MODELLING THE EFFECTS OF NEW TECHNOLOGY ON SEMI-SUBSISTENT FARM-HOUSEHOLDS IN THE PAPUA NEW GUINEA HIGHLANDS

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22 January, 1993

Paper presented at the Annual Conference
of the Australian Agricultural Economics Society, Sydney,
9-11 February, 1993.

1 Introduction

The modelling of semi-subsistent farming in Papua New Guinea (PNG)[1] was part of a broader study aimed at developing a framework for the ex-ante analysis of the expected benefits of agricultural research in that country (Anderson, Antony and Davis 1990). Within that framework, outside influences (both related and unrelated to the examined new technology) are simulated in a model of the farming system, and its performance is monitored over time (Antony and Anderson 1991). This paper contains the description of the system model used in the analysis of village agriculture.

Apart from its immediate role, the model outlined below may contribute to the remedying of the lack of PNG studies about linkages between subsistence and commodity production (Thompson 1990).

2 Farm-Household Theory and PNG

Neoclassical production economics assumes commercial firms. These firms typically buy their inputs from outside of the firm and sell their outputs at the market. Farm operations are assumed to be optimized subject to technical and resource constraints, to maximize profits. For farm-households, farm profit, together with other sources of income, constitutes the household income. In this interpretation, farm families are treated little differently from any other families in their reliance on purchased goods and their goal system, and in that they 'go to work' for a commercial firm. In this conceptual model, optimization consists of profit maximization for the farm and utility maximization for the household; farm and household decisions are separable.

Singh, Squire and Strauss (1986a, b & c) exposed the assumptions underlying this separable model. The most important of these is that farm-households are purely price takers in both the factor and product markets that, in turn, are perfect. Surplus product or resource (other than land) can be sold at the market, and if there is a deficit it can be bought at the

1 Contributions to this study by J.B. Hardaker and R.D. Ghodake are gratefully acknowledged.

same price. Household labour and hired labour are perfect substitutes as the reservation price of the former equals the cost of the latter. Ignoring risk leaves the profit motive undistorted. Apart from the fact that income generated from production enables consumption, maximizing decision in production and consumption are separate from each other. Lopez (1986) demonstrated that such a strict separability is too restrictive even in the case of presumably strongly market-oriented Canada.

The traditional PNG village production unit has been almost completely autonomous. Its purpose was to satisfy the requirements primarily of just one household,[2] and it obtained the inputs - land and labour - from that household.[3] Such a degree of autarky rarely exists anymore, but most farm-households are still semi-subsistent with varying levels of market-oriented production and consumption (Figure 1). Production and consumption decisions cannot reasonably be viewed in isolation. The field of economics dealing with such farm-households is often called peasant economics. The central issue of modelling peasant agriculture is a satisfactory, explicit representation of the goal structure. While technical relationships in the production system are relatively easy to quantify, the absence of a single (even if simplified) goal like profit maximization poses problems.

Ellis (1988) reviewed theory developments about the economic motivation of peasant farmers. The first change to the neoclassical model was the introduction of risk. The widely accepted and used assumption of risk aversion foreshadows a production structure that is likely to yield a smaller expected profit than pure profit maximization. Another part of the relevant theory revitalizes the conceptual model of Chayanov. Chayanov's thesis was that the motivation of peasants is to satisfy their needs with minimum effort, the assumption being that farm work itself gives no satisfaction

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2 The word 'household' needs to be redefined for traditional PNG society. In NSO (1980) practice, a rural household consists of a "male 'head' with his wife or wives and unmarried children" (p. 4). However, where there are more wives, they tend to live in separate houses and run semi-independent sub-households.

3 The farm 'obtains' land from the household on the basis of the household members' entitlements to it in the community.

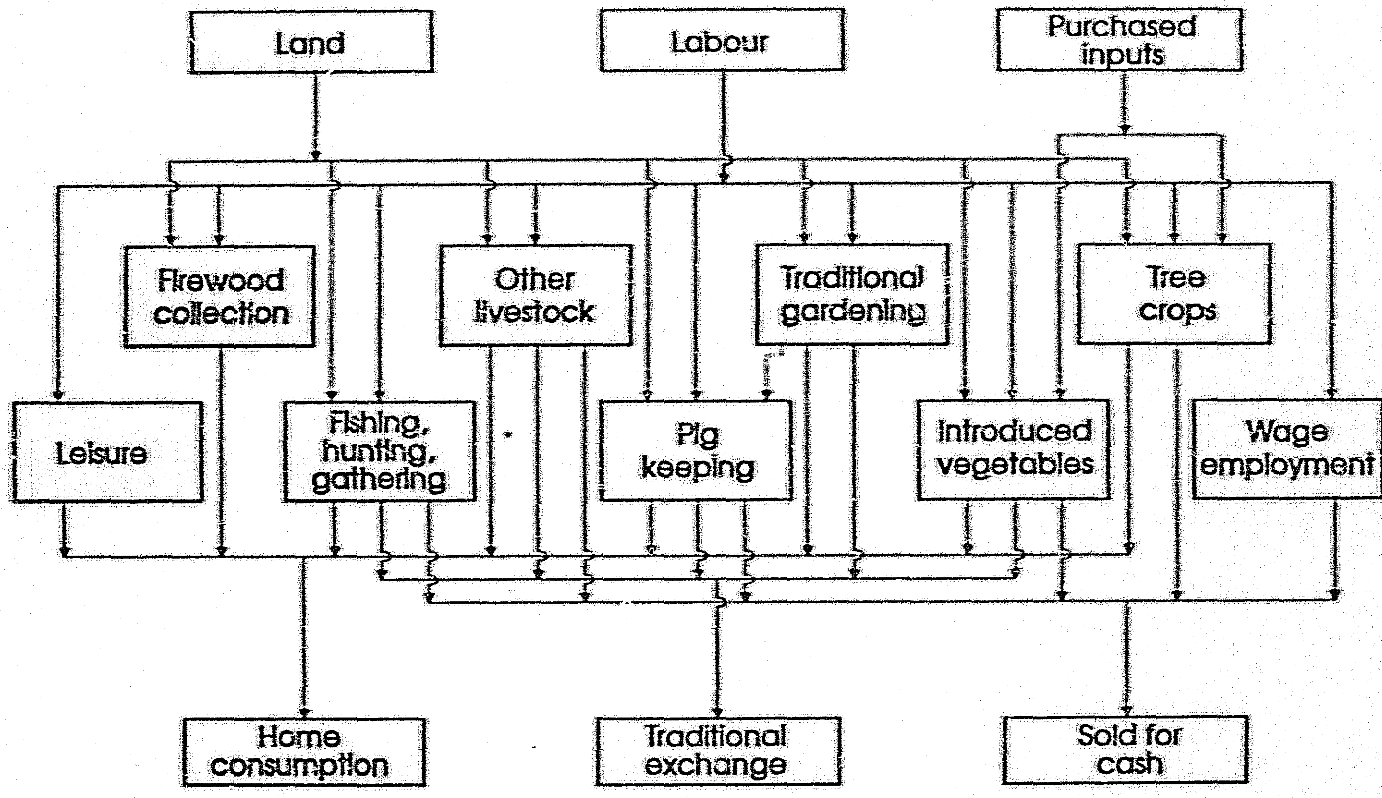

Figure 1 Functional model of a Papua New Guinea farm–household

Source: Antony, Parton and Kauzi (1990)

(Ellis 1988, Ch. 6). While produce is traded in the Chayanovian model, labour is not.

In contrast, "New household economics" (Ellis 1988, Ch. 7) incorporates a functioning labour market. All produce and inputs are valued at their opportunity cost, and explicit tradeoffs are applied between household and farm production goals. In its pure form, as outlined by Barnum and Squire (1979), the distinction between the farm-household model and that of a commercial firm is greatly reduced. The most important remaining difference is that, unlike for the commercial firm, consumption as well as production behaviour is subject to analysis.

Nakajima (1986) sought to develop a model that can be applied to any type of farm from purely subsistence to purely commercial on one hand, and purely family labour to purely hired labour on the other hand. On the foundation of Chayanov's work, Nakajima combined the adaptation of Hicks' subjective equilibrium analysis to agriculture by Tanaka with Marshall's economic surplus.

In the basic, utility-maximizing farm-household model of Nakajima the extent of production is determined by the marginal values of labour used and of the fruits of production, as perceived by the farmer. At low levels of labour use, the marginal cost of labour in work is low, while the utility of more farm produce is high as needs are still unsatisfied. As labour use and production increase, the marginal utilities of labour and produce converge. Once farmers prize a further unit of labour use higher than the marginal production that it would bring, no more labour is devoted to production.

