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The 84th Annual Conference of the Agricultural Economics Society

Edinburgh

29th to 31st March 2010

**MODELLING THE DISTRIBUTIONAL IMPACTS OF AGRICULTURAL POLICIES IN
DEVELOPING COUNTRIES:
THE DEVELOPMENT POLICY EVALUATION MODEL (DEVPEM)**

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1. Introduction

The purpose of the Development Policy Evaluation Model (DEVPEM) is to provide an appropriate modelling structure for analysing the welfare and distributional implications of alternative agricultural policies in developing countries. The aim of the model is to provide illustrative results that show how structural diversity among developing countries, and systemic differences from developed OECD countries, can affect the outcomes of alternative policy interventions. The model is relatively stylised, seeking to capture, as simply as possible, four critical aspects of rural economies in developing countries that are important when evaluating the impacts of agricultural and trade policies. These are:

- (1). The role of the household as both a producer and a consumer of food crops.
- (2). High transaction costs of participating in markets, resulting in a subsistence sector that often is important in terms of the number of households and the amount of food production it encompasses.
- (3). Market linkages that can transmit impacts of policy and market shocks among heterogeneous rural producers and consumers, particularly via factor markets (for labour, land or capital, when those markets exist).
- (4). The imperfect convertibility of land from one use to another.

OECD already has a model – the Policy Evaluation Model (PEM) – that is used to examine the effects of agricultural policies in member countries. PEM captures some of the market linkages referred to above (3), and a major strength lies in its treatment of land use (4). However, it contains no explicit recognition of (1) and (2). In building upon the PEM to account for these features, the aims of DEVPEM are to account for some of the systemic differences that are important in developing countries and to show how these differences can affect the results of specific policy interventions. As with PEM, the results of DEVPEM should be seen as illustrative of potential outcomes rather than predictive.

A detailed motivation for the modelling approach and a justification for focusing on the above features in a developing country context are provided in Brooks, Dyer and Taylor (2008). The model takes as its unit of analysis the agricultural household, as in the seminal work of Singh *et al.* (1986). This “building block” makes it possible to capture (1) and (2) above, the latter by having household farms confront a “price band,” defined by the market price plus (minus) the per-unit costs of transacting in consumption (output) markets, as in Strauss (1986) and de Janvry *et al.* (1991). Heterogeneous households are then embedded in a rural economy-wide structure in order to capture (3), as in Taylor *et al.* (2005). The specific modelling of land allocation adopted in the PEM is retained in order to address (4), with a constant elasticity of transformation function capturing the imperfect convertibility of land between agricultural and

livestock activities (OECD, 2005). The model is static, which means that it can be used to analyse the short to medium term impact of policy interventions on economic welfare and related indicators, such as incomes, poverty and inequality. However, there are no dynamics, so the longer run implications for growth and development cannot be gauged using this model.

A prototype model is presented for one country (Malawi), together with some preliminary policy simulation results. The aim is to develop six country models in total, with two countries from Africa (Ghana and Malawi); two from Asia (Indonesia and Vietnam); and two from Latin America (Guatemala and Nicaragua). The choice of countries is tentative and has been driven by two main considerations: first the need to reflect structural differences across countries and regions, and second the availability of harmonised and comparable household level data. The basic data input for DEVPEM is a disaggregated social accounting matrix (SAM) with individual accounts for each rural household group in the model, as well as household-specific activity accounts. The SAM is constructed with data from the United Nations Food and Agricultural Organisation's Rural Income Generation Activities (RIGA) database, which processes and harmonises national survey data, together with data from the FAOSTAT database. Indeed, DEVPEM has been designed explicitly to exploit the harmonised household level data that are available in the RIGA datasets.

Section 2 presents the model in its most general form. We begin in Sections 2.1 and 2.2 by assuming an environment of well functioning markets, as in the PEM. This is useful in illuminating the key differences between the firm-based PEM and the household-based DEVPEM when markets work well. In Section 2.3, we introduce transaction costs, which reflect market imperfections and result in some prices, for some household groups, diverging from market prices. Section 2.4 presents a simple estimable version of the model, which can be solved analytically. We also describe the structure of the SAM that will constitute the data input for DEVPEM. Section 3 describes the calibration of parameters in the consumption, production, and land supply functions, as well as the estimation of transaction costs. In Section 4, we describe a first prototype of the DEVPEM, with an application for Malawi. Simulations of price changes and input subsidies are discussed. Section 5 concludes the modelling exercise and discusses the next steps in the project.

