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Peasant household modelling: Farming systems evolution and sustainability in northern Zambia

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(Accepted 2 November 1992)

ABSTRACT

Holden, S.T., 1993. Peasant household modelling: Farming systems evolution and sustainability in northern Zambia. *Agric. Econ.*, 9: 000–000.

Chitemene slash-and-burn cultivation continues to be a dominating cropping system in northern Zambia even after the introduction of modern technologies such as hybrid maize and fertilizer. The rationale of farming systems evolution in northern Zambia where labour markets have been absent or highly imperfect, has been analyzed by goal programming based on the theories of Chayanov (1966) and Nakajima (1986). Carrying capacity estimation is incorporated in the models and discussed in relation to the sustainability of land use systems in the area.

The major changes in agricultural technologies in northern Zambia during this century has been the introduction of cassava, maize and fertilizer technologies. Cassava has had the most significant impact since the land could support much higher population densities and since the dependence on the *chitemene* system no longer was critical for the survival of peasants. By switching from finger-millet to cassava as the main staple the peasants could reduce their total labour requirement to meet their basic food needs by as much as 40%. The results also show that the maize-fertilizer technology has been unable to replace the *chitemene* system because economic incentives to continue the system exist as long as there is suitable woodland available. Nevertheless, the introduction of the maize-fertilizer technology may have resulted in reduced *chitemene* cultivation. The rapid expansion of maize production in northern Zambia from the late 70s to the late 80s depended critically on the government policy of equity pricing and input subsidisation. The models predicted that the removal of fertilizer subsidies would result in a dramatic reduction in maize production.

INTRODUCTION

Agriculture in Africa is considered to be one of the main causes of deforestation as 250 million African peasants still continue to practice

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slash-and-burn cultivation (Niang, 1990). From an energy efficiency viewpoint, shifting cultivation is an extremely unproductive system as it capitalizes large quantities of biomass and, therefore, is a high input system (McGrath, 1987). At the same time, it may be considered as a low external input system with high efficiency from a peasant economics perspective (Boserup, 1965; Richards, 1984). The increasing awareness of the non-sustainability of much of the current practices has led to the recent focus on the need for more sustainable development strategies.

Chitemene shifting cultivation, a slash-and-burn system, where trees are cut in a large area, piled on a smaller area, and burnt, has been the dominating traditional farming system in northern Zambia. Crops are grown in the ash for a few years. The system is only sustainable under low population density conditions as its carrying capacity has been estimated to be 2 to 4 persons per km² (Mansfield et al., 1975). It, however, continues to persist in areas with much higher population density as a non-sustainable practice. *Chitemene* was still practiced by peasants near Kasama in villages with the population densities ranging between 24 and 36 persons per km² (Holden, 1988). The soils in the area are dominantly very acid, leached Ultisols and Oxisols. The rainfall is fairly stable (1000–1600 mm/year) and spread over a period of 5 months (November–April). Most of the area is on a plateau ranging from 1200 to 1500 m.a.s.l.. The average temperature varies between 16°C and 21°C during the year. The area is sparsely populated with an average population density close to 6 persons per km². The large majority of the population belongs to the traditional farming sector and belong to the *Bemba* ethnic group. Peasants have adopted the growing of cassava in nearby gardens as well as in their more distant *chitemene* fields during this century and have also adopted a mounding system (*fundikila*) which previously was practiced only by the *Mambwe* ethnic group in the more densely populated areas near the border of Tanzania. More recently, fertilizer-based maize production has been very successful and has increased from 18 450 metric tonnes in 1978 to 83 970 t in 1987 for the Northern Province of Zambia (NCU, 1989). The present monocropping of maize is facing problems as yields are rapidly declining from year to year due to problems of acidity, aluminium toxicity and micronutrient deficiency on the typical soils in northern Zambia (Woode, 1983). Liming has not been practiced so far. Even with application of lime and micronutrients, yields of maize were not maintained in a long term fertilizer trial at Misamfu Regional Research Station. Figure 1 shows typical changes in choice of cropping systems in northern Zambia during this century. The changes are due to population pressure and availability of new technologies and markets.

There has been a tendency in the past to explain the continuation of the

Arrows showing development trends:

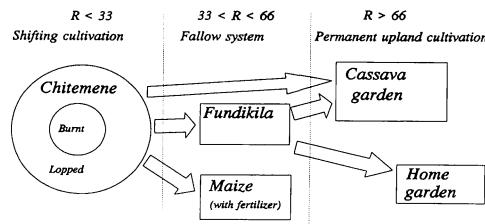


Fig. 1. Trends in cropping system evolution in northern Zambia. R -values (Ruthenberg, 1980, definition): $R = (C * 100)/(C + F)$, where C is the number of cropping years, and F is the number of fallow years.

condemned *chitemene* system in terms of peasants' non-rational and tradition-bound behaviour. The view taken in this study, however, is that peasants are largely rational beings, given their perception of the environment, opportunities and needs. They are, therefore, seen as being optimizers. Thus, it is hypothesized that:

- the persistence of the *chitemene* system is due to certain advantageous attributes of this system compared to alternative systems; and
- it is difficult to develop improved systems which are economically more favourable and which will replace the *chitemene* system where it is still viable, i.e. where sufficient woodland is available.

The objectives of this study were to develop models of peasant households in northern Zambia, incorporating both the goals and resource constraints of peasants, with a view:

- to explain and predict the past and present peasant behaviour in terms of choice of cropping systems, input demand, output supply, seasonal labour allocation and off-farm income activities; and
- to analyze the ability of peasants to meet their basic needs as a fundamental requirement of the sustainable development concept under varying conditions like those of population density, consumer/producer-ratio (C/W-ratio) in the household, household preferences, availability of technologies, market access, input prices, etc.

