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INCORPORATING MULTIPLE OBJECTIVES IN PLANNING MODELS OF LOW-RESOURCE FARMERS

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Linear goal programming provides a means of formally incorporating the multiple goals of a household into the analysis of farming systems. Using this approach, the set of plans which come as close as possible to achieving a set of desired goals under conditions of land and cash scarcity are derived for a Filipino tenant farmer. A challenge in making LGP models empirically operational is the accurate definition of the goals of the farm household being modelled.

Introduction

Low-resource farmers, like other decision makers, are goal oriented in the sense that they manage the resources at their disposal in an attempt to achieve a set of desired goals. Most researchers who study farm management in peasant agriculture do, of course, recognise the low-resource farmer's multiplicity of goals, and appreciate that they should be considered when evaluating the relevance of agricultural innovations. The more frequently identified goals of low-resource farmers include:

- (a) to maintain the social position of the household to ensure that it remains entitled to the benefits of the society;
- (b) to provide the household with as secure a supply of staple foods over time as possible;
- (c) to provide the household with a secure source of cash for the purchase of priority goods and services not produced by it; and
- (d) to accumulate a surplus to invest in the household, to purchase farm and nonfarm assets, and to accumulate wealth.

While the importance of security—that is, a lack of risk—has been intensively studied and reported (e.g. Roumasset et al. 1979; Valdés et al. 1979), less attention has been focused on explicitly incorporating other goals of farmers in management models of their farming systems.

Agricultural research networks in developing countries are becoming more aware of the need to evaluate technologies in a whole farm, as opposed to in a partial context, and to recognise that the goals of a farmer, in addition to the constraints he faces, will influence the appropriateness of a technology to him (Zandstra 1979). The purpose of this paper, therefore, is to present one approach which offers promise for explicitly incorporating farmers' goals in the whole-farm analysis of existing or proposed cropping systems.

*With the usual caveats, the authors wish to thank M. Genesila and A. Ledesma for their contributions to this research, and D. R. Byerlee and R. G. Dumsday for their comments on a draft of this paper.

Multiple Goals in Planning Models

Many strategies have been devised to solve problems characterised by multiple objectives, or multiple decision criteria (Easton 1973; Thamapillai 1978). A way in which the goals of management are frequently incorporated in planning models of peasant farms is to include these goals as vectors in the constraint sets of linear programming (LP) models. Thus, for example, minimum levels for family consumption of farm-produced goods and cash are entered as constraints which must be met before the objective of maximising a surplus can be approached (e.g. McCarl 1978; Barlow et al. 1979). Potential limitations of this widely used approach include:

- (a) the implicit assumption that all goals included in the constraint set are of equal importance to the decision maker, and that there is no trade-off between the achievement of various goals;
- (b) the requirement for a feasible solution to the LP model that all objectives (identified as constraints) are compatible and can be satisfied. In reality, goals may be conflicting and, at the margin, goals are often flexible. Further, it may not be possible to satisfy all goals, in which case the LP formulation is infeasible.

Charnes and Cooper (1961) devised a procedure to incorporate multiple objectives within an LP framework. Their approach involves use of positive and negative deviation variables that add to or subtract from constraints to remove the infeasibilities. The optimal solution is the one which minimises the sum of the deviations (which may be weighted to reflect rates of substitution between goals). This particular LP structure was used with effect by Barnett (1979) to solve a multiple-goal decision model of a low-resource farm household.

The Charnes and Cooper specification of the multiple-goal problem is appropriate when all goals are of the same level of priority. The concept of pre-emptive priorities, that is lexicographic ordering of goals, was introduced into programming models by Ijori (1965). In Ijori's model, goals are grouped into various priority levels and program results are based on the condition that lower priority goals cannot degrade the solutions at higher priority levels. The modifications of the simplex method necessary to solve 'priority' linear goal programming models (LGP) have been described by Lee (1972) and Ignizio (1976). LGP has been applied to problems of macro planning (Charnes et al. 1976), business management (Goodman 1974) and geography (McGrew 1975). However, the technique does not seem to have been applied to problems of resource allocation in agriculture, particularly peasant agriculture.

