stand in the way of large scale application of non-linear programming to farm data in India.

II The Appropriate Approach

We have so far described various approaches which have been followed by various farm economists, for studying misallocation of resources. We may summarise the implications of the main points for and against each of these techniques for their applicability to the present study.

The production function approach is not suitable for the purpose of the present study. Various econometricians are of the view that due to the possibility of wrong specification of independent variables, unsatisfactory basis of aggregation

For Stochastic programming models, see Herrin /188/, Heady and Candler /116/, Ch. 17, /32/, Stovall /284/, Bussard and Petit /30/, Scott and Baker /246/, Chen /39/.

Most of these writers introduce randomness in the linear programming models, either in the objective function or in resource constraints. Sensing difficulty in evolving satisfactory probability distributions needed in these cases, some writers keep the independent operation of linear programming in fact. They however, subject the results obtained through linear programming to the operation of certain game theoretic models to allow for the impact of the uncertainty on the final outcome. See Tadros and Casler /268/, Walker, Heady, Tweeten and Pesek /301/, McInerney /181/, Hanell /110/. See also Agrawal and Heady /7/ for a new game theoretic model. For non-linear programming
of various inputs to define a single independent variable, aggregation of output to define a single dependent variable, and wrong selection of the production function, the findings of this approach may not be dependable. This applies with much greater force to agriculture where input and output composition varies considerably from farm to farm. As Eisgruber and Schuman have pointed out, the aggregation of data which is a necessary part of the production function technique ignores all possible variabilities at the farm level and "hence may conceal even relationships which are of significance".

Kislev lists some other problems which make a production function method completely unsuitable for planning at the farm level. These are: (a) constraints on activities and resources, which a particular farmer has to deliberately impose or helplessly face, (b) inequalities which a farmer experiences in actual life and (c) only a finite number of alternatives that a farmer has, so far as use of inputs is concerned. Further, the results based upon the performance of a group as a whole may not be a useful guide if a policy for one constituent of that group is to be devised.

1 See Green, Schmitz, Theil.

2 See Heady and Dillon, Shah, Johl and Kapur.
This technique, besides the limitations cited above is not suitable for a study of resource allocation with reference to the product-product relationship because of the following reasons. Allocation studies based on production function approach generally aggregate the value of all crops on a farm on the one hand (dependent variable) and the value or quantity of input/inputs used for different crops (independent variable) on the other. Thus, the production function approach is used basically to study the allocation of resources from the point of view of factor-product and factor-factor relationships and not the product-product relationship.

Farm Budgeting technique does satisfy this requirement. It is quite suitable for micro analysis. But when its relative importance is judged in comparison with the linear programming technique, the verdict is in favour of the latter. No doubt, both the techniques are based upon the same assumptions. However, whereas the farm budgeting method is crude, the linear programming technique is quite sophisticated. Farm budgeting fails to handle the problem of resource allocation satisfactorily when the number of activities in the initial plan becomes rather large. The computational difficulties appear. Moreover, this


2 For product-product relationship, instead of aggregating the value of all crops and the value/quantity of corresponding inputs, one could fit production function to the different crops separately. Then a study of the marginal productivities of various inputs for different crops, could indicate the shifting of inputs from one crop to another. But this will not indicate how the crop mix on a particular farm will change under
method had nothing in it to indicate whether the alternative plan hit upon, is really the optimum plan or not. One can know about it only by drawing all other plans that can possibly be framed under the given resource constraints and technique. To quote Heady [113, p.1035], "Budgeting is seldom used to find the one unique production programme, out of many which gives maximum profits. Ordinarily, it is used to determine which one of the two producing methods or farm organisations are best. The many other alternative organisations are not examined... (Moreover), Linear programming also can dip deeper into the problems*. The linear programming method, thus can claim to overcome both of these difficulties. It can indicate a unique optimum plan. Due to availability of computer programmes, a large number of activities in the initial plan does not create any problem.