2. The theoretical foundation of the DEVPEM

Here, we present the model without making assumptions on the specific functional forms. We first present the benchmark agricultural household model, in the spirit of Singh, et al. (1986). We then explain how imperfect land supply and transactions costs can be added to such a model.

2.1. Benchmark model with perfect markets

We assume an economy portrayed by a single representative household. There are N items in the economy, which for the household can be consumption goods, factors of production, or both (as in the case of household time endowment and the labour/leisure choice). Though in practice many items will either only be consumed, only be produced, or only used as factors, we keep a general notation for all items.

The household derives utility from consumption (C) of items i ($i \in I = \{1, \dots, N\}$). Consumption is zero for goods which cannot be consumed (such as land, for example, or fertilizer). Maximum utility is given by:

$$U^* = \max_C \{U(C)\} \tag{1}$$

where C is the $(1 \times N)$ vector of goods and factors. The household has initial endowments $E = \{E_i, i=1, \dots, N\}$, each of which can be used in farm production, marketed, or consumed, as in the case of leisure. Farm production involves the use of factor endowments and product-specific intermediate inputs. Let $Q_{ik}^f ((i, k) \in I^2)$ be the quantity of item k used in the production of item i (superscript f indicates the factor is used on the farm), so that the production of good i depends on the $(1 \times N)$ vector Q_i^f of inputs:

$$Q_i = Q_i(Q_i^f), \quad (i = 1, 2, \dots, N) \quad (2)$$

Denote Q_i^b as the quantity of item i bought on the market and Q_i^s as the quantity sold. The market balance for each item requires that the sum of endowments and total quantities produced or bought equals the sum of total quantities consumed, sold, and used as input in production:

$$E_i + Q_i + Q_i^b = C_i + Q_i^s + \sum_{k=1}^N Q_{ik}^f \quad (3)$$

Prices for goods and wage rates for factors are all given by the $(N \times 1)$ price vector p . As long as all markets work seamlessly and are connected with the rest of the world, all prices are market prices, exogenous to the household economy. As a producer, the household, as the pure agricultural firm in the PEM (OECD, 2005), takes market prices as given and makes production decisions to maximize profit. Maximum profit (π^*) from production of each farm good i is given by:

$$\pi_i^*(p) = \max_{Q_i^f} [p_i Q_i(Q_i^f) - p \cdot Q_i^f] \quad (4)$$

The household is constrained in its consumption by its farm profits and incomes from marketed factors of production. The cash constraint is expressed as:

$$\sum_{i=1}^N p_i Q_i^b = \sum_{i=1}^N p_i Q_i^s \quad (5)$$

Using equation (3), which we multiply by p_i and sum over i ; then using equations 4 and 5 we can write the “full income” constraint as:

$$pC = \pi^* + pE \quad (6)$$

In other words, the total value of goods consumed (from own production or purchased) evaluated at market prices is equal to the sum of all profits and the total market value of all endowments (also called “full income”). This is similar to the treatment of income in the agricultural household models of Singh, et al. (1986) and others, in which markets are assumed to work efficiently and the prices households face are determined in those markets.

Despite the dual nature of the household as a producer-consumer, as long as all prices are exogenous the household solves the consumer problem and the producer problem independently (Löfgren and Robinson, 1999; Singh, et al., 1986; Taylor and Adelman, 2003). The household can be pictured as first maximizing its total income as a producer, given prices of inputs and outputs, and then using that income to maximize its utility, given prices of consumption goods. The profit maximization problem gives the farm output supply functions,

$$Q_i^* = Q_i(\mathbf{p}) \quad (7)$$

where \mathbf{p} denotes the exogenous vector of prices of all inputs. This solution determines the profit π^* and thus the full income y^* . The solutions to the utility maximization problem provide the consumer goods demand functions,

$$C_i^* = C_i(\mathbf{p}, y^*), \quad (i = 1, 2, \dots, N) \quad (8)$$

For each good, the surplus $Q^* - C^*$ determines whether the household is a seller (positive surplus) or buyer (negative surplus) of the good. The same idea applies for supply and demand of factors of production.