There seems to be a misconception among many users of LP that LGP of the philosophy and structure developed by Ijori (1965) is simply LP with certain specialised constraints and activities. This is not so; rather the LP formulation of a problem (single objective function) is a subset of the more general multiple objective, LGP problem. A limitation of LGP is the monotonic ordering of goals, with no facility for a trade-off between goals of different rank.¹ Nonetheless, goal ordering has proved a useful approximation in empirical decision models (see, for example,

¹ When two or more goals are included at the same priority level, weighting factors allow trade-off between these subgoals (Ijori 1965, p. 27).

discussions in Roumasset et al. 1979). Further, users of LP are also implicitly accepting lexicographic ordering of goals in the sense that the first priority goals (of equal rank) are embedded in the constraint set as 'absolute' objectives which must be realised before any attempt is made to satisfy the lower level (nonabsolute) goal, i.e. the LP objective function.

In the following sections of this paper the 'priority' linear goal programming model is applied to the question of determining the relevance of a cropping innovation, given the resource base and goals of a tenant farmer. The specific technical innovation considered is direct-seeded (as a substitute for transplanted) rice. The location of the research was at IRRI's Cropping Systems site in Iloilo, Philippines.

Goals and Goal Ordering

The goals, goal orderings and achievement levels were based on a survey of farmers co-operating in the farm record keeping project at the Iloilo site (Roxas et al. 1978). The goals of the farmers were first specified based on the findings of anthropologists working in the Philippines (Lynch 1976), and from discussion with Institute staff participating in the Iloilo project. These formed the basis of a survey administered to eight farmers in Iloilo regarded by project staff as key respondents. The survey consisted of two components. First, the technique of paired comparisons (Harman et al. 1972) was used to order the six goals selected.² Second, a series of open- and closed-ended questions were used to elicit the desired achievement, or satisficing levels of each goal. The responses were checked for consistency and augmented with the farm record keeping data and other agro-economic research reported in the area (Ledesma 1978; Roxas et al. 1978).

The final set of ordered goals used in the analysis and the associated desired achievement levels for the simulated peasant household are listed in Table 1.³ While the sample size of eight respondents was too small for meaningful statistical analysis within the sample or between groups of the less and more affluent farmers interviewed, the results were encouraging, as similar results were obtained with a much larger sample of 986 Filipino rice farmers (de los Reyes and Lynch 1972, p. 73).

Characteristics of the Representative Farm

The environment

The Iloilo outreach site lies on a marine terrace on the south-east of Panay Island. Annual average rainfall is of the order of 1900 mm. Monsoon rains normally begin in May and end in late November. The two major forms of land use are based on the hydrology of the landscape. The valley bottoms and lower slopes, the dominant portion of the landscape, are used to grow rice. Dryland crops are grown on the uplands.

Model family size in rural Iloilo province is 6 persons, and average farm size is 1.48 ha (Roxas et al. 1978). The most common form of

² Harman et al. (1972) also show how paired comparisons can be used to derive goal weights and so rank goals on an ordinal scale.

³ In this case, the farm household was assumed to consist of the tenant farmer, his wife and four children; they own a carabao (water buffalo), farm 1.0 ha of rainfed lowland and 0.5 ha of upland.

TABLE 1
*Ranking of Goals and Associated Achievement Levels for a
 Hypothetical Tenant Farmer in Iloilo*

Rank	Goal description	Desired achievement level	
		Unit	Level
1	To produce a basic quantity of rice sufficient for family sustenance	cavans ^a	27
2	To accumulate cash for food supplies, education, and other priority demands of the household	\$/year ^b	360
3 ^c	To minimise borrowings from relatives and friends	\$/year ^c	35
3	To minimise borrowings from a landlord	\$/year ^c	200
4	Not to become increasingly more indebted	\$/year ^d	min.
5	To generate as large a surplus as possible	\$/year ^e	max.

