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Modelling Methods for Policy Analysis in Miombo Woodlands

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Abstract

The miombo woodlands of eastern, central and southern Africa are some of the most extensive dry forests in Africa. They supply a myriad of products and services for local populations, governments and the private sector - the main stakeholders. Planning the management and use of the woodlands to meet the needs of the many and diverse stakeholders who often have conflicting interests in the woodlands continues to be a great challenge to national governments and other interested parties. This paper presents two modelling approaches, a systems dynamics model and a goal programming model, that have potential for use in planning woodland use and in analysing the implications of various policies on people and the woodlands.

Key words: Weighted Goal Programming, Miombo Woodlands, Household Sector, Private Sector, Southern Africa and System Dynamics

A. A Goal Programming Model for Planning Management of Miombo Woodlands

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Abstract

This paper presents a methodology employed in reconciling demands of households, private sector, and government on miombo woodlands of Southern Africa. A Weighted Goal Programming approach is presented for planning management and use of the woodlands as well as a framework for policy analysis. The approach is based on essentially two models, viz., household and private sector models, which are linked into a miombo woodlands model (MIOMBOGP). The MIOMBOGP provides a framework for evaluating the impact, on these two sectors and the woodlands, of some government macro-economic policies as well as some forestry and agricultural sector policies.

1. INTRODUCTION

Miombo woodland is an African woodland dominated by species of *Brachystegia*, either in pure stands or in association with those of *Julbernadia* and/or *Isoberlinia* (Lind &Morrison 1974; White 1983). It occurs in seven eastern, central and southern African countries namely Angola, Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe (White 1983). These woodlands are the major forest formations in this region. They occupy an area of about 2.7 million km^2 and support over 40 million people. The people live in the vicinity of the woodlands, while some reside in woodlands that are in public domain. They rarely live in the woodlands set aside as government forest reserves, but do encroach on them for several demands. Where the woodlands occur outside forest reserves, their clearing for agriculture has taken place over the years.

Dewees (1994) report that what is known about these woodlands is very much limited to their ecological and silvicultural characteristics. Further, most of the woodlands have been very heavily disturbed given the high local value they have to the inhabitants of this region. The woodlands offer a number of opportunities to various stakeholders.

The national governments are interested in them in terms of revenues realized from licences and concessions issued to organizations and individuals harvesting forest produce, as well as their potential for tourism. In some cases the governments are interested in conservation of woodlands important for water supplies.

The private sector (institutions and individuals) is interested in extracting commercial products from the woodlands.

The communities bordering these woodlands are interested in them for a number of reasons. The woodlands are cleared to give way to agriculture. They are used as domestic animal grazing areas. They offer a number of timber and non-timber products for local consumption and trade.

In each country there are many policies guiding socio-economic development. Some of the policies target the government as an institution, or are specific to the private sector or target the rural communities. Each of these three entities has ways through which it can respond to the policies.

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The objective of this paper is to present a methodology for planning woodland management and use, as well as for evaluating how the three principal woodland stakeholders respond to some macroeconomic and sectoral policies in ways that satisfy the achievement of their goals. The satisfaction of some of these goals makes demands on the woodland resources. It is these demands and the extent to which they manifest in the woodlands that the paper seeks to address, and especially their sustainable satisfaction.

There are several approaches for evaluating the trade-off on the demands of these three sectors on the woodland resources. A weighted goal programming model is proposed as one of the approaches which can be employed to reconcile the objectives of the State, the household, and private sectors as they relate to the miombo woodland resources in this region.

This paper shall not present the basics of goal programming. Such information and examples of relevant applications can be found in, but not limited to, Romero (1991), Romero and Rehman (1989), Rehman and Romero (1993), Norton and Schiefer (1980), Nhantumbo (1997), Mendoza and Sprouse (1989) Hazell and Norton (1986), Day (1963) McCarl (1992), and Yoon and Hwang (1995).

The goal programming (GP) approach, of the MIOMBOGP model, is used side by side with a system dynamics approach (MIOMBOSIM) to model these sectors in chosen sites in Malawi, Mozambique, Tanzania and Zimbabwe as part of a CIFOR research project funded by the European Commission and implemented in these four Southern African Development Community (SADC) countries. These two approaches are intended to operationalize one of the objectives of this research project, which is to evaluate how some selected macroeconomic and sectoral policies are impacting on local communities and the industry dependent on these woodlands. Also evaluated is how the policy responses by these two sectors are impacting on the woodland resource management, use and conservation.

The paper is organized as follows. Section 2 gives a brief overview of the problem environment. Section 3 presents the methodology for modelling the household sector, while Section 4 presents the same for the private sector. For each sector the most important activities are described, followed by a general mathematical formulation of the MIOMBOGP model. In Section 5 the two sectoral models are linked together to reflect the role these sectors play as producers and intermediaries in marketing forest products extracted from these woodlands. Section 6 demonstrates how sectoral government policies are incorporated into the MIOMBOGP model. Section 7 presents limitations of this modelling approach.

2. PROBLEM ENVIRONMENT

In the miombo woodland region planners and policy makers are faced with the challenge of maintaining land under woodland cover (Dewees 1996). This is because of the pressure for agricultural land arising from growing populations in these countries. Further, there is also pressure for increasing livestock population, not only in terms of space but also demands for fodder. The future of these woodlands would depend very much on how the demands of various sectors are reconciled in any specific location.

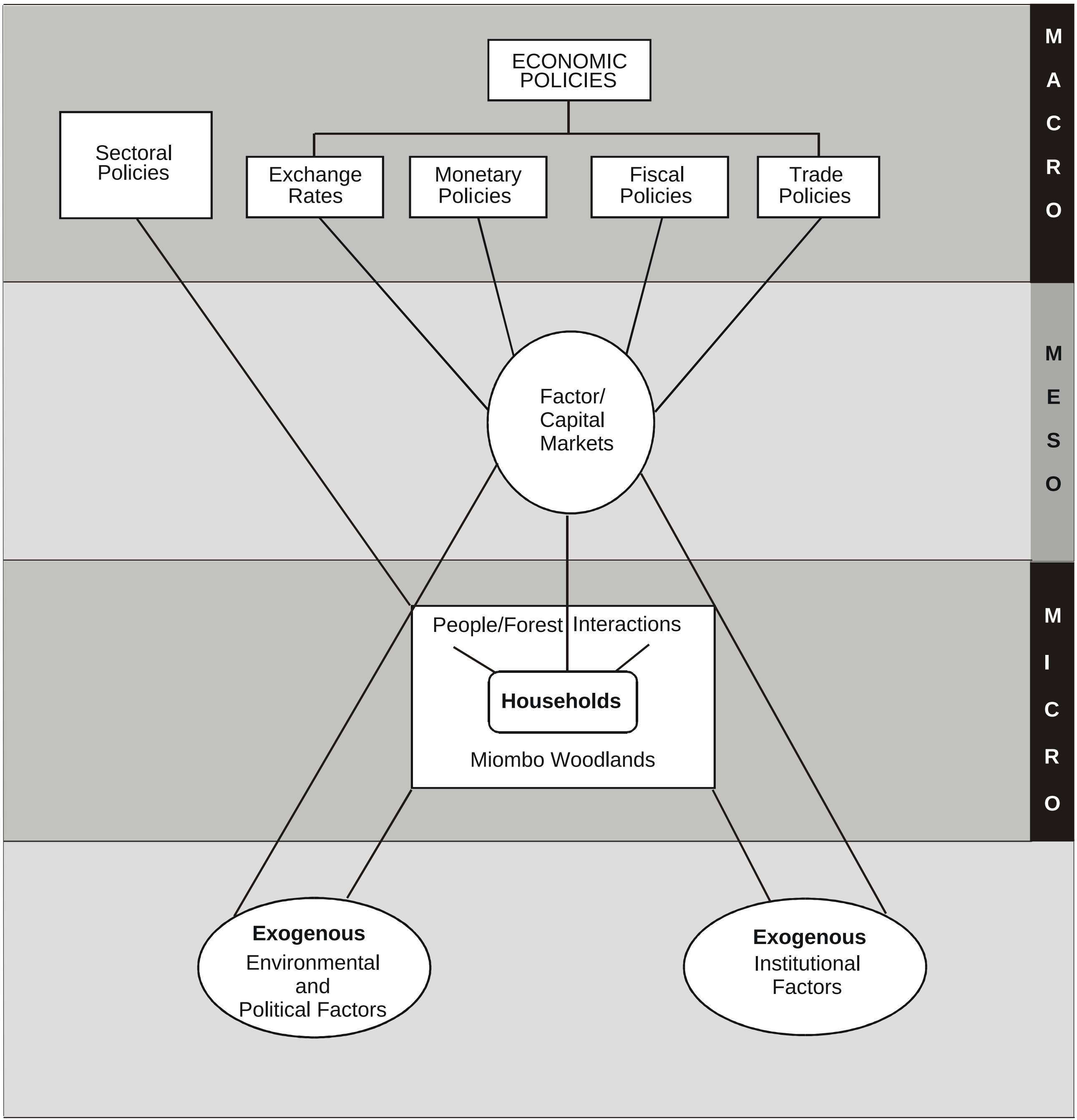
Planning for the welfare of the local communities depending on the woodlands would demand consideration of decisions and responses to policies at various levels as illustrated by Fig. 1.

The inter-relationships between macro-economic policies, food, agriculture, natural resources (woodlands) and people in these developing countries are extremely complex. Yet, understanding of the inter-relationships is paramount in influencing the process, pace, magnitude and direction of development necessary for enhancing people's welfare. There are strong linkages between macro-economic policies (such as monetary, fiscal, exchange rate, trade and employment) and sectoral policies (such as land, agriculture, forestry, population and the environment). The macro policies influence the various sectors of the economy, including households through the following tools and instruments: market reforms, tariffs, subsidies, and taxes and transfers (Minde *et al* 1997).

The markets (meso-level) from which these sectors and household obtain their inputs and sell their surpluses are in turn influenced by the macro-economic factors mainly through product and factor markets (capital, labour and land). Households (micro-level) absorb the overall effects of the macro and meso-level interactions and this in turn influences their decisions on employment, output, income sources and food consumption. Apart from their welfare being influenced directly by the outcome of these interactions, positive or negative effects result in the natural resource base and the environment of which they are a part. Positive effects may include increased employment in the short or long term, increased income from better product prices or factor prices. Negative effects may include increased deforestation, soil erosion leading to reduction in income and environmental degradation in the long term (ibid.).

