TMD DISCUSSION PAPER NO. 37

TO TRADE OR NOT TO TRADE: NON-SEPARABLE FARM HOUSEHOLD MODELS IN PARTIAL AND GENERAL EQUILIBRIUM

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January 1999

TABLE OF CONTENTS

ABSTRACT

Empirical evidence and microeconomic theory suggest that, in many settings, farm household production and consumption decisions are "non-separable." Non-separability may have important policy implications, including lack of response or threshold effects when incentives change. This paper extends the literature in two ways. First, we develop a non-separable farm household model with transaction costs and endogenous choice of market "regime" (surplus, self-sufficiency, or deficit) for production-consumption items (commodities and factors that are both demanded and supplied by the household). Second, we embed this household model in an economywide computable general equilibrium model which is formulated as a mixed-complementarity problem. Simulations with a model based on data for a stylized, low-income, Sub-Saharan African country show that the proposed formulation enhances our ability to analyze the impact of exogenous changes on African farmers.

1. INTRODUCTION*

Emerging empirical evidence and microeconomic theory strongly suggest that, in many developing country settings, farm household production and consumption decisions are "non-separable" — that is, the farm household cannot be viewed as separately or independently maximizing profits as a producer and utility as a consumer. The existence of such non-separability indicates the presence of market imperfections or failures that may have important policy implications. For example, depending on the nature of the market imperfections, there may be "threshold" effects whereby policy changes have no effect on household behavior until the change is "large" in some measure. In this environment, policy analysis assuming the existence of perfect markets may badly misstate the impact of policy changes on producer behavior and household welfare.

This paper extends the existing literature on non-separable household models in two ways. First, we develop a household model with transaction costs in which the choice of market "regime" (surplus, self-sufficiency, or deficit) is endogenous for farm household production-consumption items (commodities and factors that are both demanded and supplied by the household); *i.e.*, the market regime is not imposed exogenously, as in existing empirical simulation models (de Janvry, Fafchamps, and Sadoulet). The model is presented in optimization and mixed-complementarity versions (Section 2). Second, we embed this household model in an economywide computable general equilibrium (CGE) model which is formulated as a mixed-complementarity problem (Section 3). A partial-equilibrium framework would miss important factor and product market linkages. Simulations with a model based on data for a stylized, low-income, Sub-Saharan African country show that the proposed formulation enhances our ability to analyze the impact of exogenous changes on African farmers (Section 4). In addition to concluding remarks (Section 5), our paper includes three Appendices. Appendix A links the optimization and mixed-complementarity versions of the household model of Section 2; Appendix B provides a stylized example of factor and commodity

*The authors would like to thank Moataz El-Said and Rebecca Harris for professional research assistance.

disaggregation in the household model; and Appendix C presents the Social Accounting Matrix for the CGE model.

2. A HOUSEHOLD MODEL WITH ENDOGENOUS MARKET REGIME

The farm household is an important decision-making unit in many settings. It is distinguished by the fact that it is both a producer and a consumer of a set of "production-consumption" goods; *i.e.*, goods that are both supplied and demanded by the household. Food products and family time (used as labor or leisure) are common examples of such goods. In theory, if the farm household faces fixed and identical buying and selling prices for all production-consumption goods, it does not matter that the farm household is both a producer and consumer. The household will maximize in a two-step process that is recursive and hence separable. It will first maximize profits as a producer, which will maximize household income, and then it will allocate its income so as to maximize utility as a consumer.

The issue of separability depends on whether or not there is a difference between market prices of production-consumption goods and the value of those goods within the household — their shadow prices. *Household production and consumption decisions are non-separable whenever the household shadow price of at least one production-consumption good is not given exogenously by the market but instead is determined endogenously by the interaction between household demand and supply*.

Shadow price endogeneity may arise under a wide range of circumstances. It is potentially present whenever the market of at least one production-consumption good is "imperfect," i.e. when the household in at least one market: (a) is not a price-taker; (b) views the good sold in or purchased from the market as an imperfect substitute to the good that is produced and used on the farm; and/or (c) faces gaps between purchase and sales prices (due to transaction costs). For some types of market imperfections, shadow price endogeneity (and non-separability) follows invariably. For example, it occurs if the market price of a good is endogenous whenever trade takes place [a type (a) imperfection], or if household labor on- and off-farm are distinct arguments in the household *utility* function [a type (b) imperfection]. For other cases, a corner solution for the imperfect-market good is required for non-separability. For price gaps [a type (c) imperfection], self-sufficiency generates an endogenous shadow price that is between the sales price (the lower limit) and the purchase price (the upper limit) that prevail in the market. Similarly, shadow-price endogeneity follows when no household labor works off-farm (in spite of the option of doing so) in a setting where family and hired labor are separate arguments in the household *production* function [a second example of a type (b) imperfection].[1]

Econometric evidence is accumulating in support of household models that are non-separable because of issues related to labor and demographics. In Lopez' (1984) econometric analysis using a Canadian data set, recursiveness is rejected as a result of imperfect substitutability between on- and off-farm work. Benjamin (1992) found that, for a Javanese data set, demographic variables influence the production decision, a link that is incompatible with a recursive model. Jacoby (1993) and Skoufias (1994) have rejected the hypothesis that the household shadow wage equals the market wage, for Indian and Peruvian households, respectively, another outcome that requires a non-separable model. Similarly, in an analysis of Mexican households disaggregated according to labor regime, Sadoulet *et al.* (1996) rejected recursiveness for households self-sufficient in labor but not for sellers and buyers of labor, a finding that is implied by a non-separable model with transaction costs for labor. From another perspective, farmers in many parts of the world face significant transaction costs for production-consumption commodities. Microeconomic theory strongly implies that, as a result, a non-separable model is required.

Other analyses have generated non-separability of household decisions due to household self-sufficiency in labor (Chayanov, 1925), a positive relationship between the interest rate and the amount borrowed (Iqbal, 1986), and *ex-ante* classification of production-consumption goods as traded and non-traded in combination with a credit constraint. The latter formulation appears in de Janvry *et al.* (1991) and various more recent papers by de Janvry, Sadoulet, and coauthors. However, with one exception — the treatment of credit in de Janvry *et al.* (1991) — none of these models has permitted *endogenous* regime shifts, from an interior solution to a corner solution (for example from

[1]In addition, as shown by Roe and Graham-Tomassi (1986), when risk is introduced, production and consumption decisions typically become non-separable.

self-sufficiency to surplus in the presence of price gaps) or vice versa.[2]

As noted above, a combination of economic theory and empirical evidence suggests that an accurate simulation of the impact of non-marginal changes in exogenous conditions on household behavior requires a non-separable household model that includes price gaps (due to transaction costs) and endogenously determines the state of market participation. Table 1 shows optimization and mixed-complementarity versions of such a model. The latter version has the advantage that it can be embedded as the household module in multimarket or CGE models. In the optimization version (Equations 1-5), the household maximizes utility subject to production functions, balances for factors and commodities, a cash constraint, and non-negativity constraints for sales and purchase variables. The distinguishing characteristic of the model, which easily can be solved as a non-linear programming problem, is the distinction between purchase and sales prices, with the former exceeding the latter due to transaction costs. Such costs may, for example, reflect costs of transportation, negotiation, enforcement (including labor supervision), and/or merchant mark-ups.