At the point of equilibrium, maximum levels are achieved for both utility and economic surplus. The value of that level of labour use in production is measured by difference between the total value of production and total labour cost. The sources of economic surplus vary with the type of the farm: (a) for a small commercial farm fully utilizing the family's labour, the surplus is what Nakajima defined as the "self-employed producer's surplus" (p. 130); (b) home consumption of the produce yields consumers' surplus (p. 131), either as the only source (pure subsistence) or complementing surpluses from other sources; and (c) wage labour off the farm provides "labourer's surplus" (p. 156).

For a mixed farm, economic surplus would consist of a combination of the above three sources. The equilibrium condition for a semi-subsistent farm-household with off-farm labour option (p. 139) is the equality of marginal revenue from each source with each other, and with the marginal cost of labour.

Fisk and Shand (1970) studied Melanesian societies, and observed the change in economic behaviour as market orientation replaces subsistence. Of special interest are changes in the marginal utility of money through this transition. At an early stage, the marginal utility of additional money income may fall sharply at low levels of income while, at later stages, money becomes a more desirable commodity. Meanwhile, however, the incentive to utilize even unused resources in increased cash-crop production is restricted by a limited utility of money. In Fisk and Shand's view, labour especially was unutilized in traditional societies. This was called into question by Jones (1970) who pointed to the importance of customary activities.

In many parts of PNG, integrated markets (for labour as well as most produce) are almost totally lacking. This is close enough to the Chayanov model (although manicured gardens in PNG attest to satisfaction gained from farm work). Even so, a model of PNG farm-households, to be used in long-term analysis, should accommodate improving market integration and changing farm-household objectives.

In a transitional model of PNG farm-households that is suitable for both a near-subsistence situation and for one that is characterized by increasing commercialization, the goal structure would be represented by:

(a) the requirement to satisfy a minimum nutritional level,

(b) the maximization of the amount of produce available for traditional exchange,

(c) the maximization of leisure time,

(d) the requirement to provide a minimum (but increasing) level of cash income, and

(e) the option to replace subsistence food with (generally higher-prestige) purchased foods if there is enough cash.

With social change, (d) would become the dominant objective. Simultaneously, (b) and (c) would turn into objectives that have a desirable minimum level of achievement, but whose all-out maximization is not a goal. In all, a quantitative model of PNG farm-households would closely resemble Nakajima's model.

Given the level of complexity outlined above, mathematical programming represents best the current tradeoffs as well as being suitable for a simulation tool. Systems simulation could be used for a descriptive model but only mathematical programming is capable of optimizing the system on the basis of decision rules and subject to resource constraints (Antony and Hardaker 1991).

Multi-attribute utility functions, the best approximation of Nakajima's equilibrium condition, can be used in conjunction with mathematical programming. The optimization of farm-household production and consumption activities is driven by the maximization of the household's utility function. While the resulting measure of total utility is not very suitable for welfare measurement in a generally comparable way, Nakajima's economic-surplus categories provide that link.

3 Formulation of the PNG Farm-Household Model

Quantitative information available on PNG farming systems is little, it refers to different time periods and regions, and it comes from surveys that had diverse objectives and methods (Barker, Bodman and Remenyi 1986). Consequently, it is not very suitable for either pooling or building the farm-household model of this study. To date, the most extensive effort aimed at collecting data on village agriculture has been that undertaken by the Highlands Food Crops Research Team from 1986 to 1990. The Gumine district of

Simbu province was selected for detailed survey work as it is an area where the farming system is under stress: increasing population numbers reduce access to land and cause fallow periods to be shortened to such an extent that the nutritional status of the land cannot recover sufficiently (Ghodake and Kalit 1986).

A rapid rural appraisal (RRA) of the region was carried out from 21 July to 1 August, 1986 (Ghodake and Watinga 1986). Based on the RRA, a detailed and sustained survey was initiated (Ghodake and Kalit 1986). Unpublished data from this survey were processed and utilized for this study, complemented by primary information collected in the study area.

In the course of constructing the programming model for the analysis of FSR, a representative farm in the Gumine region was modelled first. Risk was added to the basic model next, followed by an extension to the regional level. A description of the forecasted changes in model parameters over the 30-year time span of the analysis completes the without-research stage of model development.

A schematic representation of the without-research programming model, complete with the above extensions, is presented in Figure 2. The model consists of 95 constraints and 141 activities, many of which are aggregated in the figure to reduce its size.

The first horizontal section in Figure 2 is that of the objective function. Below that can be found the cropping activities: from land use, through crop nutrition, to the production and use of produce. The sources and utilization of firewood follow, linked with the sources of home production. The block relating to the production and use of livestock is connected to activities that produce feed (fallow, crop production and use). Labour constraints (for males and females) link the available labour 'stock' with its uses in the various productive activities and leisure. Required minima for family food energy and protein, specified in the human-nutrition constraints, are satisfied from different food sources. Achievements in the material objectives of the farm-household, cash income and gift giving, are counted in the second-last horizontal section and linked to the explicit objective function. Finally, accounting constraints

		fallow	fertilizer	crop establishment	standing crop	crop production summary	crop home consumption	crop sale	firewood production	firewood sale	firewood purchase	food production summary	livestock production	livestock production summary	livestock home consumption	livestock sale	livestock traditional gift	leisure time	wage labour	outmigration	food purchase	income risk columns	cash income summary	traditional gifts summary	home consumption summary	labour costs	economic surplus
objective function	MAX																	P					P	P			
land	K=	1		1	1																						
crop rotation	0 ≥			−1	P																						
soil fertility	0 ≥	−P	−P		P																						
crop yields	0 ≥				−P	1																					
crop use	0 ≥					−1	1	1																			
firewood yield	0 ≥	−P							1																		
firewood use	−K ≥								−1	1	−1																
feed yield	0=	−P				−P	−P					1															
feed use	0 ≥											−1	P														
livestock yield	0=												−1	1													
livestock use	0=													−1	1	1	1										
labour use	K ≥		P	P	P			P	P	P	P		P			P		1	1	1							
human nutrition	−K ≥						−P								−P						−P						
income risk rows	0=		P	P				−P		−P	P					−P			−P	−P	P	1					
income	0=																					−P	1				
traditional gifts	0=																−P							1			
home consumption	0=						−P		−P	P					−P										1		
labour costs	0=		P	P	P			P	P	P	P		P			P										−1	
economic surplus	0=																						−1	−1	−1	P	1

P = technical parameter (≠0)
K = constraint value (≠0)

Figure 2 Outline of the mathematical-programming model illustrate the ways of calculating home consumption, labour costs and economic surplus.

3.1 The representative Gumine farm-household

(a) Resources

The household **land** area is separated into two categories by elevation. The first, up to 2,000 metres, is less prone to frost and is more fertile than the second, over 2,000 metres of elevation. There is roughly an equal amount of land below and above 2,000 m, and the representative household has access to both types. Correspondingly, while the enterprise choices may show similarities in the two areas, the different environments are reflected in a yield differential.

Based on the HFCRT survey, the composition of the households is set at 2.2 adult males, 2.2 adult females, and 3 children under 14 years of age. **Labour** is the most important input fully within the control of the semi-subsistence farmer. The use of time is split between work, leisure and personal necessities like sleep, meals, etc. In the definition used here, individual relaxation and non-work activities, including social commitments, constitute leisure.

Traditional PNG society places a high value on non-work social interaction, reflected in behavioural norms and the wide range of social commitments expected of the individuals. Because of their higher social status, men in PNG Highlands societies can take more time for leisure than women - the aggregate social preference weighting is higher for male leisure time than it is for females.

Options for work are on farm and off farm. On-farm work consists of cropping and animal husbandry. Although male and female labour appear substitutable in the various operations in actual data from Gumine, gender preference does exist. Household chores (cooking, washing, childminding) are an exclusively female activity. Marketing of most products is taken as gender specific; men sell coffee and pigs while women mainly sell food crops.

Table 1 contains a listing of the labour requirements of cropping activities. Labour requirements for the animal enterprises are assumed to be 30 min/day for 4 pigs or goats, and 15 min/day for 6 chickens, evenly split between male and female labour. Pigs and goats that graze fallow are assumed to require two-thirds of the time.

Wage labour and outmigration are two additional uses of male labour.[4] The former is defined as work in the relative vicinity of the home, while the latter is further away, in urban centres. In 1989, the minimum rural and urban wages were K20.1 and K53.9 per week (of 44 hours), respectively (Jarrett 1990, p. 70). Accordingly, wage labour may provide the household with the rural wage and has a nutrition demand, while outmigration may result only in a partial remittance of earnings but no demand on household food sources. A complicating factor is the shortage of employment opportunities at the minimum wage (Jarrett 1990, pp. 32-34). It is assumed here that rural employment could be encountered with a 50 per cent probability, while the likelihood of finding a job in the towns is 70 per cent. Accordingly, the expected value of rural employment is set at half of the wage rate and, for remittance, 70 per cent of the assumed K10/week that an employed man would send back to his family.

