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Linear Programming in Subsistence Agriculture

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ABSTRACT:

This paper examines the use of mathematical programming models in subsistence agriculture as an example of the use of operational research in developing countries. Differences from developed agriculture are described, and five mathematical programming formulations to cater for the major differences are given. Examples of the use of such models in published literature to produce policy oriented conclusions are summarized. This exemplified a more general point that mathematical OP formulations are relevant to policy issues in developing countries providing they are modifications of formulations used in developed countries.

1. INTRODUCTION

Various views have been expressed on the question of the applicability of operational research in developing countries. On the question of which techniques might be useful McCarthy (1978) states :" If O.R. is to be of use in developing countries, it must eschew tedious mathematical techniques in favour of simple logical models…..(e.g) decision tree analysis, network analysis and strategic risk analysis."

On the question of transferring experience from developed to developing countries Ackoff (1965) states " Most applications of OR in developed countries are relevant to developing countries although some adaptation to local conditions is usually required/" whilst Walsham (1978) states " Operational research has been applied primarily in developed countries and it is not immediately obvious that the approach will prove useful in developing countries."

It is the purpose of this paper to set these general statements against the specific example of mathematical programming applied to agriculture. It will be shown that this is a mathematical technique (i.e. it is not of the type suggested by MCCarthy) that has been successfully applied to agriculture in developing countries. But that when it is applied to subsistence farming (the vast majority of agriculture in developing countries), substantial modifications are required in both the formulation of the problem and also in the way the results are used. Just as the transference of technology from developed to developing countries requires " Appropriate Technology". So the transference of OR requires, in this case "Appropriate OR.".

2. AGRICULTURE IN DEVELOPING COUNTRIES

Agriculture development projects with massive inputs of capital in the construction of irrigation systems and employing high levels of utilization of purchased inputs (e.g. fertilizer) and mechanization about in developing countries. However the vast majority of agriculture is done by small farmers, many living at subsistence level. Wharton (1969) estimates that about half the world's population are dependent on subsistence agriculture and Szczepanik (1979) compares the least developed countries with the most developed ones as follows:

	Least developed	Most developed
Average size of agriculture holdings	3ha	70 ha
Number of tractors per 100000 ha	3.6	30
Fertilizer input per ha public credit as % agricultural	1kg	100 kg
Gross domestic product	8.5%	13%

Thus, for OP to be real useful in agriculture in developing countries, it must demonstrate its applicability to small, subsistence farmers with low levels of mechanization, purchased inputs and credit availability rather than transferring its techniques directly from developed commercial agriculture to isolated agricultural development projects. There are many aspects modification to the normal mathematical programming model.

(i). Uncertaity (in prices and yields) is sometimes dealt with in commercial agriculture by maximizing average return subject to a limit on its variance. This approach is not suitable for a subsistence farmer who must guarantee his survival in the worst conditions even if his position, on average is not much better. This is the basic reason for the failures of the "Green Revolution" with crop varieties that give high yields in good or average conditions but extremely poor yields in bad conditions. Small farmers cannot risk using such crops.

(ii). Inputs (e.g. labour) and non-cash crop out-puts may not have associated money value.

(iii). Farm management decisions are not taken is isolation, but are related to household and village constraints. This is particularly important with regard to labour which is often a limiting resource and which may have other demands made on it by the household or village; and also with regard to food output which may be dictated by subsistence requirements.

(iv). Intercropping (where different crops are interspersed within the same field) is often practiced in developing countries, but there has been relatively little research on the responses of varying crop mixtures.

(v). Farm decisions are often modified during the growing season so as to adopt to weather conditions.

In addition to these points about the farm operations themselves, there are also points about the way a mathematical programming model could be used, that distinguish the developing country situation from that in a developed country. Whereas a commercial farmer might be interested to use an LP printout to plan his operations, a peasant farmer is special about advice he received from extension workers, scepticism founded both on tradition and on experience of bad advice received in the past. Mathematical programming is useful therefore as a model of the basis on which farmers make their own decisions, incorporating their objectives and constraints, not as a means of calculating for them what decisions they ought to take. Such a model can then be used to identify limiting constraints, and to design packages of new techniques, which will satisfy the farmer's own objectives. It gives the

Ministry of Agriculture an understanding of how the farmer makes his decisions rather than giving the farmer advice on what decisions to make.