There has been a tendency in the past to regard peasants as farmers confined only to their farm, thus overlooking their engagement in off-farm activities. Evidence suggests that off-farm income opportunities are widespread (Reardon, 1989; Low, 1986). Holden (1988) found that farm income constituted 38% of total income among peasants in a study of three villages near Kasama in northern Zambia. The contribution of farm income to total income is likely to be greater in more remote areas (Pottier, 1988). The availability of off-farm income opportunities will influence farming

decisions and may even cause stagnation or decline in per-capita food production (Low, 1986; Watson, 1958).

Considering these facts, Low (1986) used the new household-economics theory (Becker, 1965) and the subjective equilibrium theory (Chayanov, 1966) to explain the stagnation in food production in Southern Africa. The question is whether the same theories can explain the rapid growth of maize production among peasants in northern Zambia during the 80s? Can these theories be further operationalized to analyze issues of the evolution of farming systems and changes in sustainability in the same environment? The subjective equilibrium theory has here been used as a basis for and supplement to a mathematical programming approach.

Due to gender-specific differences in terms of division of labour in African agriculture, the ratio of males to females assumes a great importance for household adaptation as substitution between male and female labour force may be constrained (Stølen, 1983; Geisler, Keller and Chuzu, 1985). The percentage of the female-headed households in northern Zambia was found to be as high as 37% according to the 1980 population census (Geisler, Keller and Chuzu, 1985, Central Statistical Office, 1980). Holden (1988) found large differences in the pattern of resource allocation between male and female-headed households. Such behaviour may be due to resource availability and the goals and values of male and female heads of households. These gender-specific differences have, therefore, also been incorporated in the analysis in this study.

Sustainability of agroecosystems is defined as the ability to maintain productivity in the long run when subject to disturbances (Conway, 1987). The sustainability of livelihoods in northern Zambia depends critically on the land resource base. The carrying capacity or the violation of it may therefore be a useful measure to assess the sustainability of land use practices in the area. The term economic rather than ecological carrying capacity is used signifying the basic needs, cultural norms and individual preferences, technology choices and productivities, market access, and terms of trade for peasant societies (Kirschner et al., 1984).

THEORETICAL MODEL

The analysis is based on Chayanov's 'theory of peasant economy'. According to this theory, a peasant farm household works till it achieves an equilibrium between the increasing drudgery of family labour and the decreasing marginal utility of goods produced. Chayanov underlined that the shapes of the drudgery and utility curves are subjective in character and thus likely to change. He also discussed factors that could affect the form or location of the curves (Chayanov, 1966; Durrenberger, 1984). The

C/W-ratio, rents, debts, capital accumulation, interest on debts and desire for urban goods would affect the marginal utility curve, while soil fertility, market prices of crops, distance to markets and availability of machinery are some of the important factors affecting the drudgery curve.

Chayanov's theory has been developed into a neoclassical framework by Tanaka (1951, cited in Nakajima, 1986) and Nakajima (1986). Nakajima called it the 'subjective equilibrium theory of the farm household'. He developed the theory so as to make it relevant for the analyses of the farm firms, commercial farms, farm households and subsistence farms. This general theory in its simplest form implies the maximization of a utility function:

$$U = U(A, M) \quad (1)$$

subject to a production function/income constraint, given in relation (2) (considering the simplest case of one product):

$$M = P_x F(A, B) \quad (2)$$

In relations (1) and (2) above, A represents the amount of family labour, M the money income during the period under consideration, P_x the price of the product, and B the amount and quality of land available. There exist no labour or land markets and all the produce is assumed to be sold to the market. The subjective equilibrium condition, i.e., $\max U(A, M)$ subject to $M = P_x F(A, B)$, is given by:

$$P_x F_A = -U_A/U_M \quad (3)$$

For relation (3) above, the marginal utility of labour, U_A is assumed to be negative because it gives direct disutility and because it reduces the amount of leisure. The marginal utility of income, U_M , is, however, always assumed to be positive. The trade-off between leisure and income can be measured by the term $-U_A/U_M$, which can be called the 'marginal rate of substitution of family labour for money' or the 'marginal valuation of family labour'. This term also represents the slope of the indifference curve, i.e. dA/dM . Nakajima further introduced the assumption of diminishing marginal utility of income and increasing marginal disutility of labour (decreasing marginal utility of leisure). These assumptions together with the assumption of declining marginal product ensure that the stability conditions (necessary and sufficient) for utility maximization are satisfied. The consequence of this is that indifference curves between labour (leisure) and income in labour (x -axis) and income (y -axis) space will be upward sloping and convex to the x -axis. Nakajima likewise assumed a 'physiological limit of family labour' and a 'minimum subsistence income' resulting in upper and lower limits for what can be produced by the household. This is illustrated in Fig. 2.

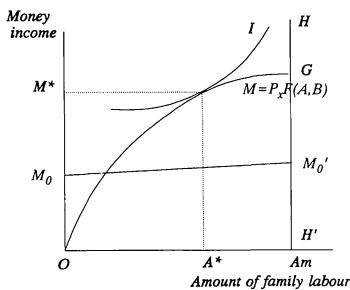


Fig. 2. Nakajima's farm household model.

In this study a theoretical model of peasant household behaviour was developed on the basis of the foregoing models by Chayanov (1966) and Nakajima (1986). The major extensions in the present model are the inclusion of risk/uncertainty and seasonality. This implies that the model holds at any one point of time (short time period).

Unlike Becker (1965), this study maintained a distinction between the household production activities and the household maintenance activities, although there is no clear-cut line between them. Household maintenance activities are then defined as those giving 'relatively immediate utility'. Thus the importance of risk/uncertainty can be ignored. There are a lot of household activities which are not production activities according to our definition and which do not give direct utility (like Z-goods do in Becker's theory). Examples of these activities are cooking, water collection, firewood collection and cleaning of the house. We may say that they give relatively immediate utility. The same will be the case for various social activities to the extent that they do not represent more long term investment to reduce risk or to increase expected utility in the future in some other way. It is evident that it may be difficult to distinguish through direct observation whether social activities are typical maintenance or production activities. Many such activities contain elements of both, and people may not even be clear in their minds to what extent a social activity gives direct utility or represents an investment, e.g., in future security.

