Farm household modelling for estimating the effectiveness of price instruments on sustainable land use in the Atlantic Zone of Costa Rica

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The programme "Sustainable land use and food security in developing countries" (DLV) is a cooperative research effort of several institutes in the Netherlands. The major research objective is: "to develop a methodology to integrate agro-ecological and socio-economic information in such a way that options for sustainable land use and food security at a regional level in developing countries can be explored and formulated with the aim of aiding policy makers." The participating institutes are:

Agricultural Research Department (DLO)
- Institute for Agrobiological and Soil Fertility Research (AB)
- Agricultural Economics Research Institute (LEI)
- Winand Staring Centre for Integrated Land, Soil and Water Research (SC)

Wageningen Agricultural University (WAU)
- Department of Development Economics
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DLV report 3 Kruseman, G., R. Ruben & H. Hengsdijk (1994) *Agrarian structure and land use in the Atlantic Zone of Costa Rica.*

Preface

The DLV programme aims at the development of an operational methodology for the formulation, exploration and evaluation of policy options for sustainable land use and food security at (sub)regional and farm level, based on the integration of agro-ecological and socio-economic information. Application of the methodology in case studies is based on cooperation with research projects in developing countries. For Costa Rica, cooperation has been established with the CATIE/MAG/WAU Atlantic Zone Programme (AZP). AZP is a cooperative research effort of the *Centro Agronómico Tropical de Investigación y Enseñanza* (CATIE), the *Ministerio de Agricultura y Ganadería* (MAG) and Wageningen Agricultural University (WAU).

In cooperation with the Atlantic Zone Programme the proposed methodology is tested in the Atlantic Zone of Costa Rica. While the Atlantic Zone Programme deals with the development of explorative long-term scenarios for sustainable land use, the DLV programme focuses on the identification of suitable policy instruments to influence farmers in preferred directions.

We thank the colleagues of the Atlantic Zone Programme for sharing data and fruitful discussions. Comments on earlier versions of this paper by K. Burger, A. Burrell, N. Heerink, H. van Keulen, A. Kuyvenhoven, and R.A. Schipper are gratefully acknowledged. We thank M.K. van Ittersum for his contribution to Chapter 9. However, the authors bear sole responsibility for the views expressed in this report.

Summary

The present report presents a modelling approach developed for response analysis of farm households in terms of adjustments of land use and technology choice, to specific (simulated) changes in the socio-economic environment. In this way the effectiveness of policy instruments to attain regional goals is estimated.

The core of the farm household modelling approach consists of a linear programming model that uses data from separate modules for expenditures, market prices, and production activities. The analysis of expenditures permits the identification of income levels (attainable consumption) in terms of household utility. Furthermore, the model takes into account linkages between production and consumption decisions at the farm level. The model contains a production structure adjustment procedure to account for incomplete specification of the household objective function. The use of linear programming permits the incorporation of discrete agro-technical data without having to specify continuous production functions.

The model is calibrated for a specific farm type in the Atlantic Zone of Costa Rica, a small peasant household, and applied to calculate the effect of simulated price changes for agricultural output, fertilizer and biocides, transaction costs, wage rates and industrial goods. The model makes use of expected prices, which are market prices adjusted for market risks. Pace and direction of change at the farm level are presented in terms of response multipliers for price changes, defined as the ratio of the relative change in an endogenous variable caused by the relative change in the price instrument.

The model is used to identify those price instruments that affect two regional development objectives: (i) improvement of the competitiveness of agricultural production in the Atlantic Zone and (ii) improved natural resource management. These objectives have been translated into four explicit goal indicators at the farm household level: Income (or utility) and plantain and cassava production served as indirect indicators for improved competitiveness, while biocide and fertilizer use were applied as indicators for natural resource management.

The results indicate that the area cultivated with beans and cassava is affected more strongly by price changes than the area under maize and plantain. Output prices, fertilizer prices and, to a lesser extent, transaction costs favour the substitution of actual by alternative production activities. The latter are in general positively correlated to agro-ecological sustainability indicators. An increase of the general output price has the strongest positive effect on the income of peasant farmers. Agro-ecological sustainability indicators are hardly affected by output prices, due to the substitution of actual by alternative technologies with similar or higher biocide and fertilizer requirements. An increase in biocide prices reduces biocide use, mainly as a result of a decrease in total cultivated area. Wage rates turn out not to be an efficient instrument to modify peasant behaviour.

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GLOSSARY OF SYMBOLS

The symbols used throughout this paper are defined here to facilitate reading, without frequent cross-references to earlier paragraphs. Please note that letters and symbols in subscripts and superscripts do not necessarily have the same meaning, nor do they necessarily correspond to letters and symbols of variables and parameters.

Capital Latin symbols

A	land
B	non-factor inputs, with B^* commercially available agro-chemical inputs
C	consumption
D	convex curve conversion dummy variable, with D^U for the relation consumption - utility, D^L for income - leisure relationship, and D^Y for income - expendable income relationship
G	goals
K	capital
L	labour with L^T total time available, L^L leisure time, L^F on-farm family labour, L^{OF} off-farm employment, L^H hired labour, L^R labour requirements for agricultural production
N	total population
Q	production volume
U	utility
VOL	volume
W	activities
X	commodities, with X^m marketed commodities, and X^f subsistence commodities
Y	income, with Y^e expected income and Y^x expendable income

Capital Greek symbols

Λ	indicator for response analysis

Small Latin symbols

b	input requirements
l^L	inverse leisure to labour ratio
n	number of members in set
p	price where p^{wm} world market price, p^e expected price, p^m market prices, and p^f farm gate prices, note that p^{fe} and p^{me} denote expected farm gate and market prices, respectively
w	wage

Small Greek symbols

α^u utility conversion factor
α^{engel} engel curve income to consumption conversion factor
β^p coefficient of expectation in price analysis
γ production structure adjustment coefficient
ϵ response multiplier
η coefficient associated with the convex curve conversion system (LP), with η^U is utility coefficient for consumption to utility, η^L idem for income to leisure, and η^Y idem for income to consumptive expenditures.
θ coefficient associated with the convex curve conversion system (LP), where θ^U is consumption level coefficient consumption to utility, θ^L idem for income to leisure, and θ^Y idem for income to consumptive expenditures.
ξ coefficient relating consumption categories to commodities.
τ transaction costs
ϕ equilibrium marginal utility
χ product characteristics coefficient
ρ policy measure
ω weight, with $\hat{\omega}$ estimated weight.

subscripts

b input type, with b^* commercially available agro-chemical inputs
c consumption category
d number of segments of a linearized curve
i commodity
j activity
q goal
s technology
t time
v harvest period
Y income level
ρ policy measure
m indicator

superscripts

act	actual, empirical finding
calc	calculated
corr	corrected
D	optimum level
e	expected
f	farm (gate)
F	family
H	hired
L	leisure
m	market
max	maximum
md	market (demand)
min	minimum
ms	market (supply)
OF	on farm
p	price
R	requirement
s	fixed
T	total
U	utility
v	variable
W	work as in working capital
Y	income

1. INTRODUCTION

1.1 General framework

Continuing degradation of natural resources is of growing concern to policy makers. It is generally accepted that much degradation is related to market failure, i.e. prices do not adequately reflect the long term costs of different production systems. The existence of market failure justifies government intervention through the use of policy instruments in an attempt to correct them. Policy does not, however, influence land use directly, but works in an indirect way through the modification of the socio-economic environment (encompassing markets, services and infrastructure) faced by individual households. Understanding the response of agrarian households is a first step in the design of a suitable policy for enhancing sustainable land use.

Farmers take decisions on land use guided by their goals and aspirations, subject to the available resources, possible productive activities, and external economic (or financial) and biophysical constraints. Taking into consideration the objective structure and resource endowments of the various farm types in the Atlantic Zone of Costa Rica, one may expect different reaction patterns to instruments of agrarian policy. The reactions, measured as response multipliers, are defined as adjustments in the selected activities and/or technology of production induced by changes in relative prices of inputs and/or outputs (Singh *et al.*, 1986). Detailed appraisal of the effectiveness and feasibility of available policy instruments (prices, interest rates, exchange rate, extension services, etc.) to induce changes at the farm level is required. This report describes a modelling approach to gain insight in the responses of farm households in the short term, in terms of adjustments of land use and technology choice. In this way, the effectiveness of various policy instruments to attain certain regional goals can be evaluated. The present study is limited to the exploration of micro-level responses and does not account for aggregation issues in relation to the regional level.

1.2 Regional setting

A detailed analysis of the agrarian structure of the Atlantic Zone is described in Kruseman *et al.* (1994). The Atlantic Zone of Costa Rica (see Figure 1.1) comprises an area of 9.218 km^2 and can be characterized as a region of recent agricultural colonization through the establishment of tropical lowland settlements. During the period 1963-84, the area experienced high population growth (3.5 - 5.3 %), but still maintained a relatively low population density (24.6 /km^2 in 1992). Changes in land use and tenancy structure were significant, especially through rapid deforestation and pasture expansion. The development of physical infrastructure created opportunities for highly commercialized agricultural production, integrated in (inter)national markets.

The regional economic structure is mainly based on agriculture and commerce, with an increasing importance of (eco-)tourism. Banana, plantain, cocoa and maize production are activities with a relative high land and labour productivity. Land productivity in livestock-based systems is generally low, although pastures occupy more than 60 % of the agricultural area. Banana plantations are of foremost economic importance with an 84 % share in the regional agricultural value added and generating 58% of all regional agricultural employment.

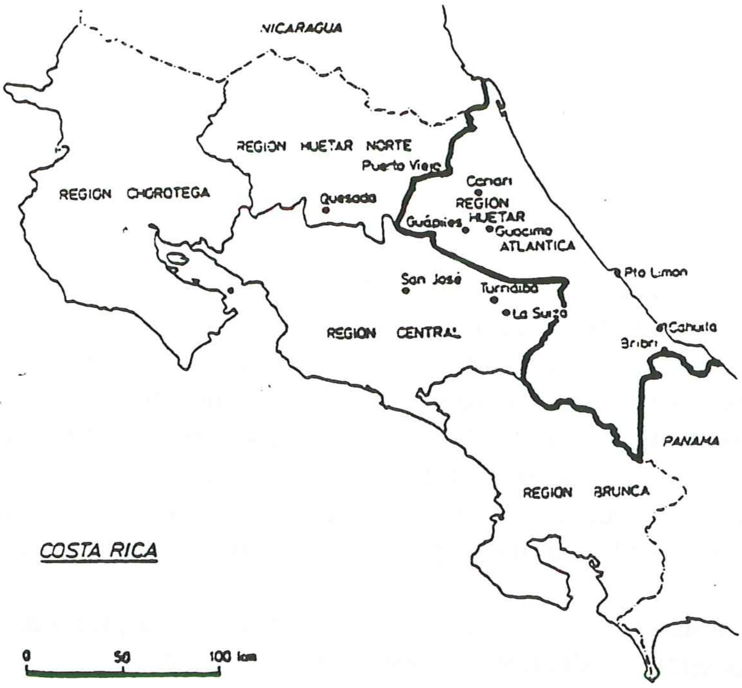

Figure 1.1 Location of the Atlantic Zone in Costa Rica

Mean family income in the Atlantic Zone is nearly 17% below the national level. Off-farm agricultural employment is becoming an important source of income; wage labour now represents 76.5 % of total agricultural employment. Unemployment rates are relatively low (4.7 % in 1992) due to the stable demand for labour by the banana plantations and services. The gap between supply and demand is covered by temporary migrants from other areas in Costa Rica and neighbouring countries.

Markets in Costa Rica are fairly well developed and integrated, but transaction costs can be high due to poor access. The prices of basic food crops reflect a steadily decreasing tendency, while prices for non-traditional crops show strong fluctuations around a somewhat increasing trend (Kruseman *et al.*, 1994). Rural incomes of peasant farms which rely primarily on traditional agricultural activities decreased strongly, while net incomes from plantation production and on more diversified medium-sized peasant farms increased during the last decade (PRIAG, 1993).

Till the early 1980s macro-economic policies of Costa Rica were oriented towards import substitution and export promotion of traditional agricultural products (coffee, cocoa, meat and bananas). Production of basic grains was supported through subsidized credit, import tariffs and producer price subsidies in order to depress consumer prices. Increasing external debts and budget deficits required structural adjustment programmes that abolished price subsidies, liberalized exchange rates and oriented economic policy towards diversification of (agricultural) exports. At the same time natural resource management for both ecological and tourism development reasons gained momentum in public decision making.

Two major regional development objectives can be identified: (1) improvement of the competitiveness of agricultural production under trade liberalization, and (2) improved natural resource management, especially in the light of expanding eco-tourism. A major constraint is the limited public budget available to finance policy measures. Stable employment opportunities are an implicit objective that is attained at present, but needs to be taken into account in analyzing regional options.

Four major agro-ecological sustainability issues are identified in the Atlantic Zone, i.e. (i) soil nutrient mining, mainly under annual crops, (ii) leaching of fertilizer nutrients predominantly under plantation crops, (iii) leaching of biocides to ground-and surface-water, and (iv) loss of nature and biodiversity. These aspects coincide with three different process types (Kruseman *et al.*, 1993): soil nutrient mining is linked to the farm level in the sense that it is a direct result of farm household decision making on land use, and that the effects of depletion of soil resources are felt at this level in terms of loss of soil productivity in the medium and long term. Leaching of fertilizer nutrients and biocides is mainly felt at the regional level because they usually do not affect the production potential directly, but do pollute public domain properties (ground- and surface-water supplies). The degree of impact of biocides and fertilizer nutrients on the environment depends on the decisions at the farm level with respect to the choice of land use systems and technologies. Loss of nature and biodiversity refers to the regional level in the sense that both causes and effects of biodiversity are primarily related to regional processes (land reclamation, land clearing, etc.) and can usually not be accounted to individual farmer's decisions.

1.3 Scope and structure of the study

The modelling approach presented in this study is one of the building blocks for the development of policy options for sustainable land use. The main questions addressed refer to the modification of land use and technology selection at farm level due to policy induced changes in the socio-economic environment. Linkage of the results derived from explorative regional studies (Alfaro *et al.*, 1994; Schipper *et al.*, 1995) and the results attained from farm household models as presented is outside the scope of this study.

This study focuses on the development of a household model for a peasant farm type and its use to measure the effectiveness of various price instruments. In Chapter 2 the approach is briefly compared to standard household models. The structure of the model is described and the different modules are summarized. In the succeeding Chapters these modules are described in more detail.

The major so-called 'management units' in the Atlantic Zone - peasant households, plantations and haciendas - are defined according to their resource endowments and objective functions, which results in differences in responses due to specific decision mechanisms. In Chapter 3, the importance of the farm stratification module of the model is elaborated. The peasant farm household is used to elaborate and illustrate the methodology. The peasant farm type is characterized by the cultivation of basic grains and other food crops for home consumption and sale. This farm type represents about 70% of the farm households and about 15% of the agricultural area in the Atlantic Zone of Costa Rica.

In Chapter 4 the price module is presented. Main attention is paid to input and output prices and transaction costs. The price structure has been adjusted for transaction costs and market risks in order to account for expected prices.

In Chapter 5 the expenditure module is highlighted. Farm household objectives are defined in terms of utility maximization, subject to constraints on the production function, and available time and income. Taking into account the composition of household budgets, the consumption pattern for different food and non-food products offers a point of departure to evaluate the influence of various policy instruments on consumption utility.

Chapter 6 describes the way the resource endowments of the farm household are incorporated in the model. Micro level restrictions regarding factor market access are accounted for.

The production activity module and underlying assumptions are briefly described in Chapter 7. Input and output coefficients are defined for actual and alternative land use activities. The actual activities describe the production systems found presently in the Atlantic Zone while the alternative activities represent possible technological options available to the farmers in the near future.

The production structure adjustment module is a procedure to adjust the calculated optimal production structure for incomplete specifications in the model. The results are used to simulate the production structure and the corresponding allocation of labour. This procedure is described in Chapter 8.

In the final Chapter 9, the elements of the farm household model are integrated to estimate a range of response multipliers to variations in prices or market conditions. The impact of variations in prices on family income, utility of consumption, land use, and agro-ecological sustainability issues is illustrated. These farm-level responses can be used tentatively for the evaluation of the impact of selected policy variables on various regional policy objectives.

Modelling exercises in developing countries are often characterized by the lack of reliable data. In this case study some data normally necessary for household modelling were missing[1]. The present approach offers some short-cuts to enable modelling of farm household response in data-scarce environments. The actual model is a clear illustration of the farm household modelling approach suitable for data-poor settings. Furthermore it allows the integration of information from bio-physical as well as socio-economic disciplines.

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[1] Although information was abundant for some specific, mainly biophysical, aspects of the Atlantic Zone, a consistent complete set for econometric estimation of a household model can only be attained through long term data collection. However, resources to do so are lacking.

2. MODELLING APPROACH

2.1 Farm household modelling

The approach presented in this study has been developed to analyze the response of farm households in terms of adjustments of land use and technology selection, to specific changes in the socio-economic environment over a period of 1-3 years.

It is assumed that decisions of farm households are based on the optimalization of a number of goals and aspirations, defined in terms of utility. Utility cannot not be equated to profit, which is often considered the guiding principle of agrarian enterprises, because farm households simultaneously take into account consumption and production objectives. Conventional profit maximization ignores the consumption component in decision making. To achieve maximum utility, the farm household uses its factor endowments (labour, land, fixed and working capital and knowledge) to undertake possible activities, both productive and reproductive, agricultural and non-agricultural. Activities should be evaluated according to their contributions to the utility at the household level.

The model is derived from Singh *et al.* (1986) based on earlier work, especially by Barnum and Squire (1978, 1979[a], 1979[b]). In this model the production and consumption decisions are dealt with sequentially, which implies maximization of a utility function subject to income and time constraints. The income constraint is defined in terms of "full income"[2] derived from product markets and labour income:

$$p^m * X^m = p^f * (Q - X^f) - w * (L^R - L^F) \tag{2.1}$$

where p^m and p^f are the prices of the market purchased commodity (X^m) and the staple (X^f), respectively, Q is the household's production of the staple (so that Q-X^f is its marketed surplus), w is the market wage, L^R is total labour input (labour requirement to attain production Q), and L^F is the total family labour input (so that if L^R-L^F is positive, external (wage) labour is hired and, if negative, the family will be engaged in off-farm labour), under the assumption of undifferentiated wage rates.

A time constraint is defined for the availability of labour which can be allocated to productive and consumptive (leisure) activities:

$$L^L + L^F \leq L^T \tag{2.2}$$

where L^T is the total stock of household time and L^L is time reserved for leisure. The household cannot allocate more time to leisure, on-farm production and off-farm employment than the total time available to the farm household.

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[2] Full income refers to net returns from agricultural production combined with implicit (for subsistence production) and explicit (for off farm labour) wages paid to the household.

2.2 Underlying assumptions

The basic Singh, Squire and Strauss (op. cit.) model contains a number of premises, some of which are of a fundamental nature, implying that the model framework is conditional on their validity, while other premises can be relaxed by extending the model to account for different circumstances.