It is assumed that the daily minimum time needed for personal necessities is 10 hours. This time is not available for either work or leisure. The disparity in male and female working time is prevalent in PNG also (Newton 1985). Women spend about 3 hours every day cooking, childminding, washing, etc, (Martin Gunther, pers. comm. 1988) and this is added to their personal necessity in the model. The rest of the time is allocated to work and leisure. The yearly amounts of 'personal necessity' for the total number of adults in the representative household are 8,030 and 10,439 hours for men and women, respectively. This leaves 11,242 and 8,833 hours per year, for men and women respectively, available for work and leisure.

4 Outmigration with the purpose of studying and obtaining skilled employment is ignored in the model. It is much less significant than searching for menial off-farm work, and its omission is not likely to compromise the study.

Table 1
Labour Use in Agricultural Activities

Crop	Crop establishment: male labour	Crop establishment: female labour	Crop establishment: total labour	Standing crop: male labour	Standing crop: female labour	Standing crop: total labour
	'000 hr/ha*year[a]					
Spt E1	4.78	13.02	17.81	0.03	13.13	13.16
Spt E2	5.62	13.20	18.82	0.10	14.00	14.10
Cfe E1	9.10	1.31	10.41	6.62	2.82	9.44
Cfe E2	1.47	2.45	3.92	6.95	5.38	12.32
SBO E1	4.61	9.18	13.79	1.79	10.90	12.69
SBO E2	10.99	18.53	29.52	0.62	9.83	10.45
SCO E1	5.15	9.57	14.72	0.45	10.19	10.64
SCO E2	5.22	8.02	13.24	1.60	6.23	7.84
CBO E1	5.14	9.92	15.06	5.35	9.32	14.67
CBO E2	n/a	n/a	n/a	n/a	n/a	n/a
SMx E1	10.44	8.60	19.04	4.64	9.62	14.26
SMx E2	7.80	11.09	18.89	0.07	7.05	7.12
Cbg E1				5.00	13.64	18.64
Cbg E2				4.41	0.60	5.02

[a] Calculated from labour-use data given in mandays, at 8 hrs/m.d.

Source: HFCRT survey

where:
- E1 = elevation ≤ 2000 m
- E2 = elevation > 2000 m
- Spt = sweet potato monocrop
- Cfe = coffee monocrop
- SBO = sweet potato, banana and other crops
- SCO = sweet potato, coffee and other crops
- CBO = coffee, banana and other crops
- SMx = sweet potato and mixed other crops
- Cbg = cabbage monocrop
- n/a = no data: elevation 1 less 50% used instead

It was decided not to make use of information about seasonal labour demand. The main source of seasonality is coffee, with a flush period of 3-4 months, and introduced vegetables. Apart from these male-dominated activities, the farming system is flexible. The seasonal subdivision of activities and the inter-seasonal constraints would have at least doubled the matrix size that was already at a premium. Even without a seasonal breakdown, none of the optimal solutions were anywhere near to allocating the male labour resource to work only. Hence one could safely assume that seasonality would be taken care of by varying the ratio of work and leisure between seasons.

(b) Production

Bush fallowing is the traditional method of restoring soil fertility in the study area. At the beginning of the production cycle, an overgrown primary or secondary bush area is cleared. Subsequently, a sequence of crops is planted over the years, reflecting the decline in soil fertility. When the soil is depleted, the plot is abandoned for some years and is overgrown by secondary bush. If land becomes scarcer and fallow periods are reduced without technical change, soil fertility declines. Presently, mineral fertilizers are hardly ever used by semi-subsistence farm-households, and certainly not on traditional food crops.

In the model, the availability of soil nutrients is a function of the proportion of fallow to total cultivable area. Soil fertility is then treated as an input in the crop enterprises The use of soil nutrients by the crops can be included in the model with relative ease (Tables 2 and 3).[5] However, as there are no data on the replenishment of such nutrients during fallow, the coefficients referring to this in the model may not be accurate. On the basis of advice from an agronomist with local experience (Martin Gunther pers. comm. 1988), it is assumed that the effect of a 1:1 fallow:productive land ratio is equivalent to 1 t/ha of mixed NPK fertilizer, and such fallow is capable of maintaining a

5 The following nutrient requirements were used for crops for which such data were unavailable: those of potato for sweet potato and taro; 50 per cent of potato for traditional greens and introduced vegetables.

Table 2
NPK Constitution of Crop Yields

Crop	Yield	N	P_2O_5	K_2O
	kg/ha	kg in yield shown		
Cassava	20,000	125	30	150
Potato	25,000	115	45	[illegible]
Maize	4,000	200	80	160
Peanuts	1,000	50	15	15
Bananas	30,000	60	15	200
Coffee (dry bean)	2,000	30	5	48
Coffee (dry bean)[b]	1,000	22	4	28
Cabbage	25,000	n/a	20	67
Carrots	15,000	n/a	21	77

Source: ILACO (1981)

b PNG figure, source: Harding, Bleeker and Freyne (1986, p. 42)

n/a = not available

Table 3
Recommended Fertilizer Applications

Crop	Yield	N	P_2O_5	K_2O	$N/P_2O_5/K_2O$
	kg/ha	kg for yield shown			kg/t yield[a]
Cassava	20,000	50-90	60-75	80-120	11.9
Potato	25,000	50-100	50-100	75-150	10.5
Maize	4,000	60-100	50-100	75-100	61.0
Peanuts	1,000	0-25	50-100	35-75	142.5
Bananas	30,000	50-90	60-100	150-250	11.7
Coffee (dry)	2,000	35-60	25-50	75-110	89.0

Source: ILACO (1981)

a Calculated as the average of recommendations yield of 20 t/ha sweet potato. As 1 t of mixed (1:1:1) fertilizer contains some 270 kg of effective $N/P_2O_5/K_2O$, 1 hectare of fallow is considered in the model as providing the same amount to 1 hectare of crop. To allow for differences between the two categories of elevation, this amount is arbitrarily reduced to 240 kg for over 2,000 m.

Table 4 contains the yields of the cropping activities, as registered by the Highlands Food Crops Research Team. In the model, in order to reduce the size of the matrix, some products were aggregated: sweet potato and taro; cabbage, corn, pumpkin and other introduced vegetables; and sugarcane and traditional greens.

In monocropped sweet potato, some 35 per cent of the harvest consists of small tubers that are only considered suitable for pig food, while the corresponding figure is 40 per cent in mixed plots, due to the shade effect (Martin Gunther, pers. comm. 1988).

Traditional Highlands farming systems include pigs as the only **domesticated** (or semi-domesticated) **animals**. Pigkeeping in the study area was described by Ghodake (1989). Although pigs are traditionally housed within the village and fed some sweet potato as a domestication measure, they are free to roam about and obtain a part of their food by rooting around especially in fallow areas. It is the productive gardens that are fenced in, not the pigs. Poultry and, more recently, goats are gaining ground in the Highlands. They are also free-ranging, and their feeding habits make them reasonably complementary to pigs in utilizing feed available in the fallow. Poultry and goats are also fed varying quantities of substandard produce and household refuse.