^a A cavan of unmilled rice weighs approximately 44 kg. The average monthly rice requirement per adult was taken to be 0.56 cavans. Respondents had a clear opinion of the quantity of paddy required for family consumption.

^b The exchange rate in January 1979 was US\$1.00 = ₱7.37. The priority demands for cash were elicited as suggested by Roumasset (1976, ch. 3).

^c This limit was taken from the survey results of Roxas et al. (1978).

^d Farmers have no choice but to pay back loans from the landlord. Thus, this goal, in effect, is minimisation of indebtedness to the family and friends.

^e Several farmers felt that the pursuit of profit was acceptable only within socially acceptable limits.

tenure is share tenancy. Generally, the tenant pays for all cash inputs, provides all the labour, and receives two-thirds of the produce. The landlord and friends are the main sources of credit. The sole source of draft power is the carabao.

Decision variables

Eighteen rice-producing activities were included in the model.⁴ The rice activities differed in terms of method and time of crop establishment (direct seeded—a new innovation for modern rice varieties—or transplanted), level of technical inputs (as reflected in differences in cash costs and labour requirements), and yields. Mungbean and cowpea are often relay planted into the late rice crop just before rice harvest. On the upland areas, maize, cowpea, mung and yam bean are the principal crops. Similarly, these crops were specified at two levels of technology for a range of planting dates.

Cash flow considerations and the need to carry rice stocks from one period to the next are important determinants of farmers' cropping strategies (Roxas et al. 1978). Thus, for cash and rice stock accounting purposes, the year was divided into three periods to reflect the dynamics of the supply (through harvest) and the demands for cash and rice for farming and household needs.

The remaining activities included in the model related to the farmer working as a harvester (paid in kind) or as a farm labourer (paid in cash up to two days a month), and the hiring of transplanters and harvesters.

⁴ Measures of yield or price variability were not explicitly incorporated in the model. However, cut-off dates (both early and late) were specified in line with decision rules used by farmers for planting at Iloilo.

Finally, most families have other sources of income (e.g. handicrafts, gifts). Nonfarm income was set at \$60 per year, based on the survey results of Roxas et al. (1978).

Resource constraints

While the tenant farmer seeks to satisfy an ordered set of goals, goal achievement is subject to a number of constraints—or in LGP terminology—pre-emptive priorities (Table 2). The land base was specified in periods of one month to enable crop yields to be related to planting dates. Off-farm work opportunities were limited to a maximum of two days a month (at a wage rate of \$1 per day), and as a harvester to a maximum wage of 8 cavans (this represents about eight days work at harvest time). Off-farm employment opportunities compete with farm tasks for the 60 days of family labour. Yam bean was restricted to 0.05 ha as the crop can be grown only on the isolated pockets of light soil in the area. In addition to these constraints, transfer rows were included to handle cash and rice flow aspects of the model.

Satisficing Farm Plans

The LGP solution to the farm situation thus described is shown in Table 3. The family is able to achieve fully the goals of meeting subsistence rice requirements and cash for household expenses, without falling into debt, given the technical and resource constraints. In addition, a cash surplus of \$102 is generated as the lowest order goal (i.e. maximum over-achievement of this goal). Direct-seeded rice is an attractive proposition for the early rice crop. The LP solution is also listed in Table 3. In the LP formulation, the higher order goals were treated as constraints (of the same rank) to the single-valued profit objective function being maximised. All of the constraints were met; hence, a feasible solution to the problem constructed in an LP framework exists. Under such circumstances, not surprisingly, the LGP and the LP models of the farm yield the same solution.