The most fundamental assumption is the separability of production and consumption. The separation property of farm household models has been introduced to permit estimation of production decisions independent of consumption and labour-supply preferences (Singh *et al.*, 1986). Separability has special implications for the treatment of labour, as both production and consumption (leisure) aspects are involved. To account for substitution among family labour, leisure and off-farm/hired labour, free mobility of labour and a uniform wage rate is required. Benjamin (1992) presents a test for separability in case of imperfect factor markets for labour, concluding that even under differential efficiencies of various categories of labour, the separability assumption cannot be rejected. Moreover, Fafchamps (1993) shows that labour allocation decisions of small farmers in the absence of a labour market are highly flexible in order to maintain control on exogenous risk parameters. If production and consumption can be separated, they can be calculated separately and the results can be combined in an iterative procedure. The separability condition often does not hold due to two phenomena. In the first place wage rates are not uniform; there are differential wage rates for hired, off-farm and on-farm employment. Differences can result from differential payment for specific labour tasks, and transaction and information costs related to participation in the labour market. In the second place there are quantitative restrictions on labour supply and demand.

To prevent this problem, the present modelling takes a slightly different approach. The assumption of separability facilitates the use of different analytical procedures for the specification of the production and consumption side of farm household behaviour. In accordance with Delforce (1994), linear programming procedures are applied to analyze decisions on crop choice and technology selection, subject to resource constraints. By simplifying the calculation method, using linear programming in the core of the model instead of econometric estimation, it is possible to connect production and consumption decisions.

In the basic farm household model, production decisions are based on continuous production functions (Singh *et al.*, 1986). The production decisions in the present model are defined using linear programming techniques described in terms of discrete technology packages (see Chapter 7). While standard continuous production functions do not adequately explain technological change, linear programming techniques often do not adequately explain farm household decisions[3]. To take the latter feature into account, a production structure adjustment module has been introduced (Chapter 8).

The basic farm household model presented by Singh *et al.* (1986) has a number of restrictions[4]. The use of a linear programming core in the present approach allows a number

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[3] The solutions are strictly optimal conditional to the correct specification of the objective function and model parameters.

[4] Other important conditions of the basic Singh, Squire & Strauss model - which have been relaxed in more extended versions (e.g.: Singh & Subramanian, 1986; Roe & Graham-Tomasi, 1986; Lopez, 1986; de Janvry *et al.*, (continued...)

of restricting conditions to be relaxed, even though the simplified peasant model still does not account for a number of important aspects. Risk is still excluded from the present model. Due to data limitations, production is defined in terms of a one-year period. Market imperfections are accounted for using transaction costs and physical constraints. Factor endowments are fixed in the short run, as is the desired level of savings. Supply of off-farm labour is defined endogenously, while demand is defined exogenously. No differentiation in labour quality is made. Farm households are considered to be price takers[5]. The objective function is defined in terms of utility maximization, subject to an income constraint. Land is a fixed resource, for which no rent has to be paid, and land markets are excluded from the analysis.

There is a time lag between decision making on the production structure and decision making regarding consumption and the allocation of labour. Therefore, the objective function is defined as the optimization of the expected utility of consumption, i.e. utility calculated with expected prices, subject to an income constraint. The utility function is determined through the analysis of household expenditure patterns (see Chapter 5). In Chapter 8 the module calculating consumption decisions and labour allocation is explained.

2.3 Model structure

The present approach has a modular model structure. This makes it possible to incorporate information from various disciplines, which leads to rather complex interactions[6]. An additional advantage of the modular approach is that separate disciplinary teams can work on the various components. The model framework must be adapted to enable the use of data from a variety of sources. These data often must be transformed to fit into the model.

In Figure 2.1 the structure of the model and its modules are presented. First, the optimum production structure is calculated with linear programming techniques using information from various modules. In a subsequent step, production decisions are simulated in the production structure adjustment module (see Chapter 8). Finally, consumption decisions and decisions related to the allocation of labour are simulated in an optimization procedure using the simulated production structure as starting point.

The production structure optimization model uses an objective function, defined in the expenditure module (see Chapter 5). It uses price data generated in the price module (see Chapter 4), and information on possible land use activities defined in the production activity module (see Chapter 7). The factor endowments of the farm household are derived from a

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[4](...continued)
1991; Benjamin, 1992; Fafchamps, 1993) - are: (1) risk is excluded; (2) production is confined to one crop year; (3) competitive markets are assumed; (4) factor endowments are fixed in the short run; (4) desired levels of savings are fixed; (5) off-farm income is endogenous; (6) perfect substitutability of family and hired labour under the assumption of perfect labour markets; (7) the households are price takers; (8) the objective is profit maximization; and (9) land is owned or rented at fixed rates, with no contractual arrangements leading to non-standard profit maximizing conditions.

[5] This term implies that individual farmers do not influence the price by the quantity of produce they market.

[6] An attempt to include all relevant processes in a single mega-model will lead to two types of difficulties: in the first place the model will be extremely difficult to understand, and the implications of the model results increasingly difficult to comprehend. In the second place the data requirements for such a mega-model will undoubtedly be more restrictive than in a modular approach.

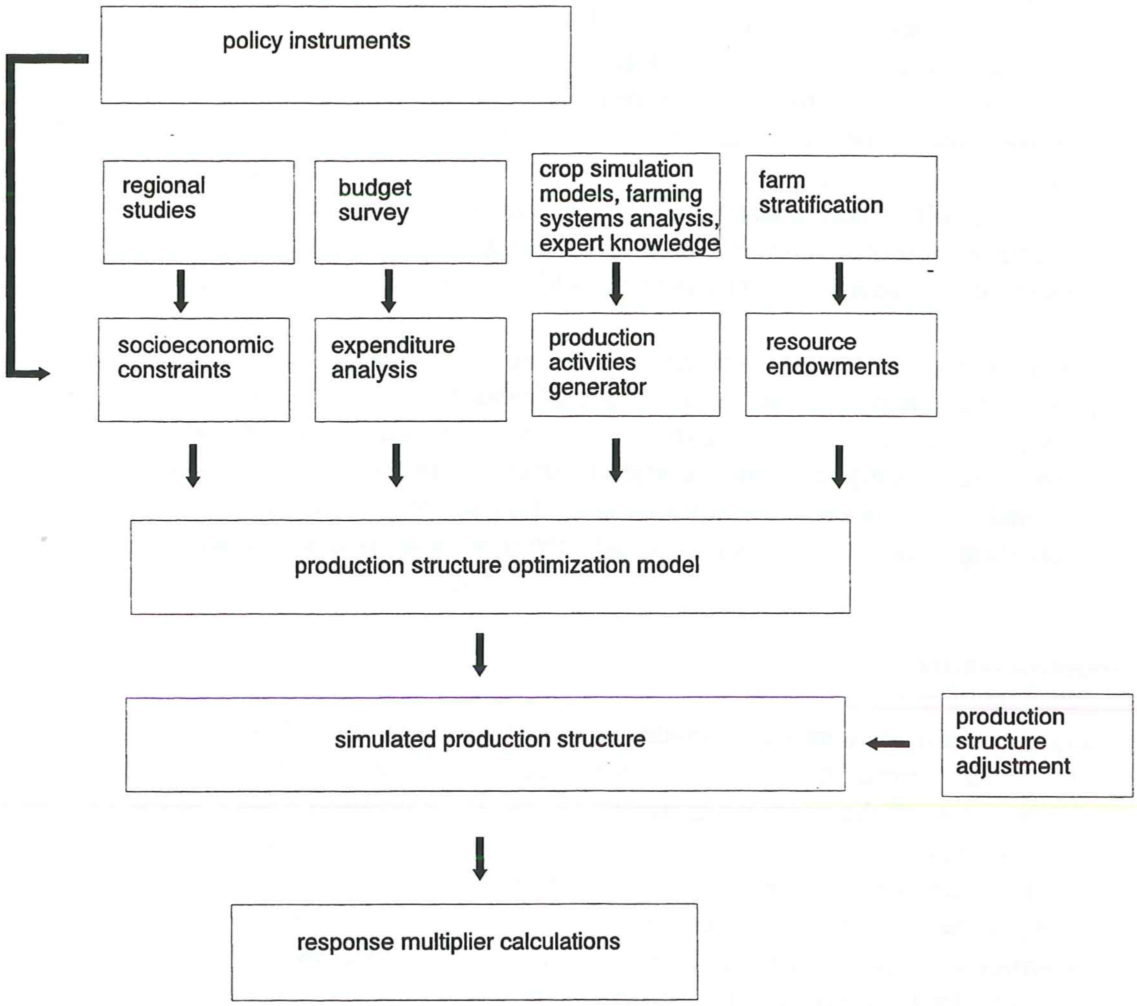

Figure 2.1 The outline of the model structure

farm stratification (see Chapter 3). A number of institutional and market constraints are derived from the regional analysis (Kruseman *et al.*, 1994) and include: limits on credit, off-farm employment and possibilities to hire labour in peak periods.

The model is used to analyze the effect of a number of price instruments on household income, utility, land use and on selected agro-ecological sustainability indicators. To calculate the effect of a particular price change, the model has been run twice: first for the base year without change and then again with a 1% change in price[7]. The differences in model results have been used to calculate price response multipliers (see Chapter 8).

The linear programming module is a two-period model to account for perennials: perennials like plantain and cassava planted in the preceding period have implications for land use in the current period, i.e. land under cultivation in the first period cannot be used for

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[7] Actually the results have been calculated for a number of price changes and the results extrapolated to the 1% change. This implies that the price range over which the multiplier is valid is known. However, for larger price changes, the *ceteris paribus* condition regarding the markets does not hold, because of aggregate response at regional level.

other purposes in the succeeding period. The complete specification of the model is given in Appendix 1 and is programmed in OMP (Beyers & partners, 1993).

2.4 Linking consumption and production

The present model is based on the assumption that it is possible to link production and consumption decisions in order to optimize them iteratively, while taking into account utility considerations in the production decisions. This implies that a number of balances must be included in the model to link production and consumption variables. The links between the two realms are labour use, including leisure, and consumption of agricultural commodities.

Standard practice in household modelling is to maximize utility, subject to a budget constraint. The budget constraint contains two components: (i) an income generation component, equation (2.3), and an expenditure component, equation (2.4). The income concept used in these equations is a modified full-income concept, in which implicit subsistence production income is added to cash income, while only productively employed time is taken into account. Leisure is not considered income nor expenditure, which is identical to the standard approach developed by Becker (1965) :

$$Y_t^e - \sum_j p_{jt}^{fe} * (X_{jt}^f + X_{jt}^{ms}) - w_t^e * (L_t^{OF} - L_t^H) + \sum_b p_{bt}^e * B_{bt} \le 0 \qquad (2.3)$$

$$Y_t^{xe} - \sum_j p_{jt}^{fe} * X_{jt}^f - \sum_j p_{jt}^{me} * X_{jt}^{md} \ge 0 \qquad \textit{all } t \qquad (2.4)$$

$$Y_t^e, Y_t^{xe} \ge 0 \qquad \textit{all } t \qquad (2.5)$$

where Y_t^e is the expected income, Y_t^{xe} is the expected expendable income, B and L are non-factor and labour inputs, p_{jt}^{fe} is the expected farm gate price of commodity j, p_{jt}^{me} is the expected market (buying) price plus transaction costs of commodity j, p_{bt}^e is the expected market (buying) price plus transaction costs of input b, w_t^e is the expected wage rate (this rate may be differentiated for different labour types, i.e. differences for normal farm labour and banana plantation work), X_{jt}^{md} is the market bought commodity j, X_{jt}^{ms} is the marketed produce j and X_{jt}^f is the subsistence production of commodity j.

Capital and land costs are not included. Capital costs are excluded because the major constraint is not the interest rate but availability of credit (Ramirez, 1994). Moreover, information on the portfolio of savings and loans to peasant farmers in the Atlantic Zone is scarce. Land costs are excluded because they are only of importance for the decision whether to continue farming or sell land, a question not addressed in the present model.

All prices used are expected prices, since at the moment of decision making on land use no information is available on the price level at the time that inputs and outputs will be bought or sold. In Chapter 4 the principle of expected prices is explained. To take into account the non-linear relationship between income and expenditures for consumptive purposes (explained in Chapter 5) a curve linearization procedure is used (for a full explanation, see Appendix 4). The link between income and expenditure is defined as:

$$Y_t^{xe} - \sum_d \eta_{dt}^Y * D_{dt}^Y \le 0 \qquad \textit{all } t \qquad (2.6)$$

$$-Y_t^e + \sum_d \theta_{dt}^Y * D_{dt}^Y \leq 0 \qquad all\ t \qquad (2.7)$$

$$\sum_d D_{dt}^Y \leq 1 \qquad all\ t \qquad (2.8)$$

$$D_{dt}^Y \geq 0 \qquad all\ d,\ t \qquad (2.9)$$

where η_{dt}^Y are expenditures associated with point d on the income - expenditure curve, D_{dt}^Y are variables denoting points d on the income - expenditure curve, and θ_{dt}^Y is the income level associated with point d on the income - expenditure curve.

3. FARM TYPE STRATIFICATION

3.1 Stratification of management units

For the evaluation of the impact of policy instruments on resource allocation at farm level, the development of a typology of agrarian households is a prerequisite. Differences in farm household response to policy change depend on variations in objective structure and resource endowments. Taking into account differences among farm households in terms of availability of and access to productive resources (land area, soil quality, credit, labour) and in terms of production strategies (e.g. risk taking, product diversification, factor intensity), a classification of farm types can be developed according to the most important (implicit) enterprise objectives and resource endowments.

A tentative stratification of farm households in the Atlantic Zone of Costa Rica resulted in three major farm types or management units[8] (Kruseman *et al.*, 1994), based on differences in resource endowment, objective function and production system (strategy):

a) Plantations; large corporate firms, based on mono-cropping, with specialized production systems, oriented to export markets and aiming at profit maximization. Plantation agriculture is integrated with agro-industrial processing. Production requires substantial amounts of fixed capital investment (supplied from corporate finance), external infrastructure and semi-permanent wage labour.

b) Haciendas; farms oriented towards livestock production or forest conservation, with quasi-rent objectives. External employment, working capital requirements and input use are extremely low. Risk reduction tends to be the major objective.

c) Peasant producers; small and medium-size households with more diversified cropping systems, based on a mixture of food crops (basic grains), root and tuber crops, perennial crops and some livestock. These farms are partially integrated in local factor and product markets and reflect production objectives that prioritize family reproduction (e.g. food security, labour use optimization, risk aversion).

Table 3.1 Farm type stratification for the Atlantic zone of Costa Rica (1984).

Farm type	Farm size (ha)	No. of farms	Area (ha)	Labour (pers.)
Banana plantations	> 100	136	21,064	12,900
Livestock haciendas	> 50	1,010	169,526	3,400
Medium peasant producers	20-50	1,690	48,472	12,300[1]
Small peasant producers	0-20	6,480	46,254	
Total		9,316	285,316	28,600

Source: DLV Report no. 3
Note 1: Small and medium peasant producers

[8] A management unit may be defined as the combination of an actor, his resource endowments (land, labour, knowledge and capital), and his long term "production" strategy.

In Table 3.1 the relative importance of these farm types in the Atlantic Zone of Costa Rica is shown in terms of farm size, cultivated area and labour absorption. Banana plantations and livestock haciendas occupy respectively 7% and 60% of the agricultural area in the region, but represent only 2% and 11% of the number of farms. Small and medium size peasant households represent 88% of all farms, occupying only 33% of the agricultural area. In terms of employment, plantations with 45 % and peasant farms with 43 % supply the majority of labour opportunities.

3.2 Peasant households

Due to recent adjustments within the peasant sub-sector, farm size only is not an adequate stratification criterion. Further differentiation within the peasant household type is therefore necessary. Because of differential access to (subsidized) credit and output markets, a specific group of medium size farm households is involved in the production and marketing of so-called non-traditional crops (palmheart, pineapple, macadamia, etc.). The production process of these crops requires substantial amounts of capital investment (supplied through subcontracting with commercial companies) and wage labour.

In the following analysis the peasant household sub-sector is classified in three different farm types:

a) Type I; semi-subsistence farm households, with production systems oriented towards food crops (maize, beans, plantain and cassava) and depending on off-farm employment for additional income generation.

b) Type II; diversified medium-size farm households with production systems comprising mixed food crops and livestock and a small component of non-traditional crops.

c) Type III; medium-size farm households mainly oriented to non-traditional commercial crops (palmheart, cocoa, pineapple), making use of external wage labour and credit funds for production.

While the dynamics of type I and II peasant households can still be explained through resource reproduction and risk aversion objectives, in type III households profit maximization and risk acceptance become increasingly important. However, the explicit definition of farm household objectives is difficult on the basis of the available data set. In section 3.3 a complementary framework is sketched to derive the objectives and the weights attached to the various household goals.

The farm household model is calibrated for peasant type I, a farm comprising 20 ha, growing four crops, maize, beans, plantain and cassava and no livestock[9]. The initial production structure is defined as: four hectares of maize, one hectare beans, one hectare of cassava, one hectare of plantain and 13 hectares of fallow and brush. The farm is located on fertile well-drained soils, albeit isolated from markets due to poor infrastructure. The households is composed of a small nuclear family.

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[9] This is a gross simplification because many peasant households do engage in livestock activities, albeit at a small scale and incomparable to livestock activities undertaken by the large cattle haciendas. The reason for this simplification was the lack of reliable data on peasant livestock production practices at the time of model design.

3.3 Further perspectives and theoretical base for stratification

The specification of farm objectives depends on the type of household involved, implying the classification of the farm households. This stratification of farm types can be built on a conceptual framework based on tentative objectives (Romero 1993). The most important objectives are: (1) profit maximization[10], (2) food security[11] and (3) maintenance of the resource base. In general one could summarize these goals as relating to production, consumption and the reproduction of the resource base (Kruseman *et al.*, 1993).

While it is impossible to elicit goals directly, it is possible to postulate a number of tentative goals ($G_1 \ldots G_q$) on the basis of theoretical considerations. In order to define the relative importance to be attached to each objective, a weighted goal programming procedure can be formulated with ω_q representing the relative weight of each goal (Romero, 1993). Since the goals refer to divergent concepts and are often expressed in incompatible indicators, the goals cannot simply be added. The weights are used to indicate the degree to which a decrease in one goal may be compensated by an increase in another, i.e. they refer to the subjective importance of the trade-offs between different goals. The pay-off matrix for an individual farm consists of the following system of equations:

$$\begin{bmatrix} G_{11} & \cdots & G_{1q} \\ \cdots & & \cdots \\ G_{q1} & \cdots & G_{qq} \end{bmatrix} * \begin{bmatrix} \omega_1 \\ \cdots \\ \omega_q \end{bmatrix} = \begin{bmatrix} G_1 \\ \cdots \\ G_q \end{bmatrix} \qquad (2.10)$$

where G_{qq} is the objective value of one goal subject to maximization of another goal, and ω_q is the subjective relative weight of goal q, with:

$$\sum_q \omega_q = 1 \qquad (2.11)$$

Given (i) a set of activities and constraints and (ii) a set of tentative goals, values for the goal indicators can be calculated under the assumption of partial optimization, i.e. optimizing a single goal. The result is the matrix $[G_{qq}]^{calc}$ in which G_{qq} is the value of the goal indicator of each goal q under optimization for one goal q. The matrix of model results $[G_{qq}]^{calc}$ can be confronted with the actual values of the goal indicators using the activity set. These actual values are calculated by entering the actual production structure (activity set) into the model. The result is the following equation which is a further specification of equation (2.10):

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10 Alternatively, the closely related consumption utility can be maximized. The results will not be identical because of the inclusion of leisure in utility, i.e. in profit maximization labour is only a productive asset, while in utility maximization it has consumptive characteristics too. Additionally, differential diminishing marginal utility of consumption for different commodities leads to specific choices regarding subsistence production.