The mixed-complementarity version is derived by manipulating the first-order conditions of the optimization problem (see Appendix A for a derivation). Like other mixed-complementarity problems, it is made up of a system of simultaneous (linear or non-linear) equations consisting of a mixture of equalities and inequalities (here Equations 9 and 10), with the latter linked to bounded variables in complementarity slackness conditions.[3] In addition to restating the production function and the commodity-factor balances, the model highlights characteristics that only were implicit in

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[2]However, since the model of de Janvry *et al.* only included one inequality constraint, they could solve it as a simultaneous equation model for which one of two possible states is imposed. If the implicit constraint is violated (for example credit demand exceeding maximum credit supply when the household interest rate is fixed at the market level), the model is resolved under the alternative state (in this case, fixing credit demand at the level of maximum credit supply with an endogenous household interest rate). In their case, the credit constraint was always binding. As the number of inequality constraints increases beyond two or three (as in any likely application of the mixed-complementarity model of Table 1), this approach rapidly becomes impractical. Instead, the model has to be solved explicitly as a mixed-complementarity problem, drawing on recent advances in solution algorithms.

[3]For details and a mathematical definition of mixed-complementarity problems, see Rutherford (1995).

the optimization version. First, the farm household maximizes profit and utility on the basis of a set of household-specific shadow prices (Equations 7, 11, and 12).[4] Second, if an item is sold or purchased, its shadow price is identical to the sales or purchase price, respectively (Equations 9 and 10, including complementarity constraints and complementary-slackness conditions). Third, if an item is not traded, its shadow price is free to vary; to the extent that trading is permitted, however, the sales and purchase prices provide lower and upper limits. (Equations 9 and 10 apply only to items that can be purchased and sold, respectively.)[5]

3. NON-SEPARABLE HOUSEHOLD DECISIONS IN A CGE MODEL

Our CGE model, which is specified as a mixed-complementarity problem, includes a non-separable farm household model and endogenous regime shifts — an innovation in CGE modeling, since virtually all existing models have assumed that farm household decisions are recursive. We treat farm household decisions in a manner that parallels the household model of Table 1. The only significant difference is that, while unit transactions costs and the resulting gaps between purchase and sales prices are implicit and exogenous in the household model, the CGE model treats them as explicit and endogenous (depending on the prices of transactions inputs). To capture this treatment of household decisions, we introduce a second innovative feature in the form of additional links between institutions (including households, enterprises, and the government) and activities. In standard CGE models, institutions are typically linked to activities only as demanders of their outputs and recipients of the value-added they generate. In our model, every activity is associated with an institution, but all institutions are not necessarily related to any activity. For each "extended institution," (*i.e.*, each core institution plus any associated activities), a balance imposes supply-

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[4]Similarly, de Janvry *et al.* (1991) observe that, for non-traded goods (in their model an exogenous set), the household behaves as a profit- and utility-maximizer using endogenous household-specific prices.

[5]For the sake of simplicity, the models in Table 1 permit all elements in I to be produced, consumed, used as inputs, sold, and purchased. In any application, overlapping subsets of I would be used to constrain the domain of relevant variables and equations to properly reflect the role of individual items (see Appendix B for a stylized example).

demand equilibrium for factors and commodities, permitting purchases and sales in the market when relevant. The core institutions and associated activities make their decisions on the basis of the institutional (shadow) prices that clear these balances and which, in the presence of transactions costs, are influenced by the institutional trading position. While our concern here is with farm household decision-making, it should be noted that our formulation, which captures the role of transactions costs, also for other types of enterprises involved in multiple, integrated lines of production.

To highlight the treatment of non-separability and links between institutions and activities, the model is relatively simple in other areas: there is no explicit treatment of savings and investment and no government. Non-farm households and activities follow standard utility- and profit-maximizing behavior. Production technology is of the Leontief type (fixed input and output coefficients) with many technologies to provide a piecewise linear approximation to a CES function. This treatment is preferred to neoclassical alternatives because it allows activities producing relatively homogeneous agricultural products to shift between positive and zero levels.[6] Commodity and factor prices are determined in perfectly competitive national markets. In foreign trade, there is no product differentiation between domestic output sold domestically, exports, and imports. Hence, for tradables, international prices impose limits on national prices: for importables (exportables), the import (export) price defines the upper (lower) limit for the national prices. This treatment is reasonable for homogeneous commodities, such as grains, for which cross-hauling (simultaneous two-way trade) tends to be insignificant. It also further exemplifies the power of mixed-complementary models: it cannot be captured in standard strict-equality, simultaneous-equation models. However, for many sectors, a formulation with product differentiation and imperfect substitutability is often more realistic.

A mathematical model statement is given in Table 2. For each inequality equation, the model includes a lower limit for the variable that is linked to this equation in a complementary-slackness

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[6]There is no straightforward way to formulate neoclassical production technology so that production and input demand functions are defined mathematically when an activity is zero. The domains of the production functions and first-order conditions do not include zero for factor inputs. The Leontief representation includes zero inputs in its domain and can allow for input substitutability by including several techniques for each activity.

relationship. Equations 1-5 are related to the price system. Given the symmetric treatment of factors and commodities, we use the term “item” to refer to both. Equation 1 states that, as long as institution *u* is permitted to purchase item *i*, the upper price limit is the sum of the market price plus the institution- and item-specific unit transaction cost for purchases (the sum of input prices times fixed unit input quantities). Since the prices of the inputs to transactions are endogenous (like the price of any other factor or commodity), unit transaction costs are endogenous. Equation 1 is linked to the corresponding non-negative purchase variable in a complementary-slackness condition. Hence, if item *i* is purchased by institution *u*, the upper price limit would be binding. According to Equation 2, a similar relationship defines the lower limit for institutional prices: if the institution is permitted to sell an item, its institutional price may not fall below the market price minus the unit transactions cost.

Equation 3 defines the prices on the basis of which activities make their profit-maximizing decisions: institutional prices are mapped to the activities to which they are linked. In Equations 4 and 5, import and export prices (international prices times the exchange rate) define the upper and lower limits for national market prices. The corresponding complementary-slackness condition with non-negative import and export variables indicates that, if a commodity is imported (exported), then the market price has to equal its import (export) price.

Equations 6–8 define output supply, input demand, and the rule for producer decisions. The model assumes that all activities use Leontief technology. Equations 6 and 7 state that supplies of outputs and demands for inputs (factors and intermediates) are a linear function of activity levels, disaggregated by technique *t*. Producers maximize profits subject to constant-returns-to-scale production functions. The first-order condition for optimal behavior is given by Equation 8: for each activity, marginal cost may not fall below marginal revenue; each positive activity is pursued up to the point where marginal cost and marginal revenue are equal.

The next two equations cover household incomes and spending. Equation 9 defines the income of each household as the rent of the factors it controls, computed at household-specific prices. According to Equation 10, each household demands commodities according to a Cobb-Douglas demand function (which may be replaced by some other expenditure function).

