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FARM LEVEL MODELLING FOR THE EVALUATION OF THE IMPACT OF TECHNOLOGY

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ABSTRACT

A linear risk programming model of small farmer decision making was formulated and employed to evauate the impact of new technology on farm organization, income and resource utilization. The model is based substantially on the neo-classical theory of the firm. However, consideration is given to the fact that profit maximizing behaviour is constrained by sub-optional farm-household decisions. In addition to the usual resource and institutional constraints,a safety first constraint on expected net income was incorporated using a MOTAD formulation. The analysis of the results is focussed mainly on the changes in (a) enterprise combination; (b) income levels; and (c) resource utilization. Despite the limitations of the linear programming approach this type of analysis is very useful to guide research and development policies.

INTRODUCTION

Small-scale agriculture in the Caribbean presents the most challenging development problems. It has been suggested that the observed stagnation in this sector is due to the persistently low incomes generated by small farms and the low levels of technology utilization (Beckford, 1969; Floyd, 1970; Maddox, 1962).

Farm household incomes in the Caribbean, as in most developing economics, are lower than those of non-farm households. Consequently the standard of living of the farmer is either one of absolute poverty or is verging on it. This group, therefore, tends to be on the margin rather than in the mainstream of their national societies.

The numerical dominance of small farm holdings is a key feature of Caribbean agriculture. Small farms and poor land quality have been recognized as major causes of poverty. It is also argued that the most important factor explaining differences in farmer decision making is farm size (e.g. Heady, 1965; Singh, 1973). This is particularly true when related to economies of scale, risk and uncertainty, and the capacity to absorb available family labour. The low level of technology employed by low resource farmers is reasoned to be responsible for low productivity. In this regard policies designed to bring small farmers into the mainstreams of economic activities have placed substantial emphasis on new techniques of production.

The justification for emphasizing new techniques of production is based on the proposition that these farmers are rational decision-makers who will respond positively to rewarding economic opportunites (Chennaredy, 1967; Gafar, 1980; Hopper, 1965; Lau & Yotopoulos, 1971; Welsch, 1965);

and that small farmers tend to optimize within the constraints under which they operate (Hill, 1970; Jones, 1960; Norman, 1970).

The above imply, firstly that there are no serious infefficiencies in resource allocation in the sector and secondly, that there is little scope for increasing production or productivity with the existing production functions. The logical prescription therefore is that new production methods which effectively relax the constraints of the present decision-making environment must be introduced (Dalton, 1971).

Research efforts to generate new technologies for Caribbean small farmers have resulted in some successes, some overt failures and many intermediate achievements. Hence there is growing concern from donor agencies and national governments regarding effectiveness of research efforts, the impacts of new technologies, and the desirable directions for future research and development. It is in recognition of these concerns that a definition of the problem which this study attempts to address is in order.

The need for assessing the impact of technology is part of the process of directing and managing agricultural research. The tasks for the technology assessor can be conceptualized as involving two main components:

Predicting or evaluating the impact of new methods at the farm-household level; and

Evaluating the cost and benefits of new method in relation to national (and other) objectives.

The complexity of small scale farm production in small economics makes technology assessment a difficult task. This is due in part to the critical importance of accounting for:

Timing of operations;

Allocations of labour at peak periods;

Limited quality and quantity of land which requires intricate sequencing of crop and livestock activities;

Necessity for balancing a need for cash with a need for secure income to avoid disaster; and

Limited market capacity and seasonal variation in supply and demand.

Given the complex nature of small-scale farming, a model which is capable of incorporating these complexities is clearly required to evaluate the possible impact of technology.

The main concern is that the consequences of new technology cannot be satisfactorily evaluated by the partial analyses which are now employed. The limitations of these partial analytical techniques are discussed by Ghodake & Hardaker (1981) and by Roth & Sanders (1986). These limitations are, firstly, that partial analysis ignores the substitutability and interrelationships between inputs and outputs and the rationale for the allocation to alternate activities. Secondly, partial analyses provide limited scope for accounting for risk and uncertainty in technology outcomes. Therefore, partial techniques (which usually do not account for risk) are likely to overestimate the mean net benefits of innovations. Thirdly, due to market imperfections and resource immobility, market prices for some farm inputs and output (e.g. family labour, animal power, crop by-products and land) are usually poor reflections of their true opportunity costs. The fourth limitation arises when one wants to evaluate technologies with respect to farmers' multiple objectives and conformity with national goals.