The animal enterprises in the model are of the traditional, extensive type. Average weight of pigs is 35 kg (Densley 1979b, p. 56) whose feed requirement is given by ILACO (1981) as 1.3 kg of dry matter per day. The average-size 30-kg goat requires 1 kg dry matter daily, while a 1-kg chicken needs 70 grams (ILACO 1981). It is assumed that even if animals are grazed, two-thirds of their food requirement is still provided by feeding at the house, as a domestication measure. As part of the assumption of low technology for the

Table 4
Crop Yields

\Product Crop\	SPT	CFE	CRN	TGR	IVG	CBG	BAN	SCN	TAR	PKN
					t/ha*year					
Spt E1	12.405	-	-	-	-	-	-	-	-	-
Spt E2	10.311	-	-	-	-	-	-	-	-	-
Cfe E1	-	3.258	-	-	-	-	-	-	-	-
Cfe E2	-	1.881	-	-	-	-	-	-	-	-
SBO E1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SBO E2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SCO E1	8.300	1.345	0.139	0.289	-	0.310	1.691	0.040	0.056	-
SCO E2	3.235	0.026	0.038	0.003	0.140	0.126	-	-	0.203	-
CBO E1	-	1.778	-	0.636	0.847	-	0.100	0.047	0.288	-
CBO E2	-	0.442	-	-	-	-	-	-	-	
SMx E1	5.317	-	0.241	0.327	0.168	-	0.024	0.202	0.348	0.379
SMx E2	5.105	-	0.152	0.029	0.180	-	0.003	-	0.092	-
Cbg E1	-	-	-	-	-	9.659	-	-	-	-
Cbg E2	-	-	-	-	-	5.102	-	-	-	-

Source: HFCRT survey

where:
- SPT = sweet potato
- CFE = coffee (cherry)
- CRN = corn
- TGR = traditional green vegetables
- IVG = introduced vegetables (other than cabbage)
- CBG = cabbage
- BAN = bananas
- SCN = sugarcane
- TAR = taro
- PKN = pumpkin
- E1 = elevation ≤ 2000 m
- E2 = elevation > 2000 m
- Spt = sweet potato monocrop
- Cfe = coffee monocrop
- SBO = sweet potato, banana and other crops
- SCO = sweet potato, coffee and other crops
- CBO = coffee, banana and other crops
- SMx = sweet potato and mixed other crops
- Cbg = cabbage monocrop
- n/a = full data set not available: incomplete data used

animal enterprises, the age of animals at disposal was set at 2 years for pigs and goats and 240 days for chickens.

It is assumed that, on a yearly basis, fallow areas produce some 500 kg/ha of raw food (with 30 per cent dry matter) accessible to pigs and 1 t/ha accessible to goats (with 20 per cent dry matter). The waste percentage from food processing that can be utilized as animal feed was set on the basis of PNGIMR (1987) (Table 5).

Table 5
Availability of Food Scraps for Animal Feed

	Root crops	Bananas	Vegetables	Pigs	Goats	Poultry
			per cent of pre-processing weight			
Waste proportion	15-20	35	5-64	35-40[a]	55-65[a]	42
Utilizable waste[b]	10	25	20	10	10	30
Utilizable dry matter	3	7	2	4	4	20

Source: PNGIMR (1987)
[a] 100 less dressing-out percentage, source: ILACO (1981)
[b] Estimate

In the utilization of produce, the backbone of the local economy is sweet potato. Except for times of great hardship, small tubers are fed only to the pigs. The bigger ones can be used either for human consumption (within the household, given away as gift or sold) or as pig feed. All three options for the human consumption of other traditional foodstuffs are included in the model, but their possible alternative use as pigfeed is ignored.

The by-products of food preparation (peelings, guts, food scraps and suchlike refuse) add to the available stock of animal feed. Recyclable waste percentages are 10 per cent for tubers and greens, 20 per cent for bananas, and 30 per cent for animals (based on PNGIMR 1987).

Pigs constitute a unique category among the animal enterprises, in that they are used primarily as a depository of wealth in traditional society (Ghodake 1989). Although they may be sold in times of hardship, their primary use is in traditional exchange (gifts, brideprice and compensation payments) and in big feasts every few years. Their nutritional value is not counted in the nutritional balances, as pork is usually eaten infrequently but in such quantities that most of it is wasted from the nutritional point of view. Interestingly, the amount of money paid in traditional exchange to replace a pig is higher than the market price of that animal (Martin Gunther, pers. comm. 1988). In the model, the gift value of a pig is 1.5 times the market value. Goats can be sold or used in traditional exchange, but they do not have a premium value as gift. Poultry are used in the household as a premium food source, and it can also be sold or given away, again representing the same value.

Of the cash crops, coffee is produced only for sale, while introduced vegetables (cabbage being the mos' important) may also be used within the household for human consumption.

The most important household fuel used in Highlands villages is firewood that comes from the secondary bush and remaining forested areas. Collection of wood is primarily a man's job. It takes 5 hours to collect and take home around 40 kg of wood from the nearer bush fallows, while bringing the same amount from the forests takes 10 hours. In the model, it is assumed that the firewood yield of bush fallow is 1 t/ha. From questioning Gumine villagers, the firewood requirement of a family appears to be some 4 kg per day, making the requirement of the average household around 1.5 tonnes annually. The price of firewood at the village market was K50/t in 1989.

There is some trade in firewood, but that would be unlikely to extend beyond the region. Firewood is becoming scarcer in Gumine as spare land is increasingly brought under cultivation and fallow periods are shortened.

(c) Human nutrition

The previous section gave an indication of the food sources available to people in the study area. These food sources are linked in the model to minimum yearly intakes of energy and protein for the average household, listed in Table 6 and calculated on the basis of WHO standards (FAO/WHO/ONU 1985).

The supply side of the nutritional balances consists of the energy and protein contents of the foods, produced or purchased. These figures have been obtained from PNGIMR (1987).[6]

(d) Farm-household objectives

The model needs to reflect the multi-objective decision-making of the farm household. One objective, that of the satisfaction of minimum nutritional requirements, is formulated as unbreachable minimum levels of energy and protein. The model does not include any incentive to over-achieve these targets.

Cash income is included as a minimum constraint. Once basic necessities like school ' ., clothing, household items, etc. are paid for, cash earnings can be used for the purchase of superior foods, tobacco, alcohol and other non-essential items. A K200/yr minimum is imposed on income, as most of the items that cash pays for cannot otherwise be included in the model.

(e) Completion of the riskless farm-household model

While the model was sufficiently close to the real-life situation, without having to resort to constraints to 'force' the 'optimal' solution, there were some aspects that were insufficiently reflected in the prices or objectives.

One anomaly was the excessive quantity of purchased rice in the optimal solution. This came as no surprise, as Joughin and Kalit (1986) pointed out that rice supplies the cheapest calories in PNG. Nevertheless, existing consumer preferences

6 Bought protein is the nutritional average of tinned fish and tinned beef, at K0.80 per 425 g tin.

Table 6
Human Nutritional Requirements

Group	Energy	Protein
	kJ	grams
Daily requirements		
Adult males (14 to 50 years old)	11,630	44[a]
Adult females (14 to 50 years old)	9,360	38[a]
Pregnancy allowance	1,200	6
Lactation allowance	2,090	12
Children	7,420[b]	33[c]
Daily requirements for representative family		
2.2 adult males	25,586	97
2.2 adult females	20,592	84
0.15 pregnancy[d]	180	1
0.33 lactation[e]	690	4
3 children	22,260	99
Total per day	69,308	285
Total per year	25,297,420	104,024

Source: FAO/WHO/ONU (1985)

a 0.75 g/day; 58 kg males, 50 kg females.
b Average 2 to 14 years: male 7,840 kJ, female 6,990 kJ.
c 1.05 g/day, for 10 to 58 kg males and 10 to 50 kg females.
d 7 pregnancies, distributed among adult females.
e 6 lactations for 2 years, distributed among adult females.

still favour the consumption of quantities of traditional staples. This is likely to be even more so in a rural area like Gumine, and this consumer preference was not reflected in the goal system. As a somewhat crude measure of correction, constraints were introduced for purchased foods. The maximum amounts of rice and tinned beef/fish to be used by a household were restricted to 200 kg and 400 cans, respectively, per annum.

The opinion of extension agents in PNG that mineral fertilization is an obvious avenue of intensifying semi-subsistent systems. This was borne out by the initial solution where a mixture of bush fallowing and fertilization provided the optimal production structure. However, as farmers presently do not widely use fertilizer, its amount was restricted to 100 kg per year.

The first solution included running a great number of chickens and goats by the farm-household. This is clearly not the case at the moment, even though otherwise unutilized resources could be mobilized this way. Subsequently, upper limits of 10 chickens and 1 goat per household were introduced. Although the solution was still not a mirror image of the actual situation, no further constraints were used to allow flexibility in the simulation use of the model.

3.2 Risk and uncertainty

(a) Risk in programming models

Weather and prices are examples of external sources of uncertainty in the natural and economic environments. Human attitudes to uncertainty also vary: farmers in general, and peasant farmers in particular, have been found to be averse to taking risks (e.g., Chibnik 1990, Binswanger 1980, Dillon and Scandizzo 1978). Hence, consideration needs to be given to the quantification of environmental uncertainty and human risk perceptions in numerical analyses of farm-households.

Baksh and Johnson (1990) pointed out that environmental conditions cause less variation in crop production in the humid tropics than in the temperate zone. On the other hand, people in tropical regions are usually exposed to more risk in terms of health and social conflict. In the PNG Highlands, periodic food shortages (taim hangri) are not unknown, but these are not as calamitous in their extent and severity as in some other parts of the world.