Exogenous factors, mainly of institutional and political nature, also impact on the households causing further (secondary) impacts on the environment. The Mozambican war and the resulting refugee influx into Malawi is one example of exogenous factors that led to considerable depletion of forest land in Malawi (ibid.).

Figure 1. Macro-meso-micro linkages in the miombo woodlands



Unfortunately macro-economic policies and strategies as well as sectoral policies and strategies for forestry, livestock, agriculture development are often drawn independent of one another and by different government departments and ministries, giving a piecemeal approach to planning.

A number of policies related to both financial and goods markets, as well as other factors have potential to influence human-woodland resource interactions. The approach presented in this paper is expected to highlight the effects of macroeconomic policies affecting prices of agricultural inputs and outputs, off-farm incomes, subsidies and credit. These are some of the key macroeconomic policies driving changes in rural areas in the region. Kaimowitz and Angelsen (1998) provide an excellent review on the impact of different policies on forest condition, and more specifically on deforestation. The impact of some agricultural and forestry sectoral policies is also expected to be demonstrated by this approach. The incorporation of different stakeholder partnerships and their impact on managing and using the woodland resources shall also be demonstrated.

The next two sections demonstrate how the weighted goal programming model (MIOMBOGP) is developed for some sites in the miombo woodland region. The research sites are located in Malawi, Mozambique, Tanzania, and Zimbabwe. Some of the assumptions made are therefore specific to those sites. Participatory Rural Appraisals (PRAs) provided the basic information on woodland condition, household economy, and demands by various sectors on the woodlands.

3. MODELLING TYPICAL HOUSEHOLD POLICY RESPONSES

The household sector is modelled in terms of major activities undertaken in order to meet daily needs and demands that such activities be based on family labour, land and woodland resources. The sector is comprised of mainly subsistence farmers whose primary goals are self-sufficiency in food (food security) and financial income for basics such as food, health, and education. Though local communities are aware of environmental values, these are largely secondary because the pressing needs are food security and income for meeting basic requirements.

3.1. Activities carried out by the typical household

There are three basic activities undertaken by most households in the miombo region. These are *agricultural crop production*, *livestock rearing* and *collection of firewood* for domestic use and sale. Each of these activities is further examined in greater detail. There are many other smaller activities, which can also be incorporated into the model, but these three will serve to illustrate how household activities can be modelled. The less important ones can be added to the model as need arises.

3.1.1. Agricultural crop production activities

Many rural communities are involved in a number of agricultural activities for cash and subsistence. However, for simplicity only three crops are used in this paper to illustrate how crop production can be taken up in a model of this nature. The crops are *maize, beans* and *peanuts*. The activities associated with these three crops can be categorised as *Production, Selling, Buying, Consumption,* and *Storage.* These activities are spread over two climatic seasons prevailing in most of the countries namely, *dry* and *wet* seasons.

For crop production, information for developing the model will be needed on the following:

- Cost of inputs such as seeds and fertilizers, so that the cost of production can be determined.
- Prices for sold and bought agricultural produce. It may be reasonable to assume that the bulk of crop harvesting takes place at the beginning of the dry season making selling prices in this season lower than in the wet season. Further, buying at the market place in either season may be assumed to be at a higher price (because of the profit margin of middlemen) than the price farmers receive. Buying is an activity that allows the households to acquire food to supplement production.
- Consumption activities should incorporate demand for calories per individual member of the family and nutrient composition per crop.
- Storage allows transference of food from one season to the other. An estimate of individual crop storage losses has to be known.
- Land area demanded per crop.
- Labour demanded per crop and as supplied by each family member, as well as hired labour.
- Quantity of production per crop.

Decisions have to be made on the following and supplemented by assumptions and observations from household studies in the region:

- Size of the household and its composition.
- Supply of family labour for agricultural activities.
- Supply of labour for other activities.

3.1.2. Livestock activities

There are a number of livestock types kept by the local communities, but the main ones considered are cattle, goats and sheep. Chicken and pigs are also found in some communities. Livestock is modelled using cattle as an example.

The main activities associated with cattle are *rearing/ grazing, reproduction,* and *selling*. For these activities the following information will be needed:

(a) Cattle rearing:

- Demand for pasture in tons of dry matter (DM) per animal unit. The assumption is that households already have the animals.
- Pasture supply (according to the type of vegetation in the locality of the household). This is to be estimated in terms of tons of DM that are available for grazing.
- Labour available for grazing.

(b) Selling of cattle:

- Selling price per animal.

(c) Reproduction:

- Number of animals per household
- Rates of reproduction

This helps to gauge the growth of the animal stock.

3.1.3 Wood related activities

The main woodland related activities of households in the region are collection of firewood and poles, as well as their selling. Processing of round wood into charcoal and selling charcoal are activities that can also be incorporated into the models developed for Tanzania, Malawi, and Mozambique. A basic assumption is that harvesting of the natural forest for firewood is free of charge. However, a scenario whereby the farmers might in future be required to pay a fee to the government for harvesting government forest reserves can be examined, as well as the impact of various levels of such fees. Another assumption is that the natural forest supplies wood for household consumption and sale.

For analysis of activities related to firewood and poles information shall be needed on:

- The quantity of the standing stock (volume of miombo per hectare) on which the household depends for these supplies.
- The annual increment/growth of the stock. One could introduce a constraint on amount of wood harvested not to exceed annual stock growth. This might already be a requirement of the forest sector policy.
- The quantity and price of firewood and poles sold per household. This is the gross income per household from this activity. One can assume a uniform price throughout the year or differentiate it into seasons since access to the forests during the wet season is difficult therefore constraining supplies and raising the price. The latter has been noted in Mozambique, i.e. higher prices of charcoal in the wet season.
- In the case of charcoal production, the data required should include the relevant conversion factors (from round wood to charcoal) for the alternative technologies of making charcoal. These are essentially efficiency parameters that will allow evaluation of the suitability of these technologies and their long-term impact on the woodlands.

3.1.4 Other activities

There are various domestic activities in any household. The labour distribution for such activities per member of the household (women, children and men) has to be established. Other relevant activities include the collection of non-timber products from the woodlands. In addition to data on their labour requirements, information will also be needed on the quantities harvested, prices (if sold), and use categories (e.g. by household, sold to markets or middlemen, etc).

Many of the activities in this category are what we may call off-farm activities. Apart from domestic and non-timber collection activities, relevant activities could include brewing beer, pottery, and small businesses. All these activities have to be identified, their labour demands estimated, their outputs known and quantified, and associated expense and income data collected.

Dietary demands

These communities are assumed to consume food that satisfies a minimum set of dietary requirements. The proportions of different foods (maize, beans, peanuts, etc.) that largely reflect the eating habits in these communities have to be established. This is important for establishing whether or not the typical household is self-sufficient in food. This parameter is very relevant since giving more rights to communities for management of the natural resources aims at reduction of poverty, and food security is one of the parameters or indicators that can gauge its achievement.

3.2 The general household sector model

The modelling approach that is proposed in this paper is to be constructed for representative households in different sites in Malawi, Mozambique, Tanzania, and Zimbabwe. There are two ways of going about this: identifying an average or a typical household in each of the sites and building the model around it. An average farm may not be found in the field. However, it is possible to identify a typical household from field data. This is advantageous in that frequency analysis using median and mode can allow us to gauge the principal combination of activities in the region. Further use can be made of a typical household in cross-checking the data input as well as gauging the outcome of the model.

The mathematical expression of the MIOMBOGP model is presented as follows:

(a) Objective function

The objective in the weighted goal programming (WGP) context is to minimise the sum of deviations, both positive and negative, from the target levels set by the decision-maker. In this case the decision-maker is the household, the private investor, and the government. The principle of WGP is simultaneous minimisation of the sum of weighted deviations, and is given as:

$$\text{Min} \sum_{i=1}^{k} (\alpha_i n_i + \beta_i p_i) \qquad (1)$$

The weights (α_i and β_i) are associated to goals and with deviations (n_i, p_i). This means that the decision maker (household, private investor or government) has to set a target associated with the objective and express whether he/she would allow a negative or positive deviation from the goal (objective + target).

On the other hand the expression for a linear programming (LP) objective function is maximisation of the total gross margin and is given as:

$$\text{Max} \sum_{j=1}^{n} g_j x_j \qquad (1')$$

where g_j = gross margin per unit of the activity, for example from cropping and livestock activities, and harvesting wood products; and

x_j is the level of activity X_j,

(b) Constraints

(i) Land availability

Land allocation to various crops should not exceed the total land available to households in a specific location.

$$\sum_{i=1}^{n} X_i <= ß \qquad (2)$$

X_i is the amount of land area allocated to crop i (i = 1,2,3...n – representing, initially, the three crops, respectively maize, beans, and peanuts) The area allocated to the crops should not exceed the size of the land, *ß,* for the average or typical household. However, other constraints on land can be introduced to ensure fair representation of land allocation to different crops grown in household.

(ii) Demand for various crops

The demand for each crop (positive sign in equation 3) for selling, storage, and consumption, should be less or equal to the quantity of that crop produced per ha in addition to supplements made through purchased food when deficits occur (negative sign in equation 3).

Let:
S_i represent the quantity of crop i sold,
A_i represent the quantity of crop i stored,
B_i represent the quantity of crop i bought,
C_i represent the quantity of crop i consumed

Total crop production in a specific area is given by $\Sigma\, y_i X_i$, where y_i is the yield per unit area of crop i. (X = 1 ha.). Total demand for each crop is then given as:

$$-\underbrace{\sum_{i=1}^{n} y_i X_{ij}}_{\text{Production}} + \underbrace{\sum_{i=1}^{n} S_{ij}}_{\text{Selling}} + \underbrace{\sum_{i=1}^{n} A_{ij}}_{\text{Storage}} - \underbrace{\sum_{i=1}^{n} B_{ij}}_{\text{Buying}} + \underbrace{\sum_{i=}^{n} C_{ij}}_{\text{Consumption}} <= 0 \qquad (3)$$

Where j represents the two seasons, viz. j = 1, 2, for respectively dry and wet seasons.