11 Food security at the household level will often refer to access to food in climatically adverse years. This implies that risk analysis is part of the concept of food security.

$$\begin{bmatrix} G_{11}^{calc} & \dots & G_{1q}^{calc} \\ \dots & & \dots \\ G_{q1}^{calc} & \dots & G_{qq}^{calc} \end{bmatrix} * \begin{bmatrix} \hat{\omega}_1 \\ \dots \\ \hat{\omega}_q \end{bmatrix} = \begin{bmatrix} G_1^{act} \\ \dots \\ G_q^{act} \end{bmatrix} \tag{2.12}$$

where G_{qq}^{calc} is the value of the goals subject to maximization of one of them, G_q^{act} is the empirical value of goal q, and $\hat{\omega}_q$ is the estimated subjective weight of goal q. On basis of the results of this model the goal weights can be estimated statistically.

4. PRICE MODULE

4.1 Price formation

The selection of land use types by a farm household depends on the profitability of each of the different options available, comparing costs and benefits. Technical options that can be identified as efficient from the point of view of resource allocation are characterized by their superior net margins between production costs and market value. The efficiency of resource allocation differs among the various types of farm households, i.e. the production factor that is relatively scarce for a particular household will be used most intensively. For haciendas it is e.g. maximization of the net income per unit of (wage) labour, while for peasant farm households maximization of the net income per unit of land tends to be more important.

Theoretically, price instruments can be a powerful tool to induce changes in the agricultural production structure. However, the degree to which policy can influence prices depends on price formation mechanisms. Although price formation is not the main theme of this study, some brief remarks need to be made.

Prices of inputs and outputs are subject to modifications due to adjustments in the macroeconomic environment (exchange rate, taxes, inflation, etc), as well as through the restructuring of local markets (liberalization). As a consequence relative net margins of different activities change, which implies shifts in allocative efficiency. These shifts are the driving force behind changes in the structure of the production system[12].

In the second half of the 1980s the Costa Rican Government started a broad structural adjustment programme (SAP) to balance foreign exchange and fiscal accounts. This programme had a profound impact on the relative factor costs of different activities and production technologies. From 1984 onwards the development of real prices of factor inputs shows a relative increase of land rents and wage labour costs, an erratic behaviour with a rising trend of capital interest costs, and more stable machinery costs (see Figure 4.1). Although the factor markets in the Atlantic Zone are not perfect, they are well developed. Labour and land markets are very dynamic, as can be expected in a region of recent colonization. In Table 4.1 real prices, i.e nominal prices corrected for the consumer price index, are highlighted.

Rules and regulations regarding the labour market exist, but are not strictly enforced. For instance, a relatively low percentage of wage labour is eligible for social security, since only for labourers contracted directly by the banana plantations, social security contributions are paid. Although there is an apparent labour shortage in the Atlantic Zone, the existence of an implicit labour pool, consisting of unemployed workers from other areas (within Costa Rica and abroad) covers the gap in local supply. Banana plantations absorb nearly 45% of the agricultural wage labour. This implies that parameters regarding the labour market extracted from the banana plantation sector can be taken as bench mark.

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[12] The argument that macroeconomic adjustment requires a corresponding adjustment at microeconomic level in order to be able to fulfil the objectives of stabilization and national economic growth is explained by CEPAL (CEPAL, 1991)

Real wages tend to rise, the only dip in the trend in the early 1980s being caused by very high inflation and the subsequent lagged adjustment of nominal wage rates. The labour market functions well in the sense that information about employment opportunities is readily available, e.g. plantations make announcements on the radio on their needs for temporary contract labour. For those seeking employment and not finding any as a contract labourer in a banana plantation, opportunities exist through labour contractors.

Table 4.1 Factor prices in real[6] terms in colons and percentages (base year = 1984)

Year	Land[1]	Labour[2]	Interest[3] agricultural rate	Interest[4] corporate finance rate	Machinery[5]
1980	17179	195	-7	5	445
1981	9711	174	-15	2	556
1982	6075	163	-38	5	544
1983	7292	182	-11	2	499
1984	9610	191	9	9	531
1985	18149	200	9	9	535
1986	15029	207	12	13	520
1987	15142	200	7	9	532
1988	15613	191	5	8	517
1989	14144	199	10	13	503
1990	13452	200	9	13	544
1991	13768	212	6	1	535
1992	13768	238	11	4	506

notes:
1 Calculated on basis of IDA data, see DLV Report no. 3.
2 Alternativas de Desarrollo (1993), price of a 6 hour working day.
3 Ramirez (1993).
4 Calculated on basis of Ramirez (1993) and Alternativas de Desarrollo (1993).
5 Estimated on basis of various sources, see DLV Report no. 3.
6 Corrected for the consumer price index.

The impact of structural adjustment on agricultural output prices gives a preliminary indication of the profitability of agricultural activities (see Figure 4.2). Producer prices for maize, beans and rice dropped in real terms with 23-38% between 1984 and 1991. In livestock production, price decreases were less extreme because of fiscal and credit support measures launched during the 1987-89 period[13], but especially milk prices fell by 30% between 1984 and 1990. Prices for forestry products - especially hard roundwood - increased with 58% and prices for export crops like banana and palmheart rose with 23% and 68% during the same period.

[13] Within the framework of the so-called FODEA law, especially large livestock haciendas were granted special facilities for the rescheduling of outstanding long-term debts with the banking system.

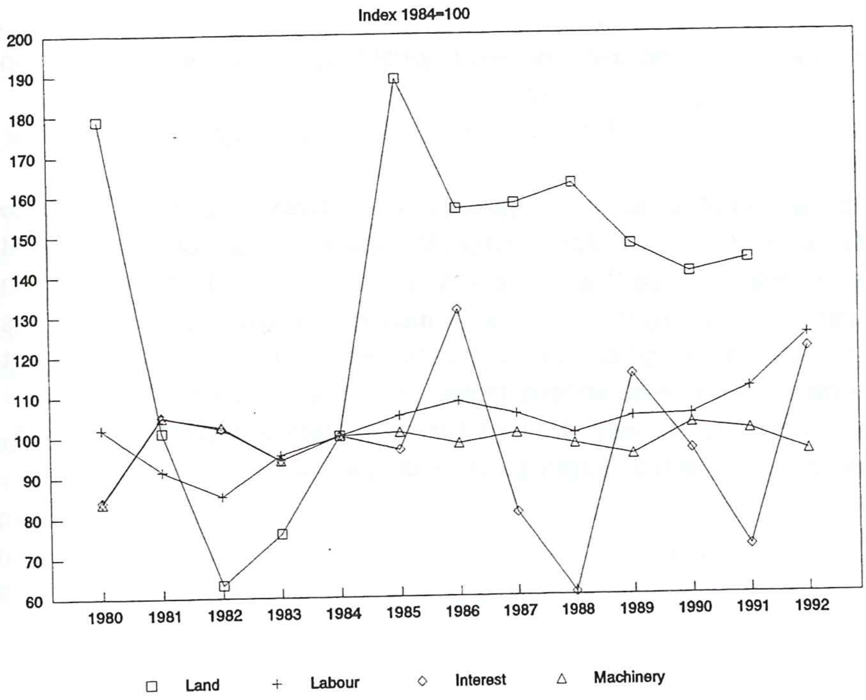

Figure 4.1 Trends in factor prices

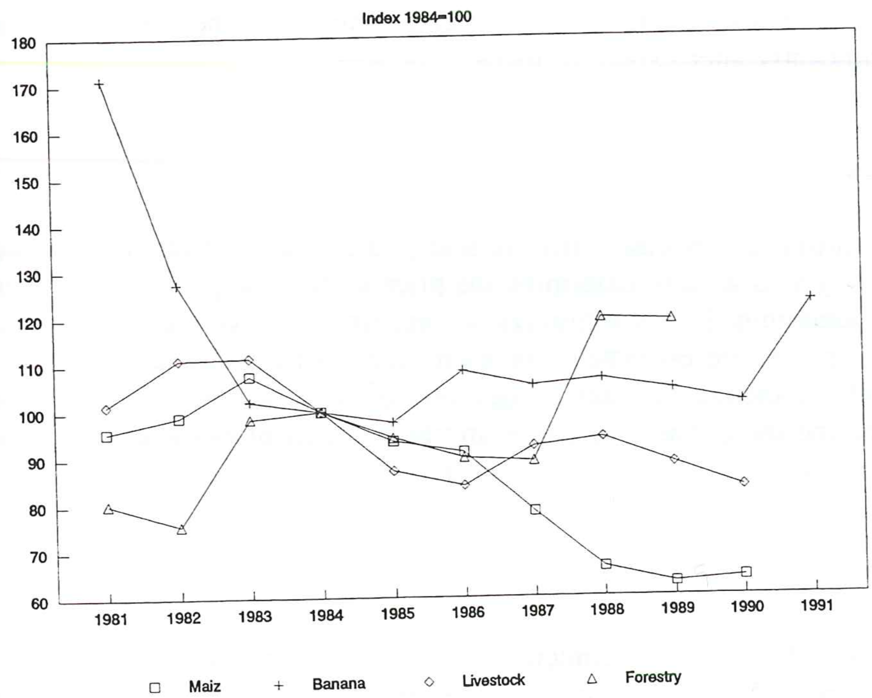

Figure 4.2 Comparison of price indices for selected crops

4.2 Expected output prices

At the moment of decision making on land use, the farm household has no information on (future) market prices. Those prices depend on a variety of factors, including policy aspects, and the supply and demand situation both within the region and in other regions. Also price fluctuations are taken into consideration.

Price expectations can be analyzed in terms of past price changes, while reactions to prices require insight in the response to changes in expected prices. This can be obtained through the analysis of supply response. In this paragraph the analysis will concentrate on expected prices, based on past price changes. If output prices are known *a priori*, e.g. as determined by a marketing board, these prices are the expected prices. In a free market situation, however, the expected price can be approximated by the weighted average of past prices. Although elaborate systems have been devised for its estimation (Nerlove, 1958, 1979), for the present purpose the expected output price is defined as:

$$p_t^e = \beta_1^p * p_{t-1} + \beta_2^p * p_{t-2} + \beta_3^p * p_{t-3} \qquad (4.1)$$

with:

$$\beta_1^p + \beta_2^p + \beta_3^p = 1 \qquad (4.2)$$

where p_t^e is the expected price in period t, and β_i^p the coefficients of expectation.

The coefficients of expectation were set at 0.5, 0.25 and 0.25, respectively. This means that the price in the preceding year affects the expected price more strongly than the prices in the two years preceding that one. Using slightly different values for the coefficients of expectation does not significantly alter expected prices.

4.3 Implicit input prices

Due to the diversity of fertilizer and biocide formulas sold in the Atlantic Zone, a so-called implicit pricing methodology was used to determine the price of the components: nitrogen (N), phosphorus (P) and potassium (K) for fertilizers and amount of active ingredients (AI) for biocides. The implicit prices are estimated, for each year, using multiple regression, where the dependent variable is the price of each of the inputs B^* (i.e. commercially available agro-chemical inputs), and the independent variables are the contents of elements b in each input B^*:

$$p_{b^*} = \sum_b p_b * \chi_{b^*b} \qquad (4.3)$$

where p_{b*} is the price of input B^*, χ_{b*b} is the content of element b in input B^*, b is a member of the set (N, P, K, AI), and p_b is the implicit price of element b. In the remainder of the study the term B is used for non-factor inputs, which refers to the generic inputs.

For biocides, the simple measure of amount of active ingredient was used. Arguably, a more differentiated measure which takes into consideration both their agro-technical and their eco-toxicological impact would be more appropriate.

4.4 Transaction costs

The structure and performance of the markets, the available infrastructure, and the degree of access to services determine transaction costs. Considering the effects of transaction costs is fundamental for the analysis of marketing strategy of farmers, i.e. the decisions to participate in the market are taken on the basis of farm gate prices of the household, which include transaction costs, and not on the basis of standard prices, e.g. wholesale prices.

Two types of transaction costs can be distinguished: (1) entrance costs, defined as a fixed amount irrespective of quantity and (2) variable transaction costs, that are related to the volumes traded. Entrance costs include information costs, i.e. costs associated with collecting information about marketing possibilities, and supervision costs, related to the process of marketing the commodities. Variable transaction costs include transportation costs from the farm to the market place. This can be summarized as:

$$p_j^{corr} * Q_j = (p_j - \tau_j^v) * Q_j - \tau_j^s \tag{4.4}$$

and:

$$p_b^{corr} * B = (p_b + \tau_b^v) * B + \tau_b^s \tag{4.5}$$

so that:

$$p^{corr} = p + (\frac{\tau^s}{VOL} + \tau^v) \tag{4.6}$$

where p^{corr} is the corrected (farm gate) price, p is the (wholesale) market price, τ^s are the fixed transaction costs, τ^v are the variable transaction costs, Q is the production volume, B are the non-factor inputs, and VOL is the volume of traded good, commodity or input.

Often, however, an approach is used that is different from the one presented in equations (4.4) to (4.6), i.e. one where the transaction costs are assumed to be some proportion of the market price. For lack of accurate data, this approach has been used in the present study. To account for imperfect access to markets, transaction costs are incorporated in terms of a 20% mark-up on prices[14].

[14] Personal communication by J. Belt, researcher formerly attached to the AZP.

5. EXPENDITURE MODULE

5.1 The utility function

Although peasant households have multiple objectives, the present model, for lack of sufficient empirical data to estimate goal weights, only considers maximization of the utility of consumption. This modelling exercise deals with peasant households, whose decision-making is characterized by simultaneously taking into account production and consumption considerations. Profit maximization as the sole objective will not take sufficient account of the consumption aspects. Therefore, the farm household is assumed to maximize utility, where utility depends on the consumption of commodities and leisure.

In the model a negative exponential utility function is used. Anderson *et al.* (1977) defined this function for the utility of wealth in risk analysis, but it can with equal ease be applied to describe the utility of consumption. This function allows for the inclusion of minimum consumption requirements as well as linearization. The function is determined by the derived utility of consumption at different levels of income.

The negative exponential utility function is preferred over the commonly used Log-Linear Expenditure System (LLES) (Lau *et al.*, 1978) or the Linear Expenditure System (Barnum and Squire, 1979a, 1979b), because LLES implies that each expenditure elasticity with respect to full income equals one, and LES implies linear Engel curves (with proportional quantities of commodities purchased if income increases). These conditions become more restrictive when commodities are less aggregated. Moreover, the data requirements for estimation of the negative utility function are less restrictive. For example, the data set does not have to include information on the production structure.

For all consumption categories c, including commodities and leisure, the utility derived from their consumption by the household can be characterized by the following negative exponential utility function:

$$U_c = U_c^{max} * (1 - e^{-\alpha_c^U * (C_c - C_c^{min})}) \tag{5.1}$$

where U_c is the utility of consumption of commodity c, U_c^{max} is the maximum attainable utility with commodity c, α_c^U is the conversion factor consumption to utility, C_c is the consumption of commodity c, C_i^{min} is the minimum consumption of commodity c.

For utility maximization, these partial utilities are added:

$$\max U = \sum_c U_c \tag{5.2}$$

For a utility maximizing household, in the equilibrium situation, total utility (max U) is at a given maximum, given the budget constraint, so that any change in expenditures will result in lower utility. In other words, the marginal utility of expenditures on commodity c is constant for all c, for a given expenditure level:

$$\frac{\delta U_c}{\delta C_c} = \phi_Y = \alpha_c^U * U_c^{\max} * e^{-\alpha_c^U(C_c - C_c^{\min})} \tag{5.3}$$

The negative exponential utility function is linearized using the convex combination constraint (Hazell and Norton, 1986, also Appendix 4). The convex properties of the utility function allow for linearization. Maximizing utility for the dummy D_{cdt}, which is related to utility, gives:

$$\max\ U = \sum_t \sum_c \sum_d \eta_{cdt}^U * D_{cdt}^U \tag{5.4}$$

such that:

$$-C_{ct} + \sum_d \theta_{cdt}^U * D_{cdt}^U \leq 0 \qquad all\ c,\ t \tag{5.5}$$

$$\sum_d D_{cdt}^U \leq 1 \qquad all\ c,\ t \tag{5.6}$$

$$C_{ct},\ D_{cdt}^U \geq 0 \qquad all\ c,\ d,\ t \tag{5.7}$$

where η^U_{cdt} is the utility associated with the corner points on the linearized utility curve for commodity c, D^U_{cdt} represents the variables denoting corner points on the linearized utility curve for commodity c, θ^U_{cdt} is the consumption level associated with corner point d on the utility curve for commodity c, and C^U_{ct} is the consumption of commodity c.

Equation (5.4) expresses utility maximization via the utility associated with points d on the utility curve. Constraint (5.5) defines consumption levels associated with points d on the utility curve. The variables D_{cdt} representing possible positions on the utility function cannot exceed unity. Solutions below the utility function are inefficient, since for the same quantity consumed, a higher value of U can be attained. Hence, the constraint effectively dictates that the model's optimal solution will be on the utility function, provided that this option is feasible.

5.2 Data set and results

Five relevant consumption categories were defined for the peasant farm household model: staples for home consumption and sale (maize, beans and cassava) and market-purchased goods (food and non-food). A fourth staple, plantain, is included in other food, because of the erratic consumption data. Cross-sectional budget survey (DGEC, 1992) allows calculation of the expenditure levels for these consumption categories for different groups.

Different levels of aggregation have been distinguished for estimation purposes. The largest number of observations is desired to enable estimation of the parameters. Aggregation requires a minimum number of observations per stratum, which implies a limited number of strata if the number of observations is not very large. Preliminary analysis suggests the use of six income categories which allows for about 50 observations per stratum. In Table 5.1

the per capita food and non-food expenditures are given for this selected level of aggregation[15]. Methodological estimation issues relating to the expenditure module are detailed in Appendix 3.

On the basis of the data presented in Table 5.1[16], C^{min} can be estimated. On the basis of a graphical presentations of cross-sectional empirical relationships between Y and C (Engel curves) and the hypothesis on the relation between utility and Engel curves, C^{max} can be estimated (Appendix 3, Section A). From the estimated extreme consumption levels, α^U can be estimated (Appendix 3, Section B). The results are presented in Table 5.2. Maximum attainable utility are calculated on the basis of regression analysis using six[17] income levels and 5 consumption commodity categories. There is cross-check on the independence of α^U with respect to income, see Appendix 3, section C.

Table 5.1 Consumption volumes of rural households in the Atlantic Zone of Costa Rica.