Risk abatement methods in the Highlands of Papua New Guinea are not fundamentally different from those on other parts of the world. Mixed cropping provides some security against short-term adverse climatic effects at critical stages of plant development, while dispersed plots are less likely to be uniformly affected by local strife, be it weather, wild animals or a raiding party from the next tribe. The intricate system of giving and receiving gifts (often food) offers a social framework for helping out those who experience some difficulty in food supply. Although these methods do not reduce the riskiness of production per se, they mitigate its effects on the individual family. As most components of traditional PNG agriculture have been proven over millenia, a necessary allowance for the riskiness of the system would be built into farmers' decisions.

Technological change would bring a new situation. Unlike the time-honoured methods currently in use, the inherent riskiness of the new techniques is not known. Another source of risk is the uncertainty of prices. Commercialization may bring the production of traditional produce increasingly for sale, using traditional technologies. While this probably would not change the perception of the production uncertainties of a technology, price risk may assume greater importance. With new technologies, one would expect farmers to consider both production and price as risky. Given the above argument about a relatively low level of environment-induced variation of yields, farmers' perceptions about the yield uncertainty of a new technology may be crudely approximated with a lowered level of expected yield.[7] On the other hand, price risk would need to be described by its expected value as well as variability.

7 In the view of Brian Hardaker (pers. comm. 1992), farmers initially perceive a new technology as having a very broad variation, but not necessarily a lower mode, of yield outcome. As experience with the new technology builds up, the perceived yield distribution converges on the unknown actual one.

The subjectively perceived riskiness of a new technique may well exceed the actual variability inherent in the technique. In the end, it is the subjective perception of the riskiness of a new technology by farmers that influences adoption within the limits set by resource constraints. From another angle, however, farmers' pre-adoption perceptions are influenced by such factors as the effectiveness of the extension service and the experience with the new technology of the earliest adopters.

The extension of riskless models to ones that formally account for price risk require the quantification of the above considerations. Depending on the formulation (Hardaker, Pandey and Patten 1991), it may also need a more specialized optimization algorithm than linear programming (Hazell and Norton 1986, Ch. 5).

Many parameters of a programming model can be uncertain. The uncertainty of external events can be represented by the probability of the occurrence of certain events or parameter values and the way the outcomes are distributed. The mechanism of quantifying independent risky events in a model is well documented (e.g., Anderson and Dillon 1991). Risk in the technical parameters is particularly prevalent if risky decisions are characteristically sequential, i.e., if subsequent decisions are taken after the outcomes of previous ones become known (Hardaker, Pandey and Patten 1991). A good example of this embedded riskiness is temperate-zone cropping that typically follows a strict sequence determined by the climate. Potential consequences of embedded risk are less serious in the PNG study area, as its agriculture is much less seasonal. The production cycle can be initiated much of the year around, hence there is much more scope for the mitigation of unfavourable effects. In such circumstances, there is a greater number of decisions with embedded riskiness, making it more difficult to represent them in a programming model. On the other hand, the individual risky decisions are of less consequence in the study area than in the temperate zone.

The most widely used measurement of the value of risky outcomes to individuals is through the use of von Neumann and Morgenstern's expected-utility theory (Schoemaker

1982). In analyses, a utility function is identified, either experimentally or on the basis of reasoning, that shows the change in 'utility' as income increases. From such a function, the utilities of different levels of income to an individual can be calculated. Decision options can be ranked on the basis of their expected utilities and the variance of that expected value. In the broad sense, income need not be money income but any kind of reward (or loss) that results from the decision in question.

The expected-utility theory is not without critics. Schoemaker (1982) reviewed evidence of violations of individual axioms of utility theory. He nevertheless concluded that, until more satisfactory models emerge, expected utility remains "a worthwhile benchmark against which to compare, and toward which to direct, behaviour" (p. 556).

The actual functional form of the utility function is determined by both the observed human behaviour and practical considerations. The phenomenon of marginal utility diminishing as ever greater amounts of the same good are acquired is a cornerstone of utility theory. The corresponding functional form is one that rises away from, but flattens out parallel with, the horizontal axis (on which units of the good are marked). Nevertheless, some practical analytical tools (e.g., quadratic programming) employ utility functions that have very different characteristics.

Utility functions tend to be individual, and Arrow (1963) demonstrated why it is not possible to obtain a utility, or welfare, function that would exactly reflect the preferences of a group of people or the whole society. Anderson, Dillon and Hardaker (1977, pp. 100, 139-140) suggest some practical measures for representing group preferences in analyses. Basically, as there is no practical method that would fulfil the theoretical requirements for deriving a group preference function (Fishburn 1987), if analysts feel the need for one they have to create it on the basis of their subjective, but hopefully informed, judgement.

(b) Risk in the Gumine model

Hardaker, Pandey and Patten (1991) present an overview of risk-programming methods. The formulation chosen for this analysis involves (a) a utility function as the objective function, and (b) the inclusion of risky parameters in the form of sampled values from distributions over a number of states of nature.

No Gumine-specific study of the utility functions of peasant farmers was available for this study. On advice from Brian Hardaker (pers. comm. 1991), a negative exponential utility function was used because of its constant risk-aversion qualities. In this study, the multiattribute functional form is as follows:

$$E[U(Y)] = \sum_{i=1}^{n} a_i * (1 - e^{-k_i y_i}) \quad (1)$$

where: $E(U)$ = expected utility;
Y = total income;
a_i = weight of attribute i;
e = base of natural logarithm;
k_i = constant coefficient of absolute risk aversion (~ 2/total wealth) (Little and Mirrlees 1974, p. 330); and
y_i = nominal value of income source i.

The above, often-used, functional form implies constant risk aversion. Nevertheless, increasing (decreasing) the level of total wealth in the k parameter lowers (raises) the utility of a given sum of income, conforming to the expected behaviour of risk-averse decision-makers who are usually considered the rule (Anderson, Dillon and Hardaker 1977, p. 89).

The components of 'income' in the study area are: (a) cash income, (b) gifts given in traditional exchange, (c) male leisure time, and (d) female leisure time. Since these income sources have different units, separate wealth levels for each were used. For cash income, total wealth of a farm-household was estimated at K2,000, including personal possessions, tools and houses. The 'total wealth' for gifts was set at K3,000. This makes explicit a preference for keeping income within the household rather than giving it away more than socially necessary. For leisure time, the total time available after personal necessities was substituted as wealth or stock value of leisure. Male leisure time was given a weight of 2 to reflect existing social preferences favouring males over females. In the summation, individual utility values of the attributes were given equal weights in the base-case model ($a_1 = ... = a_n = 1$). Hence:

$$E[U(Y)] = (1 - e^{-(2/11.42)*2*ML}) + (1 - e^{-(2/8.83)*FL}) + (1 - e^{-(2/2000)*CI}) + (1 - e^{-(2/3000)*GG}) \quad (2)$$

where: ML = male leisure time ('000 hours;
FL = female leisure time ('000 hours;
CI = cash income (K); and
GG = reservation price of gifts given (K).

The main source of risk in the study area is price risk. In this study, assumptions have been made about the extent and distribution characteristics of future price variability. Ten equally likely states of nature were included in the model, based on the observations of Hardaker and Troncoso (1979) that such a number was sufficient for a close approximation of the results from quadratic programming that they considered the benchmark. Thus, in effect, the one row of deterministic prices was replaced with 10 rows representing the risky nature of price outcomes. The individual parameter values were obtained by Latin Hypercube sampling from the appropriate distributions.[8]

The prices of purchased inputs and foods were expected to be the least variable of the stochastic price parameters. As suggested by Anderson, Dillon and Hardaker (1977, p. 59), beta distributions were used for these parameters. In this implementation, a symmetrical distribution was fitted between the extreme values marked by a 10-per-cent range of variation on either side of the expected value or mode.

Turning to output prices, anecdotal evidence suggests that sellers in Papua New Guinea tend to be rather inflexible about the asking price (Martin Gunther, pers. comm. 1988). Yearly animal sales by traditional households are relatively few, hence individual

8 This procedure was carried out with the aid of @Risk, a risk-analysis computer program attached to Lotus 1-2-3 (Palisade 1989).

sales of animals can be seen as binomially distributed at the single-farm level. That is, they either sell at the asking price or they do not. However, at the regional level, a beta distribution of prices is used, with a 50-per-cent band of uncertainty on either side of the mean value. The sale of vegetable produce is a regular activity, thus the continuous beta distribution is applicable even at the individual farm level. The price range for produce sold is 50 per cent on either side of the expected price.

Off-farm wage earnings, both work in the vicinity and remittance income, are subject to minimum-wage legislation. Work can either be found at the legislated wage rate or it cannot. Over the region, a beta distribution is applied, but the extreme values are zero on the one hand and the wage rate on the other, with the mode at the 50 per cent probability level. That is, the expected value of the rural wage is 50 per cent of the legislated minimum. For remittance income, the mode was set at 70 per cent probability, in view of the better opportunities to encounter work in urban centres that in rural areas.