As shown by Equation 11, institutional demands for transactions items (for example transportation services or additional labor needs associated with supervision of hired workers) are a function of input coefficients times sales and purchase quantities. Equation 12 defines institution-level internal markets. A market is defined for an item if the institution directly demands it (household commodity consumption), has an endowment that it supplies to the market (for factors), or is associated with any activity that produces it or uses it as an input. If the institution purchases or sells the item, the relevant trade quantity is the market-clearing variable while the price is at the level of the relevant transactions-cost-adjusted market price (cf. Equations 1 and 2). On the other hand, the institutional price is the clearing variable if the institution is not trading the item. If the institution is not permitted to trade in any direction, two regimes are possible: a market-clearing price with no excess supply or excess supply with a price of zero. If purchases and/or sales are permitted, upper and/or lower price limits are imposed by the national market, as indicated by Equations 1 and 2.

The last three equations specify the system constraints. Equation 13 defines the market equilibrium for a factor or a commodity that may be sold and/or purchased by some domestic institution. The national market functions in a manner similar to that of the institutional market. Demands (from domestic institutions and exports, if permitted) may not exceed supplies (the sum of sales from domestic institutions and imports, if permitted).[7] If the nation imports or exports the item, the relevant trade quantity is the market-clearing variable and the price is fixed at the level of the relevant trading price (see Equations 4 and 5). If the item is non-traded, the national price is market-clearing but subject to an upper limit (if importable), a positive lower limit (if exportable), and/or a lower limit of zero (if non-exportable). Equation 15 imposes equality between foreign exchange earnings and revenues, in this case all stemming from trade. The real exchange rate equilibrates the trade-balance condition. The model is homogeneous of degree zero in prices. By fixing the consumer price index, Equation 15 anchors the domestic price level. Given Walras' law, one equation is dependent on the others and may be dropped.

[7]If neither imports nor domestic institutional sales are permitted, the model would be infeasible in the presence of demand items that are positive at any price (as is the case for neoclassical consumption demand). The combination of a fixed supply quantity and no demand would not render the model infeasible: the price would simply fall to zero.

4. SIMULATIONS WITH THE CGE MODEL

The data set to which the model is calibrated includes a farm sector and a non-farm sector. The farm sector is disaggregated into three activities/commodities, each of which takes place in small and large farms linked to small and large farm households (see Table 3 for a list of the SAM accounts). The non-farm sector consists of a non-agricultural household and a non-agricultural activity/commodity. Initially, the large-farm household allocates most of its land to the non-food crop. It has a surplus in all three crops but a deficit in labor. The small-farm household uses most of its land to produce the subsistence crop. It has a labor surplus and different trading positions for each crop (surplus for the non-food crop, self-sufficiency for the high-value crop, and deficit for the subsistence crop).

Figures 1–6 show summary results for two scenarios. In Scenario A, the international price of the high-value crop increases by 15% in nine steps, for a total increase of 45%. Scenario B starts from the first scenario and, in each step, adds a 5% decrease in the transactions input coefficients for transactions inputs of both farm households (which can be seen as reflecting increased productivity), for a total decrease of 45% after three steps, at which point there are no further changes in transportation costs.

The results indicate the importance of threshold effects and regime shifts when using a non-separable household specification. As the world price of the high-value crop increases, the small-farm household response is first limited to a gradual but slight increase in its labor sales until the price rise reaches 25%,at which point it rapidly stops selling labor, instead using all its resources to produce the high-value crop (Figure 1). As it specializes in the high-value crop and enjoys higher incomes, it buys growing quantities of the subsistence crop. The large-farm household responds to the international price change by gradually shifting all its resources into the high-value crop (Figure 3). For the subsistence crop, it shifts all the way from a slight marketed surplus to purchases. It hires increasing quantities of labor, with a discontinuity at the point when the small farm stops selling labor and drives up the wage.

The lowering of transactions input coefficients speeds up and strengthens the response of the small-farm household to the price increase, leading it to producing more of the high-value crop sooner and to making a full regime switch from selling to buying labor (Figure 2). Both farm households gain more income when transactions costs are lowered, as would be expected, with the strongest gain for the large farm (Figures 5 and 6). Urban households are less affected by the price rise, but do share in the general increase in income arising from lower transactions costs.

5. CONCLUSION

Emerging empirical evidence and microeconomic theory strongly suggest that, in many settings, farm household production and consumption decisions are non-separable. In this paper, we develop optimization and mixed-complementarity versions of a non-separable micro household model with endogenous shifts between selling, self-sufficiency, and buying regimes. The mixed-complementarity version is then embedded in a CGE model. This treatment of farm household decisions is an innovation in micro and CGE modeling. The results from the experiments indicate the importance of using a non-separable household specification when appropriate. A "standard" model would have yielded smooth increases in production of the good whose price rose, and smooth increases in income of producers. This model, however, reveals threshold effects and a discontinuous response by households. Within a range of price increases, the small-farm household has no production response and gains only because it can sell some labor to the large-farm household at an increasing wage. At a price threshold, the small-farm household stops selling labor, shifts into producing the high-value crop, and gains much more income. The results also indicate the importance of transactions costs. Lowering transactions costs narrows the gap between purchasing and selling prices, increases market participation by households, and also increases their gain from changes in prices.

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Table 1. Non-Separable Household Model*

<u>Sets</u>

i, j ∈ I (= J) = {1,2,...,n} = factors and commodities

<u>Parameters</u>

$\bar{p}_i^{p}$	purchase price
$\bar{p}_i^{s}$	sales price
$\bar{q}_i^{n}$	endowment

<u>Functions</u>

U(•) X_i(•) I_{ij}(•) C_i(•)	neoclassical functions for utility, production, input demand, and consumption demand

<u>Variables</u>

p_i^{n}	shadow price $(= p_i^{*}/\lambda$, where p_i^{*} = marginal utility)
q_i^{c}	consumption
q_{ii}^{i}	quantity of *i* as input for *j*
q_i^{p}	purchases $(\bar{p}_i^{p} > \bar{p}_i^{s})$
q_i^{s}	sales
q_i^{x}	production
U	utility
y	income (valued at shadow prices)
λ	marginal utility of income