In a highly commercialized agricultural economy, the consumption decisions of agricultural households have little or no impact on production or on the amount of production that enters the market. Thus it is not unreasonable to ignore them and treat agricultural production as coming from agricultural firms, as is done in the PEM. When dealing with less developed agricultural economies, however, ignoring the consumption side may seriously undermine a model's predictive power. In a context where rural households consume a large part of their agricultural output, an increase in prices has two effects: on the producer side, the household reacts as a firm and increases output; on the consumer side, the standard ambiguity between income effects and substitution effects holds. The final consumption and production decisions can differ widely from those predicted by an agricultural firm model. For example, an increase in the price of an agricultural commodity may lead to an increase in production almost fully absorbed by a similar increase in consumption: the marketed surplus effect predicted by an agricultural firm model would, in that case, be significantly overstated (Singh, et al., 1986).

DEVPEM integrates several household models into a general equilibrium framework. Accounting for interactions among households with different asset holdings, production technologies and consumption patterns makes it possible to uncover complex responses to market shocks and heterogeneous welfare outcomes. When the agricultural economy consists of widely different actors (e.g., large commercial farms, commercial smallholders and subsistence producers) unexpected outcomes can occur through the interplay of labour, land and other markets. Such can be the case when smallholders depend on commercial farms for a significant part of their income, and commercial farms rely on labour supplied by smallholders (Dyer, et al., 2006).

This focus on heterogeneous households brought together within a general equilibrium model is the most radical difference between DEVPEM and PEM. There are, however, other differences as well as similarities between the two approaches. One important similarity is the treatment of land markets, which is a key feature of the PEM adopted into the DEVPEM.

2.2. Imperfect land transferability

The model just described assumes that all markets work perfectly. Many agricultural household models, however, assume that land is a fixed input in each production activity. That is, $Q_{iT}^f = \bar{Q}_{iT}^f$ for all production activities i (T being the subscript for land). This assumption may be appropriate in the very short run, but it does not permit land to be reallocated across activities, as is likely to occur in response to policy changes. If a household's total land endowment is given but this land is perfectly transferable from one use to another, the activity-specific land constraints ($Q_{iT}^f = \bar{Q}_{iT}^f$) are replaced by a total household land endowment constraint,

$$E_T = \sum_{i=1}^N Q_{iT}^f \quad (9)$$

which is a special case of the market balance stated in equation (3), with purchased, sold, produced and consumed quantities of land all constrained to zero.

The PEM recognizes that land may be transformable from one use to another, albeit imperfectly. Imperfect transformability of land among uses can be represented by replacing equation (9) with a continuous and convex land supply function S replacing the linear constraint on land:

$$E_T = S(\mathbf{Q}_T^f) \quad (10)$$

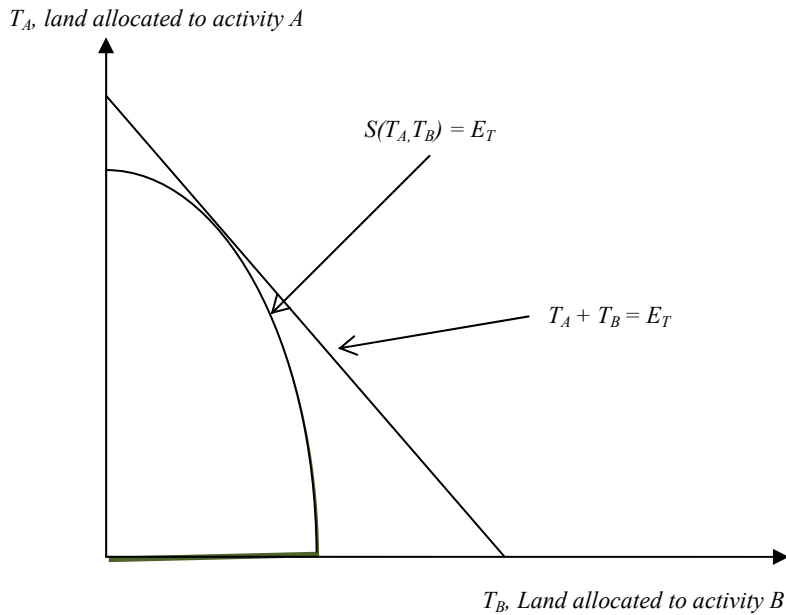
The difference between the linear and non-linear forms is illustrated in Figure 1.