Only animals given as gifts constitute a net expenditure from the point of view of the household. Gift values of chickens and goats were treated as identical to the expected market value. Pigs in gift exchange were valued at 1.5 times the expected market value, indicating their importance in traditional society.

3.3 Regional extension

(a) Aggregation problems in regional models

One way of constructing regional models is to build them from already existing models of smaller entities. In the case of rural regions, most, if not all, of these entities will be farms. The issues concerned with establishing regional results from the Gumine representative farm model are discussed in this section.

There is ample scope for introducing bias when aggregating farm models into a regional one. Hazell and Norton (1986, pp. 145-148) summarize the preconditions of theoretically satisfactory aggregation. The general requ'rement of homogeneity of farms grouped together has been specified as:

(1) Technical homogeneity, meaning that all farms are identically endowed in their physical and managerial resources, and are using the same technology.

(2) Pecunious proportionality, denoting that individual farmers' expectations about unit activity returns are proportional to the average.

(3) Institutional proportionality requires a constraint vector of each farm to be proportional to that of the average.

While there exist other, even stricter criteria, the above are said to be sufficient. Practical studies are usually hard pressed to satisfy theoretical rigour, and what is left is an examination of to what extent the ideal preconditions are satisfied in a particular case.

In the case of Gumine, casual observation suggests that farm households are similar in many respects. Hence, there seems to be at least as strong a case for assuming that aggregation bias is minimized here as there is in other studies in advanced-country agriculture.

The Gumine district is small enough to have relatively little variation in rainfall and temperature (Humphreys 1984). Differences caused by elevation have been accommodated in the model by separating land into areas above and below 2,000 m elevation. There is a greater diversity in soils (Humphreys 1984), but accounting for this would have required much more data.

In traditional Highland societies, access to land is regulated by custom. The customary allocation of land resources, whether by proof of tillage by ancestors or by tribal warfare, resulted in an access to land that was quite proportional to population numbers. In the present model, the total land resource of the region can reasonably be assumed to be evenly distributed among households. As registering title to land becomes more widespread and traditional methods of redistribution less acceptable, the land resource of households may become less equally spread in the future.

Again presently, economic activity in the district (indeed, in the province) is quite homogeneous. For the population aged 10 years and older[9], the 1980 census reported the occupation categories as shown in Table 7.

Table 7
Occupation Statistics in Simbu and Gumine

Occupation category	Gumine	all Simbu
	per cent	
Working for wage	1	3
Own business	1	1
Farming/fishing for money	49	37
Farming/fishing for subsistence	21	25
Full-time student	6	8
Housework	1	2
Too young/old, handicapped	10	11
Looking for work	3	2
Other	7	11
Not stated	1	0

Source: (NSO 1985, pp. 65, 68).

The two farming categories are evenly balanced in gender, while more men than women work for wage (8:1), own business (5:1), study full time (2:1), look for work (2:1), and do other work (2:1). The gender ratio in housework is 20:1 to women.

Production patterns are also homogeneous in the study area. Some 80 per cent of households grow coffee, while pigs are kept by 78 per cent of them (the province average is 80 per cent for both). 72 per cent of Gumine households, and 66 per cent of all rural households in Simbu, sell food crops. In the medium-long run a differentiation in the production pattern can also be expected to arise.

9 Children younger than 10 years of age constituted 23.5 per cent of the total population in Gumine (NSO 1985, p. 24).

(b) Supply and demand

Apart from planting material for coffee and introduced vegetables, there is little use of purchased inputs in the study area at the moment. Given the (by PNG standards) good road links of the region, it is expected that farmers of the region could seek additional quantities of the purchased inputs without exerting an upward pressure on their prices.

Of the outputs of farming, coffee is an internationally-traded commodity with a perfectly elastic demand at the Gumine regional level. The situation is different for other cash crops. The main market for Gumine produce is the provincial capital, Kundiawa, whence part of it may be traded further to the bigger centres such as Mount Hagen, Goroka, even Lae and perhaps Port Moresby. Long-run demand for marketed foodstuffs is mainly a function of urbanization, while short-run demand is only moderately influenced by price.[10] For the sake of modelling simplicity, it is assumed that a change in the quantities of one commodity offered for sale will not have an effect on the prices of others. This assumption of zero cross-price elasticities is made more acceptable by the fact that the 'products' in the model are not just individual commodities but, mostly, similar commodities grouped together. Under such conditions, the full price effect of a change in supply in a commodity is borne by its own price. Changes in supply will thus lead to a relatively sharp movement in the own price, while leaving others unaffected. Indications of such price behaviour have been documented by Joughin and Kalit (1986). While prices of close substitute staples such as taro and sweet potato mirrored each other in Port Moresby, the link appeared weaker in Lae, and negligible in Goroka.

An attempt to trace the demand curves for Gumine food crops and animals, by way of linear segmentation, was abandoned. The mechanism of doing this is straightforward (Hazell and Norton 1986, pp. 176-178), but the data were lacking. As only 'perceptively generated' data could have been used, the potential inaccuracy thus introduced in the model

10 Introduced vegetables are, at present, the only food produced in Gumine that is subject to government market intervention. Quantitative restrictions on vegetable imports cause a distortion of domestic price, but there are no research findings about the extent of this distortion.

would have negated the greater precision of the more life-like demand specification. Where the implicit assumption of perfect elasticity of demand was unreasonable (e.g., in selling introduced vegetables), marketing constraints were used.

The yearly increase of demand for purchased foods by people within the study area was assumed to be 2.5 per cent, to be formulated in the model as an extending limit on purchases allowed. Although overall population growth in PNG is 2.1 per cent (World Bank 1989), demand for marketed food is likely to expand faster than that, due to changing preferences and higher incomes. Fintrac (1983, p. 2-57) was of the opinion that improvements in marketing services and support for transportation are needed for growth in food marketing to exceed 5 per cent. However, much of this growth would still come from urban demand.

(c) Population and land area

Population numbers in Gumine were estimated on the basis of data from the 1980 Census. Assuming a net growth of 2.1 per cent p.a. (World Bank 1989), the population of 36,774 in 1980 would have grown to around 44,300 in 1989. At an average household size of 7.4 people, this represents 5,990 households. As there was some net outmigration from Gumine, the number of households was arbitrarily rounded down to 5,900.

The farm survey carried out in Gumine found that, on average, there were 1.6 ha of land area at the disposal of each farm-household. For 5,900 households, this would indicate an arable land area of 9,440 ha.

3.4 Measuring economic surplus

Based on Nakajima's definition of economic surplus for a farm-household, in the present model it is calculated as revenues from different sources less costs. Revenue items are: (a) cash income, (b) value of gifts given, and (c) value of home-consumed produce.

Costs are: (a) cash costs of production, and (b) value of family labour used in production activities. Gifts are costed at the exchange value, and home-consumed produce at the expected market price.

Quantification of the revenue and cash-cost items is a routine task, but the measurement of labour costs is more challenging. In-depth interviewing of villagers could have yielded information about the subjective perception of marginal labour costs as labour input is increasing, but there were no resources to undertake such a task. Therefore, logical reasoning was used to approximate the marginal-cost curve of the farm-household in Figure 3.

In the context of the semi-subsistent farm-households of Gumine, below the level of satisfying basic human needs, it is not working that has an opportunity cost: starvation or malnutrition. Thus, labour use has a negative opportunity cost until basic needs are satisfied. From then, however, the opportunity cost of using labour in production activities is expected to rise steeply, pushing up marginal costs to its highest point at the physical limits of labour use. This pattern is represented by the curve MC in Figure 3.

The approximated marginal-cost curve used in this study is linear (MC_L in Figure 3). It starts at the origin and rises to an arbitrary level at the physical limits of labour use. No evidence can be offered as to how closely MC_L may approximate MC, as the latter is not known. The linear approximation is above the marginal opportunity cost at and near the origin and it may be above or below the actual curve at the maximum marginal cost. One may try to set the maximum of the linear approximation lower than the expected actual maximum, so as to increase the likelihood of a close fit.

Once the marginal-cost curve is identified or approximated, total labour cost can be calculated as the definite integral of the function between the origin and the actual level of labour use.