The above discussion leads to two main conclusions. Firstly, very often technology assessment can best be attempted in a whole-farm context. Secondly, an approach is needed which will simultaneously value the production factors available to the decision maker and evaluate the technology with due consideration to farmers' objectives and to the socio-economic system within which he operates.

Given the problems associated with partial methods of technology assessment, the specific objectives of this paper are:

- To develop a mathematical programming model of small-farm household decision making; and

- To employ this model to study the ex-ante impact of eight potential new vegetable production techniques on the organization, income and resource use on a representative farm.

METHODOLOGY

The Study Area

This paper is based on a study of small-farm production in the Bushy Park district, located in the southwestern plains of the parish of St. Catherine, Jamaica. A typical farm size in this area is 5 acres and most families depend primarily on farming for their income (Douglas, 1985). Annual crops grown include red peas, pumpkins, tomatoes, carrots, okra, cabbage and cucumber mainly for sale in the local markets. In addition, livestock, such as goats and beef cattle, are kept.

The Mathematical Programming Model

The modelling approach has been used in numerous studies of small-farm decision making (e.g., Heyer, 1971; Ghodake & Hardaker, 1981; Roth & Sanders, 1986; Arcia et al., 1981; Lang, 1986; Escobar, 1986). A major attraction of modelling is that it allows the farmers' choice situations to be represented and the consequences of measures to influence farmers choices to be explored before policies or programmes are implemented.

Most of these models have been based on linear programming couched in either a static or dynamic framework. The linear programming models used in this study were developed to represent the main production alternatives available and the constraints imposed by the limited resource base of the farmers. Care was also taken to represent the important connections between the farm and the households in relation to such things as supply of labour and management of cash flows. In particular, the presence of risk aversion was recognized as a factor constraining farmers from achieving a profit-maximizing allocation of resources. The model is essentially a single year model in which timing of production and consumption activities are explicitly considered.

Choice Criterion

On the basis of data collected from farmers, and other studies (e.g. Johnson & Strachan, 1974; Edwards, 1961; McCulloch, 1970), the relevant choice criterion was judged to ' : the maximization of the farmers wealth over time, subject to the attainment of a minimum income each year with an acceptable level of probability.

The wealth-maximizing criterion was reflected in an objective function to maximize equivalent annuity. The use of annuities circumvents problems of different time horizons for different activities. This is equivalent to maximizing the net present value of future earnings. Annuities were calculated, using an interest rate of 20 per cent, which is approximately equal to the commercial cost of capital. All cash flows were expressed in nominal terms.

The security or minimum income constraint was developed in the form

$$(1) \quad P(Y \geqslant Ymin) \geqslant p^*$$

where Y is net income in the current year, summed across all the j-th activities; Ymin is the prescribed minimum net income; and p* is an acceptably high probability. The way in which this condition was incorporated into the linear programming model is described later.

The Activities

The model was run in two stages. Reference to Table 1 shows that in the first stage (Model 1) the existing technology represented the production opportunities available to the decision maker. In the second stage (Model 2) the new technology was included along with the "so-called" traditional activities. In other words, the initial model included 19 vegetable and two livestock activities. In the second model, eight additional vegetable (i.e. tomato 3, pumpkin 3, cucumber 3, onion 3, carrot 3, cabbage 3, hot pepepr 2, and calaloo 3) activities were added, representing an expansion of the farmers' choice situations.

Both the before and after models included activities for hiring of labour, cash transfers, short-term capital borrowing, loan repayment, withdrawals for household consumption, and activities relating to the risk formulation.

The constraints included are: land and rotation, available family labour, maximum hired labour, capacity constraints relating to farm equipments, limited markets, borrowing, cash accounting and risk.

Table 1. Enterprises and levels of technology included in the models

Enterprise	Technology/Activity Levels[1/]	
	Model 1	Model 2
Red peas	1&2	1&2
Tomato	1&2	1,2&3
Pumpkin	1&2	1,2&3
Cucumber	1&2	1,2&3
Onions	1&2	1,2&3
Okra	1&2	1,2
Carrot	1&2	1,2&3
Cabbage	1&2	1,2&3
Calaloo	1&2	1,2&3
Hot pepper	1	1&2
Beef cattle	1	1
Goats	1	1

1/ Technology levels manual land preparation and a low level of purchased inputs. Technology level 2 is intermediate involving partial or total land preparation by mechanical implements and modest use of purchased inputs. Technology level 3 is capital intensive and involves high levels of purchased inputs.