It can be shown that under those additional constraints, the optimal amount of land supplied to the production of any pair of goods, i and j , will satisfy:

$$\frac{p_i \frac{\partial Q_i}{\partial Q_{iT}^f}}{p_j \frac{\partial Q_j}{\partial Q_{jT}^f}} = \frac{\frac{\partial S}{\partial Q_{iT}^f}}{\frac{\partial S}{\partial Q_{jT}^f}} \quad (11)$$

Equation (11) expresses that the ratio of marginal value products of land in different uses must be equal to the marginal rate of transformation of land from one use to the other. Note that when S is a simple summation function (as in equation (9)), this optimality condition reduces to the well-known equalization of marginal value products condition.

Figure 1: Linear versus non-linear land supply. In the non-linear case, the maximum amount of land available for activity A and for activity B may differ.



2.3. Accounting for transaction costs

The treatment of market transaction costs is a key aspect in which DEVPEM differs from PEM (and from most general equilibrium models). DEVPEM explicitly models the effects of transaction costs and endogenous market participation.

In section 2.1 we described the household as making production and consumption decisions independently. This separability property of the utility- and profit-maximization problems relies on the assumption that all prices are exogenous to the household. As soon as the subjective value that the household places on a good (i.e. the “shadow price”) deviates from the market price, separability no longer holds. If a household lacks access to a market, or if it faces transaction costs so high that it withdraws from the market (the case of a subsistence producer), the shadow price is determined by the intersection of the household’s internal demand and supply functions.

Under what circumstances will the household choose autarky over market participation for a certain good? This generally is not an important question for developed countries (such as those modelled in the six country PEM), where most agricultural households do not consume a significant share of their own production. In developing countries, however, large distances and a lack of infrastructure can result in non-competitive market structures, imperfect information, and high costs of transportation, all of which can create an environment in which transaction costs are high and many households live in partial or total autarky.

The DEVPEM model assumes that the household faces an $(N \times 1)$ vector of unit transaction costs t^b as buyers of consumption goods or production factors. As producers, they face an $(N \times 1)$ vector t^s of transaction costs for selling their goods or tradable factors.

Faced with transaction costs on the consumption side, the household’s decision price increases from p^m_i to $p^m_i + t^b_i$ ($i = 1, 2, \dots, N$; superscript m added to prices to indicate the exogenous market price). This reduces the consumption possibilities of the household for these items. Faced with transactions costs in output

markets, the producing household perceives a wedge between market and farm gate price, such that the decision price decreases from p_i^m to $p_i^m - t_i^s$. A household's decision price thus depends on its trading status for the particular good or factor. In particular, the decision price for good i is given by:

$$p_i = \begin{cases} p_i^m - t_i^s & \text{if } Q_i^s > 0 \\ p_i^m + t_i^b & \text{if } Q_i^b > 0 \\ \tilde{p}_i & \text{if } Q_i^s = Q_i^b = 0 \end{cases} \quad (12)$$

where \tilde{p} denotes the household's internal shadow price. When the household neither buys nor sells, the shadow price is disconnected from the market price and is determined by the intersection of household supply and demand. Because the decision price is endogenous (though constrained within exogenous bounds), consumption and production decisions are inseparable from one another.

Aside from the price determination equation (12), transaction costs do not impose any additional restrictions on the model described by equations (1) through (6). Full income (equation (6)) can simply be re-labelled as "shadow income," since the decision price vector p is now a vector of shadow prices rather than market prices. Market participation for item i is determined by comparing the utility obtained from selling, buying, and remaining self-sufficient for that item (Key, et al., 2000). Key et al. note that whereas the determination of market participation for a good "may become quite cumbersome when there are several commodities that can be either purchased or sold, the principle can be shown with a simplified model in which there is choice of regime for only one commodity which is produced and consumed by the household (e.g., a food crop)" (p. 248).