In this study, the maximum available labour time of the farm-household is 20,075 hours. At this extreme level of labour use, the maximum point of the marginal-cost function

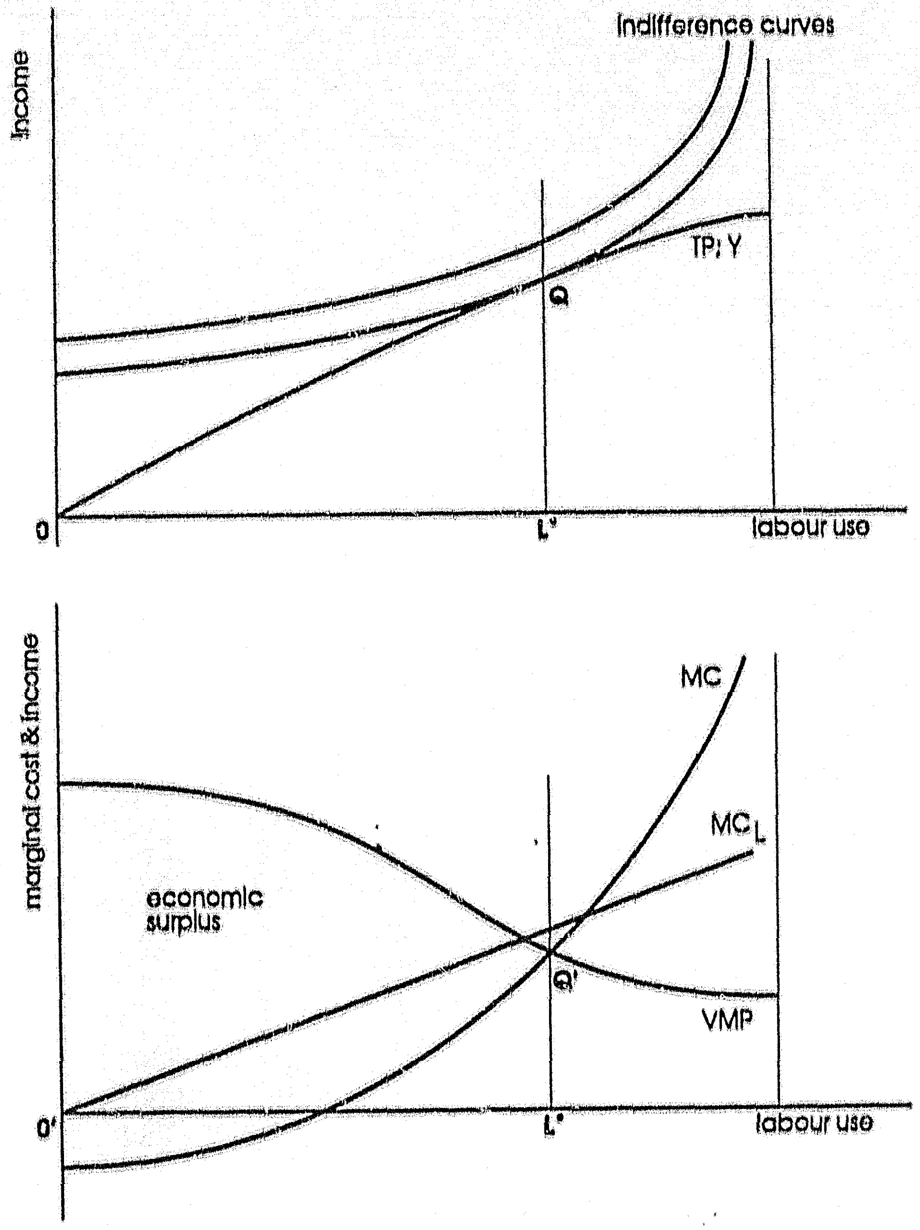

Figure ,3 The application of Nakajima's farm-household model in the study is set at the expected value of rural wage (0.5 x K456.8, per 1000 hrs of labour); yielding the following relationship:

$$MC_L = 228.4/20.1\ L = 11.4\ L \tag{3}$$

where: MC_L = linear approximation of the marginal labour cost, and
L = labour use ('000 hours).

Total cost is given by the area under the marginal labour-cost curve, and it is calculated as the definite integral of the function between the origin and L^*, the level of labour use:

$$\int_{L^*}^{0} 11.4\ L = 11.4\ (L^{*2}\ /\ 2) \tag{4}$$

It must be made clear that while an approximate measure of economic surplus is calculated in this study, it is not used for the optimization of the farm-household model. Total expected utility constitutes the objective function, and the optimal level of labour use for work is where utility reaches its maximum. While this point may or may not coincide with L^* (in Figure 3), it is nevertheless used to mark the latter.

The economic surplus (or gross margin) of the representative farm is multiplied by the number of farms to obtain regional economic surplus.[11]

Because of the rather tentative method of costing labour use, the absolute figures of the surpluses may not be very accurate. Nevertheless, the extent and direction of their change, both over time and in response to variations in technology, should be less sensitive to potential measurement inaccuracies.

11 The calculation of economic surplus is shown in Figure 2 as the last constraint of the matrix: this is a simplification merely to indicate the components of economic surplus. In the actual implementation (Appendix 2) calculations of the value of labour use and of the surplus measures were done outside of the matrix.

3.5 Time in the Gumine model

Incorporation of time in the analysis involved the recalculation of the programming model for a number of years with changed parameters, to reflect year-to-year developments in the system. This approach is different from recursive programming as there is no carry-over between the years: therefore the solution in a particular year is not connected to those in previous years. As capital formation and debt servicing are not important characteristics of semi-subsistent PNG farm-households, the added complexity of recursive programming could not be justified.

(a) Population growth

The current 2.1-per-cent national average population growth was projected to Gumine. As a less-developed region of the country, rates of population growth in Gumine are, in fact, probably above the average. Thus the likely longer-term decline in population growth may still only bring the regional figure down to around the present PNG average of 2.1 per cent. As a simplification, growth was represented in the model as a simple increase in the number of households, with household size remaining the same.

The main consequence of population growth is the reduction of land available for each household. (For the purposes of the model, it is assumed that the traditional, egalitarian way of land allocation will continue in the foreseeable future, and this reduction will be proportionate across all households.)

(b) Technical change

It is unlikely that technology would stay unchanged in Gumine in the decades to come. Even if the broad framework of semi-subsistence agriculture remains the same, continuous improvements will occur whether there is a concerted research and/or extension effort or not. Steady trends of slightly increasing yields were introduced in the model, together with an improvement of the feed transformation of livestock. The rate of change for both was set at

1.5 per cent p.a. On the side of crop nutrition, the nutritional requirements were also increased by 1.5 per cent and the fallow/crop ratio reduced by the same amount every year. The constraint on using mineral fertilizers was increased by 1.5 per cent p.a.

(c) Social change

Behavioural change is likely in the study area over the next decades. Increasing commercialization of production is a crucial attitudinal change. A consequence of increasing demand for cash income, to pay for purchased goods, such commercialization is observable in all parts of PNG. The formulation of the objective function is to represent the importance of cash income and its trade-offs with leisure time. While the total stock of leisure time stays constant, total wealth for cash income and traditional exchange were increased by 1 per cent per annum. This relative devaluation of the relative importance of traditional exchange corresponds to expectations about future developments. (The K200 minimum value of exchange was left unchanged over the years.) Cash income, however, is expected to grow in importance over time. Therefore, the preference weight (a) for cash income in the objective function is increased by 1.1 per cent every year, as compared with equations 1 and 2 that refer to the first year.

Food preferences are likely to shift away from traditional sources and towards purchased ones. This is a general trend in PNG, manifesting itself in the steady increase in the demand for rice. The yearly increase of demand for purchased foods was assumed to be 2.5 per cent, to be formulated in the model as an expanding limit on purchases allowed.

The time trends were introduced into the multi-period model by way of parametized changes of the matrix values.

3.6 Implementation

The model has been implemented as a program in the high-level programming language of the GAMS package. The programming-language feature of this package (Brooke, Kendrick and Meeraus 1988) makes it especially useful for the formulation and solution of complex mathematical-programming models.

4 Solution to the Model

The solution for year 1 contains 0.33 ha of the sweet potato, coffee and other crops enterprise and 0.45 ha of fallow below 2,000 m elevation. Above 2,000 m, the crop mix consists of 0.33 ha of sweet potato monocrop, 0.07 ha of introduced vegetables and 0.33 ha of fallow. The use of mineral fertilizers is at their maximum allowed limit of 100 kg per year. 3.5 pigs and the maximum allowed number of 10 chickens and 1 goat are kept on average through the year. Such pig numbers are close to the actual figure of around 4 in the area, whereas 1 goat per family is higher than the actual. The resources not fully utilized are feed suitable for ruminants and soil fertility above 2,000 m.