<u>Equations</u>

#	Equation	Domain	Complementarity constraint	Description
Optimization Version				
1	$U = U(q_1^{c}, q_2^{c}, ..., q_n^{c})$			Maximand
2	$q_i^{x} = X_i(q_{1i}^{i}, q_{2i}^{i}, ..., q_{ni}^{i})$	$i \in I$		Production
3	$q_i^{x} + \bar{q}_i^{h} + q_i^{p} = q_i^{c} + \sum_{j \in J} q_{ij}^{i} + q_i^{s}$	$i \in I$		Factor and commodity balance
4	$\sum_{i \in I} q_i^{p} \bar{p}_i^{p} = \sum_{i \in I} q_i^{s} \bar{p}_i^{s}$	$i \in I$		Cash constraint
5	$q_i^{p} \geq 0, \quad q_i^{s} \geq 0$	$i \in I$		Non-negativity constraints
Mixed-Complementarity Version**				
6	$q_i^{x} = X_i(q_{1i}^{i}, q_{2i}^{i}, ..., q_{ni}^{i})$	$i \in I$		Production
7	$q_{ij}^{i} = I_{ij}(p_1^{h}, p_2^{h}, ..., p_n^{h}, q_i^{x})$	$i \in I,\ j \in J$		Input demand
8	$q_i^{x} + \bar{q}_i^{h} + q_i^{p} = q_i^{c} + \sum_{j \in J} q_{ij}^{i} + q_i^{s}$	$i \in I$		Factor and commodity balance
9	$\bar{p}_i^{p} \geq p_i^{h}$	$i \in I$	$q_i^{p} \geq 0$	Upper price limit
10	$p_i^{h} \geq \bar{p}_i^{s}$	$i \in I$	$q_i^{s} \geq 0$	Lower price limit
11	$y = \sum_{i \in I} p_i^{h} \bar{q}_i^{h}$			Income
12	$q_i^{c} = C_i(p_1^{h}, p_2^{h}, ..., p_n^{h}, y)$	$i \in I$		Consumption demand

Note:
*In an applied model, the domains of most variables would be limited to a subset of I (see Appendix B).
**In this version, each inequality includes a lower limit for the associated complementary-slackness variable.

Table 2. CGE model with non-separable household production-consumption decisions

Sets	
$u \in U$	institutions (households and enterprises)
$a \in A$	activities
$i,j \in I(=J)$	factors and commodities
$c \in C\ (\subset I)$	commodities
$c \in CE\ (\subset C)$	exportable commodities
$c \in CM\ (\subset C)$	importable commodities
$f \in F\ (\subset I)$	factors
$h \in H\ (\subset U)$	households
$t \in T$	techniques
$(a,i) \in MAI$	mapping: item *i* is input or output for activity *a*
$(i,h) \in MIH$	mapping: *i* is consumed by household *h*
$(u,a) \in MUA$	mapping: institution *u* is responsible for act *a*
$(i,u) \in MTUI$	mapping: *u* may use *i* as transactions input
$(u,i) \in MUI$	mapping: *u* has a supply-demand balance for *i*
$(i,u) \in MUIP$	mapping: *u* may purchase item *i*
$(u,i) \in MUIS$	mapping: *u* may sell item *i*

Parameters	
α^{i}_{iat}	input demand for *i* per unit of activity *a* with technique *t*
α^{p}_{iuj}	transactions demand for *i* per unit of *j* purchased by *u*
α^{s}_{iuj}	transactions demand for *i* per unit of *j* sold by *u*
α^{x}_{ai}	yield of output *i* per unit of activity *a*
ω_c	weight of commodity *c* in CPI
ψ^{c}_{iu}	share for commodity *i* in consumption demand for household *u*
ψ^{f}_{hf}	share for household h in income of factor *f*
$\bar{p}^{cpi}$	CPI
$\bar{p}^{we}_{c}$	export price of commodity *c* (in foreign currency)
$\bar{p}^{wm}_{c}$	import price of commodity *c* (in foreign currency) $(\bar{p}^{wm}_{c} \geq \bar{p}^{we}_{c})$
$\bar{q}^{h}_{ui}$	supply (endowment) of factor *i* owned by household *u*

Variables	
p_i	market price of factor or commodity *i*
p_{ai}^{a}	price of commodity or factor *i* for activity *a*
p_{ui}^{u}	shadow price of commodity or factor *i* for institution *u*
q_{at}^{a}	quantity of activity *a* using technique *t*
q_{iu}^{c}	quantity of consumption demand from household *u* for commodity *i*
q_i^{e}	quantity of exports of *c*
q_{ia}^{i}	quantity of input demand for *i* from *a*
q_i^{m}	quantity of imports of *c*
q_{iu}^{p}	quantity purchased of commodity *i* by institution *u*
q_{ui}^{s}	quantity sold of item *i* by institution *u*
q_{iu}^{t}	quantity demanded of item *i* for transactions by institution *u*
q_{ai}^{x}	quantity produced of commodity *i* by activity *a*
r	exchange rate (units of domestic currency per unit of foreign currency)
y_h	income of household *h*

Table 2. (cont.)

Equations*

#	Equation	Complementarity constraint	Domain	Description
Price block				
1	$p_i + \sum_{j\in J} p_j \alpha^p_{jui} \geq p^u_{ui}$	$q^p_{iu} \geq 0$	$i\in I,\ u\in U$ $(i,u)\in MTUI$	Upper limit for institutional prices
2	$p^u_{ui} \geq p_i - \sum_{j\in J} p_j \alpha^s_{jui}$	$q^s_{ui} \geq 0$	$u\in U,\ i\in I$ $(u,i)\in MUIS$	Lower limit for institutional prices
3**	$p^a_{ai} = \sum_{u\in U \,\vert_{(u,a)\in MUA}} p^u_{ui}$		$a\in A,\ i\in I$ $(a,i)\in MAI$	Activity prices
4	$r\overline{p}^{wm}_c \geq p_c$	$q^m_i \geq 0$	$c\in CM$	Upper limit for national market price (import price)
5	$p_c \geq r\overline{p}^{we}_c$	$q^e_i \geq 0$	$c\in CE$	Lower limit for national market price (export price)
Production block				
6	$q^x_{ac} = \sum_{t\in T} \alpha^x_{ac} q^a_{at}$		$a\in A,\ c\in C$	Leontief production function
7	$q^i_{ia} = \sum_{t\in T} \alpha^i_{iat} q^a_{at}$		$i\in I,\ a\in A$	Leontief input demand
8	$\sum_{i\in I} p^a_{ai} \alpha^i_{iat} \geq \sum_{c\in C} p^a_{ac} \alpha^x_{ac}$	$q^a_{at} \geq 0$	$a\in A,\ t\in T$	Leontief FOC for profit maximization
Institution block				
9	$y_h = \sum_{f\in F} p^u_{hf} \overline{q}^h_{hf}$		$h\in H$	Household income
10	$q^c_{ih} = \dfrac{\psi^c_{ih} y_h}{p^u_{hi}}$		$i\in I,\ h\in H$ $(i,h)\in MIH$	Household consumption demand
11	$q^t_{iu} = \sum_{i\in J} \alpha^s_{iuj} q^s_{uj} + \sum_{i\in J} \alpha^p_{iuj} q^p_{ju}$		$i\in I,\ u\in U$ $(i,u)\in MTUI$	Institutional transactions demand
12	$\sum_{a\in A \,\vert_{(u,a)\in MUA}} q^x_{ai} + \overline{q}^h_{ui} + q^p_{iu} \geq q^c_{iu} + \sum_{a\in A \,\vert_{(u,a)\in MUA}} q^i_{ia} + q^s_{ui}$	$p^u_{ui} \geq 0$	$u\in U,\ i\in I$ $(i,u)\in MUI$	Institutional commodity and factor demand-supply balance
System-constraint block				
13	$\sum_{u\in U} q^s_{ui} + q^m_i \geq \sum_{u\in U} q^p_{iu} + q^e_i + \sum_{u\in U} q^t_{iu}$	$p_i \geq 0$	$i\in I$	National market for factors and commodities
14	$\sum_{c\in CE} \overline{p}^{we}_c q^e_c = \sum_{c\in CM} \overline{p}^{wm}_c q^m_c$			Current account of RoW
15	$\sum_{c\in C} p_c \omega_c = \overline{p}^{cpi}$			Price numéraire

Note:
*For simplicity, domain restrictions have been partly suppressed for variables and equations.
**On the right-hand side, the notation indicates summation over all elements in U subject to them being mapped to the element in A that is in the domain of the equation (each element in A is only mapped to one element in U but an element in U may be mapped to zero, one or more elements in A). A parallel interpretation applies to the conditional summations in Equation 12.