Let $V(p, y)$ denote the indirect utility of this commodity, where p is the decision price and y is household income. The utility levels to compare are:

$$V^s = \begin{cases} V[p^m - t^s, y(p^m - t^s)] & \text{if seller,} \\ V[p^m + t^b, y(p^m + t^b)] & \text{if buyer} \\ V[\tilde{p}, y(\tilde{p})] & \text{if autarkic.} \end{cases} \quad (13)$$

The lowest market price, \underline{p}^m , at which the household is willing to sell the good, satisfies:

$$V[\underline{p}^m - t^s, y(\underline{p}^m - t^s)] = V[\tilde{p}, y(\tilde{p})] \quad (14)$$

Similarly, the highest market price, \bar{p}^m , at which the household is willing to buy, satisfies:

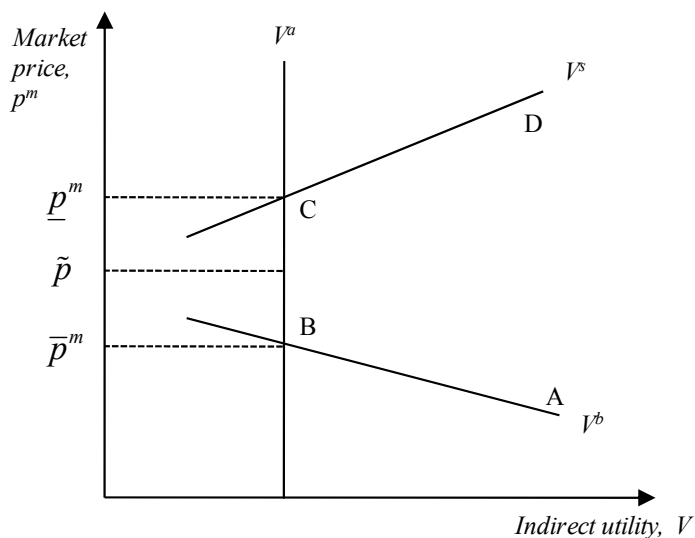
$$V[\bar{p}^m - t^b, y(\bar{p}^m - t^b)] = V[\tilde{p}, y(\tilde{p})] \quad (15)$$

Figure 2 depicts these prices. At a market price higher than the seller price threshold \underline{p}^m , the household obtains a higher utility by being a seller than by being autarkic, shown by segment CD on the indirect utility curve V^s . At a market price lower than the buyer price threshold \bar{p}^m , the household is better off as a buyer than being autarkic, shown by segment AB on the indirect utility curve V^b . For all market prices between the buyer price and the seller price thresholds the household is better off being autarkic, as shown by segment BC on curve V^a . The width of the “price band” – i.e., the interval of market prices in which the household is better off being autarkic in the good – equals the sum of seller and buyer transactions costs:

$$\underline{p}^m - \bar{p}^m = t^s + t^b \quad (16)$$

It is worth noting that while this explicit accounting for the role of transaction costs may capture an important aspect of developing country agriculture, additional constraints in input markets (e.g., fixed rather than proportional transaction costs, or seasonal cash or credit constraints) may impede the ability of households to respond to higher prices, even when the difference between the market price and shadow price exceeds transaction costs in the output market. One possibility is to modify the standard model to accommodate such features; a more practical option is to impose additional constraints on the model and explore their implications via sensitivity analysis.

Figure 2 Indirect household utility under proportional transaction costs



2.4. Specification of functional forms

This section combines the three features discussed above in a model of a single-household rural economy with transactions costs and a sluggish land supply. Here, we specify functional forms and derive first order conditions, in order to illustrate the solvability of the model we described in the previous section.

For simplicity, we treat all tradable goods and factors equally, land T being the only exception, as it cannot be purchased or sold (although it can be transformed imperfectly from one use to another). Let us denote the set of tradable items $I^- = \{1, \dots, N-1\}$.

a) Consumption

Household welfare is described by a Linear Expenditure System (LES). This builds on a Stone-Geary utility function and assumes that there are minimum quantities below which consumption cannot fall. It is the most frequently used system in empirical estimation of demand (Sadoulet and De Janvry, 1995). Parameters are zero for goods that are not being consumed, guaranteeing that their level of consumption will be zero in the solution. For goods consumed, c_i represents the incompressible (subsistence) consumption levels.

