Netherlands Journal of Agricultural Science 43 (1995) 111-123

Farm household modelling for estimating the effectiveness of price instruments in land use policy

G. KRUSEMAN[1], R. RUBEN[1], H. HENGSDIJK[2] AND M.K. VAN ITTERSUM[3]

[1] Department of Development Economics, Wageningen Agricultural University, Hollandseweg 1, NL-6706 KN Wageningen, The Netherlands
[2] Research Institute for Agrobiological and Soil Fertility Research (AB-DLO), P.O. Box 14, NL-6700 AA Wageningen, The Netherlands
[3] Department of Theoretical Production Ecology, Wageningen Agricultural University, P.O. Box 430, NL-6700 AZ Wageningen, The Netherlands

Received 12 October 1994; accepted 24 February 1995

Abstract

A farm household modelling approach using linear programming is presented that integrates biophysical and socio-economic information for simulating micro-level responses to specific changes in the socio-economic environment. The linear programming model includes separate modules for prices, production activities and expenditures from which the objective function is derived. Moreover, the model comprises a production structure adjustment coefficient to account for incomplete specification of the objectives of the farmer in the objective function. The model was calibrated for one specific farm type in the Atlantic Zone of Costa Rica, a peasant household, and applied to calculate effects of several price instruments. The results, in terms of response multipliers, give an indication of the pace and direction of land use change at the micro-level as a result of (induced) change in the socio-economic environment.

Keywords: farm household model, linear programming, sustainable land use, price instruments

Introduction

For the analysis of sustainable land use options interactions between different aggregation levels, and between socio-economic and agro-ecological variables must be taken into account (Kruseman *et al.*, 1993). In such an analysis various types of studies with different aims can be distinguished (Hengsdijk & Kruseman, 1993; Rabbinge & Van Ittersum, 1994). Possibilities and perspectives for land use in the long term are investigated in explorative studies, in which biophysical and technical information on land use is confronted with various objectives distilled from different policy views. Policy instruments to influence decisions of individual actors are investigated in (farm) household studies. These studies focus on ways to change the current situation in directions that have been derived from explorative studies. The two types of studies incorporate socio-economic factors and objectives in fundamentally different ways. In explorative studies socio-economic factors are treated as exogenous parameters, while in farm household studies they are endogenous variables.

Land use policies are usually formulated at the regional or national level. Sustainable land use is not unambiguously defined; different perceptions can be distinguished. Explorative land use studies can be used to make consequences of and trade offs between different aims and perceptions explicit (Veeneklaas *et al.*, 1991; Rabbinge & Van Latesteijn, 1992; Alfaro *et al.*, 1994). For each of the policy views, land use scenarios can be generated. Explorative land use studies focus on the technical, ecologic, agronomic and economical possibilities for the longer term, based on the limitations and potentials identified at the plot level.

Having been explicit about aims for land use at the national or regional level, policy instruments must be selected to influence land use. Decisions on land use are taken by farm households, guided by their goals and aspirations and structured by available resources, possible activities, and external biophysical and socio-economic constraints. Land use at the farm level can be optimized by selecting alternative land uses and technologies at the plot level. Based on the policy objectives, instruments are analyzed which can induce farm level response reactions in the preferred directions. Policy decisions and the farmers' responses are linked through the socio-economic environment: markets, services and infrastructure.

The present paper deals with a modelling approach used in the analysis of the response of farm households in the short term, in terms of adjustments of land use and technology choice, to specific changes in the socio-economic environment. At the moment, a detailed appraisal of the effectiveness and feasibility of available policy instruments is lacking. The methodology presented has been developed to support decision makers in choosing appropriate policy instruments to induce changes at the farm level, in order to realize aims at the aggregate, regional level.

The analysis refers to only one specific farm type in the Atlantic Zone of Costa Rica: peasant households growing basic grains and other food crops for home consumption and sale, which represent about 70 % of the farm households and about 15 % of the agricultural area in the Atlantic Zone, and focuses on price instruments.

The results of the analysis are presented in terms of response multipliers, defined as the ratio of the relative change in an endogenous variable and the relative change in the exogenous variable (instrument) that induced its change. They are indicative for the pace and direction of change in the particular farm type. Response multipliers increase the insight in the effectiveness of various price instruments to attain different goals. Aggregation of the results for different farm types should elucidate whether development in the direction of the regional aims is realized.