Contrary to Becker, but in accordance with Chayanov and Nakajima, the present theory explicitly emphasizes the increasing marginal disutility of labour input. This is an important reason for the convexity of indifference curves in output-leisure/labour space.

Production and marginal production have in the present model been replaced with the expected production and expected marginal production. The expected utility of expected marginal production then represents what the household trades off against the marginal disutility of labour. Implicit

in the utility function are time preferences and preferences towards risk/uncertainty. These may imply a consideration of the probability distribution of various outcomes and the adoption of some kind of 'survival algorithm' (Lipton, 1968). For maintenance activities the outcome and utility is assumed to be known.

The inclusion of seasonality in the model implies that there will be a new subjective equilibrium in every time interval where one day may be seen as a suitable interval for the theoretical model, although days may be aggregated to larger periods if conditions are homogeneous in that period. This implies that the household in its overall utility maximization problem maximizes the aggregated utility over all time periods subject to a set of multiple time constraints. Furthermore, there will be some possibilities for substitution between time periods. Since the marginal expected utility curves and the marginal disutility at the equilibrium point will change from period to period, the trade-offs will be complex.

This implies the maximization of the following utility function in each time period t , i.e.

$$U_t = U_t(A, H, M_t, EU_{t+}(E(M_{t+}))) \quad (7)$$

subject to production/income constraints:

$$E(M_{t+}) = E(P_{t+}) * E(F_{t+}(A, B)) \quad (8)$$

$$H = H(A) \quad (9)$$

$$M_t = P_t * F_t \quad (10)$$

where EU_{t+} is expected future utility, incorporating both time and risk preferences, of $E(M_{t+})$ which is expected future income based on expectations about prices and yields, H is the household maintenance activities only requiring labour, and M_t is income during this period. The subjective equilibrium condition becomes:

$$EU_M(E(P_x) * E(F_A)) = -U_A \quad (11)$$

which states that at the equilibrium point the expected marginal utility of expected marginal income is equal to the negative of the marginal disutility of labour.

PROGRAMMING MODELS

Households may be seen as having multiple goals. Some of these goals may have absolute preference over other goals, at least within certain ranges. Other goals may be weighed against each other when compromising

solutions have to be found. Romero and Rehman (1989) identified two types of goals, one representing the decision-maker's desires, the other representing limited resources. Some goals may, therefore, be seen as soft constraints that can be violated.

Here, models were developed for peasants where the starting point was the basic needs of peasants as they themselves perceived them, based on their observed behaviour in relation to their allocation of scarce resources to meet these needs.

The aim was to make operational models capable of providing insight into certain aspects of household behaviour, and the consequences this behaviour may have for resource use and technology choice in a sustainable development perspective.

The basic goals for a peasant household were identified to be the meeting of requirements for:

- food (energy, protein, taste, preparation);
- housing (building materials, building);
- energy for cooking (wood-fuel, collection);
- water (collection);
- certain market purchased goods and services, like salt, soap, matches, paraffin, clothes, school expenditure, travel expenditure, food, medicine, etc.;
- security (risk avoidance);
- social obligations and needs; and
- leisure assuming that peasants are drudgery-averse, i.e., they want to meet their needs with a lowest possible work effort.

Some of these goals have absolute priority over others and were taken care of by using fixed constraints. The marginal utility of increasing the level of consumption beyond a certain target level may also decline rapidly for some of these needs. The marginal utility for other goals may decline less rapidly and they may be modelled by the use of soft constraints.

Some of the needs may be met through different strategies. In the case of food, for example, the household has the choice between producing the food itself or purchasing it from the market. The choice will depend on the relative scarcity of cash and labour within the household, the productivity of self production, the cost of obtaining the food from the market, time preferences, and the risk involved in choosing various strategies.

To meet some of the goals, time (labour) is the only major scarce resource required. Culturally influenced restrictions on the use of time as defined by social obligations must also be considered. These are partly determined by the society and partly by personal preferences. This is related to the needs for security and social contact. These then also reduce the time available for production activities.

The following two alternative model formulations were used in this study:

1. *Traditional society: Minimization of labour requirements based on a 'limited material wants' hypothesis*

The need for market purchased goods and services was in this type of models rationalized into a flexible income constraint. The models were first run setting the income constraint at zero (100% subsistence production). Systematic changes in the income constraint and the 'land available for *chitemene*' constraint were thus made to see how large surpluses could be generated under different conditions and how population pressure would affect the solutions and possible surpluses generated. This also implied a kind of sensitivity analysis of the models. By varying the income constraint, simulating a varying demand for cash, its impact on land use and carrying capacity was traced.

These were developed as general models of peasant households with limited markets and access to traditional technologies only. They were then used to analyze the interrelationship between traditional cropping systems (technology choices), population density and market access with reference to past historical development, particularly the effects of the introduction of cassava in northern Zambia. A standard household composition was used with the ultimate goal of minimizing the total labour input in agriculture subject to the constraints on the basic food requirements, seasonal time, technology, and a flexible income. The rationality of such an approach lies in certain levelling (sharing) mechanisms which reduce differences between households in a kinsgroup of a traditional society (Heleiner, 1966; Norman, Newman and Oudraogo, 1981; Long, 1977; Pottier, 1988; Kakeya, 1976; Kakeya and Sugiyama, 1987). The result of this may be a kind of 'limited material wants' strategy and a strong preference for leisure. The marginal utility of producing more than one's kinsmen is low since the surplus may have to be shared. It was further assumed that inter-household relationships serve as insurance against crop failure and that households do not undertake additional measures to reduce risk.

Fixed seasonal labour constraints were used, but the upper limit was set somewhat higher in peak seasons to approximate observed allocation of labour among peasants. The year was divided into eleven periods of varying length. The most active labour use periods in farming were divided in half month intervals while the less busy periods were allowed to be from one to three-month intervals.