Table 3. Accounts of the Stylized African SAM

Factors	Activities
1. Labor-leisure (family member time)	For Small-farm household
2. Small-farm capital	1. Subsistence crop
3. Large-farm capital	2. High-value crop
4. Other capital	3. Non-food crop
5. Small-farm land	For Large-farm household
6. Large-farm land	4. Subsistence crop
	5. High-value crop
Institutions	6. Non-food crop
1. Households	Other
– Small-farm household	7. Non-agriculture
– Large-farm household	
– Other (non-agricultural) household	Commodities
2. Non-agricultural enterprise	1. Subsistence crop
3. Rest of world	2. High-value crop
	3. Non-food crop
	4. Non-agriculture

FIGURE 1. Scenario A: Small farm net sales

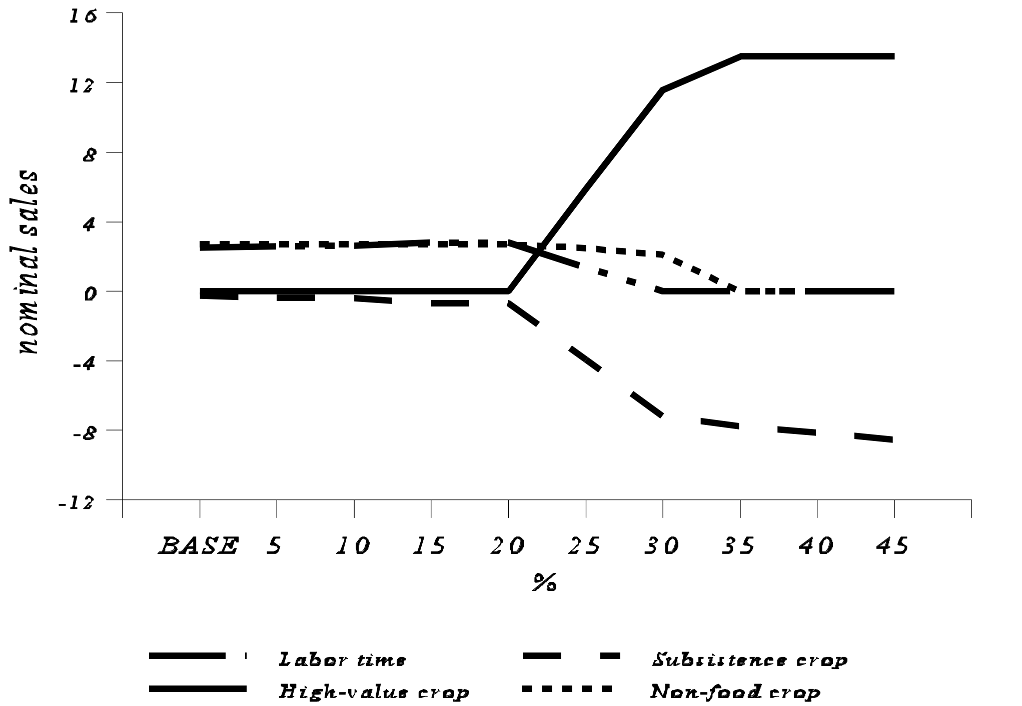
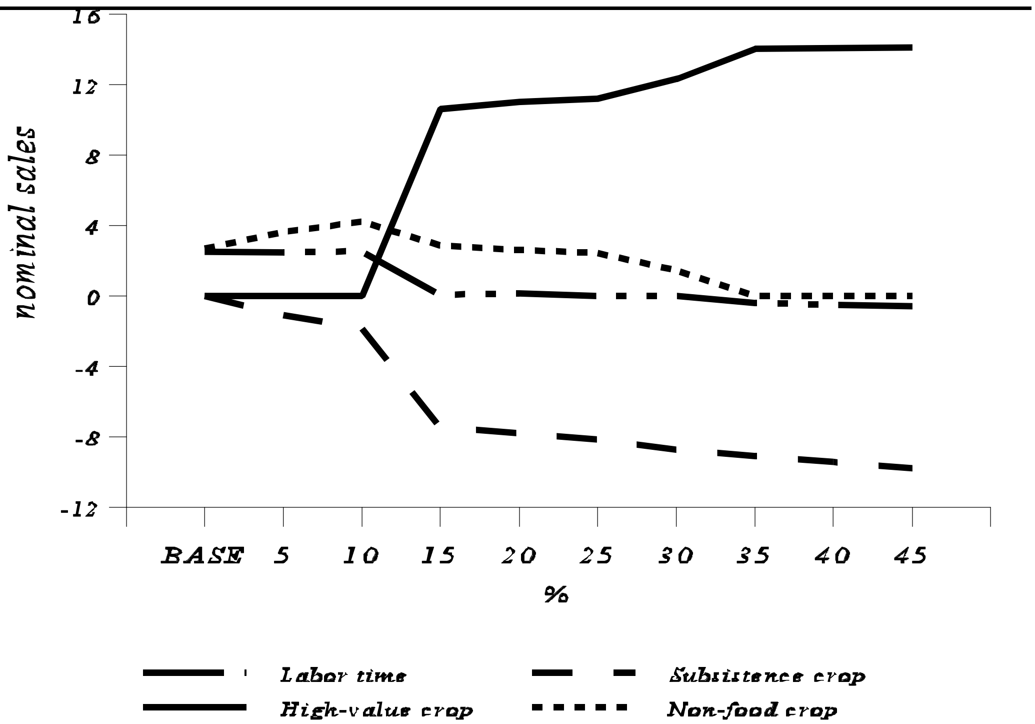


FIGURE 2. Scenario B: Small farm net sales



Scenario A: International price of high-value crop increases by 5% in nine steps
Scenario B: Scenario A plus, in the first three steps, a 15% decrease in coefficients for transactions input demand for both small and large farm households (reaching a total cut of 45%).