The prime use of production in the study areas is for consumption. Therefore it is assumed that selling activities take place after the satisfaction of family consumption and that the household stores food from one season to the other. Given that losses (*a*) occur in crop storage (A) the following equation is relevant for the wet season:

$$\sum_{I=1}^{n} aAij - \sum_{j=1}^{n} Bij + \sum_{j=1}^{n} Cij + \sum_{j=1}^{n} Sij <= 0 \qquad (4)$$

(iii) Labour demand

The total labour demand for each of the crops, ΣSL_{ik}, is the labour demanded by crop i and supplied by source k, where:
k = 1 represents male labour
k = 2 represents female labour
k = 3 represents child labour.

Let LA represent labour demand for livestock activities; LN, labour demand for non-farm/off-farm activities; and LD labour demand for domestic activities. The total labour demand for crops, livestock, off-farm and domestic activities should not exceed that available in the household (ΣSL_k); and is given as follows:

$$\sum_{k=1}^{n} L_{ik} + \sum^{n} LA_k + \sum^{n} LN_k + \sum^{n} LD_k - \sum^{n} L_k <= 0 \qquad (5)$$

(iv) Tie constraints

The family labour is tied to the size, gender, and age of the household members. For example, in the equation below it is assumed that the size of the family is 5, comprising of one adult male, one adult female and three children. All or some of the children can be assumed to be old enough to perform activities such as cattle rearing and domestic chores.

$$\Sigma L_k = 5 \qquad (6)$$

(v) Dietary constraints

The demand for food for household consumption in equation (3) is in kilograms. This is linked to the energy constraints through supply of Kilocalories (Kcal.) and grams of protein by each crop to family members. The supply should at least satisfy demand per season, which in turn depends on household size and composition as determined by Equation 5.

Energy supply (E) per crop to the household

$$- \sum_{k=1}^{n} E_i + \Sigma E_{kj} <= 0 \qquad (7)$$

The supply of energy from all crops (ΣE_i) should satisfy the energy requirements by household members (SE_k), where k = 1, 2, 3.

Protein supply (P) per crop to the household

$$-\sum_{j=1}^{n} P_j + \Sigma P_{kj} <= 0 \qquad (8)$$

(vi) Livestock constraints

Livestock grazing

The demand for feed for cattle (g tons of dry matter per head) should at least be satisfied by the amount of available pasture (p tons dry matter per ha) in a specified grazing area.

$$gC - pF <= 0 \qquad (9)$$

where:
C = cattle stock numbers.
F = land area for natural production of feed for cattle.

To take into consideration the carrying capacity of the grazing land we can set the limit on land area available or let the model calculate the grazing area necessary to satisfy the herd size of the typical household. Therefore, F can have lower and upper bounds to limit the land available or accessible for grazing by the household. In both cases the model output will indicate whether there is overgrazing or not, and this depends on the number of families keeping or owning cattle and other livestock.

Cattle herd size

The size of the cattle herd should at least equal to f.

$$C >= f \qquad (10)$$

where:
f = average herd size for a typical household

Cattle reproduction or growth of animal stock

The calving per year should supply the herd. The total herd size is therefore the sum of new borns (cvC_f) and existing stock (C); and the relationship between the two depends on the calving rate, denoted as cv net of mortality.

$$-cvC_f + C >= 0 \qquad (11)$$

where Cf is the number of female animals of reproduction age

Sale of animals

The number of animals sold, SC, should not exceed the number of the animals calved. This is assuming that the household would like to maintain a minimum stock size.

$$-cvC_f + SC <= 0 \qquad (12)$$

where SC = sale of animals

(vii) Forest products constraints

Harvesting wood for energy

The standing forest stock should at least satisfy the demand for household fuelwood consumption and for sale.

$$-SS + FwC + WdCh + SFw <= 0 \qquad (13)$$

where:

SS = Standing stock (volume of miombo per hectare)

FwC = firewood consumption

SFw = sale of firewood

Wd = quantity of wood required to produce charcoal (Ch)

and:

$$-WdCh + SCh <= 0 \qquad (14)$$

where:

SCh = selling of charcoal

This indicates the transference of the production to the market, in that charcoal sold cannot exceed that produced. We can also include upper and lower limits for Ch since there is limited capacity in terms of labour undertaking this activity in the household in each season. The limits will eliminate unrealistic allocation of labour to produce charcoal only in the season with higher selling price (e.g. wet season in Mozambique)

FwC is determined by the size of the household and estimates of consumption in the Southern Africa indicate that in average a person consumes 1 to 2 m^3/year.

Sustainable firewood harvesting

The amount of firewood sold, if the harvesting is to be sustainable, should not exceed the annual growth in the stock. If the annual growth is denoted as s, then this relationship can be given as:

$$SFw + SCh <= sSS \qquad (15)$$

This can be introduced as a goal of the regulator, which in these countries is the government. The assumption here is that harvesting for household consumption does not endanger sustainable firewood supplies.

Firewood sales

Alternatively the amount of harvested wood for sale will be limited by the capacity of the household in terms of labour. Therefore the amount sold will be tied to a maximum number of firewood sales, Qmax, in order to ensure that sufficient quantities are sold given the labour available for this.

$$SFw + SCh <= Qmax. \qquad (16)$$

Other constraints, accounting or 'tie' constraints, can be introduced in order to guarantee that the solution is logical and better reflects the household situation.

The complexity of the model can be increased depending on the number of activities households undertake and structure of the households. Any restrictions from the government will be incorporated later after linking the farm and private sector models.

(c) Goals

For realism various goals guiding household behaviour and activities have to be incorporated. This is because planning household activities based on the assumption that they are driven by profit maximisation distorts reality in households' decision-making environment in the miombo region. Most households produce food and even encroach on the forest for income generation in order to meet their basic need, i.e., food security. In a broader sense food security is achieved through production or access to the market, i.e., having a purchasing capacity/ power. This seems to suggest that the rural household plan (or combination of activities) in the miombo woodland has at least two goals. In the model, the goals are represented as equalities. Earning of cash income is one of the household goals in these countries. This then makes the sum of the gross margins of all activities (cropping, livestock, forest harvesting, etc) contribute to the target level set by the decision-maker, in this case the head of the household. This can alternatively be derived by running the household model as a simple linear programming (LP) model. Generally the decision-makers' aim would be to minimise the negative deviation from the set target. Therefore the <u>income goal</u>, I, with gross margins per activity and for all activities (X_j), could be expressed as:

$$\sum_{i=1}^{n} giX_j + n_i - p_i = I \qquad (17)$$

The other common household goal is to ensure food security or meet minimum nutritional requirements. Such requirements will be defined in terms of total N Kcal of energy required by each family. Therefore the <u>food nutritional goal</u>, (N), can be expressed as:

$$\Sigma E_k + n_i - p_i = N \quad (18)$$

The achievement of these goals in the WGP model is subject to:

$$f_i(x) + n_i - p_i = b_i$$

Where,
$f_I(x)$ is the general function of the goal as already demonstrated by Equations (17) and (18).

$x \in G$,

G is the feasible set

$x \geq 0, n \geq 0, p \geq 0$

The expected output from the model with these two goals is the opportunity cost of satisfying one goal instead of the other, i.e., giving greater weight (or higher priority) to one goal rather than the other. This means that when the income goal is given greater weight, the household can sell most of the produce in order to maximise income realised, even if in some cases this might result into minimising consumption from their own production. Alternatively, the household could harvest large areas of forest for firewood and poles for sale, while ensuring that there is food produced and any food deficits are met through purchases using such income. All this should ensure that the minimum energy requirements are met.

Two problems might arise in this process. One is associated with the fact that the coefficients might be distributed over a very wide range. This can be contained by dividing them into the constraint coefficients. The other problem is related to the fact that the simultaneous minimisation of the deviation in the WGP may result into the model mixing goals that are expressed in different units. This means that the solution might be difficult to interpret. To overcome this it is necessary to adopt a normalisation procedure, like the use of percentages. Therefore, all goal constraints have to be expressed in form of percentages.

4. MODELLING TYPICAL PRIVATE SECTOR

4.1 An overview of the sector

The private sector in most of the study areas functions like an intermediary between producers and markets for agricultural and forestry products. The producers, the household sector in this analysis, generally lack means and capacity for taking the products to the final consumer. The simple functions of the private sector are then collection of produce from farmers, transporting, storage, and selling them to retailers and rarely to final consumers. The volume of business is a function of many things, including the number of trips that the private sector entity makes between the farmers/households and the market place.

In this modelling exercise we start with a scenario in which the profit margin per unit of product, like a bag of charcoal, made by the private sector is lower than the profit margin of the household (producer). This is based on the fact that the latter does not incur high costs apart from employment of family labour. For example households do not pay harvesting fees and transaction costs. However, the private sector has a higher total profit due to the number of sales units and trips they are able to make within a specific period, e.g. a month, as compared with the household sector. Furthermore, the transport capacity in each trip surpasses the production capacity of a household.

There are two types of private sector entities for miombo woodland products. The first category comprises of people and firms exploiting wood products such as fuelwood, poles, and construction timber. This category has strong links with the household sector. The latter actually carries out all operations that make such products available. The second group is comprised of either transporters of logs to supply the industry or the industries themselves with licenses for harvesting, transporting, and processing logs. This group generally has a diffuse association with the household sector since it can hire labour from urban and other rural areas to perform all the activities required to get the products into the industry and to the final consumer. For the sake of simplicity the modeling is done with the first type of private sector entity in mind.

One general characteristic of these private sector entities is that their main capital is old transport equipment like lorries, tractors and trailers. Bicycles are commonly used in Malawi, around Lilongwe, and in Manica province in Mozambique. This has in most cases facilitated payment for amortization. The transport costs are high due to the frequent breakdowns and there is therefore need to compensate for the high maintenance costs.

Another common characteristic is that the private sector is in most cases wholesalers, supplying retailers in the urban or other markets. They are essentially intermediaries in the energy and construction material commercialization channel.