Six income categories: income[1]	maize[2]	beans[2]	cassava[2]	food[3]	non-food[4]	N
$Y < 2100$	4.51	6.98	2.41	2.09	2.93	54
$2100 < Y < 2800$	3.84	6.21	1.66	3.99	5.99	51
$2800 < Y < 3800$	5.09	8.10	3.34	5.45	7.26	54
$3800 < Y < 4800$	7.61	6.52	3.39	5.46	10.41	53
$4800 < Y < 6100$	5.05	7.38	1.64	9.79	14.02	48
$6100 < Y < 7800$	8.12	11.08	3.86	9.39	16.06	56

Source: DGEC (1992) household survey 1987/88

Notes: 1 Income per head per month in colones.
2 In kg per person per month.
3 Includes rice, plantain, meat, milk, calculated on the basis of expenditures divided by consumer price index for foodstuffs.
4 Calculated on the basis of expenditures divided by general consumer price index.

Table 5.2 Estimated parameters of equation (5.1)

	maize	beans	cassava	food	non-food
C^{min}	3.3	4.43	0.75	0.81	1.94
α^U	1.023371	1.423546	1.509892	0.685293	0.022516
U^{max}_c	13.99766	54.6718	15.79836	63.84684	126.4025

15 For cross-checking purposes, different levels of aggregation were calculated (see Appendix 3, section D).

16 Compare with data in Appendix 3 section E.

17 The analysis was performed for the case of three and 19 income categories. Although the results of these calculations should be treated with caution, they indicate the same magnitude for the values of the estimated parameters as the six income categories. As was argued earlier, using six categories will allow for sufficient numbers of observations for both aggregation and analytical purposes.

5.3 Commodity balances

The production volume can be used either for subsistence purposes or for sale:

$$Q_{jt} - X^{m}_{jt} - X^{f}_{jt} \geq 0 \qquad all\ j,\ t \qquad (5.8)$$

$$X^{ms}_{jt},\ X^{f}_{jt} \geq 0 \qquad all\ j,\ t \qquad (5.9)$$

where X^{ms}_{jt} is farm supply of commodities in the market, and X^{f}_{jt} is subsistence requirements of commodities. Consumption of commodities can be based on own farm production and/or purchase in the market:

$$C_{ct} - \xi_{cj} * (X^{f}_{jt} - X^{md}_{jt}) \leq 0 \qquad all\ c,\ j,\ t \qquad (5.10)$$

$$X^{md}_{jt} \geq 0 \qquad all\ j,\ t \qquad (5.11)$$

where X^{md}_{jt} is farm demand for commodities from the market, and ξ_{cj} is the coefficient denoting the content of consumption category *c* in commodity *j*. For consumption commodities, there may be limits in the form of minimum and maximum consumption levels. Minimum consumption levels refer to levels to prevent starvation, maximum levels refer to biologically highest levels of consumption possible. By using utility of consumption functions, however, the maximum levels are never reached:

$$C_{ct} \leq C^{\max}_{ct} \qquad (5.12)$$

$$C_{ct} \geq C^{\min}_{ct} \qquad (5.13)$$

6. RESOURCE ENDOWMENTS

6.1 Land

The model contains a number of resource constraints, related to available resources and/or to their accessibility. For land resources, a distinction is made in two periods: *t* refers to the planting period and *v* refers to the period in which the crop is harvested:

$$\sum_{j}\sum_{s}\sum_{v} W_{jsv_t} \leq A^f \qquad \textit{all } t \tag{6.1}$$

$$W_{jsv_t} \leq W_{jsv_{t-1}} \qquad \textit{all } j = \textit{perennial}, \ s, \textit{ and } v \geq t \tag{6.2}$$

$$0 \leq W_{jsv_t} \leq W_{jsv_t^{\max}} \qquad \textit{all } j, \ s, \ v, \ t \tag{6.3}$$

where W_{jsvt} is the area under activity j, technology s, harvested in period v, W_{jsvt-1} is the area under activity j, technology s, harvested in period v, already in the field in period $t-1$, and A^f is total farm area.

Constraint (6.1) refers to the standard area balance of the farm, i.e. the area under crops cannot exceed the farm area. Constraint (6.2) is the dynamic area balance for perennial crops: a crop harvested in one period must have been planted in the preceding one. Constraint (6.3) limits the area for individual activities. Peasant households tend to diversify production to spread production risk. Since production risk is not included in the present model, diversification is forced onto the farmers with this constraint. This prevents the occurrence of extreme choices, i.e. concentration of production on one crop-technology combination. The limit was arbitrarily set at 2 ha per crop technology combination.

The land market is not included in the present model which means that the farm area is fixed at 20 ha.

6.2 Labour

Labour resource constraints link labour availability and requirements. The labour balance is given in equation (6.4), while the labour requirements are specified in equation (6.7):

$$L_t^L + L_t^F + L_t^{OF} \leq L_t^T \qquad all\ t \qquad (6.4)$$

$$L_t^{OF} \leq L_{\max}^{OF} \qquad all\ t \qquad (6.5)$$

$$L_t^H \leq L_{\max}^H \qquad all\ t \qquad (6.6)$$

$$-L_t^H - L_t^F + \sum_j \sum_s \sum_v \lambda_{jsvt}^L * W_{jsvt} \leq 0 \qquad all\ t \qquad (6.7)$$

$$L_t^F,\ L_t^{OF},\ L_t^H,\ L_t^L,\ L_t^T \geq 0 \qquad all\ t \qquad (6.8)$$

where L_t^F, L_t^{OF}, L_t^L are family time dedicated to on-farm and off-farm activities and leisure, respectively, L_t^H is hired labour, and λ_{jsvt}^L is the labour requirement coefficient.

The total available farm household labour, equation (6.4), was defined as 2.160 hours per annum. This corresponds with 1.8 labour units * 200 days * 6 hours. Structural limitations to the labour market are specified in equations (6.5) and (6.6) in which off-farm labour and hired labour respectively, are subject to certain maximum levels. Off-farm labour was limited to 600 hours per annum and hired labour to the same amount. This corresponds to three man months.

Limitations related to imperfect markets are common in developing countries and usually pose a problem in farm household modelling. Although, in the Atlantic Zone, the factor market for labour is working fairly well, at least at an aggregate level, for individual households there are limitations because of regulations governing the hiring of temporary banana plantation labour. The second reason for including constraints on labour mobility is the fact that the labour market is not modelled. Therefore, the dynamics related to price formation and temporary migration of labour cannot be included at this point.

For leisure, a different approach is used. Leisure is strongly related to the income level. At very low income levels, leisure can be considered a necessity, strongly correlated to labour effort. The target of the household is the point where physical fatigue can be overcome, but no more leisure is required. For higher income levels, leisure may become a substitute for the consumption of goods. Since leisure does not have direct costs, only the opportunity costs of unused labour, care should be taken to clearly distinguish between leisure and involuntary unemployment, i.e. that portion of labour that cannot be used productively (or reproductively). Since data were lacking, a relationship between leisure and income has been postulated (Appendix 2). In this relationship the demand for leisure is related to income levels. This non-linear relation can be treated similarly to utility. The relation between income and leisure is defined as:

$$L_t^F + L_t^{OF} - l^L * L_t^L \geq 0 \qquad all\ t \qquad (6.9)$$

$$Y_e^L - \sum_d \eta_{dt}^L * D_{dt}^L \geq 0 \qquad all\ t \qquad (6.10)$$

$$L_t^L - \sum_d \theta_{dt}^L * D_{dt}^L \leq 0 \qquad all\ t \qquad (6.11)$$

$$\sum_d D_{dt}^L \leq 1 \qquad all\ t \qquad (6.12)$$

$$D_{dt}^L \geq 0 \qquad all\ d,\ t \qquad (6.13)$$

where l^L is inverse maximum leisure to labour ratio, Y_t^{eL} is expected income from labour, η_{dt}^Y is income associated with point d on the income/leisure curve, D_{dt}^Y are variables representing corner points on the linearized income/leisure curve, and θ_{dt}^Y is consumption of leisure level associated with the corner points on the linearized income/leisure curve.

6.3 Capital

Capital availability is one of the principal binding constraints for peasant farmers. Private capital is insufficient to finance input purchase, while banks are reluctant to invest in small-scale agriculture. In the current model, a constraint limits access to credit for non-factor input products and hired labour to US$ 500:

$$\sum_b p_{bt}^e * B_{bt} + w_t^e * L^H \leq K_t^{Wmax} \qquad (6.14)$$

where K_t^{Wmax} is the limit on working capital, B_{bt} represents the vector of non-factor inputs, and p_{bt}^e expected price for non-factor inputs.

7. PRODUCTION ACTIVITY MODULE

7.1 Production functions and technology choice

The analysis of the effectiveness of policy instruments to induce changes in the production structure at farm level requires inclusion of technology selection that takes into account agro-ecological sustainability issues. For the peasant farm household type, these issues refer to soil nutrient depletion due to a limited use of (in)organic fertilizers and to pollution of the environment due to (over)use of biocides.

In the production activity module continuous production functions are not used because they are inadequate to handle technological change. i.e. they disregard the synergistic properties of agricultural inputs, e.g. the higher nutrient uptake when water is in optimum supply (De Wit, 1992). This production ecological approach contradicts standard Cobb-Douglas type continuous production functions, where technology is considered an exogenous parameter.

From a technical point of view, most production resources are used more efficiently with increasing yield levels due to a further optimization of growing conditions. Therefore, technology should be applied in well-balanced packages of production resources, i.e. combinations of water, nutrients, biocides, labour and machinery. Such technology packages or LUSTs[18] are defined in terms of discrete output levels requiring certain combinations of inputs.

Linear programming techniques are especially suitable for modelling the choice between these discrete technology packages. One severe limitation of this approach, however, is the assumption that in the optimum technical efficiency and allocative efficiency coincide. Allocative efficiency[19], implying some possibilities for substitution, is determined by the point where the price ratios equal the marginal rates of transformation. If an n-dimensional production function could be estimated linking all relevant inputs and outputs (in terms of yield, residues, nutrient balances, etc.), this would be preferred for determining economic optima. However, the processes governing interactions between inputs and outputs, especially under constrained circumstances, are not known well enough to estimate such a function.

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[18] The term LUST was coined by the researchers working in the Atlantic Zone Programme. LUST stands for Land Use System and Technology and incorporates aspects of the natural resource base, the activities that can be undertaken using that resource base, as well as the way operations are carried out.

[19] In this context it is necessary to point out the similarities and differences between different concepts of efficiency. In some of the discussions surrounding agro-ecological sustainability efficiency is used as a criteria for evaluating systems. Efficiency concepts hinge on felt scarcity. Although technical efficiency is often erroneously equated with productivity, viz. minimized resource use in kg product per kg input, the concept refers to the degree to which actual production performance equates to potential production performance under the ceteris paribus condition. Allocative efficiency is determined by the point where the input-output price ratio equals the tangent of the production function. Ecological efficiency, a term sometimes used in discussions on agro-ecological sustainability, is part of technical efficiency, but also takes into account the consequences of resource use for remaining reserves (including pollution). Financial efficiency is the optimization of scarce resources in monetary terms, which often excludes externalities such as erosion, pollution, etc. However financial efficiency will include technical efficiency at going market prices. Economic efficiency is similar to financial efficiency except that the prices used in the optimization may reflect more than just the market.

Methodological foundations of linear programming techniques as used in production economics, e.g. lack of economies of scale, absence of multiplier effects, and price exogeneity, pose serious questions for its application in economic analysis[20].

7.2 Activity generator

In the peasant farm household model presented, LUSTs for maize, beans, plantain, and cassava, grown on one soil type were defined. For each crop five LUSTs were defined, including two actual and three alternative LUSTs. The former refer to currently used technologies, while the latter refer to technologies not yet applied in the region. Actual LUSTs have been derived from farm survey data (Jansen and Schipper, 1994) and farm accounts prepared by the Banco Nacional de Costa Rica (BNCR, 1993). Alternative LUSTs are based on expert knowledge. Since the model aims at simulating short- to medium-term changes in land use, the yields of alternative LUSTs included in the model are only slightly higher than the yields currently attained in the region. Tentative calculations with crop growth simulation models indicate that yield levels for maize of 8 ton per ha are feasible in the Atlantic Zone of Costa Rica (Kruseman *et al.*, 1994). In the alternative LUSTs, however, a yield level of 4 ton per ha is assumed (see Table 7.1). The actual yield levels for maize are 2,856 and 3,850 kg per ha under different technologies.

It is assumed that such alternative LUSTs[21] are agro-ecologically sustainable in terms of macro-nutrient (N, P and K) requirements, taking into account the inevitable losses due to leaching, denitrification, etc. In other words, nutrient reserves of the soil remain constant in the long run by application of fertilizers[22]. In actual LUSTs the level of fertilization is usually lower than the amount required to maintain soil nutrient reserves, resulting in nutrient depletion. In some situations, however, the actual level of fertilization exceeds withdrawal by the crop and inevitable losses, e.g. the amount of Nitrogen applied to plantain. Such situations will result in undesirable pollution of the environment.

Biocide use is reduced as much as possible in the alternative LUSTs by using improved application methods. However, in certain situations (beans and plantain) biocide use in alternative LUSTs is higher than in actual LUSTs. It is assumed that in these crops the low actual input results in reduced yields. It should be noted that the denominator of biocide use (kg active ingredient per ha) is ambiguous and insufficient to determine the eco-toxicological impact of biocides (Kruseman *et al.*, 1994). This means that the eco-toxicological impact of LUSTs with a high biocide input in terms of kg active ingredient per ha can be less than that of LUSTs with a low biocide input.

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[20] Several modifications have been introduced into linear programming to account for a non-linear objective function (quadratic programming), separable inputs (integer programming), risk analysis (stochastic programming) and multi-period analysis (recursive programming), but their applicability is limited because of difficulties to find efficient algorithms for solving the models (Romero & Rehman, 1989). It is possible to address the problem of non-linearity through simulation with linear segments approaching a continuous function.

[21] The agronomical challenge in the definition of alternative LUSTs can be found in the exploration of the minimum requirements of production factors to attain a technically feasible yield level.

[22] It is assumed that 60% of Nitrogen and Potassium applied, is removed from the field with the harvest. For Phosphate this is 30%, taking into account the Phosphate fixation capacity of the soils in the Atlantic Zone.

Labour and machinery requirements are defined on an annual basis for both actual and alternative LUSTs. Due to a higher degree of mechanization, the annual labour requirements in alternative LUSTs are generally lower than in the actual LUSTs. Substitution of labour for biocides and machinery is allowed in alternative LUSTs, particularly for weeding practices and application of fertilizers. Material inputs include poles and sacks.

Table 7.1 In- and output coefficients for actual and alternative LUSTs. MAI=maize, BEA=beans, CAS=cassava, PLA=plantain. A1, A2 = actual LUSTs. F1, F2, F3 = alternative LUSTs.

LUST code	fertilizer (kg/ha) N	P	K	biocide (kg ai/ha)	material inputs (u/ha)	machinery (mh/ha)	labour (mnh/ha)	yield (kg/ha)
MAI.A1	50	10	6	1.2	0	3	182	3850
MAI.A2	40	8	4	1	0	0.2	250	2856
MAI.F1	86	26	23	1.1	0	15	96	4000
MAI.F2	86	26	23	0.6	0	13	154	4000
MAI.F3	86	26	23	1.1	0	6	177	4000
BEA.A1	15	45	15	0.6	0	3	188	1150
BEA.A2	15	45	15	0.6	0	0	435	1150
BEA.F1	54	20	47	4	0	6	164	1500
BEA.F2	54	20	47	2	0	6	184	1500
BEA.F3	46	18	41	2	0	0	241	1300
CAS.A1	14	18	12	2.5	0	5	455	10000
CAS.A2	0	0	0	1.9	0	15	357	6727
CAS.F1	40	18	62	2	0	10	275	12500
CAS.F2	40	18	62	2	0	7	302	12500
CAS.F3	40	20	62	2	0	2	418	10500
PLA.A1	139	31	20	4	2	6	487	9000
PLA.A2	77	10	11	1.5	2	3	362	7924
PLA.F1	46	9	118	5.8	2	5	593	12500
PLA.F2	46	9	118	5.2	2	5	653	12500
PLA.F3	37	7	94	5.8	2	0	640	10000

Source : elaborated by DLV team, making use of AZP estimates
Notes: ai refers to active ingredients, u refers to units, mh refers to machine hours, mnh refers to manhours.

Inputs and outputs are not specified according to the periods distinguished in the model. Therefore, it is assumed that for perennial crops (plantain and cassava) biocide application and labour are evenly distributed over the two periods considered. Fertilizers, material and machinery inputs are used in the first period, while the yield of cassava is attained in the second period. The yield of plantain is distributed over two periods: 40% of the yield in Table 7.1 is attained in the first period and 60% in the second period.

7.3 Input balances

In addition to land and labour, non-factor inputs are needed for the activities. The input requirements must be met by input availability:

$$B_{bt} - \sum_j \sum_v \sum_s b_{bjsvt} * W_{jsvt} \geq 0 \qquad all\ t,\ b \qquad (7.1)$$

$$B_{bt} \geq 0 \qquad all\ t,\ b \qquad (7.2)$$

where B_{bt} are non-factor inputs and b_{bjsvt} are non-factor input requirements for activities W_{jsvt}.

The activities are linked to commodities through their yield coefficients:

$$Q_{jt} - \sum_s \sum_v y_{jsvt} * W_{jsvt} \leq 0 \qquad all\ j,\ t \qquad (7.3)$$

$$Q_{jt} \geq 0 \qquad all\ j,\ t \qquad (7.4)$$

where Q_{jt} is the production volume of commodity j in period t, and y_{jsvt} is the yield of commodity j with technology s in production stage v and period t.

8. THE PRODUCTION STRUCTURE ADJUSTMENT MODULE

8.1 The need for an adjustment module

The modelling approach developed for the specification of the production structure requires a specific procedure to estimate farmers decisions with respect to cultivated area and technology selection. Therefore, first the optimal production structure is calculated with the linear programming model, using expected prices. Next, the production structure is adjusted to account for the outcomes of the simulation procedure.

Linear programming solutions, however, do not properly reflect actual farm household decisions, indicating incomplete specification of the objective function of the farmer. The present model only accounts for utility optimization, while risk motives and adjustment costs for modification in cropping pattern are not yet included.

The main reason for the impossibility to further specify the objective function of the farm household was lack of accurate and complete data on the outcome of the decision-making process. If such information had existed, a goal weighing procedure could have been used (see Section 3.3). Alternatively, a production structure adjustment module was developed to account for differences between the actual production structure and the optimal structure as calculated by linear programming.

An additional step in the present modelling approach is the differentiation between decisions on production structure and those on allocation of labour, technology choice and consumption. The justification of this iterative procedure is the *ex-ante* nature of decisions on production structure, i.e. farmers face unknown markets and prices. Once the production structure is determined, adjustments in technology and labour allocation are possible on the basis of differences between actual and expected prices. This means that in this last step the simulated production structure and a set of actual prices is used to calculate labour allocation and consumption decisions.