Of the products of the cropping enterprise, all human-quality root crops (3.87 t), bananas (0.56 t) and traditional greens (0.11 t) are consumed within the household, while all coffee (0.56 t) and introduced vegetables (the maximum allowed 0.5 t) are sold for cash. The 1.7 pigs reaching maturity are used in traditional exchange, the 0.5 goat is sold for cash, 6.9 chickens are eaten within the household and 8.1 are sold for cash. Cash from produce sale and earnings from 3,030 hours of male wage labour amount to K456 per annum. (In practice, a mix of wage labour and outmigration can be observed, but the model was not sufficiently precise to reflect this.) The value of gifts given is K525. The amount of free leisure time available for males and females is, respectively, some 2,680 and 2,220 hours. 200 kg of rice and 203 cans of corned beef/tinned fish and the home consumption of produce (valued at around K1,635 at market prices) satisfy the nutritional needs.

The production of introduced vegetables, goats and poultry are at the set limits representing exogenous demand constraints. Further expansion especially in these areas could improve the value of the objective function.

The above farm-household structure resembles the actual situation. It also reflects the emerging trend of diversification of income sources in the Highlands, away from coffee and towards vegetables as well as wage/business income, pointed out by Overfield and Irog (1992).

The solution for year 30 constitutes a prognosis of the situation where no radical technical change takes place, but merely those trends manifest themselves that were described earlier. With the projected growth of the population from 5,900 families to 11,006, land area per household declines to some 0.88 ha. The decreasing land area clearly forces the intensification of production, and monocropping takes over from the earlier mixed cropping systems. Ominously, the optimal solution does not contain coffee production any more ! The maximum possible area of 0.06 ha of introduced vegetables provides produce for sale, and subsistence food is supplied by monocropped sweet potato. The value of home-consumed produce declines to K1,543. The increased rice-buying ceiling is fully utilized, while dietary protein requirement can be satisfied with somewhat fewer cans of protein food.[12]

Wage labour in the vicinity takes over as the primary use for male labour, at as much as 5,540 hours. Cash income almost doubles, to K797 per annum. In the meantime, gift giving declines to K440, whereas leisure time increases to 3,010 hours for males and 2,730 for females.

Absolute levels of the economic-surplus measures may not be accurate, but the increment between years is expected to be more reliable. In nominal terms, the value of farm

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[12] Demonstrating the limitations of such a simplified model, the diet would now consists merely of sweet potato, rice and tinned protein foods.

economic surplus rises by K304 in 30 years. Regional economic surplus increases by K9.67 million, while farm-household surplus by K355, again in current money terms.

5 Case Studies

The effects of hypothetical new technologies on the farm-household model were examined. These represent some of the options of intensification in smallholder farming systems, aimed at: (a) the resource base, (b) traditional staples, and (c) tree crops.

Examining the above hypothetical projects has advantages as well. On grounds of congruence (i.e., their relative importance in the system), the above broad options are often suggested in discussion about PNG research priorities. It is necessary, therefore, to have some idea about their relative potential contributions to the welfare of the clients of research.

To make the comparison of the research options easier, the same extent and pattern of adoption is assumed in all scenarios: adoption would start immediately; the ceiling of adoption is put at 60 per cent, to be achieved over 5 years, and; the life of the new technology would extend beyond the 30-year planning horizon allowed for in the quantitative analysis. Similarly, the same 10-per-cent yield improvement is assumed in all cases.

(i) Improvement in the resource base

One of the main problems facing the farming systems in Gumine is the declining fertility of soils. This is caused by the shortening of fallow periods in the traditional rotation, brought about by increasing land shortage. The intensification of the farming system requires new practices that maintain fertility even with shorter fallow periods. The application of mineral fertilizers would be one obvious technique in the context of modern agricultural practice. While they use some fertilizer on crops produced for the market, Gumine farmers do not consider the mineral fertilization of traditional crops a serious proposition (Martin Gunther, pers. comm. 1988).

One example of improving the resource base is alley cropping. This technology involves planting leguminous trees into the fallow. Being capable of fixing atmospheric nitrogen, these trees enrich the soil in nitrogen compounds. In addition, they grow fast and provide more biomass than natural regrowth. When cut down, they provide firewood and the branches can be used as green manure.

The unspecified, hypothetical new technology used in this study would yield a uniform 10-per-cent increase in the firewood yield, nutrient-generating capacity and grazing/rooting feed supply of fallow. On the cost side, there would be a labour requirement (either male or female) of 20 hrs/ha (on average per year, over the total years of fallow).

(ii) Germplasm improvement in sweet potato

There are strong arguments that sweet potato, the backbone of the rural economy, must be given continuous research attention. Germplasm improvement, a traditional direction of agricultural research, is aimed at producing cultivars that are more tolerant of pests and diseases and/or have a higher yield potential.

The unspecified, hypothetical new germplasm would yield a uniform 10-per-cent increase in the yield of sweet potato. On the cost side, there would be an additional labour requirement for harvesting, put at 5 per cent of the existing labour use of the standing mixed crops and 10 per cent for standing monocrops. The fallow/crop ratio was reduced by the same amounts, accounting for the increased demand for soil nutrients. To allow maximum comparison with the other research options, it is assumed that the new germplasm is already on hand

(iii) Improved management practices in coffee

Although coffee can be grown at the low management level of PNG 'village coffee', its yield remains well under the biological potential. Improving the management skills of farmers is primarily the question of a sustained extension effort, as the components of better management (e.g., pruning, weeding) are well known.

Improved management practices are assumed to raise yields by around 10 per cent in Gumine. On the cost side, there would be an additional labour requirement for harvesting, put at 5 per cent of the existing labour use of the standing mixed crops and 10 per cent for standing monocrops. The fallow/crop ratio was reduced by the same amounts, accounting for the increased demand for soil nutrients.

Of the new technologies described above, only improved coffee management does not become part of the optimal solution. All the others, consequently, contribute more towards the objectives of the farm-household than the amount of additional resources they would require. Where both the new fallow and sweet-potato technologies are made available, both enter the optimal solution.

The optimal solutions are identical in year 1, as no adoption of the new technologies is assumed in this year. Following adoption up to the allowed 60 per cent ceiling, some differences can be observed. The resulting divergence in welfare is reflected in Table 7.

Table 7
Incremental Benefits of Technical Change

Efficiency measure	Coffee management	Fallow improvement	Sweet potato	Fallow & S/P
		margin over base scenario		
Farm-household surplus in year 30 (K/farm)	0	11	21	80
Farm economic surplus in year 30 (K/farm)	0	10	20	78
Regional econ. surplus in year 30 (K'000)	0	111	211	841
Discounted reg. econ. surplus cumulated over 30 years (K'000)	0	2,229	3,347	5,607

Introduction of the new sweet potato germplasm does not change the enterprise choice compared to the base case. Adoption of the new technology results in a marginal reduction of the area under sweet potato, while production effectively remains the same. Thus, the new technology allows the reallocation of resources away from sweet potato, rather than increasing its production. Freed land is left to fallow, grazed with pigs, allowing an increase in gift giving. There is a slight reduction in labour use in economic activities. Female leisure increases more than male leisure, as a small portion of the freed male labour is used as wage labour.

The new fallow technology brings no change in total cropping area, but some sweet-potato production is shifted from high elevation to below 2000 m. The reallocation of resources allows a modest increase in goat production for cash sale. A marginal increase is observable in pig production, cash income, gift giving and leisure time. Overall, the discounted benefits from this new technology are around two-thirds of those of the new sweet potato germplasm.

It is difficult enough to make decisions about the selection of research projects for implementation from a greater number of options merely on the basis of examining them individually. However, ex-ante analysis is further complicated by the question: to what extent, if at all, would these perspective new technologies have an additive effect on production ? Mathematical programming is the modelling tool that is perhaps best suited to probe this issue.

When new technologies in both fallowing and sweet potato are made available in the model, both are chosen for the optimal solution. Interestingly, the combined effect is more than additive: it is in excess of the sums of the individual effects in Table 7. (The leap in system performance appears rather late in the 30-year time period, and hence the smaller difference in discounted overall figures than in those for year 30.)

The combined effect of both new technologies appears to be the removal of some internal bottlenecks. While the production structures under the two new technologies individually are quite similar, that with both of them is different. The amounts of wage labour are not significantly different from each other in the cases of a single new technology. With both, however, the efficiency of cropping is obviously increased to the extent that some labour is reallocated from wage labour into cropping. The specialization into monocropping, observable with the single improved technologies, is arrested with both present. The sweet potato, coffee and other technology option is still part of the optimal solution in year 30 if both fallowing and sweet potato are improved. The value of home consumption is higher with two new technologies than with either of them individually (which themselves are not different from the base case).

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