In the first section of this paper, the modelling approach is presented. Major differences with standard farm household modelling approaches are highlighted, and the empirical base is briefly acknowledged. Subsequently, regional objectives are translated into goal indicators, and price instruments are selected which may influence these indicators. Finally, the effectiveness of these instruments is investigated with the modelling approach.

The Model

Modelling approach and model structure

Farmers are assumed to maximize utility. This utility cannot be equated to profit which is often considered the guiding principle of the farm enterprise, because peasant households simultaneously take into account consumption and production. Profit maximization ignores the consumption component in decision making. The approach to farm household modelling presented is an adaptation of the basic farm household model presented by Singh *et al.* (1986) derived from earlier work, especially by Barnum & Squire (1978, 1979a,b). This model includes linked production and consumption decisions, which implies maximization of a utility function subject to budget and time constraints. The budget constraint is linked to the net returns which is derived from a (continuous) production function. Labour is incorporated in the utility function, since labour has both productive and consumptive (leisure) aspects. There is a time lag between decision making on the production structure and decision making regarding consumption and the allocation of labour. Therefore, in the model the objective function is based on optimization of the *expected* utility of consumption subject to an budget constraint. The utility function is determined through analysis of household expenditure patterns.

In the present analysis, production decisions are modelled using linear programming, instead of a continuous production function, because the production activities are described in terms of discrete technology packages, based on the complex interactions of inputs required to obtain outputs. Continuous production functions do not adequately explain technological change. Linear programming techniques, however, give optimal solutions and do not adequately explain farm household decisions. Therefore, a production structure adjustment module was used.

In Figure 1 the structure of the model is presented. First, the optimum production structure is calculated using information from various modules; objectives are defined in the expenditure module, price data are generated in the price module, and information on possible land use activities is defined in the production activity module. In a subsequent step, a production structure adjustment module is used to simulate production decisions. The model is used to analyze the effect of a number of price instruments. 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 included. The differences in model results have been used to calculate the response multipliers.

The linear programming module is a two-period model to account for perennials: the perennials plantain and cassava planted in the preceding period have implications for the current period.

The specific farm household type for the present case study was derived from a farm stratification (Kruseman *et al.*, 1994). The resource endowments of this peasant household include 1.8 man years of labour and 20 ha of land. A number of institutional and market constraints derived from the regional analysis are included: limits on credit, off-farm employment and possibilities to hire labour in peak periods. In