Two dominant constraints faced by rice farmers in Iloilo are their limited access to arable land and credit. While the shadow prices of limiting resources are generated in the LP model, they were not generated as output in the Ignizio (1976) LGP code used. Ignizio (1976, ch. 4) has provided multi-dimensional duality theorems but they do not appear, as yet, to have been incorporated into LGP solution algorithms. As a result, the sensitivity of the LGP solution to changes in key variables (in this case land and access to credit) is more easily obtained by

TABLE 2
Resource Constraints, Iloilo Tenant Farmer

Constraint	Units	Level
Lowland (for rice cultivation), per month	ha	1.0
Upland, per month	ha	0.5
Upland, suitable for yam bean	ha	0.05
Family labour, per month	d	60.0
Paddy storage	cavans	13.5
Income as harvesters (paid in kind)	cavans	4.0
Maximum days of off-farm work per month	d	2.0

TABLE 3
LGP and LP Solutions to the Tenant Farm Plan^a

Activity	Level	Unit	LGP	LP
<i>1. Goal achievement (LGP), Constraint (LP)</i>				
Rice for sustenance	27	cavans	Goal achieved	Constraint met
Cash for household	360	\$	Goal achieved	Constraint met
Borrow from relatives	35	\$	Upper acceptable level	Upper limit to constraint
Borrow from landlord	132	\$	Below upper acceptable level	Non-constraint
^a Repay landlord	172	\$	Goal achieved	Constraint met
Repay relatives	35	\$	Goal achieved	Constraint met
Cash surplus	102	\$	Level of achievement of lower-ordered goal	Gross margin of objective function
<i>2. Farm Plan</i>				
Direct-seeded rice (H) ^c	1	ha	Land constraint	Land constraint
Transplanted rice (H) ^c	1	ha	Land constraint	Land constraint
Cowpea	1	ha	Land constraint	Land constraint
Maize	0.5	ha	Land constraint	Land constraint
Mung	0.5	ha	Land constraint	Land constraint
Yam bean	0.05	ha	Land constraint	Land constraint
Harvest labour	4	cavans	max. level	max. level
Farm labourer ^b	24	d	max. allowed	max. allowed

^a LGP algorithm modified from Ignizio (1976, p. 234).

^b Family labour for on-farm work was not a constraint. However, because rice must be transplanted quickly, labour was hired for this activity. Similarly, labourers were hired to harvest rice crops.

^c H denotes that the rice crop was grown using capital-intensive technology. The major cash inputs were for fertiliser (60-0-0) and two applications of an insecticide.

parametrising the levels of these inputs. Similarly, changes or trade-offs in goal priorities could also be handled by parametric changes in goal priorities and weights. This approach could replicate the situation of overlapping and interchangeable goals where monotonic rankings are misleading.

Farm size

Increasing population pressures and land fragmentation through inheritance are resulting in a decrease in size of tenanted holdings in Iloilo (Ledesma 1978). Thus, to evaluate the impact of the farmer's land holding on goal achievement, farm size was parametrically reduced from 1.5 ha to 0.75 ha in steps of 0.15 ha (Figure 1). Because farm size was regarded as a resource constraint, the optimal farm plan identified the rice technology which maximised returns to land relative to capital.⁵

When farm size (in terms of rice land) was reduced to 0.82 ha, the farm no longer generated a cash surplus over and above that required to meet household and farm operating costs. Indeed, as farm size decreases further, the farmer is unable to repay all his loans and still meet his household needs. Loan repayment to the landlord is a pre-emptive priority in the sense that the loan is redeemable at the next harvest. Therefore, the farmer shifts to borrowing less from his landlord and more from his

⁵ This is the capital-intensive technology listed in Table 3 and, given the purpose of this paper, warrants no further discussion.

FIGURE 1—Relationships between goal achievement and cultivated area.

relatives and friends; he increasingly defaults on his loans from the latter sources and begins to fall into debt.

The model, when structured as an LP problem, became infeasible at a farm size of 0.82 ha of rice land. The LGP formulation of the model therefore provides a means of identifying the farm strategy which allows the farmer to come as close as possible to realising his goals, when constraints prevent their full achievement. Specifically, the impact of changes on the equity position of the farmer, and on the farm plan, were predicted in those circumstances when the farmer's resource base prevented the attainment of the higher priority goals.

