Conflicts over land in the Niger river delta region of Mali

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CHAPTER 5: A CGE MODEL FOR THE MADIAMA RURAL COMMUNE
5.1. Introduction

The economic interactions and social interweaving between different types of rural households at community-level with respect to natural resources is the core issue in this thesis. Interactions are dynamic and cannot be adequately captured by SAM analysis presented in the previous Chapter. We therefore need a model framework that can take into consideration farm household behaviour and at the same time village level interactions. In this Chapter we develop a household-CGE model that can shed light on the key issues of competition for natural resources and the social conflict that can arise from that competition.

For results from farm-households CGE models to be useful in this process, the complex real world in the Madiama rural commune needs to be accounted for; particularly, it should be noted that:

- For some commodities, markets exist and function to some degree since some exchanges take place there. However, this should not hide some distortions that determine supply and demand quantities which are not usually part of the competitive markets: trading conditions are frequently disturbed by high transaction costs due to bad roads and inadequate delivery systems. Local markets are usually weekly and many people converge from more or less far away for selling and buying. Such markets are the basis for the whole local economy and transaction costs are crucial to their performance. Given such facts, households facing such extra costs will participate in the markets only if some particular conditions are met. For example, a producer will not sell millet if the sales price of this commodity is, given the transaction cost, smaller than the price he gives to the commodity. The household on the contrary, will not buy any commodity if its purchase price is greater than the price he gives to the commodity. In other words, there are market distortions due to the transaction costs and market participation regime is highly dependent of such transaction costs that in turn drive households’ behavior.

- Meanwhile, other commodities or factors (such as labor) are not traded on formal markets, though they are very important to the local activities. Family labor is the main factor used by households but they can hire in some labor to supplement or hire out some extra labor on a seasonal basis. Similarly, although important, land is not traded. However, both factors are important to rural activities in the Madiama commune.

Market imperfections are thus an important part of the local economy that should be accounted for in any model addressing this commune.

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43 The price given to the commodity by the producer is the shadow price which reflects the production and other associated costs.
Since the model is basically dependent on the SAM, the limitations of the latter are examined before stepping into the considerations related to the CGE model itself.

The relevance of the CGE modelling can be depicted as a solution to overcome the limitations of SAM or a complementary approach to SAM. Below, the basic structure of a CGE model is described before examining specific models (village-level and farm-household models) and their distinctive characteristics. Finally, the calibration of the IFPRI model using the Social Accounting Matrix for Madiama is presented.

5.2. The model structure

In the following sections, a farm-household CGE model is developed aiming at providing insights into possible actions undertaken by household groups in the Madiama commune and their income impacts. The model does not pretend to generate solutions to the natural resource management but can contribute to stimulate the reflection about the issue.

In Section 5.2.1 we discuss the limitations of the social accounting matrix approach with respect to the dynamics this thesis addresses. In Section 5.2.2 we discuss the basic structure of the CGE model showing the type of linkages the modelling approach can take into consideration. We also discuss the way the SAM is incorporated into the model and how it is calibrated for the benchmark results. In the next section the specificities of village level modelling are discussed in detail.

5.2.1. SAM limitations and relevance of the CGE model

The SAM is constructed, based on the following assumptions; (i) fixed prices (ii) excess capacity (elastic supply) and (iii) linear, fixed-proportion inputs on the production side. Such assumptions make SAM-based models unable to fully and adequately address policy issues for the reasons hereafter:

The fixed-price assumption: With this assumption, prices are not explicitly present in the model, while prices play a critical role in the economy. In a perfect neoclassical context, prices are given (derived) by (from) the market forces and production and consumption decision are based on such exogenous prices. The commune of Madiama, like most Sahelian rural areas, is characterized by imperfect (non neoclassical) markets; for example, labor and staple commodities do not have perfect markets. Shadow prices on them may differ from their market prices (wages for labor and market prices for non-tradables).

Using SAM-based models for policy simulations raises the main concern about (i) whether prices change in response to exogenous shocks and (ii) whether price changes induce changes in the SAM expenditure share matrix.
Because the commune economy is a relatively small entity, it is likely to be a price-taker for some commodities, but shadow prices will replace market prices for some other goods or factors, in presence of missing or imperfect markets. Whatever the prices are (market prices or shadow prices) they need to be accounted for, in any realistic model in order to be policy relevant.

*Excess capacity or elastic supply assumption:* it is assumed in the SAM that there exists an excess capacity (elastic supply) and unemployed factors of production in all sectors. The whole system is demand-driven like in a Keynesian model where no resource constraint prevails. This is a serious limitation since there exist some binding constraints in some factors such as land, inputs (fertilizers for example, as a result of a market imperfection or of the presence of transaction costs). Prices are expected to allow for adjustments to supply variation, thus guiding resources to their most productive use inside and outside the commune. Resource constraints tend to generate high shadow prices for the related resource. This assumption, made in the SAM is not likely to be policy relevant since price effects cannot be accounted for.

*Linear, fixed-proportion inputs on the production side:* this assumption implies constant marginal productivities of factor inputs, which is not always realistic since production function may exhibit decreasing or increasing marginal productivities. CGE models were developed to overcome the above limitations to the SAM.

**5.2.2. The basic structure of the CGE standard model**

*The circular flow of exchange as a foundation to the Social Accounting Matrix*

CGE models were originally developed at the level of the national economy. The circular flow of commodities in a closed economy (Figure 5.1) is the conceptual starting point and the foundation to the SAM and the CGE models. In this framework (See Varian, 1992; Besanko et al. 2005:596-610):

- households are endowed with factors of production and are final consumers;
- firms rent factors of production from households to produce goods and services;
- Government levies taxes and deliver goods and services from and to both households and firms.

Households receive factor and capital payments from firms; they use in turn such payments as their income to purchase goods and services produced by firms.