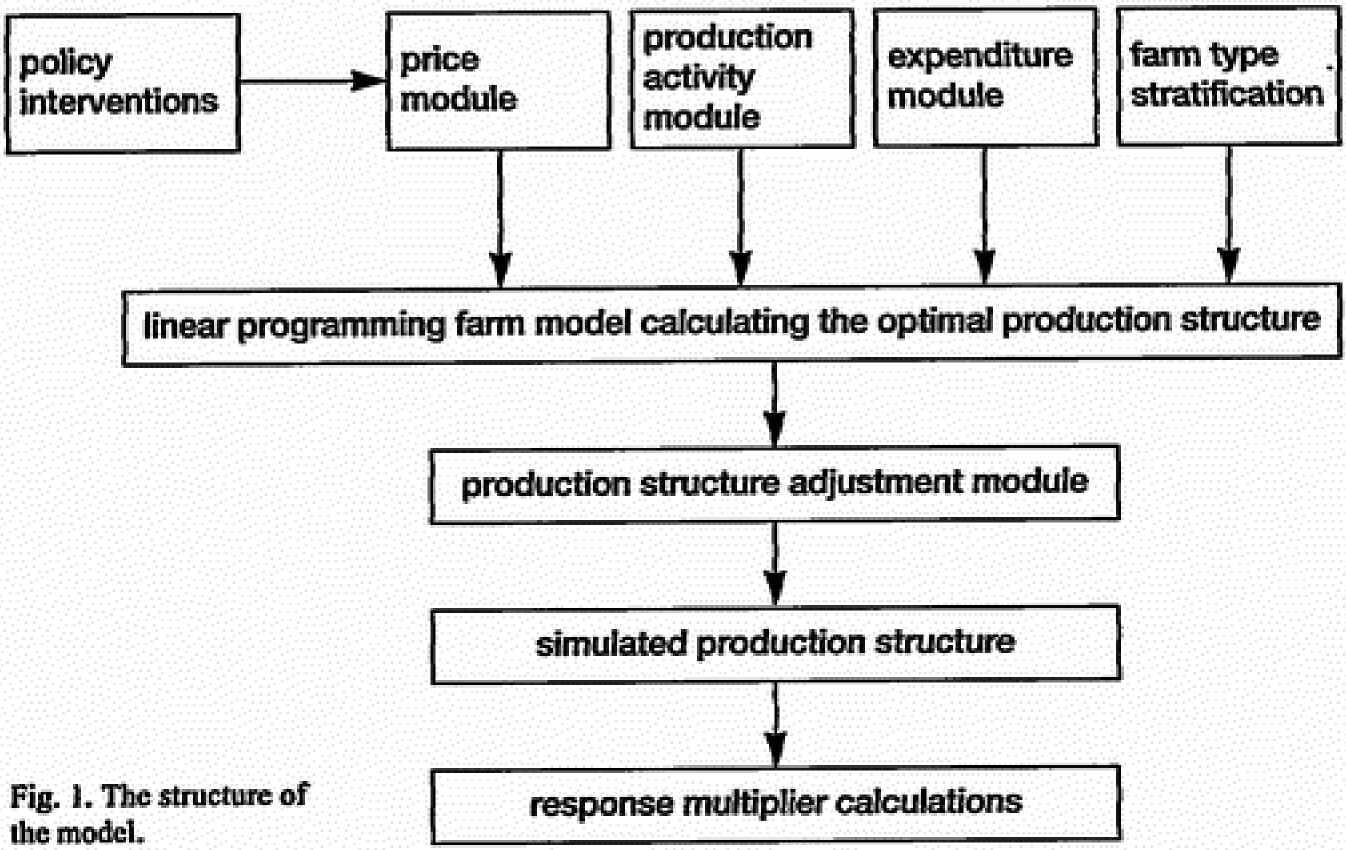

Fig. 1. The structure of the model.

the present specification of the model, interest rates and other capital costs have not been incorporated, while the access to capital resources is restricted in quantitative terms. Land costs are not accounted for, since they only play a role if a land market is incorporated in the model.

In the following paragraphs the different modules of the model are presented: (1) expenditure module; (2) price module; (3) production activities module and (4) production structure adjustment module.

Expenditure module

In the model a negative exponential utility function is used. Anderson *et al.* (1977) use this function for the utility of wealth in risk analysis, but it can also be applied to utility of consumption. This functional form allows for the inclusion of minimum consumption requirements and is determined by consumption at different levels of income. The negative exponential utility function is preferred over the commonly used Log-Linear Expenditure Systems (LLES) (Lau *et al.*, 1978) or Linear Expenditure Systems (LES) (Barnum & Squire, 1979a,b) because LLES implies that each expenditure elasticity with respect to full income equals 1, and LES implies linear Engel curves. These conditions are more restrictive when commodities are less aggregated. Moreover, the data requirements for estimation of the negative exponential utility function are not restrictive. The data set does not have to include information concerning the production structure.

The utility function is determined through the analysis of household expenditures. Consumption categories i include commodities (maize, beans, cassava, other food, non-food) and leisure. The specification of the leisure function in the model is such that leisure increases proportionally with income. Hired labour is used by the household to balance labour availability and requirements. The utility derived from its consumption by the household can be characterized by the following negative exponential utility function, of which the parameters were estimated using the DGEC cross-sectional budget survey (Anonymous, 1992):

$$U_i = U_i^{max} * (1-e^{-\alpha_i^U * (C_i - C_i^{min})}) \tag{1}$$

where: U_i = utility of consumption of commodity i

U_i^{max} = maximum attainable utility from commodity i

α_i^U = conversion factor consumption to utility for commodity i

C_i = consumption of commodity i or leisure

C_i^{min} = minimum consumption of commodity i or leisure

For utility maximization partial utilities are summed:

$$\max U = \sum_{i=1}^{n} U_i \tag{2}$$

For a utility maximizing household at equilibrium, total utility is at a maximum (max U), given the budget constraint, so that any reallocation of expenditures will result in lower total utility. In other words, the marginal utility of expenditures on commodity i is equal for all i for a given total expenditure level, i.e. $\delta U_i/\delta C_i = \phi_Y$. The marginal utility is given by:

$$\frac{\delta U_i}{\delta C_i} = \phi_Y = \alpha_i^U * U_i^{max} * e^{-\alpha_i^U (C_i - C_i^{min})} \tag{3}$$

Regression estimates of the parameters of the utility function are statistically significant and controlled for collinearity (Ruben *et al.*, 1994).