8.2 Adjustment module

The module is adapted from Nerlovian type agricultural response analysis (Nerlove, 1958, 1979; Askari and Cummings, 1976). Although this method is blunt[23], it does allow the modelling of farm household response in a data-scarce environment. The adjustment module in its adapted form results in a so-called simulated production structure:

$$W_t = W_{t-1} + \gamma * (W_t^D - W_{t-1}) \qquad (8.1)$$

[23] The method used in this case is crude in the sense that it does not differentiate between different crops with regard to the adjustment coefficients.

where γ is the production structure adjustment coefficient, W_t is the vector representing the simulated production structure in period t, W_{t-1} is the vector representing the actual production structure in period $t-1$, W_t^D is the vector representing the optimal production structure obtained with the linear programming model for period t.

Both optimization steps (the production structure and the allocation optimization model) use the same procedure to maximize utility, but essentially differ in the price set. This reflects also two different moments in the decision-making of the farmer. First, decisions are taken with respect to the selected activities (LUSTs) based on expected prices, while later on techniques of production are determined based on actual prices. An important difference is that the production structure at that moment is no longer a set of variables, but a given parameter.

The model is calibrated using time series of prices and an initial production structure of the peasant household. The model is run for a series of consecutive years in which for each run, i.e. each year, the set of expected prices is changed according to exogenous changes. The area of perennials in the field is modified according to the decisions taken in the preceding period.

In each period, the simulated production structure is the result of the adjustment of the production structure from the preceding period by some fraction γ of the difference between the optimal production structure and the production structure in the preceding period, a shown in equation (8.1). The parameter γ is a constant, called the production structure adjustment coefficient. This coefficient theoretically represents the effect of adjustment costs and time lags not accounted for in the model. These adjustment costs include the farm household's perception of the risk of adapting its production structure. Peasants are, to a fair degree, risk aversive and will not adapt their production structure as rapidly as the changes in the socio-economic environment would seem to indicate (Bardhan, 1980; Binswanger, 1980; Hazell, 1982; Pope, 1982).

The model was calibrated on the basis of data from the 1982-1992 period using different values for the production structure adjustment coefficient. One would expect its value somewhere in the middle between the extremes of 0, e.g. no adaption of the production structure under changing circumstances, and 1, e.g. full and immediate adaption. Data on the actual production structure are lacking for most years, hence statistical estimates of the best fit for different values of the production structure adjustment coefficient cannot be made. By trial and error, a production structure adjustment coefficient of 0.6 was found to give fair results with respect to long-term changes in the production structure. The model results were in line with the existing point data as well as with sector information on a restricted number of crops[24].

Table 8.1 represents the results of equation (8.1) , based on expected prices and an area adjustment coefficient of 0.6. These results show that a shift occurs in production structure from maize towards cassava. The latter is a traditional food crop as well as a non-traditional export crop that does not require high technology levels, making it relatively easy for small farmers to adopt. Beans first show an increase followed by a decrease, while for plantain the opposite holds. This can be explained by changes in the net margins of these crops which resulted in different points of allocative efficiency.

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[24] For lack of a second independent data set the model could not be validated.

The model results (Table 8.1) indicate that increasingly alternative LUSTs, especially cassava LUSTs are selected. This adoption of new technologies is, however, based on technical criteria and does not take into account access to extension services or information about these technologies. This implies that, in reality, adoption will take place at a slower rate, due to imperfect information and extension.

Table 8.1 Land use activities 1982-1992 (in ha) calculated with the model using a production structure adjustment coefficient of 0.6 and expected prices.

activities	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
maize	3.60	3.36	3.22	2.33	2.33	2.04	2.43	2.66	2.60	1.66	1.09
beans	0.93	1.00	1.07	1.84	2.30	2.58	2.28	2.15	1.54	1.17	0.95
cassava	0.90	0.74	1.05	1.57	1.81	1.98	2.41	2.78	3.54	4.97	5.94
plantain	1.75	1.14	1.08	1.12	0.98	1.11	1.26	1.38	1.95	2.37	2.62
Total area	7.18	6.23	6.42	6.87	7.42	7.72	8.38	8.97	9.63	10.17	10.60
Actual LUSTs	7.04	5.85	5.19	4.71	4.95	4.82	4.83	4.87	4.18	3.16	2.76
Alternative LUSTs	0.12	0.20	0.73	1.38	1.70	1.91	2.37	2.76	3.53	4.66	5.22
% Alternative LUSTs in total area	1.71	3.18	11.31	20.10	22.87	24.78	28.27	30.76	36.63	45.81	49.28

9. EFFECTIVENESS OF POLICY INSTRUMENTS

9.1 Regional objectives and derived policy instruments

Two important development regional objectives were identified earlier for the Atlantic Zone of Costa Rica (Kruseman *et al.*, 1994): (i) improvement of the competitiveness of agricultural production under trade liberalization, and (ii) improved natural resource management (see Section 1.2).

These rather general regional objectives have to be made explicit for operationalization in the model. The objectives have been translated into four goal indicators at the farm household level, the first two serving as indirect indicators for improved competitiveness, the latter two indicative for natural resource management:

1. Increased income and utility to improve the living standard of the peasant farmers
2. Increased plantain and cassava production, because of the export possibilities for both commodities
3. Reduced biocide use, because of their eco-toxicological impact on the environment
4. Increased fertilizer use as a proxy for reduced nutrient depletion, since in general, fertilizer applications at the peasant household level are lower than the sum of the macro-nutrients removed in crop harvest and the inevitable nutrient losses.

To attain these goals, several types of policy variables are conceivable, price instruments as well as improvement of extension facilities or infrastructure networks. In this study the effectiveness of six price instruments have been determined: (i) general output prices of agricultural products, (ii) fertilizer prices, (iii) biocide prices, (iv) transaction costs, (v) wage rates and (iv) prices of industrial consumer goods. The latter are important because they compete with agricultural produce for farm household expenditures (see Chapter 5). The general output prices refer to a price change of all agricultural products at the same time. Export taxes and import tariffs are not explicitly taken into account to determine the effectiveness of policy instruments, although they may indirectly affect input and output prices.

9.2 Response multipliers

The principle of the price instruments can be represented by a chain reaction: price modifications induce adjustments in the production structure which in turn induce changes in the (factor and non-factor) input demand and in marketed volumes and consumption. To calculate the effect of a particular price change, the model has been run twice. First for a base year without change and then again with a 1% change in price included. The differences in the model results are used to calculate response multipliers, which resemble price elasticities[25] (Singh *et al.*, 1986):

[25] response multipliers resemble elasticities, but differ in the sense that they are calculated with linear programming techniques for a specified range of policy change. Hence, they do not correspond to the first order Kuhn-Tucker conditions calculated on basis of a derived Lagrangean equation.

$$\epsilon_{\Lambda_m}^{\rho_\rho} = \frac{d\Lambda_m}{d\rho_\rho} * \frac{\rho_\rho}{\Lambda_m} \tag{9.1}$$

$$\frac{d\Lambda_m}{d\rho_\rho} = \frac{\delta\Lambda_m}{\delta\rho_\rho} + \frac{\delta\Lambda_m}{\delta U} * \frac{\delta U}{\delta\rho_\rho} \tag{9.2}$$

where Λ_m is the relevant indicator (i.e. cultivated area, income, utility, fertilizer use, biocide use), ρ_ρ the relevant policy measure (i.e. output prices, input prices, transaction costs, wage rates, consumer prices) and ϵ_Λ^ρ the response multiplier of the impact ρ on indicator m for a specified range of ρ.

The first term of the right hand side in equation (9.2) reflects the standard result of production theory, which implies that changing prices lead to changing levels of income and factor use (e.g. fertilizer use). The second term of the right hand side includes the direct effect of price change on household expenditures and explains the positive impact on the utility level. The total effect may be positive or negative, depending on the balance between production and consumption decisions.

The response multipliers are defined as ratios, valid for price changes to about 15% in either direction. For larger price changes, the independence of the reactions is lost, since such changes may induce other price changes through market linkages (Bardhan, 1980). The response multipliers refer to the short term, since the production structure adjustment coefficient is used, which dampens reactions to changes in prices.

In this way, response multipliers for land use, i.e. the adjustment of actual LUSTs to alternative LUSTs at the farm level, and multipliers for certain regional goal indicators can be derived for the six distinguished price instruments.

In Tables 9.1 and 9.2 response multipliers for land use and goal indicators, respectively are presented. The calculations with the model only refer to the 1984/85 period, using the set of expected prices for the production optimization and the set of actual prices for the labour allocation and consumption decisions module. The results illustrate the type of information generated by the model.

Price instruments can induce three types of reactions which may occur simultaneously: (1) change in cultivated area; (2) change in cultivated crops; and (3) change in technology, in terms of substitution of actual for alternative LUSTs. The latter occurs when elasticities of actual and alternative LUSTs have opposite signs and are not close to zero. This substitution may occur within a crop, but it is also possible that an actual LUST of crop A is substituted for an alternative LUST of crop B. This latter substitution does not necessarily have a positive effect on agro-ecological sustainability indicators, because the biocide and fertilizer requirements of alternative LUSTs of crop B may be higher than those of actual LUSTs of crop A. Table 9.1 shows the effect of various price instruments on cultivated area, cultivated crops and technology used, and Table 9.2 illustrates the effect of the price instruments on income and sustainability indicators.

With respect to the changes in cultivated crops, it can be observed that beans and cassava react more strongly to price changes than maize and plantain. This may be explained by the low net returns for beans and cassava.

An increase in *output prices* results in a decrease in cultivated area. In traditional economics such a decrease in cultivated area would be denoted as a perverse price reaction, in the case of peasant agriculture with utility maximization it accounts for rational behaviour, because leisure is included in the utility function (De Janvry *et al.*, 1991). While there is a positive effect on income related indicators, sustainability indicators hardly change. This can be explained by the substitution of actual for alternative LUSTs, the latter with similar or higher biocide and fertilizer requirement.

Table 9.1 Effects of various price instruments, in terms of response multipliers[1], on cultivated area per crop and total, and substitution of actual LUSTs by alternative LUSTs, calculated with the model for the base period 1984/85.

	output price[2]	fertilizer price	biocide price	transaction costs	wage rate	price industrial goods
maize	0.00	1.66	-7.53	0.00	0.00	0.00
beans	-1.75	-3.43	20.31	1.02	-0.34	0.38
cassava	1.13	-1.60	-0.60	-0.70	0.22	-0.26
plantain	0.00	0.00	0.00	0.00	0.00	0.00
cultivated area (total)	-0.10	0.01	-0.52	-0.06	-0.02	0.02
actual LUSTs	-0.35	0.35	-0.47	0.21	-0.07	0.08
alternative LUSTs	1.61	-2.29	-0.86	-1.02	0.31	-0.38

Note: 1 The response multiplier indicates the percentage change in area under the various crops for a 1% increase in price.
2 Output price change refers to a general increase in output prices and not to an increase in a single commodity price.

An increase in *biocide prices* (taxation) induces simultaneously a change in cultivated crops and a reduction in cultivated area. The overall effect is a decrease in biocide use.

Decreasing *fertilizer prices* have the strongest effect on changes in technology. The substitution of actual for alternative LUSTs has a positive effect on the agro-ecological sustainability indicators. Moreover, decreasing fertilizer prices affect income and utility positively. Therefore, changes in fertilizer prices seem to be an appropriate instrument to induce desired land use modifications.

Decrease of *transaction costs* induces substitution of actual for alternative LUSTs. This substitution has almost no effect on sustainability indicators, because the alternative LUSTs have higher biocide and fertilizer requirements than the actual LUSTs.

Wage rates do not seem to be an efficient instrument at the peasant level. There is little effect on cultivated area, cultivated crops and technology selection and even less on income and sustainability indicators. There may be two reasons for this phenomenon: (1) wages are both a cost and an income component in decision making, and (2) structural labour market constraints buffer stronger reactions, i.e. labour market access is limited. Changes in prices of industrial goods hardly induce changes in land use. Because the impact of price changes in industrial goods on income and agro-ecological sustainability indicators was negligible the response multipliers in Table 9.2 are ignored.

Table 9.2 Effects of various price instruments, in terms of response multipliers[1], on income, utility, fertilizer and biocide use, calculated with the model for the base period 1984/85.

Indicator	Output price	Fertilizer price	Biocide price	Transaction costs	Wage rate
Income	0.80	-0.21	-0.33	-0.18	0.02
Utility	0.18	-0.09	-0.08	-0.08	0.00
Fertilizer use	0.04	-0.57	0.85	-0.02	0.01
Biocide use	0.02	0.25	-1.99	-0.01	0.00

Note: 1 The response multiplier indicates the percentage change in the value of the goal indicator for a 1 % increase in price.

Tentative conclusions from the model results for the peasant farm household could be that lower fertilizer prices are associated with the attainment of two policy objectives, i.e. a positive response on income and agro-ecological sustainability indicators. At the policy level there are some limitations to reducing fertilizer prices, since government policy is aimed at abolishing input subsidies. However, world market prices for fertilizers are lower than local prices, which implies that the local prices can still be reduced as a result of trade liberalization.

9.3 Conclusions

The use of a standard farm household model allows the introduction of the concept of utility, and takes into account the linkage between production and consumption decisions. The use of linear programming enables the incorporation of agro-ecological data, without having to specify continuous production functions. It also permits incorporation of price expectations. The use of the production structure adjustment module facilitates linking of linear programming results to actual farm household decision making. The approach is well adapted for use in data-scarce environments[26], characteristic for many developing countries. However, the present, illustrative model can be improved in several ways:

1. identification of more appropriate indicators for regional objectives;
2. definition of more specific agro-technical input-output coefficients, which include desegregated labour patterns, and appropriate agro-ecological sustainability indicators;
3. specification of more detailed empirical evidence with respect to decision making on labour use and leisure;
4. further specification of a crop specific production structure adjustment coefficient;
5. inclusion of other objectives of the farmer in the model, e.g. bio-physical risk;
6. inclusion of modules simulating the interaction between the farm household and factor (labour and capital) markets.

[26] Although models tend to require a lot of information because so many relations are involved, the modular approach allows information from many different sources to be used.

In the present model production activities are defined in terms of one-year periods, not taking into account seasonality. Incorporation of nutrient balances and improvement of the measurement of the impact of biocides on the environment is needed. An activity generator that can calculate input-output coefficients for second best options in a technical sense may improve the search for allocatively efficient solutions, which may or may not be sustainable.

The labour-leisure relation in the present model is hypothetical, a small data set relating leisure to income levels will make it possible to calculate the utility of leisure in relation to the consumption of commodities.

When farm surveys are available, and tentative multiple objectives can be identified, it may be possible to use a goal-weighing procedure to calculate the simulated production structure. If either is missing, or if it does not yield unambiguous results, the production structure adjustment module will remain necessary. It is, however, likely that the adjustment coefficients for different crops or types of crops will vary.

The land and capital markets have been excluded from the present analysis, and need to be incorporated just as the labour market was. Inclusion of static factor market modules is a first step. By linking the farm household modelling approach to a regional model, interactions between farm household response and changes in the socio-economic environment can be illustrated. Often aggregate reactions dampen initial micro-level response.

The results indicate that the policy instruments analyzed differ in the effectiveness to attain certain policy goals. The presented farm household modelling approach can be applied to other farm types, and subsequently the results for the various farm types should be aggregated. The next step in the identification of options for sustainable land use is the linkage of results derived from explorative studies and the results of farm household models, to elucidate whether regional aims can be realized with the price instruments investigated. In this way the scope for policy-making can be sketched, including the required instruments to arrive at desirable situations.