The physical principle of material balance states that the quantity of a factor with which households are endowed or of a commodity that is produced by firms must be completely absorbed by the firms or the households (respectively) in the rest of the economy.
The budgetary balance principle (in value terms) says that for each sector in the economy the value of expenditures must be balanced by the value of incomes. Moreover, the production of each sector must be matched by others’ uses (both by firms and households). Similarly, each activity’s income must be balanced by others’ expenditures. Such accounting rules are the cornerstones of the Walrasian general equilibrium and the principle of no free disposability holds since all flows of goods and factors are fully absorbed by the production and consumption activities in the economy. Therefore, this implies that households’ endowment of factors is fully employed by firms and that outputs from firms are completely consumed by households.

For a given commodity the produced quantity must be equal to the sum of the quantities demanded by the other firms and households in the economy. Similarly for a given factor the quantities demanded by firms must completely exhaust the aggregate households’ supply of this factor. This is the market clearance condition (See equation (5.1) below).

On the side, total revenue from the production of goods by firms must be allocated either to households as receipts or factors income, to industries as...
payments for intermediate inputs or to government as taxes. Furthermore, the value of a unit of each commodity in the economy must then equal the sum of the values of all inputs used to produce it i.e. the cost of intermediate inputs plus the payments to the primary factors used in its production process. Such conditions imply that in equilibrium, *producers make zero profit* (See equation (5.2) hereafter).

As stated earlier, households exhaust their income (obtained as factor payments) on good purchases after fully employing their endowments; this sends back to the balanced-budget accounting known as *income balance principle* (see equation 5.3). One can analogously to the industries’ case, think of the zero profit condition as for the production of a “utility good” whose value is the aggregate of the values of the households’ expenditures on commodities and whose price is the marginal utility of income.\(^{44}\)

Conditions (5.1)-(5.3) i.e. market clearance, zero profit and income balance are the foundations to CGE models that essentially solve for the set of prices and the allocation of goods and factors that support general equilibrium.

Three assumptions are made about this economy to keep things simple. First, there are no tax or subsidy distortions, or quantitative restrictions on trade. Second, the households act collectively as a single representative agent\(^ {45}\) who rents out the factors to the industries in exchange for income. Households then spend the latter to purchase the \(N\) commodities for the purpose of satisfying \(D\) types of demands (e.g., demands for goods for the purposes of consumption and investment). Third, each industry behaves as a representative firm that hires inputs of the \(F\) primary factors and uses quantities of the \(N\) commodities as intermediate inputs to produce a quantity \(y\) of its own type of output (see list of symbols and indices in Annex 5.1) The conditions (5.1)-(5.3) can be mathematically formulated as follows, letting:

- the indices \(i \in \{1, ..., N\}\) denote the set of commodities,
- \(j \in \{1, ..., N\}\) the set of industry sectors, \(f \in \{1, ..., F\}\) the set of primary factors, and \(d \in \{1, ..., D\}\) the set of final demands, that is the demands for commodities after the intermediate inputs demands are satisfied. For simplicity, it is assumed that each firm produces one good and firms are the only producers while households are consumers who hire out their endowed factors to firms. Firms may also use intermediate goods in combination with those primary factors to produce.
- \(\bar{y}_i\) be the value of total supply of commodity \(i\), \(y_j\) the value of gross output of sector \(j\), \(\bar{x}_{ij}\) the intermediate input of good \(i\) used by firm \(j\), \(\bar{v}_{ij}\)

\(^{44}\) No assumption is needed on the utility function for this to be true. The comparison with the production’s case permits including the price of the “utility good” in the profit maximization problem and then drawing the marginal utility of consumption.

\(^{45}\) The concept of representative agents is used in this exposition on the economic flow; symbols with stripes refer to the representative agents (firms and households).
the payment for factor f by sector j, \( g_{ij} \) the final demand for good i, \( V_f \) the representative household’s endowment of factor f and \( m \) its income.

\textit{For the commodity market clearance:}

\[ \bar{y}_i = \sum_{j=1}^{N} \bar{x}_{ij} + \sum_{d=1}^{D} \bar{g}_{id} \]  

(5.1)

where \( \bar{y}_i \) stands for the value of total supply of commodity i, \( \sum_{j=1}^{N} \bar{x}_{ij} \) the value of intermediate input uses of goods i by firms and \( \sum_{d=1}^{D} \bar{g}_{id} \) the final demand of all goods.

\textit{For the factor market clearance:}

\[ \bar{V}_f = \sum_{i=1}^{N} \bar{v}_{ij} \]  

(5.2)

where \( \bar{V}_f \) is the representative agent’s endowment of factor f and \( \bar{v}_{ij} \) the use of factor f by industry j.

\textit{For the zero profit principle:}

\[ \bar{y}_j = \sum_{i=1}^{N} \bar{x}_{ij} + \sum_{f=1}^{F} \bar{v}_{jf} \]  

(5.3)

where \( \bar{y}_j \) is the value of gross output, \( \sum_{i=1}^{N} \bar{x}_{ij} \) the value of intermediate input uses of goods i and \( \sum_{f=1}^{F} \bar{v}_{jf} \) the value of primary factors employed by firms j.

\textit{For the income balance:}

\[ \bar{m} = \sum_{f=1}^{F} \bar{V}_f = \sum_{i=1}^{N} \sum_{d=1}^{D} \bar{g}_{id} \]  

(5.4)

where \( \bar{m} \) represent the representative household’s income, \( \sum_{f=1}^{F} \bar{V}_f \) stands for factor rental and \( \sum_{i=1}^{N} \sum_{d=1}^{D} \bar{g}_{id} \) is total expenditures (for final and input commodities).
Combining the above four equalities leads to a SAM which is nothing but a snapshot of the inter-industry and inter-activity flows of value within an economy that is in equilibrium in a particular benchmark period (see later in this section for analogy with the SAM).