For trading of farm produce, 1986 prices were used as a yardstick hoping that relative prices in 1986 were not much different from those in the past.

Objective 1: Minimize labour requirements with variable income constraint.

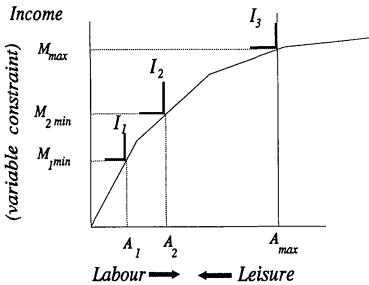


Fig. 3. Programming model for traditional society.

2. Modernized society: a weighted income and leisure goal (Fig. 4)

The models of modernized society households simulate the market conditions typical for the 1980s. These models incorporated the activities for maize production, input purchase (except for labour), commodity sale, and limited off-farm income. In such societies, the commodity markets are quite developed and the dependency on market purchased goods is likely to be higher. With modernization and increased market integration the equalizing mechanisms gradually break down and households become more autonomous units. This increases the relevance of looking at resource-rich and resource-poor households as they may have access to different sets of production possibility and may no longer share the wealth to the same extent as before. The two key resources in relation to household differentiation were considered to be labour and cash. Therefore, the standard household composition was replaced by three different household compositions, each varying in their access to off-farm income opportunities. Access to off-farm income opportunities was only included under high population

Objective 2: Weighted income and leisure goal

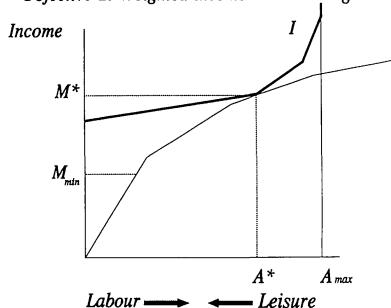


Fig. 4. Programming model for modernized society.

TABLE 1
Types of models developed

Model specifications	Large male-headed household		Small male-headed household		Female-headed household	
Off-farm income	No	Yes	No	Yes	No	Yes
Low population density	×		×		×	
High population density	×	×	×	×	×	×

density conditions. The types of models developed are summarized in Table 1 (Holden, 1991).

The models were developed for each category of households as a combination of lexicographic and weighted goal programming models, where the leisure and income goals were combined in a weighted objective function and other higher priority goals were treated as constraints. This implied that the leisure was weighted into the income goal by modelling seasonal labour constraints as soft constraints that could be violated within certain limits and with increasing marginal disutility as leisure was reduced.

The upper limit for the family labour force was determined on the basis of allocation of time studies for various household members in the peak season (Holden, 1991). Increasing marginal value of time was simulated by the inclusion of a number of constraints where deviational variables were included similar to the standard soft constraints in goal programming. This is illustrated in the following example where maximum labour for the period was set equal to 100 (hours per week):

– Objective function

$$px - d_1 - d_2 - d_3 = \max$$

– Constraints

$$\begin{aligned} a_t x &\leq 100 \\ a_t x - 1 &\leq 90 \\ a_t x - 1 &\leq 70 \\ a_t x - 1 &= 0 \end{aligned}$$

where p is a row vector of prices, x is a column vector of activity levels, and a_t is a row vector of time requirements per unit of activity in period t . The deviational variables d_1 , d_2 and d_3 were included in the objective function which was to maximize net income when an increasing value was put on family labour as it came closer to the maximum for the labour constraints. The last constraint is equal to 0 implying that all family labour

was given a basic minimum value equal to d_3 . Above 70% and 90% of the maximum, incremental values of family labour were added as d_2 and d_1 . The maximum constraint was set to be constant throughout the year. The actual use of labour would, however, vary depending on the productivity of labour and the incremental values given to family labour. With four constraints per each of the 11 time periods, a total of 45 labour constraints were used. It helped obtaining a labour distribution pattern which approximated observed behaviour with high labour input in the peak seasons and lower labour input levels in other parts of the year. The difference between this and the previous model is illustrated graphically in Figs. 3 and 4. The maximum level of the labour constraint in each model was determined by the family structure where maximum labour hours in farming activities for each household member were added together. The magnitudes of d_3 , d_2 and d_1 were determined by judging the value of labour productivity in different agricultural activities and setting d_3 below the value of the activities with lowest value of labour productivity. The sum of d_3 and d_2 was set close to the medium value of labour productivity in agricultural activities. Finally, the sum of d_3 , d_2 and d_1 was set somewhat below the value of labour productivity of the most productive agricultural activities. It was thought that these values, in a rough way, would approximate the increasing disutility of labour as indicated in the theoretical model.

Risk preferences were included in the models of modernized societies by assuming the peasants as weak risk averse. Uncertainty and risks were particularly related to production activities, where yield variability was caused by unreliable input supply, like that for fertilizer and by some climatic variation.

A more sophisticated formulation of risk/uncertainty preferences would require detailed information on the probability of all possible outcomes (or more correctly the peasants' subjective assessment). It would also require explicit studies on actual attitudes towards risk among peasants in the study area. In the absence of such studies, the observed behaviour in the more general studies and that found in the studies of peasants' attitudes towards risk elsewhere, was made use of. It was observed that peasants in many situations were willing to take risks as they often were found to plant large areas of maize before they knew if they could get fertilizer. They were not found to plant very large areas of subsistence crops to protect themselves against the possibility of very low yields for the most important crops. One may, therefore, disregard that the majority of peasants in northern Zambia have strong or very strong risk preferences.

Inter-household relations, particularly in the past, have served as an insurance system. It was assumed in the models of traditional society that no additional precautions were taken by the households. In the models of

modern society it was assumed that the inter-household system of sharing and insurance has broken down to such an extent that peasants made additional adjustments according to their risk preferences.