The security constraint of equation 1 is incorporated into the linear programming model using a MOTAD formulation. Following Hazell (1971), mean absolute deviations of net cash income is estimated as:

$$(2) \qquad MAD\ (Y) = 1/s \sum_{s=1}^{n} \left| \sum_{j=1}^{m} (C_{js} - C_j)\, X_j \right| ;$$

where

MAD(Y) is the mean absolute deviation estimated over s states, corresponding to an historical sample of observations,

C_{js} is the net income per unit of the j-th activity in the s-th state; C_j is the mean net income per unit of the j-th activity over the s-th states; and X_j is the level of the j-th activity.

MAD(Y) is converted to an estimate of the standard deviation ($\hat{\sigma}$) of net income by multiplying by Δ , where

(3) $\Delta = 0.5\,\pi\ s/(S-1)^{0.5}$ (e.g. Scandizzo et al., 1984). Using this estimate equation 1 can be rewritten as

(4) $E(Y) - \theta\sigma\ Y \geq Y_{min}$

Assuming that the distribution of Y is approximately normal, the values corresponding to any required level of probability can be obtained from tables. The value used in the current problem was 1.0, corresponding to p* = 0.84. The value for Ymin was obtained by using different values. The value giving results judged to be closest to farmers current practices was selected as best.

The risk formulation was implemented by using seven constraints to calculate the deviations in net income for each of seven states (years). These deviations were collected for each of the seven observations and converted to MAD(Y) in a further constraint. An additional constraint was used to calculate E(Y) and to provide for the full expression of the security or safety first constraint.

RESULTS AND DISCUSSION

The optimal enterprise comb'nation before (Model 1) and after (Model 2) the introduction of new technologies are compared in Table 2. The salient feature with respect to enterprise combination are, firstly, that the introduction of the new production methods did not alter the level of production of Redpeas 2, Calaloo 2, Beef feedlot, and Goats in the optimal solution, and secondly, the availability of new production methods had a substantial impact on farm organization. In particular a number of substitutions occurred between the traditional and the new methods of production. The substitutions are tomato 2 for tomato 1 (part), onion 3 for onion 1, and cabbage 3 for cabbage 1 and cabbage 2. In addition, hotpepper was not a basic activity in Model 1, but hotpepper at technology level 2 was in Model 2.

Table 2. Optimal farm organization before and after new technology

Basic Activities	Units	Activity Level	
		Model 1	Model 2
Red peas 2	acre	1.25	1.25
Tomato 1	acre	1.25	0
Tomato 2	acre	0	0.75
Onion 1	acre	1.25	0
Onion 3	acre	0	1.25
Cabbage 1	acre	0.50	0
Cabbage 2	acre	0.75	0
Cabbage 3	acre	0	1.25
Hotpepper 2	acre	0	1.25
Calaloo 2	acre	0.25	0.25
Beef Feedlot	Head	2	2
Goat	AU 1/	2	2
Crop Acreage		5.25	6.0
Crop Intensity	(%)	105	120
OBJECTIVE FUNCTION VALUE	J$	20586	27384
E(NCF)	J$	3294	4[illegible]50
Minimum Income (Ymin)	J$	17292	17292

1/ 1 AU is equivalent to 1 Ram, 2 Does and 4 kids.

Table 3 shows the shadow prices for the enterprises excluded from both models, and indicate the marginal opportunity cost (MOC) of these excluded activities relative to the optimal plans. These figures indicate the amount by which the total gross margin (i.e. the objective function value) would fall if an acre of any of these activities were forced into the farm plans. An alternate interpretation of the MOC is that it shows the increase necessary in the net revenues of the excluded activities in order to bring it into the optimal solution. Still another interpretation of the MOCs is the amount by which production costs would have to decrease to bring any of these activities into the solution. For example, in the case of Model 2, the net revenue from tomato 1 would have to increase by J$2300, or its production costs be reduced by this amount, or forcing it into the farm plan would cause a reduction in total gross margin by this amount.