**The SAM as a basis to the CGE model**

A rather relevant question is how we can proceed from a SAM to a CGE model. It should be clear that the CGE models’ algebraic framework results from the imposition of the axioms of producer and consumer maximization on the accounting framework of the SAM. Cobb-Douglas functions are usually assumed –because of their tractability– for households’ preferences and firms’ production functions.

That is, a household maximizes its utility, which can be depicted as follows:

\[
\text{Max } U(c_i) = A_i {c_i^{\alpha_1} c_2^{\alpha_2} \ldots c_N^{\alpha_N}} = A_i \prod_{i=1}^{N} c_i^{\alpha_i}
\]  

(5.5)

(with \(\alpha_1 + \alpha_2 + \ldots + \alpha_N = 1\))

subject to the budget constraint \(m = \sum p_i (c_i + s_i)\) where \(c_i\) and \(s_i\) stand for consumption and saving respectively of commodity \(i\) and \(p_i\) the price of commodity \(i\).\(^{46}\)

The household which maximizes its utility will have no surplus budget available; an alternative approach leads to the following:

\[
\text{Max } p_i U - \sum_{i=1}^{N} p_i c_i
\]  

(5.6)

subject to \(U(\cdot) = A_i \prod_{i=1}^{N} c_i^{\alpha_i}\).

Solving this problem gives the household’s demand function for the consumption of commodity \(i\) as:

\[
c_i = \alpha_i \left( m - \sum_{i=1}^{N} p_i s_i \right) / p_i
\]  

(5.7)

\(^{46}\) The first order condition is \(\lambda = \partial U / \partial c_i\) for all \(i\); \(\lambda\) is the Lagrangean, standing for the marginal consumption, identical for each commodity.
and \( \alpha_i = \frac{c_i p_i}{\left( m - \sum_{i=1}^{N} p_i s_i \right)} \) which is the exponent of the utility function and can be interpreted as the share of each commodity in the total value of consumption.

On the producers’ side, we have an analogous proceeding that is a profit maximization process. The producer’s problem is thus:

\[
\text{Max } \pi_j = p_j y_j - \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_{jf} v_{jf} \tag{5.8}
\]

(where \( p_j, p_i, w_j \) are respectively the price of output, the price of input good and factor cost), subject to the following production function:

\[ y_j = \phi_j (x_{ij}, \ldots, x_{Nj}; v_{1j}, \ldots, v_{Fj}) \] where \( y_j, x_{ij}, v_{jf} \) are as previously defined.

Assuming the tractable Cobb-Douglas production function, we can rewrite the production function as:

\[ y_j = A_j (x_{1j}^{\beta_{1j}} x_{2j}^{\beta_{2j}} \ldots x_{Nj}^{\beta_{Nj}}) (v_{1j}^{\gamma_{1j}} v_{2j}^{\gamma_{2j}} \ldots v_{Fj}^{\gamma_{Fj}}) = A_j \prod_{i=1}^{N} x_{ij}^{\beta_{ij}} \prod_{f=1}^{F} v_{jf}^{\gamma_{jf}} \] where \( \beta_{ij} \) and \( \gamma_{jf} \) are the Cobb-Douglas coefficients, with \( \beta_{1j} + \ldots + \beta_{Nj} + \gamma_{1j} + \ldots + \gamma_{Fj} = 1 \).

Solving the producer’s problem yields:

(i) his demand for intermediate inputs of commodities:

\[ x_{ij} = \beta_{ij} \frac{p_j y_j}{p_i} \tag{5.9} \]

(ii) his demand for primary factors: \( v_{jf} = \gamma_{jf} \frac{p_j y_j}{w_f} \tag{5.10} \)

Rearranging (5.9) and (5.10) gives \( \beta_{ij} = \frac{p_i x_{ij}}{p_j y_j} \) and \( \gamma_{jf} = v_{jf} \frac{p_j y_j}{w_f} \) respectively, that will be estimated later.

Similarly to the demand for consumption goods above, the exponents of the Cobb-Douglas production function represent the shares of their respective inputs to production in the value of output.

In order to step to the general equilibrium, equations (5.7), (5.9) and (5.10) are examined; they are the building blocks from which a CGE model is constructed. They are bound together by the general equilibrium conditions algebraically developed above. [Eq. (5.1)-(5.4)]. Equations (5.7), (5.9) and (5.10) are then
substituted into them in order to get the equations that a CGE model uses to solve for equilibrium.

Thus, equation (5.1) becomes: 

$$ y_i = \sum_{j=1}^{N} x_{ij} + c_i + s_i $$  

(5.11)

illustrating the commodity market clearance condition which states that the value of each commodity supplied must equal the sum of the value demand of that commodity by the $j$ producers in the economy as an intermediate input to production, and by the representative agent as an input to consumption and saving activities.

From equation (5.2) (the factor market clearance condition), the quantities of primary factor $f$ used by all producers must sum to the representative agent’s endowment of that factor $V_f$; that is

$$ V_f = \sum_{j=1}^{N} v_{fj} $$  

(5.12)

The zero profit principle states that the value of output generated by producer $j$ must equal the sum of the values of intermediate goods $i$ and of $f$ primary factors employed in production. This implies that equation (5.8) be set to 0 and be rewritten as

$$ \pi_j = p_j y_j - \sum_{i=1}^{N} p_i x_{ij} - \sum_{f=1}^{F} w_f v_{fj} = 0. $$

Rearranging this equation gives

$$ p_j y_j = \sum_{i=1}^{N} p_i x_{ij} + \sum_{f=1}^{F} w_f v_{fj} $$  

(5.13)

which is the analogous of equation (5.3).