4.2 The MIOMBOGP model

4.2.1 Context and major assumptions

Some of the assumptions, requirements and the context in which the private sector operates include:

- The private sector *buys* and *sells* firewood, charcoal and poles. This varies from one country to another. However, buying and selling are the two main activities included in the model.
- The private sector has licenses that limit the amount each of them can buy from rural markets to supply urban markets.
- The license fees are volumetric (i.e. defined per m^3) and are different for firewood and poles.
- The transportation cost should be known.
- Apart from the license fees and the transportation costs, the private entities may incur other costs. For example, they might have to pay a commercialization fee, which goes to the local council (municipality) at the urban market. Again this varies from country to country.
- The other major cost is labour. For a typical lorry or tractor operation labour could comprise of three people, a driver and two assistants. These load and unload the trucks and tractor-trailers. Nevertheless, there might be cases where some other people are hired for unloading at the market place.
- The number of trips made and capacity of trucks or other transport facility used must be known.
- The salaries or wages of the driver and assistants must be known.
- There are many buyers or retailers in the urban markets and few suppliers (represented by lorry drivers) hence the market structure can be described as oligopoly. On the other hand, at the production site, there are many producers (households) and few buyers (represented by lorry drivers) or oligopsony.

4.2.2 Mathematical presentation of the model

(a) The objective function

The LP objective function for the private sector is:

$$\text{Max} \sum_{i=1}^{n} g_i x_i \qquad (1)$$

where g_i is the gross margin of each of the products (firewood, charcoal and poles: i = 3), (i.e., revenue obtained from the sales after deducting the costs) and x_i is the level of each activity, in this case selling of each of the products. In other words this can be stated as:

$$-\sum_{i=1}^{n} Pp_i Pr_i - \sum_{i=1}^{n} Tr_i Pr_i + \sum_{i=1}^{n} Ws_i Pr_i - Mc = 0 \qquad (2)$$

$$\sum_{i=1}^{n} Pr_i (-Pp_i - Tr_i + Ws_i) - Mc = 0 \qquad (2')$$

where:

Pr_i = quantity of product i (i = 1, 2, 3)
Pp_i = producer price of the i_{th} product in rural markets
Tr_i = transportation cost of the i_{th} product to the market
Ws_i = wholesale price of the i_{th} product in urban markets
Mc = Maintenance cost per trip

Additional costs and fees specific to individual countries, like commercialization fees in Mozambique, can be incorporated in the wholesale price, hence reducing the sales price.

In the case of goal programming, the objective function is expressed as:

$$\text{Min} \sum_{i=1}^{n} (\alpha_i n_i + \beta_i p_i) \qquad (1')$$

This represents the minimisation of deviations from target levels, assuming that the private sector also has other goals, apart from profit maximisation. We can run the model as a classic LP assuming one main objective that drives the activity of the private sector. Alternatively we can assume that apart from maximising profit, it is important for the private entity to minimise risk of the business, especially that arising from frequent truck breakdowns, and therefore a desire to minimize truck maintenance costs.

(b) Constraints

The major constraints of the private sector model include:

(i) Licensed amount

The quantity transported of each of the i^{th} product with a truck of capacity a_i, should not exceed the quantity AQ stated in the licence.

$$\sum_{i=1}^{n} N_{ti} Tc_{Ii} <= AQ \quad (3)$$

where:
N_{ti} is the number of trips middlemen make in transporting forest product i
Tc_I is the lorry/truck capacity for transporting product i

(ii) Wood supply to market

The supply of i_{th} wood product should be less or equal to the amount delivered to or demanded by retailers at the market.

$$-\sum_{i=1}^{n} Pr_i + \sum_{I=1}^{n} Ws_i <=0 \quad (4)$$

(iii) Transportation capacity

The quantity of the i^{th} product transported, Pr, will be equal to the truck transport capacity, Tc, for each of the products. Measurements of capacity could be in bags or m^3.

$$Pr_i = Tc_i \quad (5)$$

(iv) Labour demand

The availability of drivers' labour and that of his assistants is expressed as ΣL_{ij}, where j=1 denotes drivers' labour and j=2 denotes drivers' assistants labour.

Truck driver assistants labour

$$\sum_{i=1}^{n} L_{i2} <= LT_a \quad (6)$$

where,
l_i is the truck driver assistants' labour allocation for loading and unloading the trucks with product i and expressed in man-hours/ trip
LT_a is the total labour available in a month or year.

Driver's labour

$$\sum_{i=1}^{n} L_{i1} <= LT_d \quad (7)$$

l_i is the driver's labour allocation to ferrying product $_i$
LT_d is the total labour available in a month or year.

Details on each of the activities in the above constraints will vary during the dry and wet seasons because the costs Pp_i, Tr_i, and Mc are different for each of the seasons.

(c) Goal

The objective function of the LP model complemented with the deviations from the set target can be expressed as:

$$\sum_{i=1}^{n} g_i x_i + n_i - p_i = \$ \quad (8)$$

Since we assume that the private sector's prime objective will be maximisation of profit, then the target $ can be derived from the LP. In this case n_i, or the negative deviation from the goal would have to be minimised.

$$Mc + n_i - p_i = b \quad (9)$$

The implication is that the maintenance cost has to be kept as low as possible, and that is set at the target level b. The decision maker's interest is to minimise the positive deviations from the target level. This means that in order to maximize profit, the targeted maintenance costs should be kept as low as possible.

5. LINKING HOUSEHOLD AND PRIVATE SECTOR MODELS

As mentioned earlier, there are two players in the exploitation and commercialization of the wood products from the miombo woodlands, the households and the private sector (middlemen).

Selling activities (for wood products) were defined for the household model. However, these were not differentiated into the three products included in the private sector model. But it is known or assumed that all the supply to the intermediaries (the private sector) comes from these rural households. It is at the buying points where we would then know what the households are selling. Therefore, a simple accounting or tie constraint should be able to link the two sectors.

Such a constraint states that the supply by the rural household should at least be equal to the quantity demanded by intermediaries or private sector in the commercialization channel. When the first part of the equation is higher than the second one, the producer takes longer to exhaust his/her stocks.

$$-\sum_{i=1}^{n} Ws_i + \sum_{i=1}^{n} Pr_i <= 0 \quad (10)$$

As far as the goals are concerned there can be several of them and the MIOMBOGP model offers the possibility of evaluating how each of the goals of the actors is affected by changes in their prioritization.

6. INCORPORATION OF GOVERNMENT SECTORAL POLICIES

This section deals with potential for using MIOMBOGP model to evaluate the impact of sectoral policies. Four example policy scenarios will highlight this.

In the household model we introduced a constraint stating that for sustainable use and management of the resource, the amount harvested for sale should not exceed the allowable cut. This restriction has potential to significantly influence the producers' output (household) as well as the supply to the intermediaries (household-private sector trade) and ultimately to the retailers and urban consumers. However, it is in the government's interest to ensure that the present and the future generations benefit from these natural resources.

The constraint for this intention can be expressed as:

$$Ws_i <= AAC \qquad (11)$$

Harvesting of miombo woodland stock for sale should be in quantities less than or equal to the annual allowable cut (AAC). The basic assumption is that harvesting for household consumption is currently at sustainable levels. Otherwise we can add such consumption to the left-hand side of this equation.

This constraint has to be tied to the buying constraint by the private sector.

A second sectoral policy worth exploring could be the introduction by government of license fees for producers (the rural households in our case) when they harvest forest produce from government forests for sale because in some countries harvesting for household consumption is free. Under such situation the unit profit realized by the household will have to shrink by the unit charge in fees. For instance, in the case of firewood or charcoal, the price will be reduced by a factor, ff. In the objective function reproduced below, Pp_i will have to be reduced by this amount.

$$-\sum_{i=1}^{n}(Pp_i - ff)\,Pr_i - \sum_{i=1}^{n}Tr_i\,Pr_i + \sum_{i=1}^{n}Ws_i\,Pr_i - Mc = 0 \qquad (12)$$

A third policy scenario is the introduction of a penalty to the private sector as well as to the household sector for harvesting any amount above that stated in the license. This also works through the objective function as an added cost, Fe, which then lowers the net revenues (Ws_i -F).

$$-\sum_{i=1}^{n}Pp_iPr_i - \sum_{i=1}^{n}Tr_i\,Pr_i + \sum_{i=1}^{n}(Ws_i - Fe)Pr_i - Mc = 0 \qquad (13)$$

The fines are imposed when the harvesting exceeds that allowed in the license when the condition below prevails (c.f. equation 13):

$$\sum_{i=1}^{n} N_{ti}Tc_i >= AQ \qquad (14)$$

A fourth example relates to national governments' concern on improving the welfare of rural people. As a measure to contain this concern national governments might allow for bigger landholdings for the farmers in order to ensure food security and cash incomes. Therefore, where land is available or can be made available through degazettment of forest reserves or resettlement of people in new adjacent areas, the land constraint can be relaxed to the appropriate size of the land.

$$\sum_{i=1}^{n}X_i >= e \qquad (15)$$

From equation (2) in the household model, we can see that the limitation now becomes one of >= e. In reality the size of farmed land depends on family labour and capital.

If this is enforced and all other conditions are favourable then households will have the potential for surplus agricultural produce, which can in turn be sold. Nevertheless, it has to be noted that despite the good intentions of governments, in practice additional land might come from clearing forests or from grazing land. This could then conflict directly with the sustainable use of resource objective.

Linking the two models with the market involves aggregation of the households in the miombo woodlands as well as determination of the aggregate number of intermediaries (size of private sector) and then linking production and the market. To link to the final consumers it is necessary to estimate the total demand in the urban market, i.e., number of households still using firewood for cooking or poles for construction.

This means that the production activities in the household part of the model would have to be summed up in terms of surplus from the production activities undertaken by the household. The quantity sold wholesale by the private sector would then be a summation of the quantities sold by each player in this sector. In the market place the sum of these wholesale quantities would have to be linked to consumer demands.

7. MAJOR LIMITATIONS OF THE MIOMBOGP MODELLING APPROACH

Apart from limitations that are implicit in the basic structure of the functions in the model, the following are some other potential limitations:

- Scarcity of and/or unreliability of data to estimate the coefficients can significantly distort the household organisation and consequently the model results.
- Inability of the decision-makers like farmers and middlemen to list and state in a consistent manner priorities or weights they attach to each target level.
- Making an appropriate choice of the number of variables and constraints capable of producing meaningful results, as well as interpretation that reflects the decision makers' space, i.e., interests, activities, and goals.