FIGURE 3. Scenario A: Large farm net sales

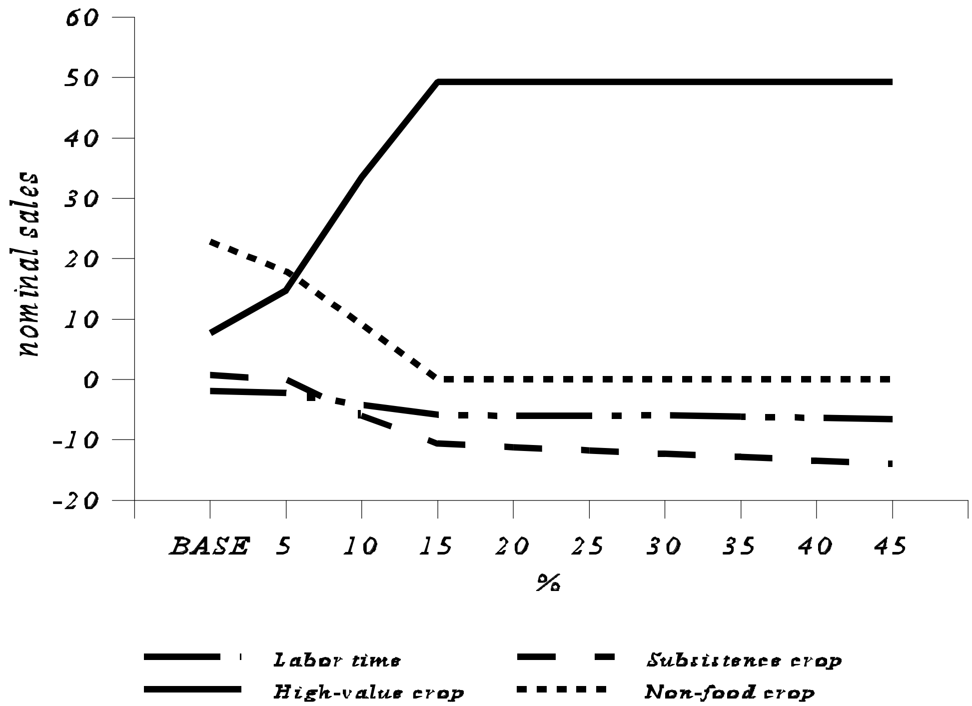
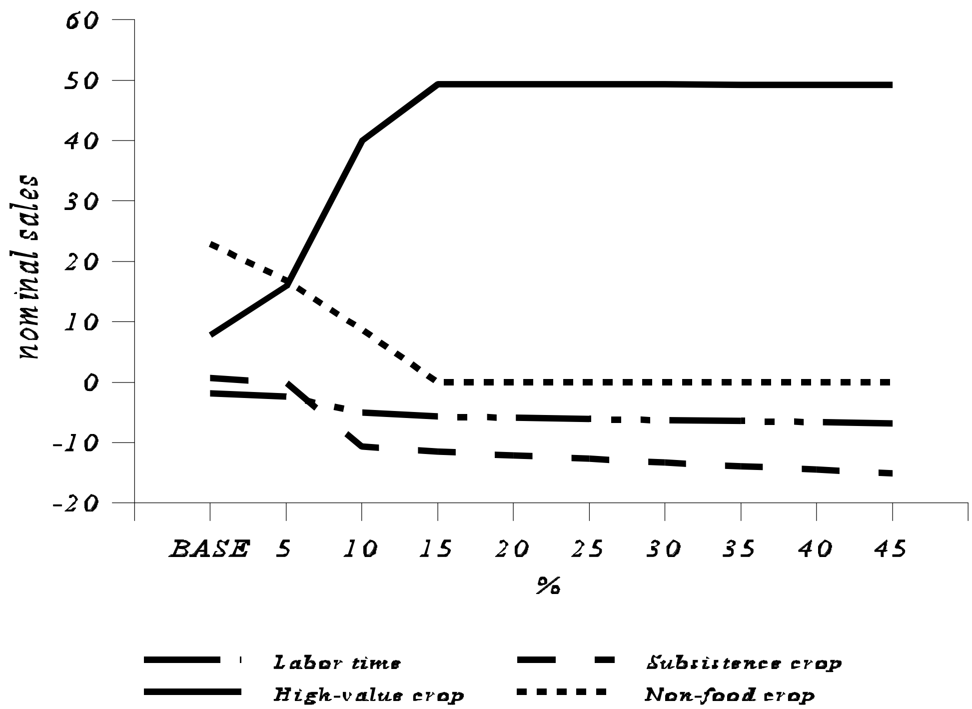


FIGURE 4. Scenario B: Large farm net sales



Scenario A: International price of high-value crop increases by 5% in nine steps
Scenario B: Scenario A plus, in the first three steps, a 15% decrease in coefficients for transactions input demand for both small and large farm households (reaching a total cut of 45%).

FIGURE 5. Scenario A: Household incomes

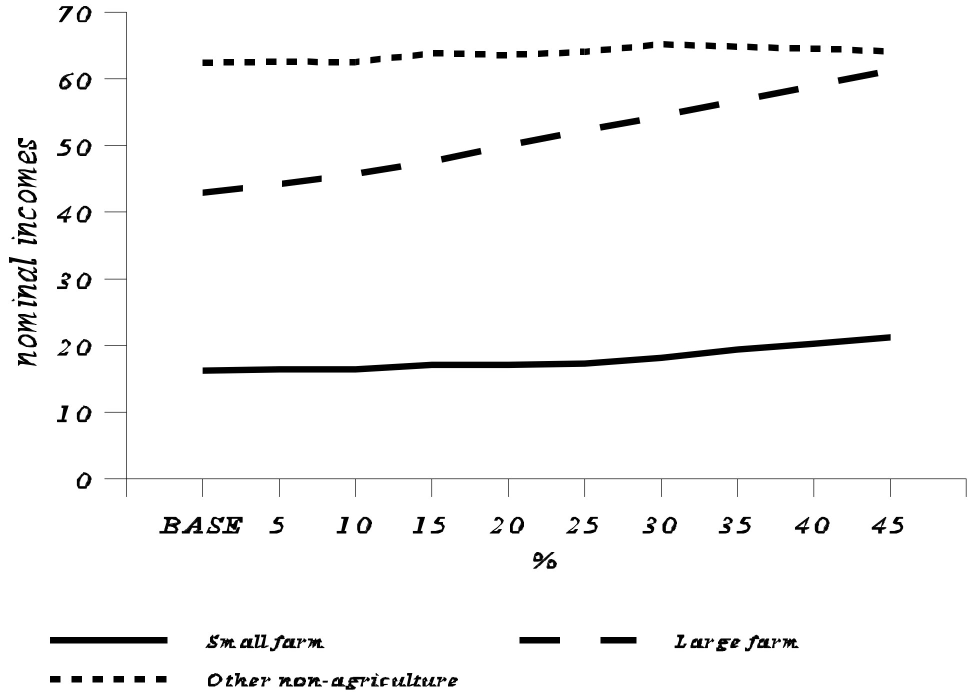
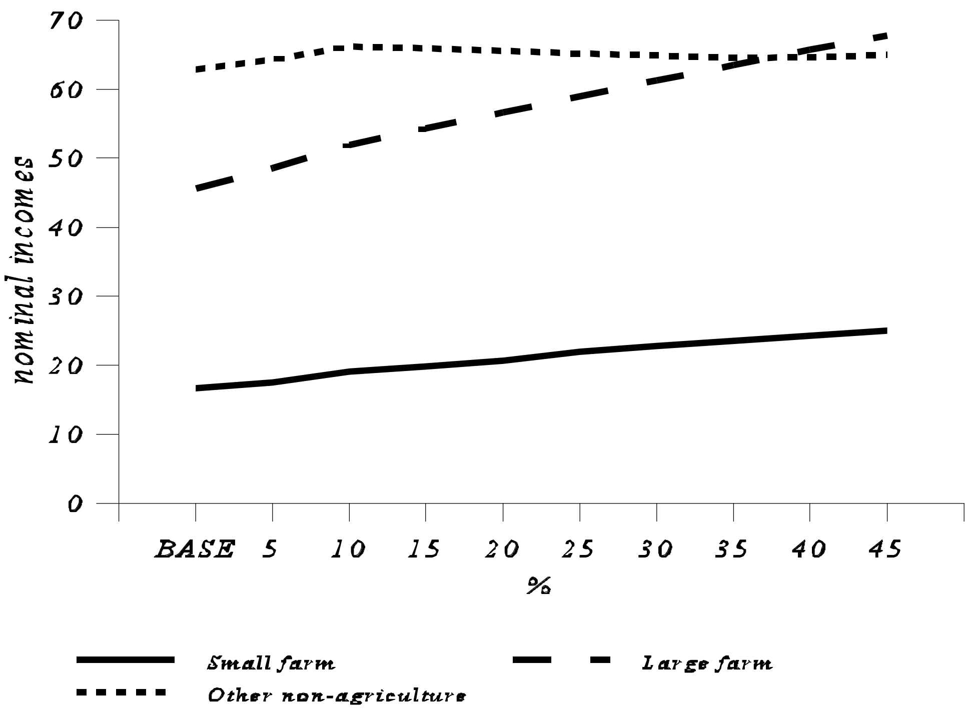