The income balance principle implies that the income of the agent must equal the value of producers’ payments to him for the use of the primary factors that he owns and hires out. Thus, as in equation (5.4), the balancing income is

$$ m = \sum_{j=1}^{F} w_j V_f $$  

(5.14)

Equations (5.11) – (5.14) form the core of a CGE model. To see how the model solves, the concept of excess quantities is used by assuming that the endowments of the representative agent are fixed at the time the general equilibrium prevails. It can be easily seen that substituting (5.9) into (5.11) and (5.13) that Walras’ law is satisfied which states that the sum of the values of market demands equal the sum of the values of market supplies (Varian, 1992: 343).
Model calibration and solution

The circular flow in this economy can be completely characterized by three data matrices: an \( N \times N \) input-output matrix of industries’ uses of commodities as intermediate inputs, denoted by \( \bar{X} \), an \( F \times N \) matrix of primary factor inputs to industries, denoted by \( \bar{V} \), and an \( N \times D \) matrix of commodity uses by final demand activities, denoted by \( \bar{G} \).

Referring to Figure 5.2 below, equations (5.1) and (5.3) are respectively checked in rows and columns for the benchmark (reference) year.

\[
\bar{X} + \bar{G} = \bar{y}_i \quad \text{in rows (Eq. 5.1)}.
\]

\[
\bar{X} + \bar{V} = \bar{y}_j \quad \text{in columns (Eq. 5.3)}.
\]

\[
\begin{array}{c|c|c|c}
1 & \cdots & j & \cdots & N \\
\hline
1 & \cdots & \cdots & \cdots & \cdots \\
\hline
\bar{X} & \bar{G} & \bar{y}_1 & \cdots & \bar{y}_N \\
\hline
\bar{V} & \bar{V}_F & \bar{G}_1 & \cdots & \bar{G}_D \\
\hline
\bar{y}_1 & \cdots & \bar{y}_N & \bar{G}_1 & \cdots & \bar{G}_D \\
\end{array}
\]

Source: Adapted from Wing (2004, op. cit.).

Figure 5.2: Input-output matrices in a closed economy

Given the assumption of a closed economy with no tax distortions, the above figure portrays the economy as the SAM describes it and the two equalities (in rows and in columns) set the relationship between the variables. This stylized format is the foundation to even more complicated (more realistic) SAMs that include government (for tax distortions) and trade (world outside the commune); the embedded logic in equations (5.1)-(5.4) is kept throughout the model.

Numerical calibration, which consists of replicating the SAM values using relationships such as utility and production functions to reflect agents’ behavior at the time the SAM was constructed. The crucial step in this regard is to compare equations (5.1)-(5.4) with equations (5.11)-(5.14). The pairs (5.1) and (5.11), (5.2) and (5.12), (5.3) and (5.13), and (5.4) and (5.14) exhibit a striking symmetry. In particular, the elements of each pair are equivalent if \( \pi_j = 0 \) (zero profit, which is assumed), \( p_i x_{ij} = \bar{x}_{ij} \) and \( w_f v_{pj} = \bar{v}_{pj} \).
Therefore, a fundamental equivalence may be drawn between the equations in a CGE model and the benchmark flows of value in a SAM by assuming that in the benchmark year all prices are equal to unity\textsuperscript{47}.

Basically, CGE models which are highly non-linear, use data from a single year (such as the SAM) to estimate input-output coefficients and different share coefficients; they draw on other partial studies for estimates of important behavioral parameters such as elasticities determining supply and demand behavior of economic actors. In other words, two kinds of parameters are present: (i) share parameters such as input costs, consumer expenditure shares estimated from the SAM under the assumption that the base year represented by the SAM as an equilibrium solution of the CGE model and (ii) elasticity parameters describing the curvature of various structural functions such as production functions, utility functions,… which are taken from other studies, based on research conducted in other contexts.

The production function is of the Leontief type (fixed input and output coefficients) with technologies to allow for a 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. The Leontief representation includes zero inputs in its domain and can allow for input substitutability by including several techniques for each activity.

All prices are treated as index numbers with a value of unity in the benchmark, and all value flows in the SAM are therefore treated as quantities for the reference period (for which the SAM is built). These assumptions allow the technical coefficients and elasticity parameters of the utility and production functions to be directly solved for. The values of those parameters replicate the benchmark equilibrium i.e. solve the numerical problem and set the quantities of the variables equal to the corresponding flows in the SAM. Input demand and primary factor demand are computed from the SAM while $\alpha_i$, $A_C$, $A_j$ are taken from Löfgren et al (2003) in order to derive other parameters such as $\gamma_j$ and $\beta_j$, as the IFPRI model is adapted to our case study.

5.3. The use of a CGE model for a site-specific economy

Because CGE models overcome the SAM limitations enlisted above, they are particularly useful for policy impact analysis. Originally developed at the national level, Computable General Equilibrium models rely on SAMs for calibration. Given that computational cost has drastically dropped, Whalley (1986) emphasized the need “to move from the general to specific-purpose

\textsuperscript{47} The excess demand function is homogenous of degree zero; multiplying all prices by a positive number does change neither the excess demand nor the agent’s behavior. We are free to set the prices to 1.
models if general equilibrium analysis has to become more policy relevant”. He suggests that future efforts be devoted to constructing special purpose models “tailored to address special issues”. In this vein, many researchers have developed general equilibrium models applied to the agricultural sector, to a specific region to address particular issues. Regional disaggregation allows to adequately capture the impact of agricultural or resource policy (Hertel, 1986). Kraybill et al. (1992) disaggregated the United States into a region (the State of Virginia) and the rest of the country in order to analyze policy impact. Similarly, Vargas et al. (1999) developed a regional CGE model for the Oklahoma state.

One decade after Whalley’s recommendation, Taylor et al. (1996) in Village Economies, go beyond SAMs constructed for villages from which they developed village computable general equilibrium models. Such micro-computable general equilibrium models “occupy a middle ground between household-farm models and aggregate national CGE models for policy analysis”. Like household models, they are rooted in the (local) micro-economy and constructed from the bottom-up, using household-farm survey data. This makes it possible to capture the complex linkages and general-equilibrium feedbacks among household-farms that shape the effects of exogenous shocks on local economies. Simulations using regional models are unique in their ground-level view of the possible impacts of exogenous policy and market changes on local economies, a view which is critical for designing development studies (Taylor et al., 1996).