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B. A System Dynamics Model for Management of Miombo Woodlands

Ussif Rashid Sumaila*, Arild Angelsen** and Godwin Kowero***

Abstract

The miombo woodlands of eastern, central and southern Africa are some of the most extensive dry forests in Africa. They supply a myriad of products and services for local populations, governments and the private sector, the main stakeholders. Planning the management and use of the woodlands by many and diverse stakeholders who often have conflicting interests in the woodlands continues to be a great challenge to national governments and other interested parties. This paper presents a system dynamic model, MIOMBOSIM, which has potential for facilitating planning developments in the woodlands in ways which reconcile the aspirations of the three major stakeholders. The model holds potential for analysing various policy implications on people and the woodlands, as well as the desirability of various partnership arrangements for managing and using the woodland resources.

1. INTRODUCTION

Miombo woodland is one of the most extensive dry forest vegetation types in Africa occurring in seven countries in eastern, central and southern Africa; namely Angola, Malawi, Mozambique, Tanzania, Democratic Republic of Congo, Zambia and Zimbabwe (White 1983). They occupy an area of about 2.7 million square kilometres, almost equal to the combined land area of Mozambique, Malawi, Zimbabwe, Tanzania and Zambia.

The miombo ecosystem forms an integral part of rural communities living in them or in their proximity by providing them with virtually all their energy requirements in terms of fuelwood. The woodlands also provide building materials like poles and grass for thatching, medicines, wild meat and other types of food and fruits, fodder for livestock and wild game, and many other timber and non timber products.

The woodlands offer a number of opportunities to various stakeholders. *National governments* are interested in them in terms of their capacity to support wildlife that is important for tourism, a major foreign currency earner. Governments also consider society wide interests which the private sector and local communities might not give high priority. These include conservation of woodlands important for water supplies and control of soil erosion.

The *private sector* (firms and individuals) is interested in the woodlands for commercial products, which may be extracted from them. The *communities* bordering these woodlands are interested in them for a number of reasons, including their clearing for agriculture, their use for livestock grazing, and as a source of a number of products for local consumption and trade.

In each country there are general policies guiding socio-economic development, which affect these three stakeholders in complex ways. Other policies attempt to target the government as an institution, are specific to the private sector, or target the rural communities. Each of these three entities responds to the policies in their own different ways.

The objective of this paper is to analyse the interaction between these three stakeholders: How do local communities and the private/commercial sectors respond to sectoral and macroeconomic policies? Given the reactions of these two agents to policy initiatives, is it possible for the country to achieve its stated goals with respect to miombo woodland use? The fulfilment of some of these goals may create undue demands on the woodland resources. It is these demands and the extent

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to which they manifest themselves in the woodlands that the current paper addresses. In particular, the paper focuses on how to meet these demands in a sustainable manner.

There are several approaches that can be used to reconcile the demands of these three sectors on the woodland resources. This paper presents a systems based model for miombo woodlands, MIOMBOSIM (miombo simulation), to serve as a tool for the analysis of the sustainable use of these important natural resources, given the prevailing socio-economic environment in the region. The paper is organised as follows. The next section presents some background information, and especially the context in which woodlands are managed. Section 3 presents the conceptual model and gives a description of its interpretation for purposes of empirical application. Particular attention is given to the modelling of the household sector. In Section 4 data requirements for the empirical implementation of the model are identified.

2. BACKGROUND

2.1 CIFOR research

In 1996-98, CIFOR in collaboration with institutions from Malawi, Tanzania and Zimbabwe implemented an exploratory study in these countries with the broad objective of evaluating the potential for improving the livelihoods of miombo woodland dependant communities. This exploratory project took into account the impact of some of the macro-economic policies implemented by the respective national governments in their efforts to promote economic development. The study confirmed varying dependency of these communities on the woodlands for their incomes, with the woodlands contributing up to 70% of household incomes in some study sites in Tanzania (Monela *et al*. 2000) and as little as 10% in some sites in Zimbabwe (Campbell *et al*. 1999). Further, the study through regression analysis, confirmed the expansion of agricultural cropland (Chipika and Kowero 2000; Minde *et al.* 2000), though not always conclusively into the woodlands and/or grazing fields.

Macroeconomic policies such as the liberalization of trade, and the elimination of government subsidies to agriculture, were arguably responsible for these outcomes. Also market and policy failures lead to the under-valuation of natural forest resources. The basis for governments to jointly manage the natural forests with the local communities was challenged in both Zimbabwe (Mukamuri *et al*. 1999) and Malawi (Luhanga *et al*. 1999). The study also raised a number of potential research questions. In addition, the study did not constitute a strong basis for understanding the policy impacts and their pathways. Neither did it facilitate generating scenarios useful for developing plans to guide sustainable management and use of these woodland resources.

With financial support from the European Commission, CIFOR embarked on a four-year research initiative in 1998, which sought to carry this work further and specifically address the issue of multiple stakeholders in sustainable management of these woodlands. This was considered to be crucial because governments in the region continued to implement macro-economic reforms, which affect the stakeholders differently, with the consequence that their reactions with regards to their use of the woodlands are unclear. The emphasis has been on understanding the pathways of the policies. Such information is useful in generating alternative scenarios useful for managing and using the woodland resources sustainably. Some of the candidate policy oriented hypotheses proposed for evaluating and generating such scenarios include:

- Economic reform policies, especially those that improve credit availability to smallholder farmers and agricultural input and output prices, serve as incentives for increased agricultural land expansion into woodland areas.

- Higher incomes and the increased demand for food that accompanies population growth boost the demand for agricultural production as well as trade in forest products, and this has the potential to degrade the woodlands.

On the other hand, governments in the region are very weak in managing natural forest resources. With economic reforms central government resources are becoming increasingly limited, to the point where the central government is unable to effectively manage large tracts of land in their countries. However the emphasis on liberalization of the economies of these countries and promotion of democracy has led to increasing participation of local communities and other entities in decision making, even in natural forest resource ownership and management.

2.2 New perspectives in forest management

According to Matose and Wily (1996), there is a clear move away from the centralised and state-driven forest and woodland management of the colonial and post-independence periods towards decentralised, and mainly community-based regimes. This shift has prompted governments and non-government agencies to realign their own functions away from direct management functions towards supporting technical and advisory roles. The local communities, who are actually the main user groups, are increasingly becoming partners in natural forest management. In some cases they manage the forests on their own.

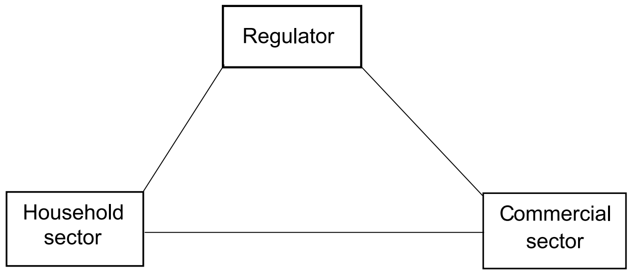
However, local management and control of natural forest resources is constrained by the weakened state of local institutions and presence or even absence of policies and legislation not enabling to local management and control. Further, the rural communities are undergoing rapid social, economic and political change, due to economic development and modernisation. The question is whether local management of these resources will survive and persist, in the face of modernisation pressures and other socio-economic developments. This notwithstanding, the said changes have increased the number of stakeholders in natural forest resources, with the government (central and local), private sector, and local communities as the major stakeholders in this region.

Besides providing a methodology for analysing the effect of various economic policies, the paper also presents a framework for evaluating different partnership arrangements for managing the woodlands and especially those involving local communities, private/commercial sector and the government/state. The methodology can be employed to demonstrate impacts on long-term resource use and income for different user groups. For example, to answer questions like what will be the gains of some form of joint forest management (*cooperative*) compared to a situation of unregulated resource competition (*non-cooperative*) among the groups.

3. THE CONCEPTUAL MODEL

A model is developed with two user groups (that is, commercial and household users) of miombo woodland resources who are under the control of a *regulator* (Figure 1). The regulator can be a central/local/village government, or any other authority. Three different versions of the model are presented and are based on some assumptions on the relationship between the user groups and the regulator. In what is denoted as the *command* model, the regulator can dictate the behaviour of the two sectors directly. In the *cooperative* model the users reach an agreement on how best to jointly use the miombo resources. On the other hand, in the *non-cooperative* model each of the different user groups aims to maximize its own private benefits without any regard to the implications of their actions on the other groups (see Sumaila, 1999 and the reference therein).[1] It should be noted that in the cooperative and non-cooperative versions of the model, the regulator could influence the use of miombo resources indirectly by changing the parameters that affect the decisions taken by the commercial and household users.

Figure 1. The main agents in the model



3.1 Modelling woodland resources

The miombo woodland resource is defined in terms of the land area on which the miombo is standing or the average volume of miombo on the land. Analytically and computationally, it does not really matter which of this is considered in the model. This is especially because for simulation purposes this quantity is normalised to one. At the start of the analysis, part of the woodland is cleared for agricultural production while the rest remains forested. This is the initial condition, and conforms to reality in the region (Minde *et al* 2000; Chipika and Kowero 2000). As described in detail later, the area maintained as miombo woodland can change from year to year due to conversion to agricultural use. Hence, in each year in the time horizon of the model, the amount of land under agricultural production is the sum of the land already under cultivation plus the *new land* converted from miombo woodland to agricultural use that year. One of the important outputs from this modelling exercise is therefore the amount of woodland resources cleared for agriculture in each year.

3.2 Modelling household users

It is assumed that household users face three economic sectors, that is, miombo products (firewood, charcoal and poles), agriculture, and off-miombo/off-farm. Modelling agricultural household behaviour is complicated by the fact that farmers are not fully integrated in the market and/or that markets do not function perfectly. This implies that market prices and

[1] By developing both the cooperative and non-cooperative models, it is possible to demonstrate whether decentralization of forest management could lead to the emergence of a cooperative management regime.

wages cannot be used as the only guide for economic behaviour. The opportunity cost of labour will be determined within the households by variables such as the degree of poverty, assets held, labour force participation level, etc. The market assumptions form the basis for the distinction between non-separable and separable models. In a separable model the production decisions are solved first, and then the consumption decisions. In a non-separable model they must be solved simultaneously.