The purchase of farm inputs was also regulated by a cash constraint, signifying the limited cash availability for the purchase of farm inputs (fertilizer and seeds) at the beginning of the cropping season. Such a constraint was related to the observed expenditure of the households on farm inputs.

Uncertainty/risk were included in the production activities as safety-first constraints as done by Hazell and Norton (1986) and Low (1974), making sure that basic needs for food and other commodities were met also during the years when the fertilizer was unavailable and the rains commenced late. It was further assumed that the peasants in the area did not have risk preferences requiring them to take additional precautions in relation to incidents that may occur less frequently. Late start of the rains implied that planting did not start till early December, requiring the postponement of activities that involved planting in the second part of November. Non-availability of fertilizer implied very low yields of maize and low yields of millet as against those obtained with the planned application of this input. These low yields were based on observed yields in the Kasama area in cases when peasants failed to obtain fertilizers. The risk constraints incorporated in the models included one each for energy, protein and minimum cash tied to input purchase in the following season (good year). The minimum values of these constraints were determined by the basic minimum needs of the model households. It was assumed that male-headed households were willing to use up to 16% of their income in a bad year on input purchase in the following year as against only up to 5% by the female-headed households (Holden, 1988, 1991). A specification of the model for the large male-headed household follows:

Constraints	Activities			Risk income
	Fertilizer	Seeds		
Riskcash	px_r	0	0	-1 = 0
Riskin		-1	-1	0.16 = 0
Riskmin				1 ≥ 400

where x_r is a column vector of quantities in a bad year. The risk income (Riskincome) activity gives the net income in years when fertilizer arrives late and influences the cash availability for the purchase of fertilizer and seeds in the following year, the year for which the model optimizes. A minimum constraint (Riskmin) for the lowest acceptable income in a bad

year was also included in the model. The fertilizer and seed activities were specified in monetary terms.

This simple risk constraint system did not allow any dynamic adjustments by peasants after they experienced the worse possible outcome. In practice, they may have some possibilities for dynamic adjustments, like planting another crop in stead of fertilized maize, or taking off-farm work to get additional cash. Such possibilities for dynamic adjustments were considered rather small and were, therefore, neglected in the models used in this study.

The models incorporated production possibilities in the form of a set of activities, their resource requirements and the resource constraints of households. The activities were related to production, consumption and trading. Production also included off-farm work opportunities. The cropping activities were regulated by a set of constraints to simulate typical cropping systems, crop rotation and intercropping patterns, staggered planting, etc.

The models were specified on the basis of both primary and secondary sources (Holden, 1983, 1988, 1991; SPRP, 1987, 1989; Alder, 1958, 1960; Bolt and Holdsworth, 1987; Boyd, 1959; Richards, 1939; Woode, 1983; Strømgaard, 1984). These sources provide a detailed picture of changes in land use and living conditions in northern Zambia from the 1930s to the late 1980s. Primary data were collected in the period 1986 to 1989 from random samples of 20 households each from three villages with population densities from 26 to 82 persons per km². Twenty-two of the households were female-headed. Land use and yield data were obtained through measurement of fields (triangulation), sampling, weighing, measurement of storebins, and multiple visit interviews. Household income and expenditure data, including off-farm income and farm input expenditure, were collected. Detailed allocation of time and cash-flow studies were carried out for 14 households (seven male-headed and seven female-headed) for a whole year. Some additional studies of the *chitemene* system were carried out in the Chimbola area, where the population density was much lower, to get supplementary data on labour input and yields. These studies were of a more informal character. Table 2 summarizes some of the household data for male and female-headed households (Holden, 1991).

It was assumed that the internal and external variables were stable enough over time and that the optimal solution approximates the long term equilibrium in a situation with imperfect markets. Free disposal of the produce within a given year and efficient cooperation and appropriate sharing within the households were some other simplifying assumptions. We have assumed equal distribution of land between households within an area. Increasing population density was simulated by restricting the possi-

TABLE 2
Household data from the Kasama area (high population density) 1986

Variable	Type of household	
	Male-headed	Female-headed
Income		
Total	1124	980
Farm	506	232
Employment	347	164
Business	35	484
Input use		
Fertilizer (kg)	174	22
Seeds (value)	16	1
Production (kg)		
Maize	594	54
Finger-millet	290	127
Areas (ha)		
Total	1.49	0.77
Chitemene	0.13	0.12
Fundikila	0.55	0.22
Cassava garden	0.48	0.34
Maize	0.41	0.17

Comment: Some maize was grown under the fundikila and cassava garden systems. Average data for 38 male-headed and 22 female-headed households.

bilities for *chitemene* production as this system is very land demanding. High population density was also simulated by restricting possibilities for maize production on virgin land.

A number of soft constraints were included to estimate the carrying capacity (area requirement) for sustainable land use in relation to the various model solutions. These estimates were based on some assumptions about the outfield-infield ratio for the *chitemene* system, fallow requirement (regeneration period) and the proportion of the land which was suitable for each system. These assumptions or estimates are presented in Table 3. The fallow requirement estimates were based on Higgins et al. (1982), who estimated the cultivation factors for major soil types in the tropics with low, intermediate and high input levels, Mansfield et al. (1975), who estimated the carrying capacities of the *chitemene* and the *fundikila* systems, and Schultz (1976) and Chidumayo (1987), who estimated the proportion of arable land in the *chitemene* region in northern Zambia. There was considerable uncertainty regarding the fallow requirements for the *fundikila*, cassava garden and maize systems. Regeneration is a gradual process and may in some cases take very long time, i.e. several decades or even centuries to neutralize the effects of an intensive cropping period. In

TABLE 3
Assumptions for carrying capacity estimates

System	Outfield/infield ratio	Regeneration period
<i>Chitemene</i>	10	25
<i>Fundikila</i> , no fertilizer	1	16
<i>Fundikila</i> , with fertilizer	1	10
Cassava garden	1	10
Maize	1	10

many cases the actual fallow (regeneration) periods were shorter than the estimates of fallow periods for sustainable use. This means that the estimates of carrying capacities by no means act as fixed constraints or upper limits of population densities in the short run. Rather, one may consider these estimates of carrying capacities as rough indicators or guides for population levels that may be recommended as upper limits, given the even land distribution. For modernized society such an estimate was replaced with that of area requirement per capita for different types of households. An overview of the structure of the models is presented in Appendix 1.