The negative exponential utility function is linearized using the convex combination constraint (Hazell & Norton, 1986). The convex properties of the utility function allow it to be linearized without any difficulty.

Price module

The basic principle of supply response models is the existence of a relationship between prices and production volume which reflects the relative elasticities of supply and demand. At the start of a growing season the farmer has to make his decisions on the production structure, while he does not know the prices. Thus, the farmer has to make his decisions based on expected prices.

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 weighed average of past prices. Although elaborate systems have been devised for its estimation, for the present purpose the expected price is defined as:

$$p_t^e = \beta_1^p * p_{t-1} + \beta_2^p * p_{t-2} + \beta_3^p * p_{t-3} \tag{4}$$

with

$$\beta_1^p + \beta_2^p + \beta_3^p = 1 \tag{5}$$

where: p_t^e = expected price in period t

β_i^p = coefficient of expectation

The coefficients of expectation were set at 0.5, 0.25 and 0.25 respectively. Using slightly different values for the coefficients of expectation does not significantly alter expected prices in the long run. To account for the imperfect access to markets transaction costs are incorporated in terms of a 20% margin on input and output prices.

Production activity module

For the analysis of production decisions with special emphasis on issues related to agro-ecological sustainability, it is imperative to include technology choices. Standard continuous production functions are not used, because they disregard the synergistic properties of agricultural inputs (De Wit, 1992). Technology should be applied in balanced packages, i.e. combinations of water, fertilizers, biocides, labour and machines. Linear programming is suitable for modelling the choice between discrete technology packages. Such technology packages or LUSTs (a particular Land Use System and a specified Technology) are defined in terms of certain 'outputs' requiring certain 'inputs' (Jansen & Schipper, 1995). LUSTs included in the model refer to actual production technologies plus a number of alternative production technologies defined for maize, plantain, cassava and beans.

The LUSTs used in this model differ slightly from those defined in USTED (Stoorvogel *et al.*, 1995). Only a limited number of crops grown at one soil type is considered. The actual LUSTs refer to presently used technologies, while the alternative LUSTs represent technologies not yet applied in the region. Actual LUSTs are derived from farm survey data (Jansen & Schipper, 1995) and farm accounts prepared by the Banco Nacional de Costa Rica (Anonymous, 1993), while alternative LUSTs are based on expert knowledge. Since the model aims at simulating short term changes in land use, alternative LUSTs included in the model have yields that are only slightly higher than yields currently attained in the region. Alternative LUSTs in the current study have been defined in such a way that the macro nutrient (N, P and K) reserves of the soil remain constant in the long run, by supplying more nutrients in the form of fertilizers, while LUSTs defined in USTED permit some soil depletion. In both approaches the efficiency of biocide use (kg biocide per kg yield) has been optimized in the alternative LUSTs by using new application techniques. Nevertheless, biocide use per ha can be higher in the alternative LUSTs than in the actual LUSTs because yields are higher in the first than in the latter. Biocide and fertilizer inputs, the latter as a proxy for nutrient depletion, are used as agro-ecological sustainability indicators. Labour and machinery requirements are defined on an annual basis for both actual and alternative LUSTs, and not on a monthly basis as in USTED. Annual labour requirements in the alternative LUSTs are generally lower than in the actual LUSTs due to a higher degree of mechanization in the alternative LUSTs.