In the separable model, all prices (including wages) are assumed to be constant, and given by the market (perfect market assumption). Households' production decisions can be studied as a profit maximising problem. Market prices and technology determine the behaviour. Variables such as population size and poverty level are assumed to have *no* direct effect on resource use.

A more realistic, but also more complex, non-separable household model takes these factors into account, as it determines the shadow price or opportunity cost of labour within the model. The standard formulation of a non-separable model is to assume that households maximize utility, which increases consumption and leisure time. The households balance the drudgery or disutility of work against the utility of consumption, and reach a "subjective equilibrium". Further, they must allocate their labour time to different activities in the most optimal way (marginal return to labour is the same for all activities). This is often referred to as the Chayanovian model (see Angelsen 1999).

In this article, the focus will be on a representative household, whose objective is to maximize utility (U(.)), a function of income (I) and leisure ($T = L^{max} - L$);

$$Max\ U(I,T) = (I - I^{min})^{\alpha} + v(L^{max} - L)^{\beta} \quad (1)$$

This specification of the utility function, which draws on Angelsen (1999), includes both a subsistence level of consumption (I^{min}) and a limit on labour input (L^{max}). In the above equation, L is total labour used by the household in the activities they undertake, I is the gross income to households, α and β are parameters of the utility function.

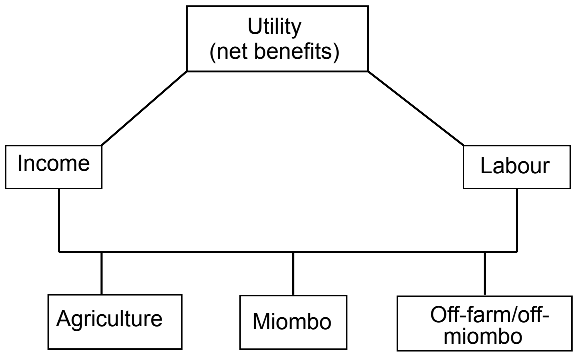
Total differentiation of the utility function in (1) yields the shadow wage rate, z:[2]

$$z = z(I, L) \equiv \frac{-U_T}{U_I} = \frac{v\beta\left(I - I^{min}\right)^{1-\alpha}}{\alpha\left(L^{max} - L\right)^{1-\beta}}\ 1 \quad (2)$$

where v is a parameter. In the current model, the household is assumed to allocate labour such that the marginal productivity of labour or marginal return to labour – *MRL* - is the same across all activities and equal to the shadow wage rate. For instance, the marginal return to labour employed in agriculture (L_a) should equal that to labour employed in harvesting wood products (L_m):

$$z = MRL_a = MRL_m \quad (3)$$

Figure 2. Main structure of the household component of the model



3.2.1 Adding-up equations

The gross household income comes from the net sale of miombo woodland products (I_m), agricultural produce (I_a), and off-miombo/off-farm activities (I_{of}), that is,

$$I_h = I_m + I_a + I_{of} \quad (4)$$

Total labour is found by simply adding the time devoted to the three main activities the household is involved in:

$$L_h = l_m + (l_a + L_n) + l_{of} \quad (5)$$

Within the agricultural work, a distinction is made between labour for cultivation (L_a) and labour for clearing new land (L_n) (i.e., converting miombo woodland into agricultural land).

3.2.2 Agricultural activities

Farmers are assumed to apply only two inputs, that is, labour and fertilizer, in addition to land. But since use is made of yield functions (and outputs and inputs are on a hectares basis), land becomes an implicit input in the model. Labour per ha (l) is assumed to be constant, whereas fertilizer (f) is a variable input. For computational simplicity (and as a fair approximation) use is made of

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[2] This is alternatively called the marginal rate of substitution between labour and consumption (income), the virtual price of labour, the opportunity costs of labour, or the subjective wage rate.

an additive production function. Output per ha or yield (x) is then given by:

$$x = a + bl + cf^{d} \quad (6)$$

a, b, c, d are parameters to be estimated from household survey data.

The farmers decide how much fertilizer to apply per ha in such a way that the income, ignoring labour costs for the time being, is maximized:

$$Max \quad p_a x - p_f f \quad (7)$$

The condition for optimal fertilizer use is then:

$$p_a cdf^{d-1} - p_f = 0 \quad \Leftrightarrow \quad f = \left(\frac{p_f}{p_a cd}\right)^{\frac{1}{b-1}} \quad (8)$$

This formulation makes this part of the model recursive and easier to compute. First, fertilizer use in each period is determined by the exogenous agricultural output price (p_a) and fertilizer price (p_f) ratio, plus the parameters. The next step is to put this into the production function to determine the yield.

Net agricultural income is then defined as:

$$I_a = (p_a x - p_a f)H_a \quad (9)$$

Total labour employed in the agricultural sector is similarly expressed as:

$$L_a = lH_a \quad (10)$$

H_a is the total agricultural area, given by the sum of their initial agricultural land area (H_I) and new land converted from miombo to agriculture (H_n). A key decision for the households is whether or not to expand their land area, and if they do, by how many hectares. The starting point is to compare the net benefit that accrues to them per ha of miombo used for wood products (B_m), and that which accrues to them from the conversion of the woodland resources for agricultural production (B_a).

Current benefits from one ha of agricultural land are defined as:

$$B_a = p_a x - p_f f - zl \quad (11)$$

For new agricultural land we must also subtract the clearing costs per ha, zl. These should be convex in land cleared (e.g., as they move further away to convert miombo to cropping land), and a possible function would be:

$$l_c = gH_n^{\tau} \quad (12)$$

where l_c is the labour required for clearing per ha, g and τ are parameters, and H_n denotes new land cleared. The key is that the labour inputs should be convex in area, H^C, and therefore be raised to a number greater than one ($\tau > 1$; set to 1.5 in Equation 13). Total labour for clearing new land is then given by:

$$L_n = \int_0^{H_n} gx^{1.5}dx = g\frac{1}{2.5}H_n^{2.5} \quad (13)$$

Note that the calculation of labour for clearing becomes a bit more complex as the labour requirements per hectare increase.

Thus, if the benefits from miombo are greater than those from agriculture on new land:

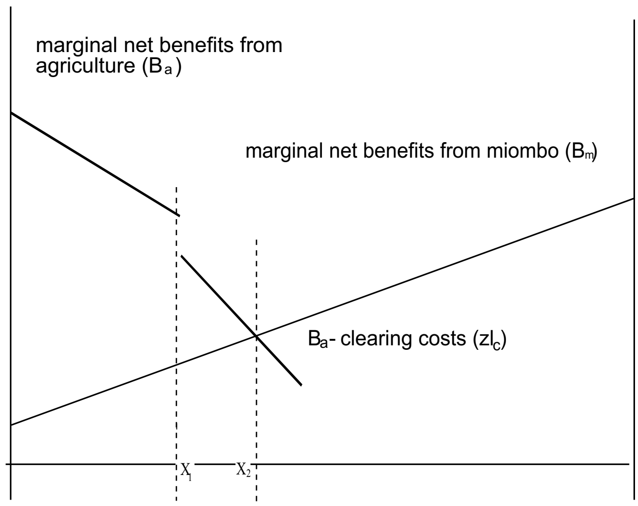
$$B_m > B_a - zl_c \quad (14)$$

for all positive values of H_n, *then* there will be no conversion of miombo to agriculture. If this is not the case, then agriculture will be expanded up to the point where:

$$B_m = B_a - zl_c \quad (15)$$

The situation can be illustrated graphically in a box-diagram as in Figure 3. The length of the box represents total land area. Agricultural land is measured from the left *y-axis* to the right, while miombo land is measured from the right *y-axis* and to the left.

Figure 3. Farmer choice of agricultural land expansion



The initial amount of land under agricultural cultivation is depicted at point X_1. Net marginal benefit from agriculture (B_a) is denoted by the thick line. This line is discontinuous at point X_1 as the net benefits from agricultural production on land beyond this point has to include the clearing costs (zl_c). As the figure is drawn, it will be beneficial to the farmer to clear some new land, up to point X_2 where the $(B_a - zl_c)$ is equal to the marginal net benefits of the remaining miombo land (B_m). Thus, in this situation there will be some deforestation.

3.2.3 Miombo activities

Farm households are assumed to collect three different products from miombo woodlands: poles, fuelwood and timber. The gross income from this activity is given by:

$$I_m = p_{ave} H_m \quad (16)$$

where H_m is the quantity of miombo harvested for use as poles, fuelwood and timber, p_{ave} is the average weighted price received for the three different wood products. The portion of H_m that is used as poles, fuelwood or timber is determine by multiplying H_m by the corresponding relative prices.

Harvest (or miombo use) is a function of both the labour used in the miombo sector (L_m) and volume of standing miombo (N). Using a Cobb-Douglas function we get:

$$H_m = q_h N^{\mu} L_m^{\psi} \quad (17)$$

where μ and $\psi \in$ are parameters of the harvest function, and q_h is the harvest efficiency coefficient for the household sector. This is a fraction depicting the rate or portion of N that can be harvested or used in a given period if all the labour available to household were to be used for this activity.

3.2.4 Off-farm/off-miombo activities

We introduce a fixed off-farm and off-miombo employment (L^{OF}) and a given market wage rate (w), such that total off-farm/off-miombo income is:

$$I^{OF} = wL^{OF} \quad (18)$$

Since both the wage rate and off-farm labour are fixed, these variables can be used to study the effects of more economy-wide changes in the economy (e.g., high economic growth or recession), which usually affect both the wage rate and employment opportunities.

In summary, the total net benefits to household users, B_h, of miombo is given by

$$B_h = I_h - zL_h \quad (19)$$

where $B_h = B_a + B_m$

3.3 Commercial users

Commercial users are assumed to decide on how much miombo to harvest in each year in order to maximize their discounted economic benefits. This means they face only one economic sector, namely, the miombo products sector. Modelling commercial users behaviour is a lot simpler than modelling household user behaviour because they are involved in only one activity, that is, harvesting miombo woodland. In addition, the wage rate for commercial users (k) is exogenously fixed. In a similar fashion to the household users, we define the harvest function of commercial users as:

$$H_c = q_c N^{\mu} L_c^{\psi} \quad (20)$$

where L_c is the labour used by commercial users, and q_c is the harvest efficiency coefficient for the commercial sector. Note that the total labour available to both household and commercial sectors, L_t, is then $L_c + L_h$.