5.3.1. The village CGE model developed by Taylor et al. (1996)

Taylor et al. (1996) pioneered in developing village CGE using village SAMs. They accounted for households and village specificities, following (Singh et al. 1986). It is true that in the village economy, purchase and sale prices may differ for the same commodity, or some markets are imperfect. This leads to the farm-households assuming non-separability (non-recursiveness). A household model is said to be non-separable when the household’s decisions regarding production (use of inputs, choice of activities, desired production levels) are affected by its consumer characteristics (consumption preferences, demographic composition, etc.). By contrast, in a separable model, the household behaves as a pure profit maximizing producer. The profit level achieved in turn affects consumption, but without feedback on production decisions (De Janvry et al. 2006: chapter 8, page 2).

Taylor et al. (1996) depart from the neoclassical household-farm model: they do not make the assumption that all goods are household tradables. For example, hired labor is not a perfect substitute for family labor and we are then in presence of a missing market for the family labor. Therefore, the household faces a constraint of balancing its total (fixed) supply of time with its demand for leisure time and income activities. The allocation of family time between
leisure and income activities is guided by the opportunity cost (shadow price) of family time (which is equal to the marginal utility of leisure), and by marginal utility of income. They assume that the village and the households are price-takers for most goods and only few households are self-sufficient. Most goods can therefore be considered to be tradable at the household level and their prices are determined inside or outside the village. Imported or exported goods are village tradables. Since village SAMs are consistent benchmark data sets reflect observable behaviors and specify relationships; Taylor et al. (1996) used them, as village-wide economy equilibrium picture, to develop their village CGE models for different locations. Households are assumed to be utility and profit maximizing units; utility and production are of Cobb-Douglas functional forms whose parameters are estimated from the data contained in the SAM. The other relationships in the CGE model also derive from the SAM as seen in the previous section.

Basically the village CGE model developed by Taylor et al. (1996) lies on the same theoretical foundations as the standard one presented earlier; they just qualify it according to the local specificities of the village and to the circumstances and behavior of the households.

Their model assumes that households and producers maximize Cobb-Douglas utility and production functions subject to some constraints largely deriving from the usual CGE model foundations highlighted above. Some interesting features include the re-specification of the utility function as well as the constraints accounting for the village and the farm-households’ specificities. Namely, the utility function includes leisure as a contributor to the households’ utility along with goods. The cash income (budget) constraint accounts for the households’ net profit and remittances from internal and international migrants (an exchange rate converts them into local currency).

The production function includes tradable inputs (hired labor for example), capital inputs and family labor. The important concept of tradables is thus relevantly accounted for, highlighting the site-specificity of the village and particular circumstances of farm-households. Not all commodities or factors are sold or purchased in the context of a village; sometimes there is no market for some of them.

So far, it can be noted that household time availability enters the model in three ways: in the utility function as leisure, as a production factor (family labor) and in the form devoted to migration.

Assuming the household’s budget and income constraints binding, the model gives (i) the conditions determining the endogenous village market-clearing (material-balance): it includes government demand, investment and village marketed surplus; (ii) the factor supply-demand balance including imported factors; (iii) the equilibrium condition in the local capital market and (iv) the village trade (with outside) balance conditions. It should be noted that for the village the outside world is the rest of Mali.
Although enriching in terms of providing insights into a local economy with its own specificities, the model developed by Taylor et al. op.cit. does not explicitly account for the household market participation regime, which has critical implications for policy decision-making.

5.3.2. The IFPRI Non-separable farm-household CGE model

The IFPRI model is developed to simulate farm-household behavior; rooted into non-separability it includes price gaps (due to transaction costs) and endogenously determines household’s market participation regime.

The optimization version of the model is first developed and its mixed complementary version is derived to better address the market participation regime shift issue and operationalize the whole model.

The household maximizes utility $U(.)$. In the present case, a Cobb-Douglas utility function is assumed.

$$MaxU = U(q_1^c, q_2^c, ..., q_n^c)$$

(5.15)

where $U(.)$ is the utility function, $q_i^c$ is the consumption of commodity $i$ ($i=1,2,\ldots,n$) subject to:

a. Production function

$$q_i^c = X_i(q_1^c, q_2^c, ..., q_n^c)$$

(5.16)

where $X(.)$ is the neo-classical production function, $q_i^c$ the production of commodity $i$ as it is derived from the first order conditions of the profit maximization problem, and $q_i^c$ as input factors.

B. Balances for factors and commodities

$$q_i^c + q_i^h + q_i^n = q_i^c + \sum_{j=1}^{n} q_j^h + q_i^c$$

(5.17)

References:

48 The model formulation is drawn from Löfgren et al. (1999) and the GAMS code for the farm-household was obtained from IFPRI and adapted to the Madiama case.

49 The $i$ indices should be replaced with $f$ throughout in this section, when dealing with factors in relevant cases. In the case of (5.17) above, the factor counterpart would be

$$q_j^h + q_j^p = q_j^h + \sum_{j=1}^{n} q_j^h + q_j^p$$

The reasoning for commodities applies, when relevant to factors; equations are not rewritten with the $f$ index for ease of presentation.
where \( q_i^p \) is the production of commodity i, \( q_i^b \) the endowment of commodity/factor i, \( q_i^p \) the quantity i purchased, \( q_i^c \) the consumption of commodity/factor i, \( q_i^j \) the quantity of i as an input for j and \( q_i^s \) the quantity of commodity sold. On one hand, for a given commodity/factor, the produced quantity plus the household endowment and the purchased quantity should be equal to the quantity consumed, plus the quantity sold and the quantity demanded as inputs, on the other hand.

\[
\text{b. Cash constraint}
\]

\[
\sum q_i^p \overline{p}_i^p = \sum q_i^s \overline{p}_i^s \tag{5.18}
\]

where \( \overline{p}_i^p \) and \( \overline{p}_i^s \) are purchase and sales prices respectively.