$$U(\mathbf{C}) = \prod_{i \in I^-} (C_i - c_i)^{\alpha_i}, \quad \text{with } 0 < c_i < C_i, \text{ and } \sum_I \alpha_i = 1 \quad (17)$$

b) Production

Production technology is described using a constant elasticity of substitution (CES) production function:

$$Q_i = \left[\sum_{k=1}^N b_{ik} (Q_{ik}^f)^\beta \right]^{1/\beta} \quad (i \in I^-) \quad (18)$$

with known parameters b_{ik} and β .

c) Market Constraints

The market constraint on all items except land is of the form

$$C_i + Q_i^s + \sum_{j=1}^N Q_{ji}^f = E_i + Q_i + Q_i^b, \quad (i \in I^-) \quad (19)$$

As in the PEM, a constant elasticity of transformation (CET) land supply function shapes the allocation of land among production activities, as follows:

$$E_T = a_T \left(\sum_{i \in I^-} \eta_i (Q_{iT}^f)^\rho \right)^{1/\rho} \quad (20)$$

where the parameters a_T , ρ the η are all known. For simplicity, we can write $\gamma_i = (a_T)^\rho \times \eta_i$ and reduce the above equation to:

$$E_T = \left(\sum_{i \in I^-} \gamma_i (Q_{iT}^f)^\rho \right)^{1/\rho} \quad (21)$$

In addition, we constrain exchanged quantities to be positive:

$$Q_i^b \geq 0; \quad Q_i^s \geq 0$$

d) Cash constraint

Provided that land is the only factor for which there is no market, there exists an $((N-1) \times 1)$ vector of market prices p^m . If households face transaction cost vectors t^s and t^b for selling and buying goods, respectively, then the cash constraint is:

$$\sum_{i=1}^{N-1} (p_i^m + t_i^b) Q_i^b = \sum_{i=1}^{N-1} (p_i^m - t_i^s) Q_i^s \quad (22)$$

3. Calibration of the model

The model presented above consists of a set of variables (for which we have observations) and a set of relationships among variables, defined by equations with parameters (for most of which we do not have observations). In order to make the model operational and tractable, we must calibrate it (find missing parameter values) using actual production and consumption data. The central aim of calibration procedures is to find parameter values such that the observed data represent a solution to the model. In other words, calibration consists of plugging in the observed variable values into the equations of our model to “reverse-compute” the parameter values which would have led to those observed variable values as the equilibrium solution. It is, in a sense, the mirror operation to simulations, which rely on the fixed parameter values to estimate the values of variables.

Our calibration procedure is based on a Social Accounting Matrix (SAM).¹ Computable general equilibrium (CGE) practitioners often parameterize models using SAMs because they offer a convenient framework and a simple way to use secondary data. A SAM provides a picture of all flows of money and goods in an economy in matrix form, where rows represent the incomes of economic actors and columns represent expenditures, such that row and column totals must be equal. Thus, one advantage of using a SAM is that, by construction, all cash constraints and market clearing conditions are satisfied for all accounts in the matrix. The SAM thus provides a data framework consistent with general equilibrium theory.

Table 1 provides the general structure of the SAM used to calibrate the DEVPEM model. The cells indicate which variable of DEVPEM can be read from which part of the table. The SAM is a matrix of

¹ See Pyatt (1988) for the SAM approach to modelling, and Keuning and Ruijter (1988) for how to construct a SAM.

values rather than quantities, but without loss of generality one can set all initial prices and rents to unity, thus implicitly converting the matrix into money-metric quantity units. Prices and rents are determined by this assumption, such that all other variables of the model appear in the SAM: quantities produced, consumed, used as factors, imported and exported. Sums along rows or columns provide us with total incomes and expenditures, total supplies and demands, all of which match to make markets clear.