3. MATHEMATICAL PROGRAMMING FORMULATIONS

Of the points (i)-(v) listed above, (iv) cannot be dealt with by modifications to mathematical programming formulations since it is a question of lack of data on intercropped mixtures. What follows is concerned instead with sole crops. Point (v) is not generally dealt with completely in published work in the sense of adaptive dynamic optimisation. However the growing season is normally divided into different periods of time so that resource constraints, particularly in labour, are considered in each of these periods. Point (ii) is taken account of by considering constraints on labour rather than costing it, and since non-cash crops are normally required for subsistence which is dealt with again as a constraint. These labour constraints plus subsistence constraints serve to ap-proximate point (iii) leaving point (i): uncertainty. There have been studies in developing countries which ignore these factors and which are able therefore to employ standard linear programming formulations. Abalu (1975) does this in Cameroon for perennial crops (therefore requiring optimization over several years). However, Wolgin (1975) shows that, for small farmers in Kenya, uncertainty is an important element in decision making. We shall therefore be concerned now with applications where the mathematical programming formulation has been adapted to take account of subsistence requirements and uncertainty. Where possible policy, implications are indicated.

3. 1. Method 1 (The maximum criterion)

The first method involves maximising the total gross margin which the farmer gets in the worst State of Nature. These States of Nature reflect annual variation in weather (particularly rainfall) and also such factors as pests, diseases and market conditions.

As

Max M,

$$\sum_j C_{ij} x_j \geq M$$

$$\sum_j A_{kj} x_j \leq B_k$$

$$x_j, \mathrm{M} \geq 0,$$

$$\text{for } \mathrm{i} = 1........\mathrm{n}$$

$$\mathrm{j} = 1.........\mathrm{m}$$

$$\mathrm{k} = 1.........\mathrm{p}.$$

where

m= number of farm activities

n= number of states of Nature

p= number of resources

xj= level of activity j

C_{ij}= the gross margin of activity j in weather i.

A_{kj}= requirement for resources k from one unit of activity j

B_k= the availability of resource k

M= gross margin

Akj and Bk could also be made to depend on the state of Nature but, in practice, this is not done since inputs must be planned before the State of nature is known. Farrington (1976) has used this method in Malawi and compared it with maximizing gross margin in the best State of Nature. His survey results indicate that actual farmer decision maiing is intermediate between these extremes. He concludes that farmers consider longer term optimization.

Heyer (1972) has also used this method in Masii, Kenya maximizing (a) gross margin in the worst year, (b) gross margin in the best year, and (c) gross margin in an average year. His study shows clearly how the solution to an LP representation of peasant farming can vary substantially in terms of gross margins and crop mixtures as the objective function is changed. Such sensitivity indicates the importance of considering sub-optimal solutions. Tyler and Tweeten (1968) employed sensitivity analysis to do this.

Various solutions to the drought problem in Mash have been suggested including cotton which gives high returns per hectare and millet and sorghum which withstand drought well. However, none of these crops substantially affects the opti¬mal solutions because of their high labour require¬ments. The major policy implication of Heyer's study comes from the great difference between returns and crop mixtures under objective functions (a) and (c). This indicates that if farmers were confident of famine relief being provided in bad years, then they could plan for better returns on average.

3.2. Method 2

The second method maximizes the expected gross margin given an additional constraint that the yield in the worst State of Nature exceeds a basic subsistence requirement.

Max

$$\sum_j e_j x_j$$

$$\sum_j C_{kj} x_j \geq S$$

$$\sum_j A_{kj} x_j \leq B_k$$

for i = 1........n

j = 1.........m

k = 1.........p.

where

ej= expected gross margin of activity j averaged over all states of Nature

S= the minimum subsistence requirement

Low (19'4) uses this method in Ghana and validates the model by observing agreement between the model results and those recorded in a survey. In a later paper (Low, 1975) he indicates some policy implication as follows:

(a) Tractors are found not to be useful above two per village because of the labour requirement for associated farm activities, e.g. harvesting which cannot be mechanized easily.