In other words, the income spent for the different purchases is strictly equal to the total receipts (earnings) from the sales of all commodities.

\[
\text{c. Non-negativity constraints:} \text{ purchase and sales quantities should be non-negative.}
\]

\[
q_i^p \geq 0 \quad ; \quad q_i^s \geq 0 \tag{5.19}
\]

where \( q_i^p \) is the purchased quantity of commodity/factor i and \( q_i^s \) the sold quantity of commodity/factor i.

The Mixed Complementary Problem\(^{50}\) (MCP)
The above maximization model can be solved as a non-linear programming problem but purchase prices should be distinguished from sales prices, with \( \overline{p}_i^p > \overline{p}_i^s \), due to transaction costs.

The MCP version is derived from the optimization one, after manipulating the first order conditions. This version is rather useful because it highlights some features of the model kept implicit in the optimization version, namely: (i) profits and utility are maximized on the basis of a household-specific shadow prices, (ii) if an item is sold or purchased, its shadow price is the same as sales or purchase price (iii) if an item is not traded, its shadow price is free to vary; to the extent that trading takes place, the sales and purchase prices have lower and upper limits respectively. That is, the shadow price is equal or less than purchase price or it is equal or greater than sales price. In other words, the MCP version

\(^{50}\) See Rutherford (1995); Tin-Loi et al. (1996), Ferris and Munson (1998); Ferris and Kanzow (1998) for mixed complementarity problems.
includes not only some equations of the optimization (production function, the level of production, commodity/factor balances) version but also equations related to institutional consumption, income and input demand (based on shadow prices) and inequalities on price conditions. Formally, the equations included in this version are:

**Production Function**

\[ q_i^* = X_i(q_1^*, q_2^*, \ldots, q_n^*) \] as defined above in (5.16) (5.20)

**Input demand**

\[ q_{ij}^* = I_i(p_i^h, p_j^h, \ldots, p_n^h, q_i^c) \] (5.21)

where \( q_{ij}^* \) is the input demand, \( I(.) \) the neo-classical demand function, \( p_i^h \) and \( q_i^c \) are respectively the shadow price for commodity/factor i and produced quantity of i \( (p_i^h = p_i^c / \lambda \) where \( p_i^c \) is marginal utility).

**Factor and Commodity balance**

\[ q_i^* + q_i^p + q_i^c = q_i^c + \sum_{j=1} q_{ij}^* + q_i^c \] defined as above in equation (5.17). (5.22)

**Price conditions / Market regime** (only for items that can be sold or purchased).

For \( p_i^p \geq p_i^h \)

\[ : \] if the item is sold \( (q_i^c \geq 0); p_i^h \) and \( p_i^c \) are the commodity/factor shadow price and sales price. If \( p_i^h > p_i^c \), then \( q_i^c = 0; \) for \( p_i^h = p_i^c \), \( q_i^c > 0 \). The market regime (participation in the market) is thus determined by some limits to the commodity shadow price.

The mixed complementarity approach allows explicit specification of market regimes. The first regime is characteristic of goods and factors of production for which the commune is a price taker (traded commodities with the world outside the commune setting the price). In the second regime, goods and factors of production are not traded outside the commune but are traded amongst households. The third regime is the case where the goods and factors of production are not traded at all. These regimes can vary between households.
Income

\[ y = \sum_{i=1}^{n} p_i^h q_i^h \]  

(5.24)

where \( p_i^h \) and \( q_i^h \) are defined as above. The household income \( y \) is equal to all its commodities (or factors, see footnote 49) valued at their shadow prices.

Consumption

\[ q_i^c = c_i(p_i^h, p_i^s, \ldots, p_i^u, y) \]  

(5.25)

where \( C(.) \) is the neo-classical consumption function; \( q_i^c \) which is the consumption of commodity(factor) \( i \) depends on shadow prices of all commodities/factors and the income.

5.3.3. The merits of the IFPRI model

Conversely to most CGE models, the current one accounts for the mixed complementarity problem and the non-separability (non-recursiveness) in farm-household decision. While price gaps between purchase and sales prices are implicit and exogenous in the Taylor’s household model, the IFPRI CGE model treats them as explicit and endogenous i.e. depending on the prices of transaction inputs or factors. Another desirable and innovative feature of the model is the introduction of additional links between decision making units (households) and activities: every activity is associated with a decision making unit but all decision making units are not necessarily related to any activity. This further disaggregation allows for an in-depth analysis of policy impact. This model is reasonably adequate for the Madiama commune due to the presence of market imperfections and transaction costs for most goods. For example, shadow prices are given not only for different goods and factors but also for the different categories of households since they don’t have the same factor endowments and do not produce the same type of goods. Farmers are probably more self-sufficient in millet than transhumant pastoralists who rely on market for this cereal. In contrast, farmers are far needier in milk than pastoralists and should enter the market to purchase it.

The Madiama SAM was modified to fit into this innovative CGE model, namely linking activities and decision making units (household). Table 5.1 gives the link activities-households as they were introduced in the model.

Decisions by households as decision making units associated with activities are made on the basis of the household-type shadow prices that clear balances. In the presence of transaction costs, those shadow prices are influenced by household-type trading position (sale, purchase or self-sufficient).
Equations of the farm-household CGE model are presented in Annex 5.2. Equations 1-5 are related to the price system. The term item is used for both commodities and factors. Equation 1 states that the household $u$ may purchase item $i$ but the upper price limit should be the sum of the market price plus the household and item specific unit transaction cost for purchase. It is linked to an associated non-negative variable $q_{iu}$ (the purchased quantity of commodity $i$ by household $u$) in a complementary-slackness condition. A similar interpretation is given to Equation 2 in the case of sales. Equation 3 defines the prices on the basis of which activities make profit maximizing conditions and there is a mapping between household prices to the corresponding activities. Equations 4 and 5 define the upper and lower limits for commune market prices; they are associated with complementary-slackness conditions: non-negative quantities of imports and exports.