Table 1: General structure of a SAM used to calibrate the DEVPEM model

		<i>Expenditures</i>				
<i>Incomes</i>	Households	Activities for each household	Goods i	Factors i	Rest of World	TOTALS
Households				Factor Endowments E_i	Exogenous income	Total Income y
Activities			Domestic production Q_i (maps activities with the goods they produce)			Total Production Value Q_i
Goods j	Household Consumption C_j	Intermediate inputs and			Exports of goods Q_i^s	Total demand for goods
Factors j		Factor demands Q_{ij}^f			Exports of tradable factors Q_i^s	Total factor demand
Rest of World			Imports of goods Q_i^b	Imports of tradable factors Q_i^b		Total imports
TOTALS	Total Expenditures Y	Total Production Value Q_i	Total supply of goods	Total supply of factors	Total exports	

3.1. Calibration of the consumption function

In models which use the simplest functional forms (such as the Leontiev or Cobb-Douglas forms), the SAM provides all the information needed to find all the parameters. This, however, is not the case with the linear expenditure system. The utility function assumed in (17) features $2(N-1)$ parameters: “incompressible consumption” c_i for each good and the α exponents. The former will need to be determined from LSMS data, for example using consumption values for the poorest households, or using econometric estimation techniques. We then plug in the values from the SAM into the consumption demand equation with prices set to unity and obtain:

$$\alpha_i = \frac{C_i - c_i}{\left(y - \sum_I c_j\right)} \quad (23)$$

The consumption side of the model is calibrated in this way.

3.2. Calibration of the production function

The calibration of CES production functions also requires that some external data be used. The production function assumed in (18) features $N+1$ parameters: b_{ik} for all k and β . Since we only have N observations on input values in the data, we cannot estimate this function without additional data on one of those parameters. It is convenient to use an estimated elasticity of substitution between inputs²:

$$\zeta = \frac{1}{1-\beta}$$

This parameter can be estimated using various forms of log-linear regressions of value added on factor inputs and costs (McFadden, 1978), but in practice it is often borrowed from other studies because the data for direct estimation usually are lacking. Once β is known, calibrating the b_{ik} shares is relatively straightforward. Since we scale all prices to be equal to one, the optimality condition for factor input ratios (Annex 1) can be written as:

$$b_{ik} = b_{il} \times \left(\frac{Q_{il,0}^f}{Q_{ik,0}^f} \right)^{\beta-1}$$

(The subscript 0 signifies that this relationship is only true in the calibration data.). We can then substitute this expression into the CES production function:

$$Q_{i,0} = \left[\sum_{k=1}^N b_{il} \left(\frac{Q_{il,0}^f}{Q_{ik,0}^f} \right)^{\beta-1} \times (Q_{ik,0}^f)^\beta \right]^{1/\beta}$$

which then simplifies to:

$$b_{ik} = \frac{(Q_{i,0})^\beta}{(Q_{ik,0}^f)^{\beta-1} \times \sum_{l=1}^N Q_{il,0}^f} = \left(\frac{Q_{ik,0}^f}{Q_{i,0}} \right)^{1-\beta} \quad (24)$$

where the last equality follows from the fact that, in the calibration data, the sum of factor values is equal to the production value. This completes our calibration requirements for the CES production function.

² See Sancho (2007) and Rutherford (2002) for CES function calibration techniques.

3.3. Calibration of the land supply function

Calibration of CET parameters mirrors CES calibration. As we count the parameters to estimate in equation (21), there are N parameters to estimate but only have $(N-1)$ observations from which to estimate them. The parameter to be estimated is the (constant) elasticity of transformation, σ :

$$\sigma = \frac{1}{1-\rho}$$

This parameter is not usually estimated directly. Instead, we use the existing relationship between σ , the own-price elasticity of land supply ε_{ii} , and the share of land in a crop s_i :³

$$\varepsilon_{ii} = \sigma(1-s_i)$$

Obtaining our parameter of interest thus depends on the availability of ε_{ii} which, again, is often borrowed from exiting literature, as it is in the PEM model (OECD, 2005). Once σ is estimated and ρ inferred, the γ_i parameters are estimated in the same fashion as the b_i parameters in the CES production function:

$$\gamma_i = \left(\frac{Q_{iT,0}}{E_T} \right)^{1-\rho} \quad (25)$$

3.4. Estimating transaction costs

This issue relates to a rather small body of literature, namely, the estimation of transaction costs for developing rural economies.⁴ Two published articles address this issue. The first is by Renkow et al. (2004), who work with Kenyan data. Using maximum likelihood estimation they find that “on average the ad valorem tax equivalent of the fixed transactions costs in the sample is 15.5%.” The second attempt is made by Cadot et al. (2006), who use Malagasy data and define transaction costs as the revenues foregone due to non-participation in markets. They use switching regression estimates to calculate “the opportunity cost of not switching” for the “marginal” farmer, and evaluate this cost at a surprisingly high level: “more than one year of the typical subsistence farmer's output valued at market prices.”