RESULTS AND DISCUSSION

The results in respect of the different models used in the study are presented in this section in detail.

1. Models of traditional society

(a) *Low population density and no cassava cultivation.* These models were used to analyze the productivity and choice between the *chitemene* and *fundikila* systems before cassava was introduced in northern Zambia. The results of such models are presented in Table 4 (Holden, 1991).

Only *chitemene* activities were in the solution after optimization. The *fundikila* system was not chosen before the *chitemene* system when abundant woodland was available. Creation of a cash surplus of 200 Kw required additional 350 hours of labour. The maximum income that could be generated with this model was 272 Kw. The estimated carrying capacity in the models was reduced from 2.5 to 2.2 persons per km² when a surplus with a value of 200 Kw was to be produced.

1 Kw = US\$0.125 in 1986.

TABLE 4

Models of traditional society without and with cassava and with low and high population density

Model specification	No Low	No Low	No Low	Yes Low	Yes Low	Yes Low	Yes High	Yes High	Yes High
Cassava technology	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Population density	Low	Low	Low	Low	Low	Low	High	High	High
Net income constraint (Kw)	0	200	300	0	300	1 000	0	300	400
Labour requirement in production (hours per year)	2 303	2 653	Infeasible	1 374	1 762	3 176	1 570	2 375	2 697
Consumption activities (kg consumed)									
Finger-millet	996	1 108		143	100	379	128	100	100
Groundnuts	305	231		44	44	44	0	0	0
Beans	67	67		67	67	67	95	103	103
Cassava	0	0		3 046	3 151	2 470	3 183	3 233	3 233
Selling activities (kg sold)									
Groundnuts	0	74		0	52	211	0	0	0
Beans	0	38		0	0	147	0	15	9
Cassava, dried and pounded	0	0		0	0	0	0	50	50
Beer	0	0		0	190	333	0	240	341
Annual cropped area (ha per household)									
Total	1.45	1.72		0.64	0.88	1.93	0.90	1.38	1.52
Chitemene	1.45	1.72		0.51	0.88	1.82	0	0	0
Fundikila	0	0		0	0	0	0.69	1.21	1.35
Cassava garden	0	0		0.13	0	0.10	0.22	0.17	0.17
Carrying capacity (persons per km ²)	2.46	2.20		14.8	7.8	3.4	57.4	28.6	24.6

(b) *Low population density, with cassava cultivation.* Cassava was introduced in northern Zambia during this century. It was rapidly adopted and adapted to the local production systems. In this model we have included cassava as a crop in both the *chitemene* and *fundikila* systems and in a separate system (cassava garden), without making any changes as compared to the models above.

Table 4 shows that the introduction of cassava reduced the labour needed for meeting the annual food requirements from 2303 to 1374 h per year, i.e. a reduction of 40%. With an income constraint of 300 Kw the labour requirement was 1762 h and the income constraint could be raised above 1000 Kw without getting an infeasible solution. These results were based on a dietary change and the taste constraints became binding. Such constraints were set at a minimum consumption of 100 kg of finger-millet, 67 kg of beans and 44 kg of groundnuts per year for the standard household. These constraints were observed to secure a sufficient protein supply as the protein constraint did not become binding. It is worth noticing that the introduction of cassava has considerably increased the carrying capacity of the *chitemene* system, the dominating system in these models. It was also from the *chitemene* system that most of the surplus produce for sale was generated. It is the relative prices ratio of beans, groundnuts and beer that determined the choice of sale activities. An increase in the cash demand reduced the carrying capacity of the land use systems, particularly due to the need to increase finger-millet, groundnut and bean production in the *chitemene* system.

(c) *High population density.* High population density conditions were simulated by restricting the possibilities for *chitemene* production and by including more market opportunities, like markets for cassava and finger-millet. An upper limit was set for the cassava sale equal to 5000 kg fresh weight signifying a limited market outlet.

It turned out that no feasible solution was available without cassava and possibilities for *chitemene* production. The *fundikila* system without cassava was not able to support people alone with the existing productivity and efficiency levels. This explained the dominating role of the *chitemene* system in this region in the past when the region only was very thinly populated. Putting a partial restriction on the *chitemene* system forced *fundikila* activities into the solution but this quickly increased the labour requirements nearly up to the upper limits.

We will now turn to the model with cassava cultivation but no possibilities for *chitemene* production. As can be seen in Table 4, with the introduction of cassava it has become possible to survive without the *chitemene* system and even produce a surplus for sale worth above 400 Kw. However, relatively more labour was required to produce the surplus for

sale compared to the low population density model case since this surplus must be produced in the *fundikila* and cassava garden systems instead of in the *chitemene* system. With no surplus requirement, only 200 additional hours were required to meet household food needs in the model without *chitemene* as compared to the model with *chitemene*. However, when the income constraint was set at 300 Kw, more than 600 additional hours were required in the model without *chitemene*. The carrying capacity estimates of the land use systems were considerably increased when no *chitemene* production was possible. Cassava made it possible for the *chitemene* region to carry a much higher population than before and the *chitemene* system could be replaced by the *fundikila* and cassava garden systems. The introduction of cassava may also have encouraged the region to export a larger labour surplus through migration to the Copperbelt and Lusaka during the 20th century than otherwise would have been possible.