Production structure adjustment module

Even when including actual production activities, linear programming solutions usually do not reflect the actual situation, indicating incomplete specification of the objective function of the farmer. The production structure adjustment module, which was adapted from Nerlovian type supply response analysis (Nerlove, 1958, 1979; Askari & Cummings, 1976), is used to account for the fact that the linear programming solutions do not necessarily reflect the decisions taken by the farmer. The production structure adjustment module results in a so called simulated production structure:

$$W_t = W_{t-1} + \gamma * (W_t^D - W_{t-1}) \qquad (6)$$

where: γ = production structure adjustment coefficient

W_t = vector representing the simulated production structure in period t

W_{t-1} = vector representing the production structure in period t–1

W_t^D = vector representing optimal production structure obtained with the linear programming model for period t

In each period, the simulated production structure is the result of the adjustment of the production structure in the preceding period by some fraction γ of the difference between the optimal production structure and the production structure in the preceding period. 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 linear programming 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).

Data on the actual production structure were lacking for most years, hence statistical estimates of the best fit for different values of the production structure adjustment coefficient could not be made. 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. 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 production structure. For lack of a second independent data set the model could not be validated.

Regional objectives and price instruments

Two important regional objectives have been identified for the Atlantic Zone of Costa Rica (Kruseman *et al.*, 1994): (1) improvement of the competitiveness of agricultural production under trade liberalization, and (2) better natural resource management.

Regional objectives cannot be equated to farm household objectives. Therefore, the rather general regional objectives were translated into four specific indicators, which can be measured at farm level. The first two serve as indirect indicators for improved competitiveness, while the latter two are indicative for natural resource management: (i) income and utility increase; (ii) increase in plantain and cassava production, because of the comparative advantages for export; (iii) decrease in biocide use, because of their eco-toxicological impact on the environment; (iv) increase in fertilizer use as a proxy for reduced nutrient depletion, since generally fertilizer applications by peasant households are lower than the sum of the macro-nutrients removed in the crop and the inevitable nutrient losses.

Response multipliers for land use – i.e. the adjustment of LUSTs at the farm level – and response multipliers for goal indicators were determined with the model for 5 types of price instruments: (i) general output price of agricultural activities; (ii) fertilizer price; (iii) biocide price; (iv) transaction costs and (v) wage rate. Export taxes and import tariffs are not identified as separate instruments, although they may indirectly affect input and output prices.

Response multipliers

Tables 1 and 2 present various response multipliers for land use and goal indicators, respectively. The calculations with the model only refer to the 1984/1985 period, using the set of expected and actual prices relevant for that period. These results illustrate the type of information generated by the model. It should be emphasized that the results are tentative.

The response multipliers are defined as ratios, valid for price changes up to 15% in either direction. The use of linear programming techniques results in less flexible response, while sensitivity analysis indicates that response multipliers are non-proportional beyond 15% change. For these large price changes, the independence of the reactions is lost, since such changes may induce other price changes through market linkages. The response reactions refer to the short term, since the production structure adjustment coefficient is used, which dampens reactions to changes in prices. Therefore, the response multipliers for the unadjusted LP model are larger than those shown in the tables.

The principle of response reactions can be represented by a chain reaction: price modifications induce adjustments in the production structure. Adjustments in the production structure induce changes in (factor and non-factor) input demand and changes in volumes marketed and consumed.

The values in the tables are response multipliers, which are defined as:

$$\varepsilon_{X_i}^{p_j} = \frac{dX_i}{dp_j} * \frac{p_j}{X_i} \tag{7}$$

$$\frac{dX_i}{dp_j} = (\frac{\delta X_i}{\delta p_j} + \frac{\delta X_i}{\delta U} * \frac{\delta U}{\delta p_j}) \tag{8}$$

where: X_i = relevant indicators: cultivated area, income, utility, fertilizer and biocide use

U = utility of consumption

p_j = relevant prices: general output price, fertilizer price, biocide price, transaction costs, and wage rate

$\varepsilon_{X_i}^{p_j}$ = response multiplier j of indicator i

These response multipliers resemble elasticities, but differ in the sense that they are determined with linear programming techniques for a specified range of policy change. Hence they do not correspond to the strict definition of elasticities, i.e., the first derivative of a continuous function. Equation (8) is based on the concept of response elasticity as defined by Singh *et al.* (1986). The first term between the brackets reflects the standard result of production theory, which implies that decreasing output or increasing input prices lead to decreasing levels of income and factor use (e.g. fertilizer use). The second term includes the direct effect of higher prices 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.