Equations 6-8 define output supply, input demand and the profit maximization rule in Leontief technology conditions. Equations 9 and 10 are related to the household incomes and spending. The Cobb-Douglas consumption demand function which is used in the model allows the derivation of equation 10. Equation 11 gives institutional demands for transaction items, while equation 12 defines institution-level market: participation in the market (or not) depending on the price level (this equation is associated with a complementary-slackness condition on price). Equation 13 defines the market equilibrium condition for exchanged item by the household while equation 14 is the commune account balance and equation 15 the price numéraire.
Table 5.1: Association between Activities and households in the farm-household CGE model

<table>
<thead>
<tr>
<th>PRODUCTION ACTIVITIES</th>
<th>MICRO-ENTREPRISE ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Activity</strong></td>
<td><strong>Household</strong></td>
</tr>
<tr>
<td>Mil</td>
<td>Farmer</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Farmer</td>
</tr>
<tr>
<td>Rice</td>
<td>Farmer</td>
</tr>
<tr>
<td>Other cereals</td>
<td>Farmer</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Farmer</td>
</tr>
<tr>
<td>Legumes</td>
<td>Farmer</td>
</tr>
<tr>
<td>Small Ruminants</td>
<td>Farmer</td>
</tr>
<tr>
<td>Large Ruminants</td>
<td>Farmer</td>
</tr>
<tr>
<td>Poultry</td>
<td>Farmer</td>
</tr>
<tr>
<td>Fish</td>
<td>Farmer</td>
</tr>
<tr>
<td>Mil</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Rice</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Other cereals</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Legumes</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Small Ruminants</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Large Ruminants</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Poultry</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Fish</td>
<td>Agro-pastoralist</td>
</tr>
<tr>
<td>Mil</td>
<td>Sed. Pastoralist</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Sed. Pastoralist</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Sed. Pastoralist</td>
</tr>
<tr>
<td>Small Ruminants</td>
<td>Sed. Pastoralist</td>
</tr>
<tr>
<td>Large Ruminants</td>
<td>Sed. Pastoralist</td>
</tr>
<tr>
<td>Poultry</td>
<td>Sed. Pastoralist</td>
</tr>
<tr>
<td>Milk</td>
<td>Sed. Pastoralist</td>
</tr>
<tr>
<td>Mil</td>
<td>Transhumants</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Transhumants</td>
</tr>
<tr>
<td>Rice</td>
<td>Transhumants</td>
</tr>
<tr>
<td>Small Ruminants</td>
<td>Transhumants</td>
</tr>
<tr>
<td>Large Ruminants</td>
<td>Transhumants</td>
</tr>
<tr>
<td>Poultry</td>
<td>Transhumants</td>
</tr>
<tr>
<td>Milk</td>
<td>Transhumants</td>
</tr>
</tbody>
</table>
5.4. Parameterization and Calibration of the commune CGE model

CGE models essentially replicate a Walrasian system in which only relative prices matter. Relative prices in this material exchange economy lead to an equilibrium by making the set of excess demand equations equal zero given that consumers maximize utility under their budget constraints and producers their profits under technological constraints. However, for the Madiama commune characterized by market imperfection and transaction costs, as stated in the previous chapter, households do not sequentially maximize profit and then utility; the CGE is not built on those neo-classical assumptions of separability (De Janvry et al. 2006) but rather on non-separability hypothesis. The farm household maximizes profit and utility on the basis of a set of household-specific shadow prices. If an item is sold or purchased, its shadow price is identical to the sales or purchase price, respectively. 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.

In the section on model calibration in Section 5.2.2 we discussed the basic source of the core data, namely the SAM which can be considered as the base run outcome or benchmark of the CGE model. The parameters that dictate the curvature of the non-linear relationships in the CGE model can be determined in different ways.

There are usually two alternative approaches to the specification of parameters in CGE models: econometric estimation and calibration\(^{51}\) to a benchmark. Econometric estimation appears to be the most accurate way to get parameters that enter the CGE model but requires a lot of data which are available neither in quantity nor in quality, particularly in developing countries. Calibration is therefore conducted by using secondary sources or making “learned guesses” on parameters entering the calibration process.

Many elaborate specifications of demand and supply functions are often used which lead to a high number of parameters to be obtained exogenously. Simpler specifications are clearly to be preferred if they adequately can be used to address the issues at hand and computationally tractable functions are generally used. In the CGE model for the Madiama rural commune, a Leontief production function and a Cobb-Douglas utility function were used. In both cases, most parameters were determined by the calibration process given the first order conditions for the Leontief and the Cobb-Douglas functions (see equations 6-12 in Annex 5.2), except for the elasticity substitution parameter which was taken from Löfgren et al. (2003).

SAM transaction cost is disaggregated between decision making units: for commodities, transactions costs are associated with a marketed surplus. The

---

\(^{51}\) The calibration consists of replicating the SAM (the benchmark situation) using the CGE model.
share of surplus commodity that is traded by household is computed (Table 5.2) as the total proportion of transaction spending on a given item with the surplus of commodity that is faced by the household. The computation is based on field data collected in the commune.