FIGURE 6. Scenario B: Household incomes



Scenario A: International price of high-value crop increases by 5% in nine steps
Scenario B: Scenario A plus, in the first three steps, a 15% decrease in coefficients for transactions input demand for both small and large farm households (reaching a total cut of 45%).

APPENDIX A

A model corresponding to Equations 6-12 in Table 1 is derived here starting from the initial optimization model, Equations 1-5 in the same Table. For simplicity, the derivation uses a specific functional form (Cobb-Douglas), both for consumption and production.

New Notation

Parameters

β_i share of commodity *i* in household consumption value

ψ_{ij} share of factor *i* in output value of commodity *j*

Variables

p_i^* shadow price of factor and commodity balance *i*

λ shadow price of cash balance

Optimization model

$$\max\ U = \prod_{i \in I} {q_i^c}^{\beta_i} \tag{1}$$

subject to

$$q_i^x = \prod_{j \in J} q_{ji}^{\psi_{ji}} \qquad i \in I \tag{2}$$

$$q_i^c + \sum_{j \in J} q_{ij}^i + q_i^s = q_i^x + \bar{q}_i^h + q_i^p \qquad i \in I \tag{3}$$

$$\sum_{i \in I} q_i^p \bar{p}_i^p = \sum_{i \in I} q_i^s \bar{p}_i^s \qquad i \in I \tag{4}$$

$$q_i^p \geq 0; \qquad q_i^s \geq 0 \qquad i \in I \tag{5}$$

Lagrangean

$$L = \prod_{i \in I} {q_i^c}^{\beta_i} + \sum_{i \in I} p_i^* \left(\prod_{j \in J} q_{ji}^{\psi_{ji}} + \bar{q}_i^h + q_i^p - q_i^c - \sum_{j \in J} q_{ij}^i - q_i^s \right) + \lambda \left(\sum_{i \in I} q_i^s \bar{p}_i^s - \sum_{i \in I} q_i^p \bar{p}_i^p \right)$$

First-Order Conditions

$$\frac{\partial L}{\partial q_{ij}} = p_j^* \psi_{ij} \frac{\prod_{i \in I} q_{ij}^{\psi_{ij}}}{q_{ij}} - p_i^* = 0 \qquad i \in I, \quad j \in J \qquad (6)$$

$$\frac{\partial L}{\partial p_i^*} = \prod_{j \in J} q_{ji}^{\psi_{ji}} + \bar{q}_i^h + q_i^p - q_i^c - \sum_{j \in J} q_{ij}^i - q_i^s = 0 \qquad i \in I \qquad (7)$$

$$\frac{\partial L}{\partial q_i^p} = p_i^* - \lambda \bar{p}_i^p \le 0; \quad q_i^p \ge 0; \quad q_i^p (p_i^* - \lambda \bar{p}_i^p) = 0 \qquad i \in I \qquad (8)$$

$$\frac{\partial L}{\partial q_i^s} = - p_i^* + \lambda \bar{p}_i^s \le 0; \quad q_i^s \ge 0; \quad q_i^s (\lambda \bar{p}_i^s - p_i^*) = 0 \qquad i \in I \qquad (9)$$

$$\frac{\partial L}{\partial \lambda} = \sum_{i \in I} q_i^p \bar{p}_i^p - \sum_{i \in I} q_i^s \bar{p}_i^s = 0 \qquad (10)$$

$$\frac{\partial L}{\partial q_i^c} = \frac{\beta_i \prod_{j \in J} q_j^{c\ \beta_j}}{q_i^c} - p_i^* = 0 \qquad i \in I \qquad (11)$$

Introducing the production function (2) into the model, using it to simplify (6) and (7), and rearranging:

$$q_{ij} = p_j^* \psi_{ij} \frac{q_j^x}{p_i^*} \qquad i \in I, \quad j \in J \qquad (12)$$

$$q_i^c + \sum_{j \in J} q_{ij}^i + q_i^s = q_i^x + \bar{q}_i^h + q_i^p \qquad i \in I \qquad (13)$$

Rearranging (8) and (9), using the following definition for the household shadow price (in the context, noting that λ by construction always is positive): $p_i^h = \frac{p_i^*}{\lambda}$

$$\bar{p}_i^p \ge p_i^h; \quad q_i^p \ge 0; \quad q_i^p (\bar{p}_i^p - p_i^h) = 0 \qquad i \in I \qquad (14)$$

$$p_i^h \ge \bar{p}_i^s; \quad q_i^s \ge 0; \quad q_i^s (p_i^h - \bar{p}_i^s) = 0 \qquad (15)$$

Equation (11) may be reexpressed as:

$$q_i^{\,c} = \frac{\beta_i \frac{U}{\lambda}}{p_i^{\,h}} \tag{15'}$$

after multiplying (11) by $\frac{q_i^{\,c}}{\lambda}$, substituting in $p_i^{\,h}$ and U, and rearranging. Defining y as $\frac{U}{\lambda}$, (15') may be rewritten as:

$$q_i^{\,c} = \frac{\beta_i y}{p_i^{\,h}} \tag{16}$$

and (16) can replace (11). After rearranging (16), summing over *i*, and noting that $\sum_{i \in I} \beta_i = 1$, total consumption spending (or income) may be expressed as

$$\sum_{i \in I} p_i^{\,h} q_i^{\,c} = y \tag{16'}$$

Our remaining task is to show that (10) implies $y = \sum_{i \in I} p_i^{\,h} \bar{q}_i^{\,h}$.