Net income (benefits) for the commercial users is then:

$$B_c = p_c H_c - kL_c \quad (21)$$

3.4 Miombo woodland dynamics

The ecology of miombo is represented by the following equations

$$R_t = K_t \quad (22)$$

$$N_t = sN_{t-1} + R_t - H_{c,t} - H_{h,t}; \quad N_o \textit{ given} \quad (23)$$

Equation (22) captures any natural re-generation, R_t, that takes place; with K_t denoting the volume in a given year. Equation (23) states that the volume of miombo this period, N_t, is determined by the volume in the previous period, N_{t-1}, the survival rate, s, the natural regeneration rate and the amount of woodland resources used this period by the commercial ($H_{c,t}$) and household ($H_{h,t}$) users, respectively. N_o is the initial standing volume of miombo.

3.5 Institutional aspects of the model

In all countries with miombo woodlands it is assumed that a body (a stakeholder) regulates the use of this resource. This body may be a government authority, a community-based management entity or a sole owner of the resource. This body is assumed to be concerned with maximizing *overall* benefits from the use of the resource through time. Elements of the overall benefit function may include *direct economic* benefits; *social* benefits, e.g., the need to preserve settlement patterns in rural areas; and *environmental* benefits not traded in the market, e.g. benefits derived from biodiversity. The challenge facing the regulator is to determine the quantity of the woodlands to be used by the households and the commercial sectors in each year in order to maximize the management objectives.

The problem can be conceived in the following way. Let the net private benefits to the commercial and household users (from the use of the woodland resources) be B_c, and B_h, respectively, as defined in equations (19) and (21). Social benefits are denoted B_s, while B_e represents environmental benefits. Social benefits may depend in some way on the amount of woodland resources used by one of the groups, say household users, for social, cultural or other reasons. Environmental benefits will depend positively on the amount of standing miombo ($N - H_c - H_h$) or negatively on the total woodland harvested ($H_c + H_h$), where N is the total volume (or even biomass) of miombo woodland resources at a given time.

Formally, we have:

$$B_s(\theta_c H_c, \theta_h H_h);\ B_e(N - H_c - H_h);\ or\ B_e(H_c + H_h) \quad (24)$$

Where

$$\partial B_s / \partial H_c < \text{or} > 0;$$
$$\partial B_s / \partial H_h < \text{or} > 0;$$
$$\partial B_e / \partial (N - H_c - H_h) > 0;$$
or
$$\partial B_e / \partial (H_c + H_h) < 0;$$

It should be noted that θ_c and θ_h are the weights put on the harvests of the commercial and household users due to social concerns. These express the social preferences of society. These parameters can take values of 0 or 1. They take a value of 0 if society does not have any social preference for the harvest of a given participant, and a value of 1 if otherwise. Later we introduce an environmental parameter, θ, to reflect the extent to which society-wide environmental concerns are incorporated into the decision making process (see Lopez *et al* 1994).

3.5.1 Decision making by household and commercial users

Before going into detailed discussions of the different game theoretic models in this paper, it is proper to give an overview description of how decisions by household and commercial users are made in the model. At the start of the game or simulation, we begin with the volume (or even land area) of miombo woodland (N_t). As illustrated in Figure 4, part of N_t is cleared for agricultural cultivation (N_a), while the remaining, N_m, is retained under miombo.

The models that are developed are therefore concerned with the further use and allocation of N_m among household and commercial users.

Commercial users decide how much of N_m to harvest (H_c) in order to maximize their discounted benefits (profits). This is done in a single step. In the case of the households, however, their decision-making is made in three stages. First, they decide how much of N_m to retain under miombo for their use (H_h) so as to maximize their utility over time. In the second stage, household users decide how much of H_h to clear and put the land into agricultural production (H_a), and how much to retain as woodland (H_m) for supply of their forest products (see Figure 4). Again, this decision is made with a view to maximizing their utility. Finally, household users decide how much of H_m to use as fuelwood (H_{fw}), poles (H_{po}) and timber (H_{tim}).

The allocation of resources to all of these activities depends on the relative prices or utilities received from each of them by the households. To elaborate more on this important aspect of the MIOMBOSIM model, let the price for agricultural produce be given by p_a and that for fuelwood, poles and timber be p_{fw}, p_{po}, and p_{tim}, respectively. If the optimal amount/quantity of miombo resources for household use from Equation (25) is H_h^*, then the portion of this quantity forgone in preference to agricultural cultivation is given by

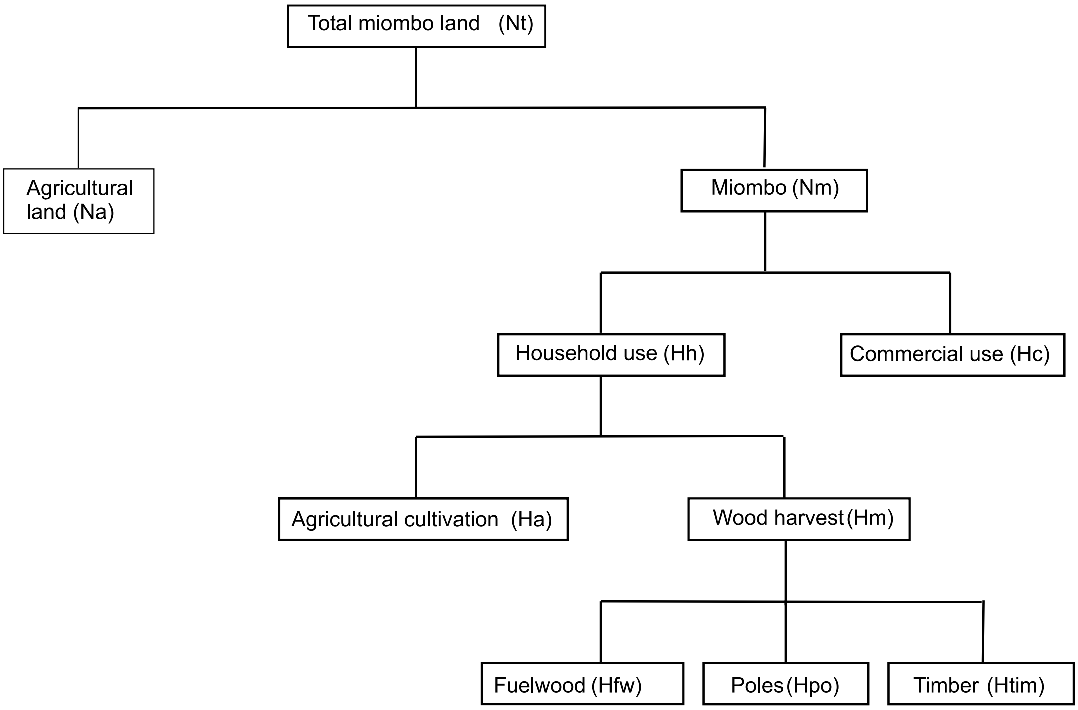
$$H_a = \frac{p_a H_h^*}{p_a + (p_{fw} + p_{po} + p_{tim}} \quad (25)$$

The quantity of miombo exploited for wood products, H_{wd}, is then given by the difference between H_h^* and H_a. Finally, the portions of H_a that go to fuelwood (and similarly for poles and timber), is given by

$$H_{fw} = \frac{p_{fw} H_a}{p_{fw} + p_{po} + p_{tim})} \quad (26)$$

In any given year, each of the above H quantities can be computed, and the total amount of land under agricultural cultivation determined by adding N_a to H_a.

Figure 4. Steps in decision making by the household and commercial sectors



The total area under agricultural production is determined using relevant conversion factors.

3.5.2 The command model

The *command model* mimics the approach employed by many government forestry departments in the eastern and southern African region in the planning, management and use of their natural forest resources. Usually governments consider forest benefits to households (B_h), the private/commercial sector (B_c), the society as a whole (B_s), as well as national and international public goods like environmental benefits (B_e). The model developed in this paper shows potential for use as a planning tool in government forestry departments. It is hence assumed in the model that the "commander" seeks to maximize total net benefits B_t through the choice of the amount of labour to be used by the commercial sector and the households in each year in the time horizon of the model, t=1.T, where T is the last (terminal) period:

$$\max_{L_h, L_c} \sum_{t=1}^{T} [B_t] \rho_{t-1} \qquad (27)$$

subject to the ecological and household labour constraints described earlier.

In the above equation,

$$B_t = B_{c,t} + B_{h,t} + \theta B_{e,t} + B_{s,t}$$

$$\rho_{t-1} = \frac{1}{(1+r)^{t-1}}, \; \rho_0 = 1, \; t = 1,\ldots,T.$$

ρ is the discount factor and r is the discount rate. It is important to note that the amount of miombo resources to be used for both agricultural cultivation and supply of wood products is determined from Equation (27). The division of these into the various activities carried out by the household users is already described in section 3.5.1.

3.5.3 The cooperative model

As mentioned earlier there are moves towards participatory management of the natural forestry resources. The command model can be modified so as to incorporate the involvement of the stakeholders in the management of the resource in a cooperative setting. For instance, if we consider a situation in which there is joint management of natural forest resources between the households (local communities) and the private sector, a cooperative management objective can be presented as follows:

$$\max_{l_h, l_c} \sum_{t=1}^{T} \left[\alpha \rho_{h,t-1} B_{h,t} + (1-\alpha) \rho_{c,t-1} B_{c,t}\right] \qquad (28)$$

subject to the constraint in Equation (27).

In the cooperative setting the households and the private sector put weights α and (1-α) respectively on their individual benefits (which is a measure of their preferences) so as to maximize their combined benefits from exploiting the woodland resource (see Munro 1979). The private benefits are likely to differ from the social planner's benefits as represented in the command model. For instance, private stakeholders may not care much about social, cultural or environmental benefits from the woodlands, and even if they do, it is likely to be in a manner different from that of a social planner.

3.5.4 The non-cooperative model

There are situations in which local communities (households) or the private sector own and manage natural forest resources on their own and without taking the interest of other stakeholders into account. Under such situations, we have a *non-cooperative model*. The management problem facing household users can be defined as follows:

$$\max_{L_h} \sum_{t=1}^{T} \left[\rho_{h,t-1} B_{h,t} \right] \quad (29)$$

subject to the stock constraint in Equation (27).