Table 5.2: Shares of Transaction spending

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Farmers</th>
<th>AGP</th>
<th>SP</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millet</td>
<td>0.703</td>
<td>0.222</td>
<td>0.058</td>
<td>0.017</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rice</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OCER</td>
<td>0.143</td>
<td>0</td>
<td>0</td>
<td>0.857</td>
</tr>
<tr>
<td>Veget</td>
<td>0.487</td>
<td>0.305</td>
<td>0.012</td>
<td>0.197</td>
</tr>
<tr>
<td>Legumes</td>
<td>0.284</td>
<td>0.195</td>
<td>0.469</td>
<td>0.052</td>
</tr>
<tr>
<td>Srum</td>
<td>0.257</td>
<td>0.257</td>
<td>0.395</td>
<td>0.09</td>
</tr>
<tr>
<td>LRum</td>
<td>0.069</td>
<td>0.069</td>
<td>0.697</td>
<td>0.165</td>
</tr>
<tr>
<td>Pltry</td>
<td>0.328</td>
<td>0.328</td>
<td>0.209</td>
<td>0.136</td>
</tr>
<tr>
<td>Milk</td>
<td>0.453</td>
<td>0.254</td>
<td>0.293</td>
<td>0</td>
</tr>
<tr>
<td>Fish</td>
<td>0.43</td>
<td>0.357</td>
<td>0.153</td>
<td>0.06</td>
</tr>
<tr>
<td>Millet M</td>
<td>0.278</td>
<td>0.722</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SorghM</td>
<td>0.278</td>
<td>0.722</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RiceM</td>
<td>0.278</td>
<td>0.722</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OCERM</td>
<td>0.278</td>
<td>0.722</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SRumM</td>
<td>0.148</td>
<td>0.606</td>
<td>0.178</td>
<td>0.069</td>
</tr>
<tr>
<td>LRumM</td>
<td>0.18</td>
<td>0.289</td>
<td>0.345</td>
<td>0.186</td>
</tr>
<tr>
<td>PltryM</td>
<td>0.385</td>
<td>0.267</td>
<td>0.255</td>
<td>0.093</td>
</tr>
<tr>
<td>MilkM</td>
<td>0.167</td>
<td>0.074</td>
<td>0.608</td>
<td>0.151</td>
</tr>
<tr>
<td>FshSmk</td>
<td>0.247</td>
<td>0.753</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Retail</td>
<td>0.39</td>
<td>0.605</td>
<td>0</td>
<td>0.005</td>
</tr>
<tr>
<td>TXTLES</td>
<td>0.743</td>
<td>0.111</td>
<td>0.146</td>
<td>0</td>
</tr>
<tr>
<td>NRFP</td>
<td>0.759</td>
<td>0.198</td>
<td>0.016</td>
<td>0.027</td>
</tr>
</tbody>
</table>

For labor, transactions costs are associated with a marketed deficit. Factor transactions costs (in the form of supervision labor) are included in the payment of activities to labor.

The transaction effect was accounted for in the model by considering that the traded surplus is reduced as the transaction cost increases.

Transaction coefficients for commodities with marketed surplus are computed from the SAM as the ratio \[\text{transaction cost/commodity price market}/[(\text{value of marketed surplus of commodity i by DMU u})/\text{(price of commodity i for DMU u)}].

The market participation decision for the household is highly dependent of transaction costs; as stated above, price regimes are specified: a price regime for
goods and factors of production traded with the world outside the commune (the commune is therefore a price-taker); they are commodities traded for income generating such as crops (millet, sorghum, rice) and animals (small and large ruminants); another price regime is relative to commodities and factors not traded outside the commune but are traded amongst households (family labor that can be hired in or hired out).

Other parameters (obtained from the SAM) were used to facilitate computations. Among such parameters are:

- the value of marketed surplus of commodity i by DMU u which is computed as: \( [\text{sales of commodity i by DMU u for activity a}] - [\text{purchases of commodity i by DMU u}] - [\text{purchases of commodity i for activity a}] \).
- the marketed surplus of factor by DMU u as \( [\text{the sales of factor f by DMU u}] - [\text{purchases of factors f by activity a}] \). Institutions do not purchase factors.

### 5.5 Software considerations

The Madiama commune CGE model is implemented on the General Algebraic Modeling Systems (GAMS) improved by GTREE and eased for results display and management by DATAVIEWER module\(^\text{52}\). GAMS is a powerful and concise software based on codes for computation; it allowed for segmenting the computation code file into linked portions in order to get a higher computational performance. Our code file includes the following sub-files\(^\text{53}\):  
- The main file which contains the sets, parameters and variables as well as associated relations;  
- The calibration file which includes the calibration procedure with a test procedure providing the level of accuracy of results;  
- The scenario definition in which all parameters related to scenarios are defined;  
- The scenario execution file from which scenario options are launched.

GAMS is a powerful tool for mathematical programming problems, such as CGE modeling. It is a script-based modeling language that closely resembles the mathematical formulation of the problem, hence ensures transparency of code. Analysis results are stored and can be accessed and managed by using DATAVIEWER: options for charts, tables and export to other softwares are available.

\(^{52}\) GTREE and DATAVIEWER are both developed by LEI (Landbouw Economisch Instituut in The Hague, Netherlands) as GAMS performance boosters.

\(^{53}\) In the absence of this technique, the computation is dramatically longer.
5.6. Conclusions

The CGE model constructed and calibrated for Madiama commune shows that the distribution of productive activities is quite segmented amongst households, implying that constraints in factor availability are easily reached and exchange transactions tend to be intensified. This has profound implications for the potential effectiveness of policy incentives for both production and expenditure elasticities, as well as for local income distribution (that will be further discussed in Chapter 6).

The importance of a policy assessment model is the ability to conduct what-if analyses. Scenarios based on conditions that arise from implementing certain policies should give insight into the effects on specified indicators. The household-CGE model allows such scenario analyses.

It is important to note the assumptions made to construct the computable model, since these assumptions may influence the outcomes. We summarize the most important assumptions:

- Cobb-Douglas specifications for both consumption utility and production functions. These assumptions imply that consumer expenditure shares per consumer commodity category will remain stable, while for production there is perfect substitution. Both assumptions will hold if the shocks are not too great. For large shocks, the assumption may be unrealistic.
- Transaction costs are linked to market shares. This is a plausible assumption if the market shares in transactions for different household categories do not change dramatically. The fixed production structures in the production part of the model help prevent radical shifts so common in mathematical programming models. Again the assumption holds for not too great shocks.
- The perfect information assumption of the CGE model is limited to the commune level.