Multiplying (12) by $\frac{p_i^{\,*}}{\lambda}$; using the definition of $p_i^{\,h}$; summing over *i* and *j*; noting that, for all *j*, $\sum_{i \in I} \psi_{ij} = 1$; and rearranging

$$\sum_{i \in I} \sum_{j \in J} p_i^{\,h} q_{ij}^{\,i} = \sum_{j \in J} q_j^{\,x} p_j^{\,h} \tag{17}$$

Equation (17) will be used below. Given (14) and (15), and the fact that, for non-traded items, $q_i^{\,p} = q_i^{\,s} = 0$, (10) may be rewritten as

$$\sum_{i \in I} p_i^{\,h} \left(q_i^{\,p} - q_i^{\,s} \right) = 0 \tag{18}$$

Using (13) to substitute for $q_i^{\,p} - q_i^{\,s}$ in (18), multiplying through and rearranging,

$$\sum_{i \in I} p_i^{\,h} q_i^{\,c} + \sum_{i \in I} \sum_{j \in J} p_i^{\,h} q_{ij}^{\,i} - \sum_{i \in I} p_i^{\,h} q_i^{\,x} = \sum_{i \in I} p_i^{\,h} \bar{q}_i^{\,h} \tag{19}$$

Given (17), (19) simplifies to

$$\sum_{i \in I} p_i^{\,h} q_i^{\,c} = \sum_{i \in I} p_i^{\,h} \overline{q}_i^{\,h} \tag{19'}$$

Using (16') to substitute for the left-hand side in (19'),

$$\sum_{i \in I} p_i^{\,h} \overline{q}_i^{\,h} = y \tag{20}$$

and (20) can replace (10). To conclude, the optimization model (in Cobb-Douglas functional form) implies a set of first order conditions — Equations 2, 12, 13, 14, 15, 16 and 20 — that correspond to Equations 6-12 in the mixed-complementarity model of Table 1.

APPENDIX B

For the sake of simplicity, the models in Table 1 permit all elements in I to be produced, consumed, used as inputs, sold, and purchased. Applied models would divide I into subsets reflecting the roles of individual elements. A relatively aggregated applied model could, for example, include the following set definitions:

I = factors and commodities = {food crop, non-food crop, labor/leisure, capital, non-food consumption good}

IO ($\subset$ I) = farm outputs = {food crop, non-food crop}

IC ($\subset$ I) = consumption commodities = {food crop, labor/leisure, non-food consumption good}

IF ($\subset$ I) = factors = {labor/leisure, capital}

IS ($\subset$ I) = factors and commodities that may be rented out or sold = {food crop, non-food crop, labor/leisure, capital}

IP ($\subset$ I) = factors and commodities that may be rented in or purchased = {food crop, labor/leisure, capital, non-food consumption good}

The domains of relevant variables and equations should be constrained accordingly. Moreover, the model in Table 1 assumes that, for items that may be both sold and purchased (IS $\cap$ IP), the purchase price exceeds the sales price $(\overline{p}_i^{\,p} > \overline{p}_i^{\,s})$. If they are equal for some items (i.e., transaction costs are zero), the model can only explain net sales and should be modified, for example by dropping the item from the set IP, fixing the household price at the level of the purchase price, and dropping the non-negativity constraint on the sales variable.

APPENDIX C

Social Accounting Matrix (SAM) for CGE Household Model

	LAB	CAP-SF	CAP-LF	CAP-OTH	LND-SF	LND-LF
LAB						
CAP-SF						
CAP-LF						
CAP-OTH						
LND-SF						
LND-LF						
SF-HH	7.50	2.72			2.28	
LF-HH	10.83		15.83			10.83
OTH-HH	25.00			25.00		
ROW						
SUB-ASF						
HIV-ASF						
NFC-ASF						
SUB-ALF						
HIV-ALF						
NFC-ALF						
NAG-A						
SUB-C						
HIV-C						
NFC-C						
NAG-C						
TOTAL	43.33	2.72	15.83	25.00	2.28	10.83

Note: Row totals (not in Table) are equal to column totals. In each segment, rows with no values (all zeros) have been suppressed. Abbreviations are explained at the end of the Table.

cont. SAM

	SF-HH	LF-HH	OTH-HH	ROW	SUB-ASF	HIV-ASF
LAB					3.00	1.32
CAP-SF					1.50	0.34
CAP-LF						
CAP-OTH						
LND-SF					1.50	0.34
LND-LF						
SF-HH						
LF-HH						
OTH-HH						
ROW						
SUB-ASF						
HIV-ASF						
NFC-ASF						
SUB-ALF						
HIV-ALF						
NFC-ALF						
NAG-A						
SUB-C	6.25	9.38	7.50			
HIV-C	2.00	3.75	5.00	2.75		
NFC-C				25.60		
NAG-C	4.25	24.38	37.50	5.00		
TOTAL	12.50	37.50	50.00	33.35	6.00	2.00

cont. SAM

	NFC-ASF	SUB-ALF	HIV-ALF	NFC-ALF	NAG-A
LAB	0.68	3.33	5.00	5.00	25.00
CAP-SF	0.88				
CAP-LF		3.33	2.50	10.00	
CAP-OTH					25.00
LND-SF	0.44				
LND-LF		3.33	2.50	5.00	
SF-HH					
LF-HH					
OTH-HH					
ROW					
SUB-ASF					
HIV-ASF					
NFC-ASF					
SUB-ALF					
HIV-ALF					
NFC-ALF					
NAG-A					
SUB-C					
HIV-C					
NFC-C					
NAG-C					
TOTAL	2.00	10.00	10.00	20.00	50.00

cont. SAM

	SUB-C	HIV-C	NFC-C	NAG-C
LAB				
CAP-SF				
CAP-LF				
CAP-OTH				
LND-SF				
LND-LF				
SF-HH				
LF-HH				
OTH-HH				
ROW	7.03			26.32
SUB-ASF	6.00			
HIV-ASF		2.00		
NFC-ASF			2.00	
SUB-ALF	10.00			
HIV-ALF		10.00		
NFC-ALF			20.00	
NAG-A				50.00
SUB-C				
HIV-C				
NFC-C				
NAG-C	0.09	1.50	3.60	
TOTAL	23.13	13.50	25.60	76.32

Abbreviations

LAB = labor-leisure (family member time)
CAP-SF = small-farm capital
CAP-LF = large-farm capital
CAP-OTH = other capital
LND-SF = small-farm land
LND-LF = large-farm land
SF-HH = small-farm household
LF-HH = large-farm household
OTH-HH = other (non-agricultural) household
ROW = rest of world
SUB-ASF = subsistence crop activity for small farm household
HIV-ASF = high-value crop activity for small farm household
NFC-ASF = non-food crop activity for small farm household
SUB-ALF = subsistence crop activity for large farm household
HIV-ALF = high-value crop activity for large farm household
NFC-ALF = non-food crop activity for large farm household
NAG-A = non-agriculture activity
SUB-C = subsistence crop commodity
HIV-C = high-value crop commodity
NFC-C = non-food crop commodity
NAG-C = non-agriculture

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