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 by alternative LUSTs. The latter occurs when response multipliers 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 by 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 can be higher than those of actual LUSTs of crop A. Moreover, substitution within a crop can result in a higher biocide use per ha because the yields of alternative LUSTs are higher than those of actual LUSTs, since the efficiency of biocide use per kg yield has been optimized in alternative LUSTs. Table 1 shows the effect of various price instruments on cultivated area, cultivated crops and technolo-

Table 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.

Activities	Output price[2]	Fertilizer price	Biocide price	Transaction costs	Wage rate
Maize	0.00	1.66	−7.53	0.00	0.00
Beans	−1.75	−3.43	20.31	1.02	−0.34
Cassava	1.13	−1.60	−0.60	−0.70	0.22
Plantain	0.00	0.00	0.00	0.00	0.00
Cultivated area (total)	−0.10	0.01	−0.52	−0.06	−0.02
Actual LUSTs	−0.35	0.35	−0.47	0.21	−0.07
Alternative LUSTs	1.61	−2.29	−0.86	−1.02	0.31

[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.

Table 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[2]	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

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

gy used, and table 2 illustrates the effect of the price instruments on income and sustainability related 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 beans. 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 by alternative LUSTs, the latter with similar or higher biocide and fertilizer requirement.

An increase in biocide prices (taxation) induces simultaneously a change in cultivated crops and a reduction in cultivated area. The over all effect is a decrease in biocide use, but at the expense of a reduction in income.

Decreasing fertilizer prices have the strongest effect on changes in technology. The substitution of actual by alternative LUST's has a positive effect on both 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 by alternative LUSTs. This substitution has almost no effect on sustainability indicators, because there is a simultaneous shift in cropping pattern to crops with higher biocide and lower fertilizer requirements.

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 choice 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.

Tentative conclusions from the model outcomes 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 on the agro-ecological sustainability indicators used in this study. At the policy level there are some limitations to lowering 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 decrease as a result of trade liberalization.

Discussion

The farm household modelling approach presented in this paper integrates econometric techniques, based on continuous functions, with linear programming techniques, based on discrete technical options. The use of a standard farm household model allows introduction of the concept of utility, as well as linkage between production and consumption decisions. The use of linear programming allows incorporation of agro-technical data, without having to specify continuous production functions. The present approach also enables 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 deficient environments, a characteristic for many developing countries. Its modular structure allows for adaptation of the relevant module in case of improved data availability. By contrast, traditional farm household models make use of complicated econometric estimates, which require large and complex farm level surveys.

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 in-

clude disaggregated 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, for instance those related to risk; together with general farm surveys it will then be possible to include goal weighing procedures to calculate the simulated production structure, instead of using a production structure adjustment module;
6. inclusion of modules simulating the interaction between the farm household and factor (labour and capital) markets.

The results indicate that the policy instruments analyzed in this study 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 the aggregated results of farm household studies and the long term perspectives derived from explorative studies for the regional level, 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.

Acknowledgements

The comments and advise on earlier versions of this paper by colleagues of the Atlantic Zone Programme and the Wageningen Agricultural University are gratefully acknowledged. We thank the Atlantic Zone Programme for sharing data.

References

Alfaro, R., J. Bouma, L.O. Fresco, D.M. Jansen, S.B. Kroonenberg, A.C.J. Van Leeuwen, R.A. Schipper, R.J. Sevenhuysen, J.J. Stoorvogel & V. Watson, 1994. Sustainable land use planning in Costa Rica: a methodological case study on farm and regional level. In: L.O. Fresco, L. Stroosnijder, J. Bouma & H. van Keulen (eds.). The future of the land: mobilizing and integrating knowledge for land use options. John Wiley & Sons Ltd, Chichester, pp. 183–202.

Anderson, J.R., J.L. Dillon & J.B. Hardaker, 1977. Agricultural decision analysis. Iowa State University Press, Ames, 344 pp.

Anonymous, 1992. Encuesta Nacional de hogares 1986–87. San José, computer files.

Anonymous, 1993. Data bank of the Banco Nacional de Costa Rica, San José, 50 pp.

Askari, H. & J.T. Cummings, 1976. Agricultural supply response: a survey of the econometric evidence. Praeger Publishers, New York, 443 pp.