2. Models of modernized society

(a) *Low population density.* These models specified the market conditions typical of sparsely populated rural areas in northern Zambia during the 1980s. Off-farm income opportunities have not been included as it is assumed that such possibilities were very limited. Producing maize on virgin land where the yields were expected to be high was assumed to be feasible. It was further assumed that there was no market for cassava and only a limited market for beer existed. Finally, it was assumed to be impossible to buy mealie meal but possible to buy beans and groundnuts in a retail market at a price higher than that of the producer.

The impact of the introduction of the maize and fertilizer technologies and related risk in production is illustrated for a large male-headed household in Table 5 (Holden, 1991). The introduction of maize and input markets increased net income by more than 80% when risk constraints were not included. It required a 3% increase in total labour input. The household grew 2.3 ha of maize producing more than 7 metric tonnes of maize. The household still maintained *chitemene* production, although the area under *chitemene* was reduced to one third.

With the introduction of risk and the other related cash constraints, net income was noticed to reduce by 21% as compared to that in the model without these constraints while the total labour requirement was further increased by 5%. Net income in a bad year was, however, more than double that for the model without risk constraints. The maize area was reduced to one third while the maize output was reduced to less than 3 t. The better maize yield was due to better timing of the maize planting. The *chitemene* area was, on the other hand, considerably larger here than in the

model without risk constraints, and closer to the area in the model without access to maize technology. This can explain why peasants who are in a position to produce maize for sale still maintain *chitemene* production as long as they have access to suitable woodland (Kakeya and Sugiyama, 1987). The hypothesis that peasants largely are rational and adapt to the changing conditions to maximize their utility could, therefore, not be rejected, since the persistence of the *chitemene* system could be explained as rational peasant behaviour. The hypothesis, that it is very difficult to find a technology which can replace the *chitemene* system where woodland still is available, could not be rejected. Even the models of households with access to secure input and maize markets and with high subsidies on fertilizer, maintained a significant proportion of *chitemene* production. This was due to the profitability of this system and the annual distribution of labour which makes it advantageous to combine *chitemene* and maize production. When the high risk in relation to maize production and the fact

TABLE 5

Modernized society: Low population density; Large male-headed vs. female-headed household

Model specification				
Sex of head of household	Male			Female
	No	Yes	Yes	Yes
Maize and input markets				
Risk constraints	Yes	No	Yes	Yes
Objective function	870	2 766	1 769	81
Net income (Kw)	2334	4 345	3 417	473
Net income, bad year	2334	986	2 051	444
Labour requirement (h per year)	6 387	6 575	6 910	1 765
Input use (kg)				
Fertilizer	0	897	294	20
Seeds	0	103	34	2
Selling activities (kg sold)				
Groundnuts	650	323	574	16
Beans	458	26	375	51
Beer	333	333	333	333
Maize	0	7 133	2 772	84
Annual cropped area (ha per household)				
Total	4.62	4.13	4.80	0.99
Chitemene	4.51	1.47	3.88	0.50
Fundikila	0	0	0	0.42
Cassava garden	0.11	0.32	0.15	0.01
Maize	0	2.34	0.77	0.5
Area requirement per capita (ha)	59	36	55	12

that cash resources and credit opportunities are limited, are considered, additional advantages of the *chitemene* system become apparent.

The area requirement for sustainable land use was reduced by the introduction of maize when risk was not considered but when risk was incorporated the area requirement was reduced much less.

A model representing a labour-poor female-headed household with access to the maize and fertilizer technologies and incorporating risk in production and cash constraints, is also presented in Table 5 (Holden, 1991). It was assumed that the female-headed households had more limited capacity to utilize the *chitemene* system due to the gender-specific division of labour within this system. Traditionally, females were not allowed to climb trees and relied on male labour for this work or had to cut the trees near the ground. It was, therefore, assumed that the female-headed household was only capable of cutting 1 ha of woodland each year to produce 0.1 ha of *chitemene* finger-millet.

The impact of the maize and fertilizer technologies was much smaller for the female-headed household than for the large male-headed household due to the more severe cash and labour constraints. The per-capita area requirement for female-headed households was considerably lower than for the male-headed households due to the lower production capacity and ability to use the *chitemene* system and it was little influenced by the introduction of maize and fertilizer markets.

TABLE 6

Modernized society: High population density; Small male-headed household

Model specification	Normal		Double	
	No	Yes	No	Yes
Fertilizer price	325	2547	240	2545
Employment				
Objective function	954	3334	782	3145
Net income (Kw)	736	3219	764	3145
Net income, bad year	2535	2816	2325	2544
Labour requirement (h per year)				
Annual cropped area (ha per household)				
Total	0.85	0.37	0.66	0.20
Chitemene	0	0	0	0
Fundikila	0	0	0	0
Cassava garden	0.57	0.23	0.64	0.20
Maize	0.28	0.14	0.02	0
Fertilizer cost	106	52	14	0
Maize sale (kg)	550	283	54	0
Area requirement per capita (ha)	4.3	1.9	3.2	1.0

(b) *High population density.* In these models the impacts of introducing access to off-farm employment and that of an increase in fertilizer prices were analyzed. The employment activity was limited to one household member and the wage rate was typical for a general worker in 1986. The doubling of fertilizer prices simulated the effect of removing most of the subsidies which existed on fertilizer in 1986. These subsidies were removed a couple of years later. The model therefore predicts the first impact of the introduction of the Structural Adjustment Program in Zambia. Only results for a small male-headed household are presented, see Table 6 (Holden, 1991). With the introduction of employment opportunities, farming activity was considerably reduced. The maize area and sales were reduced to half while the cassava area was reduced to less than half. The doubling of fertilizer prices had a drastic impact on the maize production. For the model without employment, maize production and sales were reduced to less than 10% of that with the normal fertilizer prices while they were reduced to zero in the model with employment.