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Appendix 1: Specification of the farm household model

```
**********************************************
*MODEL FOR PEASANT FARM IN COSTA RICA
*VERSION 2.7 PART A          22/02/94
*PRODUCTION STRUCTURE OPTIMIZATION
*CALCULATION OF LONG TERM EQUILIBRIUM OUTPUT (NERLOVE)
*USING A NEGATIVE EXPONENTIAL UTILITY FUNCTION
*THE MODEL INCLUDES LEISURE
*OMP modelling language
**********************************************
SCENARIO = PEASANT
MAXIMIZE
**********************************************
*       DECLARATION OF INDICES
**********************************************
*
* variable to be used as output in report:
* N means not to be used as output, OC (crops) and O (general) are to be
* used as output.
SET = OUT  : OC,NO,O
*
* crops:
* File containing the crops to be incorporated as options for the farm plan
* SET = CRP ,F=EXIST.DIF   ,L=1
SET = CRP  : MAI,BEA,CAS,PLA
*
* year of analysis:
* Since the model works with price series, the year to be analysed has to be
* entered
SET = YR  ,F=YEAR.DIF    ,C=1
*
* production techniques:
* There are different production techniques and levels possible (technology
* part of a LUST), defined as actual 1, 2 and future 1, 2, 3.
SET = PT  :A1,A2,F1,F2,F3
*
* periods:
* The model is based on a two year optimization to account for perennial
* crops, which may be in the field at the beginning of a run. SET=PER refers to
* the time periods per se, while SET=INF refers to the harvest period of a crop.
SET = PER  :ONE,TWO
SET = INF  :ON,TW
*
* inputs:
* There are factor (labour=L, land=A, capital=C and knowledge=E), non-factor=N
* (fertilizers, biocides, materials) and service (agricultural machinery)
* inputs. Capital and knowledge are excluded in this version of thye model
* since extension services are not considered a variable at this point in model
* development. A simple capital constraint is used, instead of a full fledged
* credit module.
SET = I   :L,G,N
* property relation to factor input:
* Inputs can be owned=O or rented, hired, etc (= H).
SET = OWN  :OW,H
* type of input:
* Further specification of the inputs:NF=on-farm labour, FF=off farm labour,
* LE=leisure, LU=involuntary unemployment; FN=nitrogen fertilizer, FP=phosphate
* fertilizer, FK= potassium fertilizer; AI=active ingredients of biocides; MA=
* materials; MS=agricultural machinery by machine hours.
```

```
SET = TY1 :NF,FF,LE,LU,FN,FP,FK,AI,MA,MS
*
* type of output volume:
* Agricultural production can be consumed at home QF or sold in the market QM.
* Agricultural produce can also be bought for consumption purposes MM.
SET = TY2 :QF,QM,MM
* expected or actual volume:
* This refers to whether actual or expected prices are used in the calculation.
SET = XA  :X,A
*
* consumption category:
* There are a number of consumption categories, namely agricultural produce,
* other food, non-food or industrial products, and leisure. These categories
* are found in a file.
SET = CCAT:MAI,BEA,CAS,PLA,LEI,AGR,IND
*
* dummy sets:
* All variables are constructed in terms of a name and five sets, for output
* technical purposes. Where necessary a dummy set is added.
SET = D   :Z,Y
*goal activities
SET = GOALS :INCOME,LABOUR,UTIL
*utility function steps
SET = UF ,F=XUFUNC.DIF           ,L=1
*informative rows
SET = QUE: QNPK, QAI, VOLQ, VOLC, VOLM
*expendible income dummies
SET = YF ,F=YFUNC.DIF            ,L=1
*leisure income relationship
SET = LF , F=LFUNC.DIF           ,L=1
************************************************
*       DECLARATION OF RELATIONS
************************************************

* feasible crop and field combinations
* The set INF indicates in which period a crop is harvested, this implies
* that certain combinations of INF and PER cannot exist for specifies crops.
REL=CRI  ,S=CRP(&).PT(&).INF(&).PER(&),  DATA=EKZIST

* The set OUT is used to define the type of output, all relationships that
* include OUT(&) define this aspect.
REL=CO   ,S=CRACT.OUT(&),              DATA=CO

* feasible goal:
* This relationship specifies which goals are feasible in the model. The fact
* that more than one model is used in the excercise makes this necessary.
REL=GL   ,S=OUT(&).XA(&).GOALS(&).PER(&),      DATA=GOALZ

* dummy: this relationship defines the dummy set where applicable
REL=D    ,S=D(&),                    DATA=DUMMY

* feasible input combinations
* As can be seen above in the set structure there are a large number of
* illogical combinations possible with regard to inputs: the following
* relations get rid of these infeasabilities.
REL=INO  ,S=INP.OUT(&),                DATA=INO
REL=RINP ,S=I(&).OWN(&).TY1(&),          DATA=RINP

* feasible volume combinations:
* this relationship defines both output type and whether the model deals with
* expected or actual volumes.
```

```
REL=V      ,S=VOL.OUT(&).XA(&),           DATA=V
REL=TYT    ,S=TY2(&).CCAT(&),             DATA=TYT

* feasible consumption and utility combinations
* This relationship defines feasible combinations of output type, consumption
* category, etc. for consumption and utility calculations.
REL=CU   ,S=OUT(&).XA(&).CCAT(&).PER(&).UF(&),  DATA=CU
REL=CU2  ,S=OUT(&).XA(&).CCAT(&).PER(&),        DATA=CU2

* perrenials
* the two period model refers to perennials, not all crops are perennials.
REL=PER,S=PERBAL.CRP(&).PT(&),                  DATA=PERBAL

* relation to exclude labour from non-factor inputs
REL=LGN  ,S=ICTOT.TY1(&)     ,DATA=LGN

*************************************************
*        DECLARATION OF VARIABLES
*************************************************
* goal activities
X = GCT.OUT(&).XA(&).GOALS(&).PER(&).D(&)=C   $/GOAL/   >/MIN/   </MAX/
* crop activities
X = CRACT.OUT(&).CRP(&).PT(&).INF(&).PER(&)=C
* inputs
X = INP.OUT(&).I(&).OWN(&).TY1(&).PER(&)=C
*  crop home consumption and market supply/demand
X=VOL.OUT(&).XA(&).TY2(&).CCAT(&).PER(&)=C
*  household consumption
X=C.OUT(&).XA(&).CCAT(&).PER(&).T   =C
*   utility variables based on Chapter 8 of Norton & Hazell
X=U.OUT(&).XA(&).CCAT(&).PER(&).UF(&)=C
* informative variables
X=INF.O.X.QT.QUE(&).ONE   =C
* expendable income variables based on Chapter 8 of Norton & Hazell
X=YEXPB.PER(&).YF(&)   =C
* leisure dummy variables for income leidsure relationship
X=LEIF.PER(&).LF(&)   =C


*************************************************
*        DECLARATION OF CONSTRAINTS
*************************************************
*
*        AREA BALANCES
*
* area balance for farm see equation 6.1
* In each year the area under crops may not exceed the total area
C = ARCULT.PER(&)  =  + /LANDINP/ * CRACT.OC.CRP(S&).PT(S&).INF(S&).PER(&)
               < /FARMAREA/

* area balance for perrenials see equation 6.2
* A perrenial harvested in period one, must have been sown in the previous
* period. Similarly a perrenial harvested in period two must have been sown
* in period one.
C = PERREN.CRP(&).PT(&)  =  + CRACT.OC.CRP(&).PT(&).ON.ONE  - /DYNAMO/  < 0
C = PERBAL.CRP(&).PT(&)  =  + CRACT.OC.CRP(&).PT(&).TW.TWO
                    - CRACT.OC.CRP(&).PT(&).TW.ONE  < 0

* maximum areas for crop activities
* This constraint sets a limit on the area for different crops, ideally this
```

```
* constraint is excluded but may be necessary to avoid concentration in  a
* single crop.
C = MAXAR.CRP(&).PT(&).INF(&).PER(&)  =    + CRACT.OC.CRP(&).PT(&).INF(&).PER(&)
                                    - /MAXAREA/ < 0
*
*
*          LABOUR BALANCES
*
* family labour availability see equation 6.4
* The amount of labour used for both agriculture and off farm activities
* may not exceed the family labour availability.
C = FLAB.PER(&)  =  + INP.OUT(S&).L.OW.TY1(S&).PER(&)  < /LABAV/

* off farm employment limitation see equation 6.5
* This constraint sets a limit on off farm employment. In the banana plantations
* contract labour is used for three months periods, making a limitation
* acceptable.
C = OFFLAB.PER(&)  =  + INP.OUT(S&).L.OW.FF.PER(&)  < /OFFLIMIT/

* hired labour constraint see equation 6.6
* This constraint puts a limit on hired labour. Although neo-classical peasant
* household theory postulates perfect substitution between hiree and family
* labour, there are transaction costs involved in hired labour, namely
* supervision costs.
C = HIRLAB.PER(&)  =  + INP.OUT(S&).L.H.NF.PER(&)  < /HIRLIMIT/

* labour balances for productive activities see equation 6.7
* Labour requirements of crop activities must equal labour input by family
* and hired labour. Leisure is not only a labour catagory, but also a
* consumption category.
C = CRLAB.PER(&)  =  + /LINP/*CRACT.OC.CRP(S&).PT(S&).INF(S&).PER(&)
               - INP.OC.L.OWN(S&).NF.PER(&)   < 0
C =  LEICON.PER(&)  = INP.OUT(S&).L.OW.LE.PER(&)  - VOL.O.X.QF.LEI.PER(&)  > 0
*
*          CAPITAL BALANCES
*
* limit on investment in working capital see equation 6.14
* external non-factor and hired factor inputs rrequire working scarce capital.
C = WCAPL.PER(&)  =  + /PRICEI/*INP.OUT(S&).I(S&).H.TY1(S&).PER(&)
               < /CAPLIMIT/
*
*          INPUT BALANCES
* total non-factor and services input use see equation 7.1
* input requirements of crop activities must equal input availability.
C = ICTOT.TY1(&).PER(&)  =  + /INP/ * CRACT.OC.CRP(S&).PT(S&).INF(S&).PER(&)
                    - INP.OC.N.OWN(S&).TY1(&).PER(&)  =0
*
*          PRODUCT BALANCES
*
* production balance see equation 7.3
* The harvested produce can either be kept for home consumption QF or sold in
* the market QM.
C = PRODCRP.CRP(&).PER(&)  =  + /YIELD/ * CRACT.OC.CRP(&).PT(S&).INF(S&).PER(&)
                    - /CONS/ * VOL.O.X.QF.CCAT(S&).PER(&)
                    - /CONS/ * VOL.O.X.QM.CCAT(S&).PER(&)  > 0



*          CONSUMPTION BALANCES
*
```

```
* minimum and maximum consumption see equations 5.12 and 5.13
* There may be upper and lower bounds to consumption, while consumption is
* made up of produce produced on the farm and market bought commodities. The
* consumption data used in the utility function are on a monthly basis and per
* capita which means a correction factor has to be used.
C = XCON.CCAT(&).PER(&)  =  + C.O.X.CCAT(&).PER(&).T
                    - VOL.O.X.QF.CCAT(&).PER(&)
                    - VOL.O.X.MM.CCAT(&).PER(&)  < 0
C = XMICONS.CCAT(&).PER(&)  =  + C.O.X.CCAT(&).PER(&).T  - /CMIN/  > 0
C = XMACONS.CCAT(&).PER(&)  =  + C.O.X.CCAT(&).PER(&).T  - /CMAX/  < 0

**************************************************
*     LEISURE FUNCTIONS
**************************************************
C=LEISURE.PER(&)  =  + INP.OUT(S&).L.OW.NF.PER(&)
            + INP.OUT(S&).L.OW.FF.PER(&)
            - /PERC/ * INP.OUT(S&).L.OW.LE.PER(&)   > 0

C=LEISYA.PER(&)  =  + /LFUNC/ * LEIF.PER(&).LF(S&)
            - GCT.O.X.INCOME.PER(&).D(S&)   < 0
C=LEISYB.PER(&)  =  + LEIF.PER(&).LF(S&)   < 1
C=LEIFYC.PER(&)  =  + INP.OUT(S&).L.OW.LE.PER(&)
            - /LMAX/ * LEIF.PER(&).LF(S&)   < 0

**************************************************
*        UTILITY FUNCTIONS
**************************************************
* expected utility see equation 5.4 for the relation between UF and C, and equation 5.6
* for the convex combination constraint
* The linearized negative exponential utility function contains UF segements.
* consumption may be found on one line segment only.
C = XUF.CCAT(&).PER(&)  =  + /UFUNC/ * U.O.X.CCAT(&).PER(&).UF(S&)
                    - C.O.X.CCAT(&).PER(&).T     < 0
C = XUB.CCAT(&).PER(&)  =  + U.O.X.CCAT(&).PER(&).UF(S&)   < 1



****************************************************
*       INCOME-EXPENDITURE RELATIONSHIP
****************************************************
* expenditure levels are related to income through a curve
* the linearized function depicting this relationship contains YF segments.
* see equations 2.6, 2.7, 2.8
C = YUFA.PER(&)  =  + /YFUNC/ * YEXPB.PER(&).YF(S&)
            - GCT.O.X.INCOME.PER(&).D(S&)   < 0
C = YUFB.PER(&)  =  + YEXPB.PER(&).YF(S&)   < 1

********************************************************
*          INFORMATION FOR ELASTICITIES
* the following constraints are informative rows that give basic information
* necessary to calculate elasticities.
********************************************************
* production volume
 C = QVOL.QUE(&)  =  + INF.O.X.QT.QUE(&).ONE
            - /INFO1/ * VOL.O.X.TY2(S&).CCAT(S&).ONE
            - /INFO2/ * INP.OUT(S&).N.OWN(S&).TY1(S&).ONE   = 0
*
**************************************************
*       OBJECTIVE FUNCTIONS
**************************************************
```

```
*
* expected income see equation 2.3
* Expected (full) income is equal to gross return to agricultural activities
* plus income from labour use on and off farm; minus all factor and non-factor
* costs related to individual LUSTs and the cost of land (all land whether it
* is used or left fallow..
C = YEXPECT.PER(&) = + GCT.O.X.INCOME.PER(&).D(S&)
        - /PRICEQ/ * VOL.O.X.QM.CCAT(S&).PER(&)
        - /PRICEQ/ * VOL.O.X.QF.CCAT(S&).PER(&)
        - /PRICEI/ * INP.OUT(S&).L.OW.FF.PER(&)
        - /PRICEI/ * INP.OUT(S&).L.OW.NF.PER(&)
        + /PRICEIT/ * INP.OUT(S&).N.OWN(S&).TY1(S&).PER(&)
        + /PRICEI/ * INP.OUT(S&).L.OWN(S&).NF.PER(&)
        + /LANDCST/ < 0


* expected expenditures see equation 2.4
* Full income, corrected for expenditures, i.e. expendable full income,
* can be spend on the consumption of own farm produce, market bought
* produce.
C = EXPEXP.PER(&) = + /EXPEND/ * YEXPB.PER(&).YF(S&)
        - /PRICEQ/ * VOL.O.X.QF.CCAT(S&).PER(&)
        - /PRICEM/ * VOL.O.X.MM.CCAT(S&).PER(&) > 0

* expected utility see equation 5.4
* Expected utility is the sum of the utility of consumption of goods.
C = EXPUTIL.PER(&) = + GCT.O.X.UTIL.PER(&).D(S&)
        - /UTIL/ * U.O.X.CCAT(S&).PER(&).UF(S&) < 0

************************************************
*       DATA DEFINITION
************************************************
*
* relational data definitions
DATA=EKZIST     ,F=EXIST.DIF,  L=CRP(&).PT(&)  ,C=INF(&).PER(&)
DATA=GOALZ      ,F=RELA.DIF,   L=OUT(&).XA(&).GOALS(&).PER(&),C=RELA
DATA=CO         ,F=RELA.DIF,   L=CRACT.OUT(&)  ,C=RELA
DATA=DUMMY      ,F=RELA.DIF,   L=D(&)          ,C=RELA
DATA=INO        ,F=RELA.DIF,   L=INP.OUT(&)    ,C=RELA
DATA=RINP       ,F=RELA.DIF,   L=I(&).OWN(&)   ,C=TY1(&)
DATA=V          ,F=RELA.DIF,   L=VOL.OUT(&).XA(&),C=RELA
DATA=TYT        ,F=RELA.DIF,   L=TY2(&).CCAT(&),C=RELA
DATA=PERBAL     ,F=RELA.DIF,   L=PERBAL.CRP(&).PT(&)  ,C=RELA
DATA=CU         ,F=CU.DIF,     L=OUT(&).XA(&).CCAT(&),C=PER(&).UF(&)
DATA=CU2        ,F=CU.DIF,     L=OUT(&).XA(&).CCAT(&),C=PER(&).T
DATA=LGN        ,F=RELA.DIF,   L=ICTOT.TY1(&),    C=RELA

* limits
DATA=LABAV      ,F=LIMIT.DIF,  L=LABAV      ,C=LIMIT
DATA=OFFLIMIT   ,F=LIMIT.DIF,  L=OFFLIMIT   ,C=LIMIT
DATA=HIRLIMIT   ,F=LIMIT.DIF,  L=HIRLIMIT   ,C=LIMIT
DATA=FARMAREA   ,F=LIMIT.DIF,  L=FARMAREA   ,C=LIMIT
DATA=CAPLIMIT   ,F=LIMIT.DIF,  L=CAPLIMIT   ,C=LIMIT
DATA=MAXA       ,F=LIMIT.DIF,  L=MAXAREA    ,C=LIMIT
DATA=MAXAREA    ,S=CRP(&).PT(&).INF(&).PER(&)  ,TP=MAXA

* definition of year
DATA=YEAR       ,F=YEAR.DIF,   L=CONSTANT   ,C=YR(&)

* production structure previous period
```

```
DATA=DYNAMO2      ,F=DYNAMO2.DIF,L=CRP(&).PT(&),C=TW.ONE
DATA=DYNAMO1      ,F=DYNAMO.DIF, L=CRP(&).PT(&),C=MAX
DATA=DYNAMO       ,S=CRP(&).PT(&), TP=DYNAMO1+DYNAMO2

* constants
DATA=CCORR        ,F=CONSTANT.DIF,   L=CCORR      ,C=CONSTANT
DATA=CMINA        ,F=CONSTANT.DIF,   L=CCAT(&)    ,C=CONSTANT
DATA=CMIN         ,TP=CMINA*CCORR
DATA=CMAXA        ,F=CONSTANT.DIF,   L=CCAT(&)    ,C=MAX
DATA=CMAX         ,TP=CMAXA*CCORR
DATA=LANDYN       ,F=CONSTANT.DIF,   L=LANDYN     ,C=CONSTANT

* input use data
DATA=LANDINPZ     ,F=INOUTPUT.DIF,  L=CRP(&).PT(&),          C=G
DATA=LANDINPW     ,F=IO.DIF,        L=CRP(&).PT(&).INF(&),  C=G.PER(&)
DATA=LANDINP      ,S=CRP(&).PT(&).INF(&).PER(&)   ,TP=LANDINPW*LANDINPZ
DATA=LABINPZ      ,F=INOUTPUT.DIF,  L=CRP(&).PT(&),          C=L
DATA=LABINPW      ,F=IO.DIF,        L=CRP(&).PT(&).INF(&),  C=L.PER(&)
DATA=LINP         ,S=CRP(&).PT(&).INF(&).PER(&)   ,TP=LABINPW*LABINPZ
DATA=INPZ         ,F=INOUTPUT.DIF,  L=CRP(&).PT(&),          C=N.TY1(&)
DATA=INPW         ,F=IO.DIF,        L=CRP(&).PT(&).INF(&),  C=N.TY1(&).PER(&)
DATA=INP          ,S=TY1(&).CRP(&).PT(&).INF(&).PER(&)   ,TP=INPW*INPZ
DATA=YIELDZ       ,F=INOUTPUT.DIF,  L=CRP(&).PT(&),          C=YLD
DATA=YIELDW       ,F=IO.DIF,        L=CRP(&).PT(&).INF(&),  C=YLD.PER(&)
DATA=YIELD        ,S=CRP(&).PT(&).INF(&).PER(&)   ,TP=YIELDW*YIELDZ

* price data
DATA=PPROD        ,F=PRICE.DIF,      L=CCAT(&),         C=YR(&)
DATA=PRPRODX      ,TP=PPROD*YEAR
DATA=PRPROD       ,S=CCAT(&).PER(&).YR(M&)     ,TP=PRPRODX
DATA=TRANS1       ,F=CONSTANT.DIF,   L=TRANS1,          C=CONSTANT
DATA=TRANS2       ,F=CONSTANT.DIF,   L=CCAT(&),         C=TRANS
DATA=PRICEQ       ,S=CCAT(&).PER(&)     ,TP=PRPROD-TRANS2/TRANS1
DATA=PRICEM       ,S=CCAT(&).PER(&)     ,TP=PRPROD*TRANS1
DATA=PPLAND       ,F=PRICE.DIF,      L=G.OW.NF,         C=YR(&)
DATA=PRLANDX      ,TP=PPLAND*YEAR
DATA=PRLAND       ,S=PER(&).YR(M&)              ,TP=PRLANDX
DATA=LANDCST      ,TP=PRLAND*FARMAREA*LANDYN
DATA=PINPA        ,F=PRICE.DIF,      L=I(&).OWN(&).TY1(&),  C=YR(&)
DATA=PINPB        ,TP=PINPA*YEAR
DATA=PRICEI       ,S=I(&).OWN(&).TY1(&).PER(&).YR(M&),  TP=PINPB
DATA=PRICEIT      ,S=I(&).OWN(&).TY1(&).PER(&),         TP=PRICEI*TRANS1

* data regarding the relation between produce and consumption categories
DATA=CONS         ,F=CONS.DIF       ,L=CRP(&)     ,C=CCAT(&)

* data regarding the information needed for elasticity calculations
DATA=INFO1        ,F=INFO.DIF       ,L=QUE(&)     ,C=TY2(&).CCAT(&)
DATA=INFO2        ,F=INFO.DIF       ,L=QUE(&)     ,C=OWN(&).TY1(&)

* basic data regarding goals
DATA=GOAL         ,F=GOAL.DIF,      L=XA(&).GOALS(&).PER(&),      C=VALUE
DATA=MIN          ,F=GOAL.DIF,      L=XA(&).GOALS(&).PER(&),      C=MIN
DATA=MAX          ,F=GOAL.DIF,      L=XA(&).GOALS(&).PER(&),      C=MAX

* utility function data
DATA=UFUNC        ,F=NFUNC.DIF      ,L=UF(&),        C=CCAT(&)
DATA= UTIL        ,F=UTIL.DIF       ,L=UF(&),        C=CCAT(&)

* expendable income data
DATA=YFUNC        ,F=YFUNC.DIF      ,L=YF(&),        C=Y
```

```
DATA=EXPEND        ,F=YFUNC.DIF       ,L=YF(&),       C=EXP

* leisure function data
DATA=PERC          ,F=CONSTANT.DIF    ,L=PERC,        C=CONSTANT
DATA=LFUNC         ,F=LFUNC.DIF       ,L=LF(&),       C=Y
DATA=LMAX          ,F=LFUNC.DIF       ,L=LF(&),       C=LMAX

* report definition
REP=MODA
```

```
**********************************************
*MODEL FOR PEASANT FARM IN COSTA RICA
*VERSION 2.7 PART B          22/02/94
*CONSUMPTION OPTIMIZATION
*USING ACTUAL PRODUCTION = FUNCTION OF W^D AND W_t-1
*AND A NEGATIVE EXPONENTIAL UTILITY FUNCTION
*THE MODEL INCLUDES LEISURE
**********************************************
SCENARIO = PEASANT
MAXIMIZE
**********************************************
*       DECLARATION OF INDICES
**********************************************
*
* for explication see module A
*
SET = OUT  : OC,NO,O
SET = CRP  : MAI,BEA,CAS,PLA
SET = YR  ,F=YEAR.DIF    ,C=1
SET = PT  :A1,A2,F1,F2,F3
SET = PER  :ONE,TWO
SET = INF  :ON,TW
SET = I   :L,G,N
SET = OWN  :OW,H
SET = TY1 :NF,FF,LE,LU,FN,FP,FK,AI,MA,MS
SET = TY2 :QF,QM,MM
SET = XA  :X,A
SET = CCAT:MAI,BEA,CAS,PLA,LEI,AGR,IND
SET = D   :Z,Y
SET = GOALS :INCOME,LABOUR,UTIL
SET = UF ,F=XUFUNC.DIF          ,L=1
SET = QUE: QNPK, QAI, VOLQ, VOLC, VOLM
SET = YF ,F=YFUNC.DIF           ,L=1
SET = LF , F=LFUNC.DIF          ,L=1

**********************************************
*       DECLARATION OF RELATIONS
**********************************************

REL=CO    ,S=CRACT.OUT(&),                DATA=CO
REL=GL    ,S=OUT(&).XA(&).GOALS(&).PER(&),      DATA=GOALZ
REL=D     ,S=D(&),                        DATA=DUMMY
REL=PERO  ,S=PER(&),                      DATA=PERO
REL=INO   ,S=INP.OUT(&),                  DATA=INO
REL=RINP  ,S=I(&).OWN(&).TY1(&),          DATA=RINP
REL=V     ,S=VOL.OUT(&).XA(&),            DATA=V
REL=TYT   ,S=TY2(&).CCAT(&),              DATA=TYT
REL=CU    ,S=OUT(&).XA(&).CCAT(&).PER(&).UF(&),  DATA=CU
REL=CU2   ,S=OUT(&).XA(&).CCAT(&).PER(&),        DATA=CU2
REL=LGN   ,S=ICTOT.TY1(&)      ,DATA=LGN

**********************************************
*       DECLARATION OF VARIABLES
**********************************************
X = GCT.OUT(&).XA(&).GOALS(&).PER(&).D(&)=C   $/GOAL/  >/MIN/  </MAX/
X = INP.OUT(&).I(&).OWN(&).TY1(&).PER(&)=C
X=VOL.OUT(&).XA(&).TY2(&).CCAT(&).PER(&)=C
X=C.OUT(&).XA(&).CCAT(&).PER(&).T  =C
X=U.OUT(&).XA(&).CCAT(&).PER(&).UF(&)=C
X=INF.O.A.QT.QUE(&).ONE  =C
X=YEXPB.PER(&).YF(&)  =C
```

```
X=LEIF.PER(&).LF(&)  =C

************************************************
*         DECLARATION OF CONSTRAINTS
************************************************
*
*         LABOUR BALANCES
*
C = FLAB.PER(&) = + INP.OUT(S&).L.OW.TY1(S&).PER(&)  < /LABAV/
C = OFFLAB.PER(&) = + INP.OUT(S&).L.OW.FF.PER(&)  < /OFFLIMIT/
* where the hire limit in module A is set at 720 hours per annum
* it is set at 1000 in module B to allow for sufficient substitution between various
* types of labour use.
C = HIRLAB.PER(&) = + INP.OUT(S&).L.H.NF.PER(&)  < /HIRLIMIT/
C = CRLAB.PER(&) = + /LINP/ - INP.OC.L.OWN(S&).NF.PER(&)   < 0
C = LEICON.PER(&) = INP.OUT(S&).L.OW.LE.PER(&) - VOL.O.A.QF.LEI.PER(&)  > 0
*
*         INPUT BALANCES
*
C = ICTOT.TY1(&).PER(&) = + /INP/ - INP.OC.N.OWN(S&).TY1(&).PER(&)  =0
*
*         PRODUCT BALANCES
*
C = PRODCRP.CRP(&).PER(&) = + /YIELD/ - /CONS/ * VOL.O.A.QF.CCAT(S&).PER(&)
                    - /CONS/ * VOL.O.A.QM.CCAT(S&).PER(&)  > 0
*
*          CONSUMPTION BALANCES
*
C = XCON.CCAT(&).PER(&) = + C.O.A.CCAT(&).PER(&).T
                   - VOL.O.A.QF.CCAT(&).PER(&)
                   - VOL.O.A.MM.CCAT(&).PER(&)  < 0
* C = XMICONS.CCAT(&).PER(&) = + C.O.A.CCAT(&).PER(&).T - /CMIN/ > 0
* C = XMACONS.CCAT(&).PER(&) = + C.O.A.CCAT(&).PER(&).T - /CMAX/ < 0

************************************************
*       LEISURE FUNCTIONS
************************************************
*
C=LEISURE.PER(&) = + INP.OUT(S&).L.OW.NF.PER(&)
              + INP.OUT(S&).L.OW.FF.PER(&)
              - /PERC/ * INP.OUT(S&).L.OW.LE.PER(&)  > 0

C=LEISYA.PER(&) = + /LFUNC/ * LEIF.PER(&).LF(S&)
             - GCT.O.A.INCOME.PER(&).D(S&)  < 0
C=LEISYB.PER(&) = + LEIF.PER(&).LF(S&)  < 1
C=LEIFYC.PER(&) = + INP.OUT(S&).L.OW.LE.PER(&)
             - /LMAX/ * LEIF.PER(&).LF(S&)  < 0

************************************************
*       UTILITY FUNCTIONS
************************************************
C = XUF.CCAT(&).PER(&) = + /UFUNC/ * U.O.A.CCAT(&).PER(&).UF(S&)
                    - C.O.A.CCAT(&).PER(&).T    < 0
C = XUB.CCAT(&).PER(&) = + U.O.A.CCAT(&).PER(&).UF(S&)  < 1
************************************************
*       INCOME-EXPENDITURE RELATIONSHIP
************************************************

C = YUFA.PER(&) = + /YFUNC/ * YACTB.PER(&).YF(S&)
            - GCT.O.A.INCOME.PER(&).D(S&)  < 0
C = YUFB.PER(&) = + YEXPB.PER(&).YF(S&)  < 1
```

```
*
**************************************************
*           INFORMATION FOR ELASTICITIES
**************************************************
C = QVOL.QUE(&) = + INF.O.A.QT.QUE(&).ONE
          - /INFO1/ * VOL.O.A.TY2(S&).CCAT(S&).ONE
          - /INFO2/ * INP.OUT(S&).N.OWN(S&).TY1(S&).ONE  = 0

*
**********************************************
*        OBJECTIVE FUNCTIONS
**********************************************
*
C = YACTUAL.PER(&) = + GCT.O.A.INCOME.PER(&).D(S&)
        - /PRICEQ/ * VOL.O.A.QM.CCAT(S&).PER(&)
        - /PRICEQ/ * VOL.O.A.QF.CCAT(S&).PER(&)
        - /PRICEI/ * INP.OUT(S&).L.OW.FF.PER(&)
        + /PRICEI/ * INP.OUT(S&).L.H.NF.PER(&)
        + /COSTI/ < 0

C = ACTEXP.PER(&) = + /EXPEND/ * YACTB.PER(&).YF(S&)
        - /PRICEQ/ * VOL.O.A.QF.CCAT(S&).PER(&)
        - /PRICEM/ * VOL.O.A.MM.CCAT(S&).PER(&)  > 0

C = ACTUTIL.PER(&) = + GCT.O.A.UTIL.PER(&).D(S&)
        - /UTIL/ * U.O.A.CCAT(S&).PER(&).UF(S&)  < 0

*
**********************************************
*        DATA DEFINITION
**********************************************
DATA=PERO        ,F=RELA2.DIF ,  L=PER(&)          ,C=RELA
DATA=EKZIST      ,F=EXIST.DIF,  L=CRP(&).PT(&)   ,C=INF(&).PER(&)
DATA=GOALZ       ,F=RELA2.DIF,   L=OUT(&).XA(&).GOALS(&).PER(&),  C=RELA
DATA=CO          ,F=RELA2.DIF,   L=CRACT.OUT(&)  ,C=RELA
DATA=DUMMY       ,F=RELA2.DIF,   L=D(&)            ,C=RELA
DATA=INO         ,F=RELA2.DIF,   L=INP.OUT(&)     ,C=RELA
DATA=RINP        ,F=RELA2.DIF,   L=I(&).OWN(&)    ,C=TY1(&)
DATA=V           ,F=RELA2.DIF,   L=VOL.OUT(&).XA(&),C=RELA
DATA=TYT         ,F=RELA2.DIF,   L=TY2(&).CCAT(&),C=RELA
DATA=PERBAL      ,F=RELA2.DIF,   L=PERBAL.CRP(&).PT(&)  ,C=RELA
DATA=CU          ,F=CU2.DIF,     L=OUT(&).XA(&).CCAT(&),C=PER(&).UF(&)
DATA=CU2         ,F=CU2.DIF,     L=OUT(&).XA(&).CCAT(&),C=PER(&).T
DATA=LGN         ,F=RELA2.DIF,   L=ICTOT.TY1(&),     C=RELA
DATA=LABAV       ,F=LIMIT.DIF,   L=LABAV       ,C=LIMIT
DATA=OFFLIMIT    ,F=LIMIT.DIF,   L=OFFLIMIT   ,C=LIMIT
DATA=HIRLIMIT    ,F=LIMIT.DIF,   L=HIRLIM   ,C=LIMIT
***********************************************************************
* calculation of production structure from the long term equilibrium
* see equation 8.1
***********************************************************************
DATA=LAMBDA      ,F=CONSTANT.DIF, L=LAMBDA      ,C=CONSTANT
DATA=QD          ,F=CROPS.DIF,   L=CRP(&).PT(&),  C=INF(&).PER(&)
DATA=QDH         ,S=CRP(&).PT(&).INF(&).PER(&),TP=LAMBDA*QD
DATA=QMINA       ,F=QTMIN.DIF,   L=CRP(&).PT(&),  C=INF(&).PER(&)
DATA=QMINB       ,F=QTMINB.DIF,  L=CRP(&).PT(&),  C=INF(&).PER(&)
DATA=QMIN        ,TP=QMINA*QMINB
DATA=QT          ,S=CRP(&).PT(&).INF(&).PER(&)  ,TP=LAMBDA*QMIN + QDH
OUT=QT           ,F=DYNAMO2.DIF, L=CRP(&).PT(&),   C=TW.ONE
OUT=QT           ,F=ACTIV.PRI, L=CRP(&).PT(&).INF(&).PER(&),  C=AREA
DATA=SOW         ,F=SOW.DIF,     L=CRP(&),  C=INF(&)
DATA=QTNEO       ,S=CRP(&).PT(&).PER(&).INF(&),   TP=QT*SOW
DATA=QTNEW       ,S=CRP(&).PT(&).PER(&).INF(S&),  TP=QTNEO
```

```
OUT=QTNEW         ,F=QTMIN.DIF, L=CRP(&).PT(&), C=INF(&).PER(&)
******************************************************************************
* output of information for new run (dynamic model), dynamo2.dif and qtmin.dif
* output pof QT calculation of production structure from the long term equilibrium
******************************************************************************
DATA=YEAR         ,F=YEAR.DIF,    L=CONSTANT   ,C=YR(&)
DATA=CCORR        ,F=CONSTANT.DIF,   L=CCORR    ,C=CONSTANT
DATA=CMINA        ,F=CONSTANT.DIF,   L=CCAT(&)  ,C=CONSTANT
DATA=CMIN         ,TP=CMINA*CCORR
DATA=CMAXA        ,F=CONSTANT.DIF,   L=CCAT(&)  ,C=MAX
DATA=CMAX         ,TP=CMAXA*CCORR
DATA=LANDYN       ,F=CONSTANT.DIF,   L=LANDYN   ,C=CONSTANT
DATA=LABINPZ      ,F=INOUTPUT.DIF,   L=CRP(&).PT(&),         C=L
DATA=LABINPW      ,F=IO.DIF,         L=CRP(&).PT(&).INF(&),  C=L.PER(&)
DATA=LINPX        ,S=CRP(&).PT(&).INF(&).PER(&)   ,TP=LABINPW*LABINPZ
DATA=LINPV        ,S=CRP(&).PT(&).INF(&).PER(&),  TP=LINPX*QT
DATA=LINP         ,S=PER(&).CRP(S&).PT(S&).INF(S&),  TP=LINPV
DATA=INPZ         ,F=INOUTPUT.DIF,   L=CRP(&).PT(&),         C=N.TY1(&)
DATA=INPW         ,F=IO.DIF,         L=CRP(&).PT(&).INF(&),  C=N.TY1(&).PER(&)
DATA=INPX         ,S=TY1(&).CRP(&).PT(&).INF(&).PER(&)   ,TP=INPW*INPZ
DATA=INPV         ,S=TY1(&).CRP(&).PT(&).INF(&).PER(&),  TP=INPX*QT
DATA=INP          ,S=PER(&).TY1(&).CRP(S&).PT(S&).INF(S&).,  TP=INPV
DATA=YIELDZ       ,F=INOUTPUT.DIF,   L=CRP(&).PT(&),         C=YLD
DATA=YIELDW       ,F=IO.DIF,         L=CRP(&).PT(&).INF(&),  C=YLD.PER(&)
DATA=YIELDX       ,S=CRP(&).PT(&).INF(&).PER(&)  ,TP=YIELDW*YIELDZ
DATA=YIELDV       ,S=CRP(&).PT(&).INF(&).PER(&)  ,TP=YIELDX*QT
DATA=YIELD        ,S=PER(&).CRP(&).PT(S&).INF(S&)  ,TP=YIELDV
DATA=PPROD        ,F=PRICE1.DIF,     L=CCAT(&),      C=YR(&)
DATA=PRPRODX      ,TP=PPROD*YEAR
DATA=PRPROD       ,S=CCAT(&).PER(&).YR(M&)     ,TP=PRPRODX
DATA=TRANS1       ,F=CONSTANT.DIF,   L=TRANS1,       C=CONSTANT
DATA=TRANS2       ,F=CONSTANT.DIF,   L=CCAT(&),      C=TRANS
DATA=PRICEQ       ,S=CCAT(&).PER(&)      ,TP=PRPROD-TRANS2/TRANS1
DATA=PRICEM       ,S=CCAT(&).PER(&)      ,TP=PRPROD*TRANS1
DATA=PINPA        ,F=PRICE1.DIF,     L=I(&).OWN(&).TY1(&),  C=YR(&)
DATA=PINPB        ,TP=PINPA*YEAR
DATA=PRICEI       ,S=I(&).OWN(&).TY1(&).PER(&).YR(M&),  TP=PINPB
DATA=PRICEIT      ,S=I(&).OWN(&).TY1(&).PER(&),  TP=PRICEI*TRANS1
DATA=COSTIX       ,S=PER(&).TY1(&).I(&).OWN(&),  TP=PRICEIT*INP
DATA=COSTI        ,S=PER(&).TY1(S&).I(S&).OWN(S&),  TP=COSTIX
DATA=CONS         ,F=CONS.DIF     ,L=CRP(&)    ,C=CCAT(&)
DATA=INFO1        ,F=INFO.DIF     ,L=QUE(&)    ,C=TY2(&).CCAT(&)
DATA=INFO2        ,F=INFO.DIF     ,L=QUE(&)    ,C=OWN(&).TY1(&)
DATA=GOAL         ,F=GOAL2.DIF,      L=XA(&).GOALS(&).PER(&),     C=VALUE
DATA=MIN          ,F=GOAL2.DIF,      L=XA(&).GOALS(&).PER(&),     C=MIN
DATA=MAX          ,F=GOAL2.DIF,      L=XA(&).GOALS(&).PER(&),     C=MAX
DATA=UFUNC        ,F=NFUNC.DIF     ,L=UF(&),       C=CCAT(&)
DATA= UTIL        ,F=UTIL.DIF      ,L=UF(&),       C=CCAT(&)
DATA=YFUNC        ,F=YFUNC.DIF     ,L=YF(&),       C=Y
DATA=EXPEND       ,F=YFUNC.DIF     ,L=YF(&),       C=EXP
DATA=PERC         ,F=CONSTANT.DIF  ,L=PERC,        C=CONSTANT
DATA=LFUNC        ,F=LFUNC.DIF     ,L=LF(&),       C=Y
DATA=LMAX         ,F=LFUNC.DIF     ,L=LF(&),       C=LMAX

* report definition
REP=MODB
```