(b) Improved varieties of maize are of use only in farms above a certain size. Smaller farmers have to concentrate on satisfying their subsistence requirements in poor weather conditions when the improved maize gives lower yields than the traditional varieties.

(c) Credit is of no use to the poor farmer unless he can repeat it over several years, again because his main concern is subsistence in bad years.

3.3. Method3 (The E- V criterion)

The third method involves the use of Quadratic Programming to minimize the variance, V, of the total gross margin which is equivalent to minimizing uncertainty, subject to the expected total gross margin E, being equal to a given amount, L.

Max

$$\sum_j V_{ij} x_j x_i = V$$

$$\sum_j C_{kj} x_j \geq B_k$$

$$\sum_j A_{kj} x_j \leq L$$

$$\text{for } i = 1........n$$

$$j = 1.........m$$

$$k = 1.........p.$$

where

Vij= covariance of gross margins between jth and ith activities.

Wiens (1976) has used this method in China and found it to agree with survey data far more closely than straight forward linear programming. An earlier study by Odero-Ogwell and Clayton (1973) in Kenya compares this method, survey data and Method 2 above, and finds them to differ markedly in the areas given to different crops. They use their results to suggest areas that should be planted with tea, coffee, pyrethrum, pineapple, banana, pota¬toes, maize and beans.

3.4. Method 4 (The focus-loss method)

In this formulation the average gross margin is maximised subject to a minimum permitted in-come and also some "focus-loss" constraints. (The "focus of loss" is defined as the level of loss that a decision maker would be "very surprised" to reach, in any eventuality.) The "focus of loss" on any one crop is assumed to be not more than a certain proportion p of the total permitted loss.

Max

$$\sum_j V_{ij} x_j x_i = V$$

$$\sum_j C_{kj} x_j \geq B_k$$

$$\sum_j A_{kj} x_j \leq L$$

for i = 1........n

j = 1.........m

k = 1.........p.

where

I= the minimum permitted income to cover unavoidable expenses

P= the total permitted loss

Pj= the focus of loss on the jth crop hectare

This method has been used (Boussard and Petit, 1967) successfully to represent the decisions of small farmers in France. It can therefore be taken as a potentially useful model of farmers decision making under uncertainty in subsistence agriculture.

3.5. Method54 (TheE-Acriterion)

Method 3, above, has the disadvantage that it relies on the availability of quadratic programming computer codes. Method 5 is proposed by Hazell as an alternative which requires only a standard linear programming package.

Suppose we seek to estimate the variability in the gross margins (due to weather or price fluctuations) from s observations Chj, h=1….s, of the gross margin from the jth activity, with mean ej.

Then, instead of minimising the variance, V, of the total gross margin, as in Method 3, we minimise the estimated mean absolute deviation, A, subject to the expected total gross margin, E, being equal to a given amount, L.

$$A = \frac{1}{s} \sum_{k=1}^{s} \left| \sum_{j=1}^{m} (C_{hj} - e_j) x_j \right|$$

for i = 1........n

j = 1.........m

k = 1.........p.

We now define

This method has been used by Sanders and Dias de Hollanda (1979) in Brazil. They find that survey data agrees very well with the output of the model, indicating that crop diversification to reduce the risk of drought is the basis of small farmer decision making. The model, thus substantiated, is used to assess policy alternatives of different crop mixtures and a combination of tree¬ cotton and sorghum is found which can double farm income compared to traditional crops without increasing risk.

4. CONCLUSIONS

Five examples have been given of ways in which the standard linear programming formulation .of optimal agricultural decision making has to be modified before it can be used to represent the decisions of subsistence farmers in developing countries faced with uncertain weather conditions. Some of these methods have been used in developed countries but here we have concentrated on applications and policy implications in developing countries. This illustrates a general point that mathematical O.R. techniques can be used in developing countries so long as they are appropriately modified. Other aspects of the developing country situation that require further modification to the formulations have been listed. In particular points (iii), (v) have only been taken account of in a simplified manner and point (iv) has been avoided. Palmer-Jones (1977, 1979) has given other criticisms of simple models. These points further illustrate the extent to which "Appropriate O.R." for developing countries needs to use modifications of formulations used in developed countries.

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