CONCLUSIONS

Low (1986) explained the stagnation of agricultural production in Southern Africa as being due to favourable off-farm opportunities. Adoption of new high yielding varieties had not given the favourable results one could have hoped. Contrary to Low's findings elsewhere in Southern Africa, this study observed a rapid expansion in maize production among the peasant population in northern Zambia in the late 70s and 80s. This was found to be a result of a favourable price ratio between fertilizer and maize output at the farm gate, limited access to off-farm employment, presence of cassava as the main staple for home consumption, and supply of infrastructure to handle fertilizer supply and maize marketing.

Models of peasant households developed in this study confirmed that maize production was very profitable during this period. With better marketing conditions, maize production would have expanded even faster. Access to off-farm income reduced surplus production of maize for a model of a typical small male-headed household because off-farm activities, like employment as a general worker under the government, were more profitable than the surplus maize production. However, relatively few households in northern Zambia have household members with access to off-farm employment. The adoption of cassava as the main staple in large parts of northern Zambia has increased the peasants' capacity to produce a surplus for sale. With the removal of the cassava technology in the models of peasant households, the maize surplus for sale was considerably reduced and could instead become a deficit. The ability to produce a surplus was

also dependent on factors internal to the household, like the ratio between consumers and producers and the size of the male labour force as was found by Holden (1991). Likewise, female-headed households appeared to be less interested in investing in fertilizer-based maize production. Instead they preferred various forms of business activities like trading and beer-brewing to generate their cash needs. Lack of cash to buy fertilizer was another important constraint that limited maize production for cash-poor households.

Doubling of the fertilizer price, *ceteris paribus*, considerably reduced the profitability of maize production and caused a drastic reduction in its surplus produced for sale. Whether maize production in northern Zambia is economically sustainable will, on the demand side, depend on the purchasing power of the urban population and their willingness to substitute cheaper staples, particularly cassava, for maize. On the supply side it will depend on the cost of fertilizer, crop response to fertilizer, cost of marketing, etc. It will also depend on the preferences for maize within northern Zambia. The willingness and ability of the government to support maize production and marketing may be crucial. It may, however, be more wise to divert some of these resources to the development of cassava production and marketing in the long run since this is a much cheaper way of producing food energy for the urban poor. Market conditions are also likely to continue to be highly imperfect. It may, therefore, be wise to spread the risk by diversifying the food production strategy.

Peasants in northern Zambia seem to have developed preferences for purchased commodities and they are not likely to turn back to a more subsistence-oriented production unless they are forced to do so by disadvantageous terms of trade or non-availability of consumer goods. A removal of subsidies on fertilizers will inevitably lead to a contraction of the cash economy in the area, and it is the maize producers who will be most affected. The direct effect on poorer households, including a large part of the female-headed households, will be less but an indirect effect may be a reduced demand for beer. The subsidy removal will also result in expanded level of *chitemene* production.

The analysis has confirmed that the *chitemene* system is very favourable in areas where suitable woodland is available and it was difficult to find alternative technologies which could create incentives for peasants in northern Zambia to leave the system under low population conditions. Thus, the fertilizer/maize technology which was investigated, cannot be expected to replace the *chitemene* system where woodland for *chitemene* is still available. The hypotheses about the persistence of the *chitemene* system could, therefore, not be rejected.

The introduction of cassava has made intensification possible and it may

be possible that a cassava based system can be maintained at a low steady state. However, more research is required to find this out. In any case, the introduction of cassava has made it possible to feed a much larger population in these areas for a longer period of time. The introduction of cassava has therefore also facilitated the population concentration along roads, lakes and the railway in northern Zambia.

Carrying capacity estimates, although rough and uncertain, were considered useful tools for research and planning purposes in relation to land use. Estimates of carrying capacities or area requirements for the *chitemene* region were developed which are consistent with the productivity of cropping systems, the choice and mix of systems (technology), the basic needs and preferences of peasants, their resources, terms of trade and market integration, and consequently their standard of living, than what has been done in the past. These estimates are certainly more useful than the 'maximum potential supporting capacities' that were estimated by Higgins et al. (1982) and other studies more specific to Zambia. Higgins et al. (1982) estimated that 50–100 persons per km^2 could be supported in northern Zambia. This may be contrasted with previous estimates of carrying capacities for the *chitemene* system of 2–4 persons per km^2 (Schultz, 1976). The introduction of new technologies, particularly cassava, has drastically increased the carrying capacity of the land in northern Zambia. Cassava has also increased the maximum potential supporting capacity of the *chitemene* system to close to 15 persons per km^2 . If the *chitemene* system is abandoned or broken down, the *chitemene* region may have a carrying capacity close to 30 persons per km^2 , based on the conditions specified in our models.

It is important to note that these carrying capacities do not work as constraints for peasant behaviour in the short run. Unfortunately, there exist economic incentives to choose land use practices which are more extensive than the actual population density 'recommends' as a sustainable practice. This is a main cause of deforestation in northern Zambia. There are also fears that it may cause a degradation of the soil resources to a lower productive equilibrium level. A careful demographic policy based on an understanding of the incentive structure of peasants is required to make land use practices more sustainable. Further research is required to develop alternative sustainable systems.

APPENDIX 1

Model structure overview

Constraints	Activities							
	Production systems (30–64)	Consump- tion (5)	Food purchase (0–4)	Input purchase (0–2)	Sale (0–21)	Income (1–2)	Area counting (4–10)	Labour valuation (0–34)
Income (1)			$-p_f$	$-p_i$	p_s	-1		
Labour (11–45)	a_{tn}		a_f	a_i	a_s			-1
Land use (4–17)	I_{mn}							
Transfer rows (5)	-1	1	-1			1		
Input cost (2)	c_{mn}				$-p_i$			
Food requirement (6)		f_e						
Market (6)				m_i	m_s			
Risk (0–5)	y_{rn}			-1		r_r		
Area requirement (4–10)	b_{an}						-1	

Note: The figures in the parentheses are the number of activities/constraints used in various models.

ACKNOWLEDGEMENTS

I am thankful for valuable comments from Prem Sankhayan and Eirik Romstad on an earlier version of this paper.

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