Heady and Candler [116, p.197] refer to an operational defect from which farm budgeting technique is likely to suffer. To quote them, "Linear Programming procedure will cause most analysts to consider carefully the accuracy and reasonableness of their data and model. This is true because the data as well as the assumptions underlying the resource situation and planning objective, are brought out into the open through the model used. They are brought out into the open, as compared to budgeting because they must be set forth explicitly for

(2 pre-page contd.) optimum allocation. The conclusions arrived at through this approach are diagnostic in character and are valid only at the macro level. The shifts in inputs, suggested by this technique will not be always valid at the farm level.
computational procedures. In budgeting, basic data and assumptions can be less formal and need not be set out explicitly. They are seldom stated in empirical form. For this reason, the inadequacy of data and assumptions are more likely to go undetected in budgeting studies." According to one economist Shastri: 263-7, farm budgeting may be more suitable for Indian farmers, in view of their illiteracy. This is a valid argument. But it cannot be extended to an investigator who is interested in the scientific study of allocation of resources in agriculture.

The summary of the arguments, as they exist in the literature and their implications for our study is now complete. This favours a linear programming model for the problem, we wish to embark upon. However, it must be emphasised that much of the theoretical discussion regarding relative superiority of the techniques is really redundant, since the three approaches are not mutually exclusive. The production function approach and linear programming approach are essentially similar optimization approaches. The so called production function approach, although quite general, suffers from the difficulties of Lagrange multiplier technique (indivisibility, non negativity and inequality). The linear programming approach gets over these difficulties but only at the cost of assuming fixed input-input ratio and fixed input-output ratio and thereby making the production function underlying the linear programming model less general. Both these approaches can be used to improve farm budgeting which in its present
form is very crude and based on trial and error and guess work. As we explain below, the linearity of the objective function and constraints may be safely assumed for the data we are going to deal with! The choice of linear programming as a technique of analysis will thus look natural.

The linear programming technique, however, should be used with caution. Selection of right type of resource constraints and activities, realistic technical coefficients and reasonable prices is a must [Ready and Candler: 116, Ch.6]. There is also a need to take precautions so as to avoid the aggregation bias which may creep into the results when an attempt is made to prepare one single input-output matrix for the whole region. We are specifically referring to this precaution because some farm economists have actually adopted this approach. We have already referred to Coffey's study, [44]. Mann, Moore and Johl [175] have also followed the same technique. Some other studies too, make use of aggregated model for finding out the optimum values through linear programming.

R. Day [52] has expressed doubts about the logic of using a single input-output matrix (of a representative farm) for finding out the total optimum output of the group.

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1 We have explained the basis of this assumption on page 35-36.

2 See R. Day [52]. He refers to many such studies being conducted in the Farm Production Economists Division of the United States of America. See also Desai [58].
of the farms. He has cautioned the users of linear programming technique about the fact that it is only under certain suitable conditions that a single linear programming model for the aggregate is equivalent to the direct aggregating of the solutions of individual farm models. These conditions are (a) the proportional variation of all resources or 'behavioural bounds' of various farms; (b) proportional variations in the net return expectations among all farms and finally a common technical coefficient matrix for all firms. If these conditions exist, then (a) the decision variable in the primal solution for different farms will be proportional to the variation in resource constraints and (b) the decision variable in the dual (i.e. marginal net productivity of the scarce factors for various firms) will be in the same ratio in which the net returns stand. If these conditions are fulfilled, it is possible to aggregate the constraints and find out an objective function based upon the weighted average of various objective functions (he gives a technique to develop the weights). An optimum solution based upon this aggregated model will be equal to the aggregate of the optima of various individual models.

R. Day recommends more refined categorisation of the sample farms, stratifying farms into much smaller typical farm aggregates than is now being done, if realistic aggregate results from adding up the solution of these typical farm models are to be obtained. He emphasised the importance of resource proportionalities as the basis of classification.
This caution is of great importance to a farm planner. Not only are the technical coefficients in the same area generally different from farm to farm but also the constraints as well as the objective functions are not (rather never) proportional. As far as possible, when a group of farms is to be studied, linear models for each separate farm should be prepared. Day's study especially cautions us about extending the results achieved under experimental conditions to the region as a whole.