Table 3. Shadow prices of activities excluded from the optimal solutions

Excluded Activities	Marginal Opportunity Cost	
	Model 1 (J$)	Model 2 (J$)
Redpeas 1	441	299
Tomato 1	BA1/	2299
Tomato 2	442	BA
Tomato 3	NA1/	617
Pumpkin 1	1759	4058
Pumpkin 2	2190	4299
Pumpkin 3	NA	3113
Cucumber 1	2355	4655
Cucumber 2	2577	4126
Cucumber 3	NA	3881
Onion 1	BA	2609
Onion 2	1061	3909
Okra 1	2937	5238
Okra 2	2936	5093
Carrot 1	3655	6502
Carrot 2	3295	6143
Carrot 3	NA	4902
Cabbage 1	BA	624
Cabbage 2	BA	464
Hotpepper 1	1429	3576
Calaloo 1	564	918
Calaloo 3	NA	409

1/ BA = Basic activity, NA = technology not available.

In terms of farm-household income, Table 3 shows that the availability of new production methods and the consequent reorganization of the farm resulted in a 33 per cent increase in total gross margin. The table further shows that when minimum income (Ymin) is held constant at J$ 17292 the innovations did not result in more risky farm plans, as indicted by the standard deviation in net cash flow.

Comparative data relating to resource utilization in the optimal soluitons are presented in Table 4. Examination of this table shows that land was more intensively used in Model 2. This is in agreement with data in Table 2 which shows cropping intensities of 105 and 120 per cent for Models 1 and 2, respectively. The zero MVP associated with each land use period indicate that land was not a limiting factor, i.e., not scarce in the particular planning context.

Table 4 shows that Model 1 used 79 per cent of the available family labour, whereas Model 2 used only 71 per cent. This means that the new production practices are land intensive but less labour intensive. However, they are more capital intensive. This implies that the new production practices would offer farmers more leisure or the opportunity to supplement family income by selling labour.

It should be noted also that in the sub-period January to April all the available family labour was utilized (Model 1). The corresponding MVP of J$3.55 indicates that total gross margin would increase by this amount if an additional man day was available. The hired labour section of Table 4 shows that no labour was hired and if one man day of this resource was purchased total gross margin would decrease by the amounts indicated.

Table 4. Resource utilization and shadow prices for the optimal solutions

Resources	Units	Amounts Used		Shadow Prices	
		Model 1	Model 2	Model 1	Model 2
LAND					
Jan-April	Acres	4.0	4.50	0*	0*
May-Aug	Acres	4.5	4.50	0*	0*
Sept-Dec	Acres	2.75	3.50	0*	0*
FAMILY LABOUR					
Jan-Apr	Man-day	165.00	121.75	3.55*	0
May-Aug		158.00	99.25	0	0
Sept-Dec		74.00	138.00	0	0
		Amounts unused**			
HIRED LABOUR					
Jan-Apr		165	165	8.44	12.0
May-Aug		175	175	12.0	12.0

* Denotes marginal value product (MVP)
** Denotes marginal opportunity cost (MOC)

To summarize, the results indicate that the new production practices resulted in a change in farm organization, which in turn resulted in a 33 per cent increase in total gross margin, more time available for leisure or opportunities for off-farm employment; and more intensive land utilization.

CONCLUSIONS

A linear programming risk model was formulated and used to analyze the impact of new production practices on small-farm organizations, income and resource use. Two alternative production systems were compared--a traditional system (Model 1) and a traditional plus new technology (Model 2). The results demonstrate the usefulness of this type of analysis in providing important information on:

- optimal product mixes and production techniques;
- shadow prices of critical resources;
- the consequences of innovations with respect to resource utilization; and
- the acceptability of new productior techniques by farmers.

The model as developed is subject to a number of limitations. First, it assumes that the constrained profit maximizing model adequately approximatesthe farmer's objectives and choice situations. However, it is quite likely that farmers' objectives and choice situations are more complex than specified in the model. Secondly, the managerial element in decision making, particularly with regard to attitudes toward change, learning, expectations, and managerial capacity, although recognized as important, were not explicitly modelled. Thirdly, the model is based on assumptions of linearity, finiteness in forms of activities and constraints and infinite divisibility of activities levels and of resources.

Despite these drawbacks the model can be regarded as providing a reasonable basis for studying the impacts of new production practices.

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