Appendix 2: Postulated leisure-income relationship

For lack of data on the leisure-income relation, the following relationship was postulated. Maximum leisure was set at 800 hours per annum, i.e. 37% of the available labour time. The relationship was assumed to be a slight S-curve (Figure A-1.2).

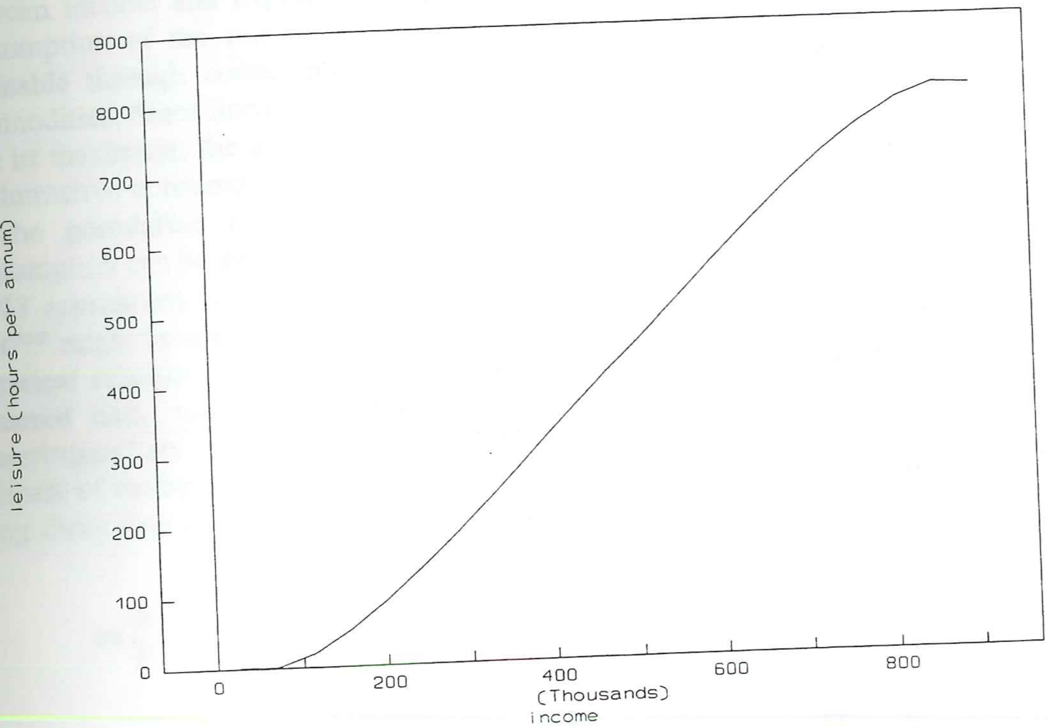

Figure A-2.1 The postulated leisure-income relationship.