Day's analysis refers to the aggregation bias in the optimum values of net returns for a group of farms. Hartley has discussed the aggregation bias in the step supply functions derived with the help of linear programming. According to him a careless sampling design could lead to a serious aggregation bias, particularly near the extreme end of price range. (An aggregation bias in the supply response is the difference that would arise in the total supply computed by actually studying all the farms and that estimated for all the farms with the help of the performance of typical and benchmark farms.) The reason for this bias according to him, was the defective classification for delineating homogeneous groups of farms.

1 See also Day, Lee M. While reviewing R. Day's work, he proposes that the relationship between the bias and variance in resource proportionalities should be quantified, so as to enable better judgement to be made in constructing benchmark farms.
To overcome this bias, Sheehy and McAlexander considered various methods of classification of farms. Farms could be classified either according to the absolute amount of the resources available on these farms or according to their relative scarcity. They are of the view that grouping of farms according to the most scarce factors would give the least aggregation bias. Frick and Andrews tried four methods of grouping the farms under study for deriving a step supply function free from aggregation bias and finally support Sheehy and McAlexander.

These methods are as follows:

(a) Average farm for the region: This was developed by taking the mean of the resources and output of the farms in the sample. Supply response was studied according to the method of linear programming for a particular commodity and the results multiplied by the number of farms in the universe.

(b) Farms were classified into 6 groups according to their size. Mean size of the farm in each group was then determined; supply function for each group was then obtained and then all the supply functions were aggregated.

(c) Homogeneous restriction method: According to this method, the authors in the first instance found out the most limiting factor on a farm by dividing the quantity of each one of the available resources on a farm by the appropriate coefficient in the technology matrix. "This formed a primary basis for classification, based on the order in which each resource was restrictive". After grouping the farms according to the most limiting resource, procedure as indicated in (a) was followed.

(d) The potential size of the farm criterion: Potential size of the farm was found by dividing the available
Kottke [157], however, expressed his doubts about the derivation of such supply functions at the aggregate level unless the interdependencies of farms and the diversity of long run situations at the aggregate level are incorporated in the analysis.

III Our Approach

We have indicated our choice of linear programming earlier. We decided to prepare input-output matrix for each farm separately. The objective functions for each farm as well as the technical co-efficients for various crop sown on it, were based upon the actual inputs used and actual output produced. This procedure helped in avoiding the possible aggregation errors, besides making it possible to study each farm in detail. Further it was felt that the assumptions of linear programming technique would be quite reasonable when resource allocation was studied for each farm separately. On a given farm operated by the same manager-farmer, with same farm practices, and

(1 prep-page contd.) land on a farm by the technical coefficient relevant to the commodity in question. Grouping of farms could then be formed according to their potential size. Supply response function would then be found according to the method used in (b).

(2 prep-page contd). For a few other suggestions for avoiding aggregation bias, see Barker and Stantam [16], Bolton [27], Thompson [292]. Also see Stovall [283] for various causes responsible for errors in step supply function.
under same agro-climatic and environmental surroundings, the output of a crop is likely to change in the same proportion as the input till its availability limit is reached, even if it may not hold good for the group of farms as a whole. Also price of inputs/outputs may be taken to be constant for any individual farm in view of their large number.

Though we took precaution to reduce the impact of non-linearity to the minimum, we could not do anything to find out the optimum returns of a farm on the assumption of uncertainty. That optimum may be different from the one based upon a single valued expectation. The misallocation too, would have been accordingly different. We could not have a stochastic programming due to non-availability of necessary data. Our study of misallocation is thus based upon the assumption of complete certainty in input-output relations. This is a limitation from which the present study (like many others) suffers.

1 See Heady 114, p.83. See also Flaxico 208, pp. 1049. He says, "Consequently, I would conclude that the linearity assumption of linear programming does not limit the usefulness of the method in Farm Management Production Economics."