Access to credit

The impact of credit availability on the farm plans and the farmer's capacity to achieve his goals were also explored (Figure 2).⁶ As access to credit diminishes, the cropping pattern shifts from a capital-intensive to a less capital-intensive technology. At a credit supply of \$62 from the landlord, a portion of the rice land remains vacant because the area under the late-season rice crop is reduced due to the cost of hired labour necessary to transplant the crop. At a credit limit of \$30, the farmer is no longer able to achieve his target of \$360 a year for living expenses, although sufficient rice continues to be produced to meet family consumption and still leave a surplus for sale.

A comparison of Figures 1 and 2 shows that, when land is the scarce resource relative to capital, the capital-intensive technology continues to be attractive at the small farm size examined. Alternatively, if capital is scarce relative to land, there is a rapid shift from the 'modern' to the lower cost (as a result, lower yield) methods of producing the rice crop. However, under the range of situations examined, the direct-seeded rice was clearly more profitable than transplanted rice for the early crop. The validity of this prediction is borne out by the rapid substitution of direct-seeded for the early-transplanted rice at the Iloilo site in the past four years.

Summary and Inferences

The LGP model provides an intuitively appealing way to investigate resource allocation problems characterised by multiple goals and multiple constraints. The method also has appeal in that it forces the researcher to consider the farmer's goals, and specifies the plan (and its consequences) which approaches as closely as possible the goal set in those situations in which technology, markets, institutional factors or resource endowments prevent all goals being achieved.

The LGP model was developed as one approach to provide a procedure to evaluate alternative cropping pattern designs within a whole-farm framework. From an agronomic viewpoint, the model reported is simplistic due to a lack of precision in interaction between planting dates,

⁶ For the purpose of the analysis, the maximum of \$35 per year available from relatives and friends was entered as a pre-emptive priority, and maximum borrowings from the landlord (which must be repaid at 100 per cent interest) parametrised from zero until it became nonlimiting.

FIGURE 2—Relationship between credit availability, goal achievement and cropping patterns.

landscape positions and yields. Further, no account was taken of yield variability. Current evaluation of the model has led to decisions:

- (a) to obtain better estimates of the farmers' goals;
- (b) to generate yield distributions by planting date for different hydrological aspects of the landscape.

These estimates of goals and yield distributions will be incorporated in a revised LGP model. At this point the approach can be realistically evaluated.

LGP methodology

With ingenuity, several of the drawbacks inherent in the LGP formulation of a resource allocation problem—for example, the assumptions of divisibility in activities and resources, and not incorporating risk preferences—may be handled in a manner similar to the approaches taken when constructing LP models. The risk-avoidance question could be explicitly addressed using a MOTAD approach (Anderson et al. 1977, p. 207), with a lower order goal being specified to minimise the mean absolute deviation of a higher order production or income goal. As an alternative, income and income variability could be specified as two subgoals at the same priority level. Similarly, integer linear goal programming algorithms exist. Hence, the questions of continuous versus integer solutions can, in principle, be handled in this manner (Ignizio 1976, ch. 5). A more vexing limitation of LGP is the assumption that goals of different rank are independent. However, trade-offs between subgoals of the same achievement level are readily incorporated in LGP models, providing the analyst can specify appropriate goal weights.

Quantifying goals

In the authors' view, the most significant challenge in LGP is found in the somewhat neglected area of research within agricultural economics into the goals of peasant farmers (except possibly for risk). In addition to identifying farmers' goals, priorities and trade-offs, it seems important to identify the subset of goals relevant for management decisions, both in the short run and the longer term.

The evidence related to the motivations and goals of peasant farmers reported by other disciplines (e.g. Firth 1967; Lynch 1976) provide obvious starting points for agricultural economists concerned with these questions. Collaborative studies with anthropologists, sociologists and psychologists may prove valuable in developing approaches which will enable the goals, ranks and desired achievement levels of different economic or cultural groups to be more precisely specified for use in management studies.

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