Appendix 3: Methodological issues related to the expenditures module

A. Estimation technique C^{max}

Given an empirical data base estimation of C^{max} should be tested for the sensitivity to the choice of the level of $U^{\to max}/U^{max}$. As consumption increases, the marginal utility decreases, see equation (5.3); under the assumption of utility maximization an increase in income will result in a decrease in marginal consumption. The Engel curve expresses the relationship between income and expenditure levels, it indicates the relative utility derived from the consumption of the relevant commodities. The utility curve indicates the partial utility attainable through consumption of a commodity, without taking into account the other commodities. Since linear optimization techniques will find the solution for which total utility is at its maximum, the assumption, that utility of consumption can only be measured relative to alternative consumption, is met.

The postulation of a negative exponential utility function implies that maximum consumption can be derived from the asymptotic value of C for large values of Y, i.e. where $\delta C/\delta Y$ approaches zero; $\delta U/\delta C$ also approaches zero.

C^{max} might be approximated by guessing the asymptote from graphic presentation of the empirical relation between Y and C. Because it is an attempt to estimate the extremes of scattered data, mathematical and statistical techniques are not always suitable. These "guestimates" are "good judgement" instead of scientifically founded estimations. A statistical estimate of the basic parameters could be obtained by guestimating the first derivatives, and using those data in a linear regression model:

$$\ln(\frac{\delta C}{\delta Y}) = \ln\alpha * C^{max} + (-\alpha) * Y \qquad \text{(A-3.1)}$$

where $\delta C/\delta Y$ is the first derivative (slope) of the Engel curve, α^{engel} is the Engel conversion factor, C^{max} is the asymptotic value of C for $\delta C/\delta Y \Rightarrow 0$, Y is income. The mathematical model is rather sensitive to the guestimations, therefore, an alternative method has been used:

$$C^{corr} = -\alpha^{engel} * Y \qquad \text{(A-3.2)}$$

where C^{corr} is corrected consumption, i.e. $ln(1-C/C^{max})$. The results with the best fit, i.e. the highest R^2, are summarized in Table A-3.1.

Table A-3.1 Estimated parameters of equation (5.1)

	maize	beans	cassava	food	non-food
C^{max}	14.3	10.90	6.85	14.25	411.00
R^2	0.35	0.60	0.58	0.92	0.97

note: R^2 values of 0.35 and higher are acceptable

B. *Estimation technique* α_c^U

For estimation of the parameters of marginal utility, using linear regression, equation (5.3) must take on a linear form. Rearranging the equation gives:

$$C_c = \frac{\ln\phi_Y - \ln\alpha_c^U - \ln U_c^{\max} - \alpha_c^U * C_c^{\min}}{-\alpha_c^U} \qquad \text{(A-3.3)}$$

i.e. an equation that does not directly fit into a linear functional form. This seems to imply that α_c^U has to be estimated separately. U/U^{max} for any commodity or good gives the relative utility of consumption on a scale 0 to 1. The point where maximum utility is attained corresponds with the maximum consumption of good *c*. The coefficient α_c^U can be estimated by assuming that estimated maximum consumption is reached at a certain utility level, e.g. at 99.99% of the maximum attainable utility. In general, this is formulated as:

$$\alpha_c^U \approx -\frac{\ln(1-\frac{U_c^{*\max}}{U_c^{\max}})}{C_c^{\max}-C_c^{\min}} \qquad \text{(A-3.4)}$$

An additional assumption is that α_c^U is constant across income levels. This assumption is necessary because the available data do not permit estimation of α_c^U which varies across income levels. It therefore becomes necessary to test the independence of α with respect to *Y*, see Section C.

C. *Testing for independence*

An interesting aspect of the negative exponential utility function and the way it is estimated is that the coefficients of ϕ_Y estimated through linear regression must characterize the slope of the utility function, i.e. a built-in check exists, see Table A-3.2.

Table A-3.2 ϕ_Y calculations for six income categories.

	maize[1]	beans[1]	cassava[1]	food[1]	non-food[1]	ϕ_Y[2]
E1	4.15	2.06	1.95	18.20	2.78	3.69
E2	8.24	6.18	6.04	4.95	2.60	4.81
E3	2.29	0.42	0.48	1.82	2.52	1.00
E4	0.17	3.97	0.44	1.81	2.35	1.00
E5	2.39	1.17	6.22	0.09	2.17	1.00
E6	0.10	0.14	0.22	0.12	2.07	0.19

note: 1 expected slope of the utility function of good c in the equilibrium situation for income E, i.e. the result of substituting C^{min}, U^{max}, and α_c^U in equation (5.3)
2 estimated slope of the utility function of good c in the equilibrium situation for income category E, i.e. based on the regression estimate for ϕ_Y.

Independence of α from income implies a close correlation between the calculated and estimated values of ϕ_Y. For the food commodities this assumption holds more or less, but for the non-food not at all (see Table A-3.3). With values of 0.86 to 0.97, the hypothesis that α and Y are independent cannot be rejected, especially taking into consideration that the value of α for industrial goods, which is certainly not independent of Y, has affected the estimated value of ϕ_Y, which serves as bench mark in the test.

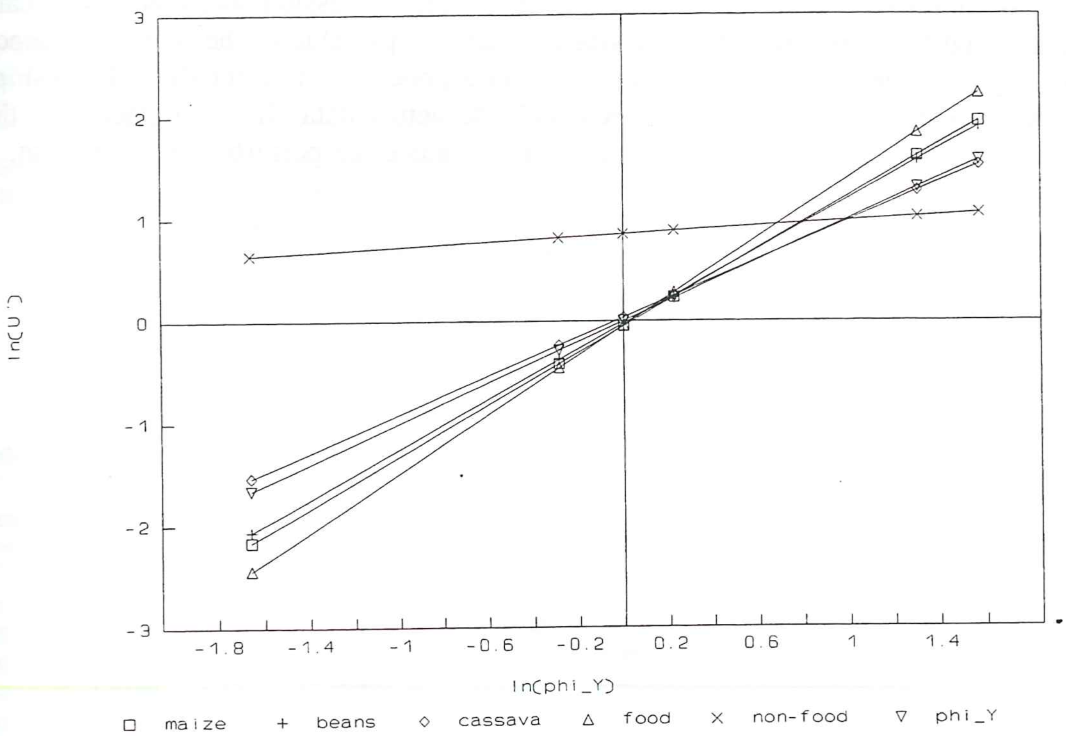

Figure A-3.1 Testing for independence of α and Y

In Figure A-3.1 the results are presented graphically. In the case of independence between α and Y the curves fitted through the data points should lie around the diagonal axis. This is the case for food commodities but not for industrial (non-food) products.

Table A-3.3 Test for independence of α and Y

variable	estimate for α^Y	standard error α^Y	beta	T-Student test	significance level of T
non-food	6.038041	1.939492	0.166887	3.113	0.0046
other food	0.878349	0.094782	0.496774	9.267	0.0000
cassava	0.931616	0.118155	0.422668	7.885	0.0000
beans	0.970268	0.088101	0.590375	11.013	0.0000
maize	0.862185	0.130034	0.355434	6.630	0.0000

D. Expendable income

Between actual income and expenditures lies a gap. This can be explained by the fact that not all expenditures are included in the consumption, especially those on durable goods as well as non-consumptive expenditures such as direct taxes, levies, etc. This implies that the income available for consumption has to be adjusted. Expendable income was postulated to be that part of income spent on consumption. On the basis of the budget data, the relation between expenditures and consumption was estimated. The relationship is not linear (higher incomes have more expenditures that are not included in the consumption), but this is not so pronounced as to warrant a log-linear relationship. Using regression analysis, significant results were found for both linear and log-linear relationships. Due to the interdependence of the data, significance in regression analysis is not a good indicator for the relationship. In Figure A5.1 both relationships are shown with the actual data. It is assumed that the combination of the two relationships is a fair estimate, since the perturbation is random.

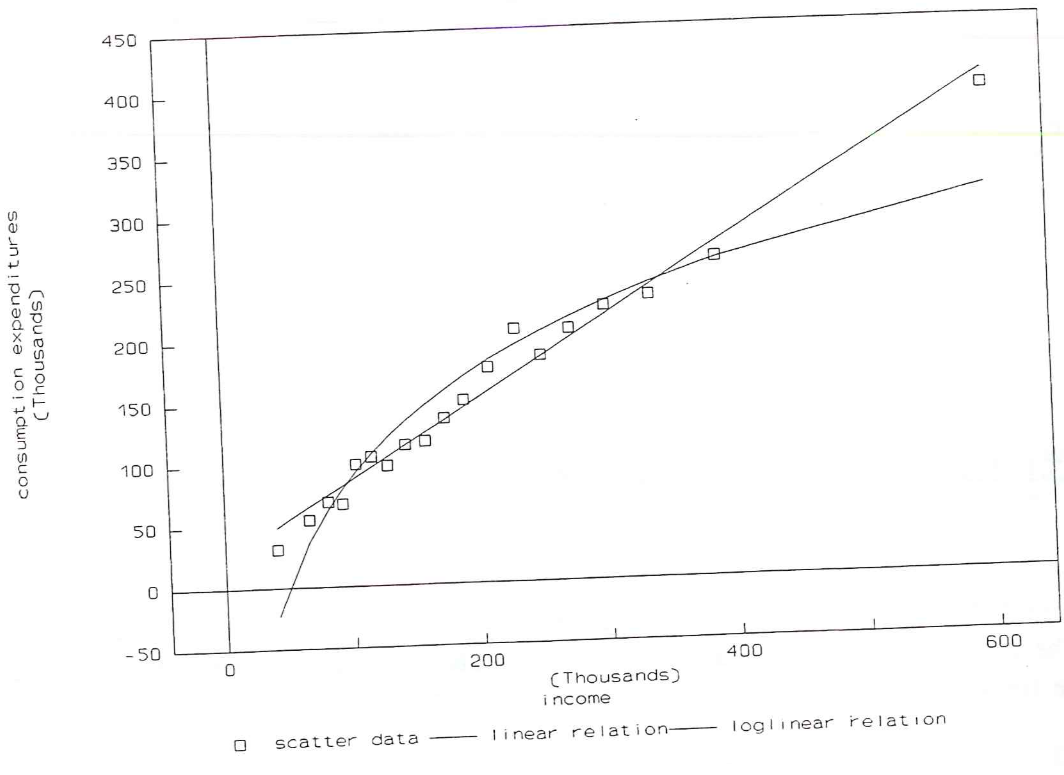

Figure A-3.2 estimated income - expenditure relationship

E. Aggregation of expenditure data

In Tables A-3.4 and A-3.5 the consumption volumes of rural households in the Atlantic Zone of Costa Rica are presented

Table A-3.4 Consumption volumes of rural households in the Atlantic Zone of Costa Rica

Three income categories: Income[1]	maize[2]	beans[2]	cassava[2]	food[3]	non-food[4]	N
Y < 2800	4.18	6.61	2.05	3.01	4.41	105
2800 < Y < 4800	6.34	7.32	3.37	5.45	8.82	107
4800 < Y < 7800	6.70	9.37	2.83	9.57	15.12	104

Source: DGEC (1992) household survey 1987/88

Notes: 1 Income per head per month in colones.

2 In kg per head per month.

3 Includes rice, plantain, meat, milk, calculated on the basis of expenditures divided by consumer price index for foodstuffs.

4 Calculated on the basis of expenditures divided by general consumer price index.

Table A-3.5 Consumption volumes of rural households in the Atlantic Zone of Costa Rica

Nineteen income categories: income[1]	maize[2]	beans[2]	cassava[2]	food[3]	non-food[4]	N
Y < 1350	4.66	5.94	1.58	0.81	1.94	20
1350 < Y < 1850	4.22	5.92	3.63	2.91	3.05	20
1850 < Y < 2200	3.30	9.85	3.76	2.98	4.26	20
2200 < Y < 2500	4.39	4.43	0.85	2.94	5.2	20
2500 < Y < 2700	5.15	6.83	0.89	5.07	6.97	21
2700 < Y < 3050	3.92	7.81	4.60	4.84	7.71	21
3050 < Y < 3400	5.08	8.06	1.79	4.78	6.74	18
3400 < Y < 3800	5.33	8.20	2.71	6.53	7.22	19
3800 < Y < 4150	8.12	6.18	2.28	5.12	9.18	22
4150 < Y < 4550	7.38	7.92	2.85	5.41	11.08	19
4550 < Y < 4950	4.98	5.47	3.59	7.67	11.43	21
4950 < Y < 5500	5.37	6.99	1.14	10.16	12.33	19
5500 < Y < 6100	5.99	8.29	2.86	9.47	16.89	20
6100 < Y < 6550	5.27	14.82	5.23	9.61	12.35	20
6550 < Y < 7250	8.30	9.55	0.75	9.09	16.85	21
7250 < Y < 7900	12.26	7.02	5.03	9.80	18.53	19
7900 < Y < 9250	6.70	10.72	3.64	10.50	18.61	20
9250 < Y < 10600	12.10	8.25	4.78	10.01	23.19	20
Y > 10600	9.49	10.89	6.66	13.05	38.16	58

Source: DGEC (1992) household survey 1987/88

Notes: 1 Income per head per month in colones.

2 In kg per head per month.

3 Includes rice, plantain, meat, milk, calculated on the basis of expenditures divided by consumer price index for foodstuffs.

4 Calculated on the basis of expenditures divided by general consumer price index.

Appendix 4: Convex combination constraint

The convex utility curve can be considered a finite number of points each representing a combination of consumption C_c and utility U_c. Since each point represents alternative choices, it is included as an activity in the model. Customarily, they are given the symbol D. The model includes activities D_{jd} associated with different consumption levels C_c. In Figure A-4.2 this relationship is presented graphically for a hypothetical curve (Figure A-4.1).

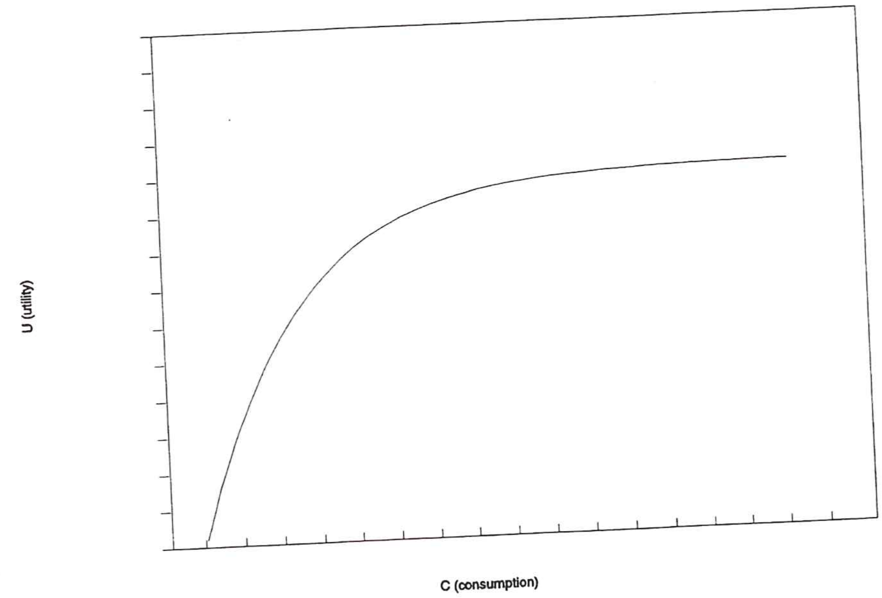

Figure A-4.1 Hypothetical utility curve

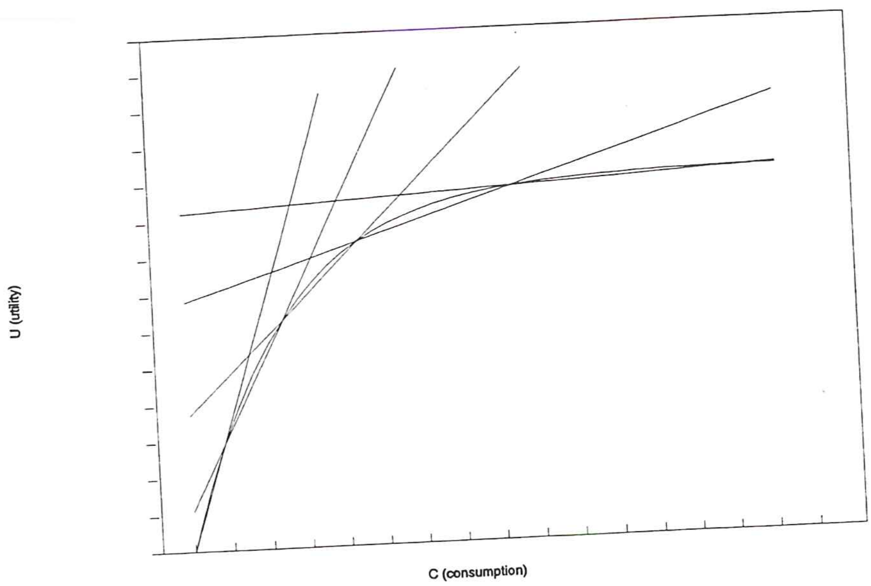

Figure A-4.2 Segments related to the convex conversion constraint