Bardhan, P.K., 1980. Interlocking factor markets and agrarian development: a review of issues. *Oxford Economic Papers* 32: 82–97.

Barnum, H.N. & L. Squire, 1978. Technology and relative economic efficiency. *Oxford Economic Papers* 30: 181–198.

Barnum, H.N. & L. Squire, 1979a. A model of an agricultural household: theory and evidence. World Bank/ John Hopkins University Press, Baltimore, 107 pp.

Barnum, H.N. & L. Squire, 1979b. An econometric application of the theory of the farm household. *Journal of Development Economics* 6: 79–102.

Binswanger, H.P., 1980. Attitudes towards risk: experimental measurement in rural India. *American Journal of Agricultural Economics* 64, 391–393.

De Janvry, A., M. Fafchamps & E. Sadoulet, 1991. Peasant household behaviour with missing markets: some paradoxes explained. *The Economic Journal* 101: 1400–1417.

De Wit, C.T., 1992. Resource use efficiency in agriculture. *Agricultural Systems* 40: 125–151.

Hazell, P.B.R., 1982. Application of risk preference estimates in farm-household and agricultural sector models. *American Journal of Agricultural Economics* 64 :384–390.

Hazell, P.B.R. & R.D. Norton, 1986. Mathematical programming for economic analysis in agriculture. MacMillan Publishing Company, New York, 400 pp.

Hengsdijk, H. & G. Kruseman, 1993. Operationalizing the DLV program: an integrated agro-economic and agro-ecological approach to a methodology for analysis of sustainable land use and regional agricultural policy. DLV report no.1, Wageningen, 107 pp.

Jansen, D.M. & R.A. Schipper, 1995. A systematic description of land use systems on field and farm level. *Netherlands Journal of Agricultural Science* 43: .

Kruseman, G., H. Hengsdijk & R. Ruben, 1993. Disentangling the concept of sustainability: Conceptual definitions, analytical framework and operational techniques regarding sustainable land use. DLV report no. 2, Wageningen, 61 pp.

Kruseman, G., R. Ruben & H. Hengsdijk, 1994. Agrarian structure and land use in the Atlantic Zone of Costa Rica. DLV report no. 3, Wageningen, 106 pp.

Lau, L.J., W-L Lin & P.A. Yotopoulos, 1978. The linear logarithmic expenditure system: an application to consumption-leisure choice. *Econometrica* 46: 843–868.

Nerlove, M., 1958. The dynamics of supply: estimation of farmers response to price. John Hopkins University Press, Baltimore, 268 pp.

Nerlove, M., 1979. The dynamics of supply: retrospect and prospect. *American Journal of Economics* 61: 874–888.

Pope, R.D., 1982. Empirical estimation and use of risk preference: an appraisal of estimation methods that use actual economic decisions. *American Journal of Agricultural Economics* 64: 376–383.

Rabbinge, R. & M.K. Van Ittersum, 1994. Tension between aggregation levels. In: L.O. Fresco, L. Stroosnijder, J. Bouma & H. Van Keulen (Eds.). The future of the land: mobilizing and integrating knowledge for land use options. John Wiley & Sons Ltd, Chichester, pp. 31–40.

Rabbinge, R. & H.C. van Latesteijn, 1992. Long-term options for land use in the European Community. *Agricultural Systems* 40: 195–210.

Ruben, R., G. Kruseman, H. Hengsdijk, 1994. Farm household modelling for estimating the effectiveness of price instruments on sustainable land use in the Atlantic Zone of Costa Rica. DLV report no. 4, Wageningen, 44 pp.

Singh, I., L. Squire & J. Strauss, 1986. Agricultural household models: extensions, applications and policy. Baltimore, John Hopkins University Press for the World Bank, 335 pp.

Stoorvogel, J.J., R.A. Schipper & D.M. Jansen, 1995. USTED: a methodology for quantitative land use analysis including sustainability aspects. *Netherlands Journal of Agricultural Science* 43:.

Veeneklaas, F.R., S. Cissé, P.A. Gosseye, N. Van Duivenbooden & H. Van Keulen, 1991. Competing for limited resources: the case of the fifth region of Mali. Report 4: Development scenarios. CABO/ESPR, CABO, Wageningen, 180 pp.