Similarly, the non-cooperative management problem facing the private sector can be stated as follows:

$$\max_{Lc} \sum_{t=1}^{T} \left[\rho_{c,t-1} B_{c,t} \right] \quad (30)$$

subject to the stock constraint in Equation (27).

3.6 Solving the models

To solve the above general models, appropriate Lagrangian functions have to developed. The command model is used to illustrate how this is done. In this case the Lagrangian is given by:

$$Lag = \sum_{t=1}^{T} \rho_{t-1} \begin{bmatrix} B_c(H_{c,t}) + B_h(H_{h,t,}) + B_s(\theta_c H_{c,t}, \theta_h H_{h,t}) \\ -\theta B_e(H_{c,t} + H_{h,t}) \end{bmatrix} + \sum_{t=1}^{T} \lambda_t \left[N_{t-1} + K_t - N_t - H_{c,t} - H_{h,t} \right] + \sum_{t=1}^{T} \xi_t \left[L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t} \right] \quad (31)$$

The first order conditions for optimisation are:

$$\frac{\partial Lag}{\partial L_{c,t}} = \rho_{t-1} \begin{bmatrix} \partial B_c / \partial e_{c,t} + \partial B_s / \partial e_{c,t} \\ -\theta \partial B_e / \partial e_{c,t} \end{bmatrix} - \lambda_t = 0 \quad (32)$$

$$\frac{\partial Lag}{\partial L_{h,t}} = \rho_{t-1} \begin{bmatrix} \partial B_h / \partial e_{h,t} + \partial B_s / \partial e_{h,t} \\ -\theta \partial B_e / \partial e_{h,t} \end{bmatrix} - \lambda_t = 0 \quad (33)$$

$$\frac{\partial Lag}{\partial \lambda_t} = N_{t-1} + K_t - N_t - H_{c,t} - H_{h,t} = 0 \quad (34)$$

$$\frac{\partial Lag}{\partial \xi_t} = L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t} = 0 \quad (35)$$

In the above system of equations, λ and ξ are defined as the Lagrangian multipliers or the shadow price of miombo and household labour, respectively. Equation (32) states that in any given period the net present value of the marginal harvest by commercial users plus the discounted net marginal social benefit from the exploitation of the resource by this group minus the net marginal stock effect of their exploitation activities on the environment, must equal the shadow price of the miombo resource. A similar interpretation stems from equation (33), with respect to the harvesting activities of the household users. When combined the two equations demonstrate that the optimal allocation of harvest to the two groups of users must be such that the marginal net benefit to the commercial users must equal that to the household users. Solving these equations for the unknown variables yields the optimal harvest to each user and the optimal stock levels in each period. Once these are determined the remaining task of the regulator is to ensure, by some means, that the user's harvest precisely the optimal quantities determined by the model.

3.7 Model simulations

The numerical approach presented in Flåm (1993) and applied in Sumaila (1995), the system dynamics simulation package Powersim, and data collected during fieldwork can be combined to help us provide quantitative answers to a number of questions, including but not limited to the following[3]:

[3] Such work is currently in progress in a study being implemented in Malawi, Mozambique, Tanzania, and Zimbabwe.

How much (i) harvest, (ii) benefits and (iii) employment will different woodland management options translate into for the commercial and household sectors?

How much woodland is lost under different management regimes, government and macroeconomic policies?

How does the harvesting technology used by the stakeholders affect the benefits they derive from using the woodlands?

How sustainable are the harvest levels that will emerge from various government regulatory policies?

How do prices of inputs and outputs (in agriculture and forestry) impact on production volume and methods, employment potential, and structure of the industry?

How does off-miombo and/or off-farm income change the various outcomes of the model?

How does change in subsistence income to household users impact on the outcomes of the model?

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APPENDIX 1. LIST OF VARIABLES AND PARAMETERS FOR MIOMBOSIM

	Model parameter
A	parameter in production function
A	superscripts agricultural sector
B	parameter in production function
B	Benefits
C	parameter in production function, subscript commercial sector
D	parameter in production function (yield effect of fertilizer)
E	effort in commercial sector
F	fertilizer (per ha)
G	parameter in labour for clearing function
H	subscript household sector
H	hectare of land
I	Income
K	costs of effort in commercial sector
L	labour per ha in agriculture
	Model variables
L	Labour
M	subscript miombo sector
N	subscript new (cleared) land)
N	stock of miombo resources
Of	subscript off-farm sector (OF)
	Model functions
P	Price
Q	efficiency parameter in harvest function
S	survival rate in miombo growth function
T	leisure for household (L^{max} – L)
U	utility for household
V	parameter in utility function
W	market wage rate for household
X	agricultural yield
	Subscripts and superscripts
Y	miombo harvest
Z	shadow wage rate for household
α	parameter in utility function
β	parameter in utility function
μ	parameter in harvest function
ψ	parameter in harvest function
θ	weights in social benefit function
ρ	discount factor
τ	parameter in labour for clearing function
ε	parameter in miombo growth function
ϕ	parameter in miombo growth function
γ	parameter in miombo growth function

APPENDIX 2. THE SOLUTION PROCEDURE (See Sumaila, 1997)

$$\frac{\partial \ell}{\partial L_{c,t}} = \rho_{t-1}(\psi p_c q_c N_t^{\mu} L_{c,t}^{\psi-1}\nu - 0.5 k_c L_{c,t}^{-0.5}) - 0.5(\theta - \theta_c) q_c N_t^{\mu} L_{c,t}^{\psi-1} - 0.5\lambda_t \, switch1 \, q_c N_t^{\mu} L_{c,t}^{\psi-1} \tag{1}$$

$$\frac{\partial \ell}{\partial L_{h,t}} = \rho_{t-1}(\psi p_h q_h N_t^{\mu} L_{h,t}^{\psi-1}\nu - \xi z L_{h,t}^{\mu-1}) - \psi(\theta - \theta_h) q_h N_t^{\mu} L_{h,t}^{\psi-1} - \psi\lambda_t \, switch1 \, q_h N_t^{\mu} L_{h,t}^{\psi-1} \tag{2}$$

$$\begin{aligned} \frac{\partial \ell}{\partial N_t} &= \rho_{t-1}(\mu p_c q_c N_t^{\mu-1} L_{c,t}^{\psi}\nu + \mu p_h q_h N_t^{\mu-1} L_{h,t}^{\psi}\nu) + \theta(\mu q_c N_t^{\mu-1} L_{c,t}^{\psi} + \mu q_h N_t^{\mu-1} L_{h,t}^{\psi}) \\ &- (\theta_c \mu q_c N_t^{\mu-1} L_{c,t}^{\psi} + \theta_h \mu q_h N_t^{\mu-1} L_{h,t}^{\psi}) + \lambda_t \, switch1 \, (s - \mu q_c N_t^{\mu-1} L_{c,t}^{\psi} - \mu q_h N_t^{\mu-1} L_{h,t}^{\psi}) - \lambda_{t+1} \, switch2 \end{aligned} \tag{3}$$

$$\frac{\partial L}{\partial \lambda_t} = -switch1(switch1 \text{ arg}) \tag{4}$$

$$\frac{\partial L}{\partial \xi_t} = -switch3\,(switch3 \text{ arg}) \tag{5}$$

where,

$$switch1 = \begin{cases} 1 \; if \; (N_{t-1} + R_t - N_t - H_{c,t} - H_{h,t}) < 0 \\ 0 \; otherwise \end{cases}$$

$$switch2 = \begin{cases} 1 \; if \; (N_t + R_{t+1} - N_{t+1} - H_{c,t+1} - H_{h,t+1}) < 0 \\ 0 \; otherwise \end{cases}$$

$$switch3 = \begin{cases} 1 \; if \; (L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t}) < 0 \\ 0 \; otherwise \end{cases}$$

$$switch1 \; arg = N_{t-1} + R_t - N_t - H_{c,t} - H_{h,t}$$

$$switch2 \; arg = N_t + R_{t+1} - N_{t+1} - H_{c,t+1} - H_{h,t+1}$$

$$switch3 \; arg = L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t}$$

The above adjustment equations can be manipulated to capture:

The command model: when q, and either q_c or q_h are not zero. It should be noted that there is room for flexibility in the command model in the sense that one can give varying emphasis to social and environment values by selecting different values for the qs.

The command model reduces to a **cooperative model** if all the qs are set equal to zero.

The command model collapses to a **non-cooperative model** if in addition to all the qs being zero, the marginal stock effect on benefits of each stakeholder is not internalised by the users. That is, when the first term in the stock adjustment Equation (27) is set equal to zero.

APPENDIX 3. SCIENTISTS WHO PARTICIPATED IN DEVELOPING THE MODELS

Country and Institution	Area of specialization
A. Malawi	
University of Malawi	
Dr. Charles Mataya	Agricultural economics
Mr. Charles Jumbe	Economics
Mr. Richard Kachule	Agricultural economics
Mr. Hardwick Tchale	Agricultural economics
B. Mozambique	
1. Eduardo Mondlane University	
Dr. Isilda Nhantumbo (now with IUCN)	Natural resource management
Dr. Gilead Mlay	Agricultural economics
Mr. Mario Falcao	Forest economics
2. Forestry Research Centre	
Mr. Jose Soares	Forestry
C. Tanzania	
Sokoine University of Agriculture	
Dr. Gerald Monela	Forest economics and management
Dr. Abdallah Kaoneka (late)	Forest economics and management
Dr. Yonika Ngaga	Forest economics
Dr. George Kajembe	Anthropology and social forestry
Dr. Zebedayo Mvena	Rural sociology
Dr. Florens Turuka	Agricultural economics
D. Zimbabwe	
University of Zimbabwe	
Dr. Ramos Mabugu	Economics
Dr. Chris Sukume	Agricultural economics
Southern Alliance For Indigenous Resources (SAFIRE)	
Mr. Peter Gondo	Forestry
E. Canada	
University of British Columbia	
Dr. Ussif Rashid Sumaila (also with CMI, Bergen, Norway)	Environmental and Natural Resource Economics and Management
F. Norway	
Agricultural University of Norway	
Dr. Arild Angelsen (also with CIFOR)	Economics
G. CIFOR	
Dr. Godwin Kowero	Forest economics and management
Prof. Bruce Campbell	Ecologist