Lacking authoritative data on transaction costs, a combination of rough estimation (e.g., using RIGA data, if possible) and sensitivity analysis may be required. The specific estimation method will depend on the available data for each country to which DEVPEM is applied.

4. Prototype model for Malawi

This section presents an application of the model to the case of Malawi. Malawi is the first of six countries for which the DEVPEM model will be used in policy simulation exercises, the other countries being (provisionally) Ghana, Indonesia, Guatemala, Nicaragua and Vietnam. Malawi and Ghana are distinguished from the other countries in terms of their considerably lower per-capita income and their high

³ This relationship becomes more complex in case of 2-level or 3-level CET functions, which is used in the PEM.

⁴ The empirical literature on transactions costs in staple markets of developing countries is rather limited; it is reviewed in Barrett (2008).

share of agriculture in GDP. Malawi also differs from the other countries by virtue of the high share of its population still living in rural areas (88% in our sample). Malawi is one of the poorest countries in the world, with households often struggling to meet their immediate consumption needs and confronting either prohibitive transaction costs, or missing markets, for outputs and inputs. It thus represents the polar opposite of the PEM model for developed countries, which can ignore the consumption side of farmers' decisions and can assume that markets function seamlessly without prohibitive transaction costs. A further benefit of selecting Malawi as a prototype is the availability of earlier work on the country undertaken for OECD by Professor Andrew Dorward and others (see OECD, 2005). This makes it possible to compare the insights available from the stylised DEVPEM, which seeks to be flexible enough for application across a range of countries, with those obtainable from a more elaborate yet country-specific model. The aim is to ensure that the most important structural features of the economy are represented in DEVPEM and that no crucial determinant of policy impacts is overlooked.

Our main data source for the model application is the 2004 Malawi Integrated Household Survey. The survey data have been processed by the RIGA team at FAO, which has greatly facilitated the construction of the variables needed for the model (Carletto, et al., 2007). FAOSTAT is used as a complementary data source for information on aggregate production and consumption of agricultural goods.

4.1. Specifications of the Malawi prototype model

The Malawi prototype model differs from the above-described analytical model in two ways, one simplifying the model, the other complicating it. First, due to lack of data, certain assumptions about missing parameters were made. We assumed the subsistence quantities in the linear expenditure system to be zero, and the substitution parameter of the production functions to be one in the limit. Both these assumptions are tantamount to assuming a Cobb-Douglas functional form, which is a special case of the more general forms we introduced.

Second, we specify six distinct household groups with household-specific activities, instead of the single representative household depicted in the theoretical model. The six household groups include both rural and urban households and thus represent the whole economy. The purpose of distinguishing between household groups is to capture heterogeneity in the constraints households face, which are likely to affect their response to external shocks. It is important, however, to rely on exogenous constraints while defining the household groups. This is of particular importance in the DEVPEM, which treats household market participation as an endogenous outcome, such that any information on sales or purchases has to be ignored when defining household groups. We define these household groups based on land ownership and remoteness to markets.

Land ownership, which is assumed to be fixed (exogenous) in the short run, is used as the main indicator to define the household categories. These differences in land ownership are assumed to capture differences in production technology, and it is well-established that land ownership is strongly correlated with market participation (Barrett and Dorosh, 1996). We distinguish between landless households and small, medium, and large landowners.

We also assume that households differ in the extent to which they face transaction costs in markets for goods and factors of production. Given that transaction costs are a function of distance to markets and that households are unable to relocate in the short run, these are also exogenous to the household. We define households as remote if they are above a certain threshold on a "remoteness scale".⁵ To limit the number of

⁵ The Integrated Household Survey features several distance variables for each surveyed community. We selected twelve distance variables, and classified the communities into distance quintiles (5 being most remote) for each

household groups, we assume that remoteness for medium-sized and large farmers have smaller effects on market participation than for small farmers and only make the remote/non-remote distinction for small farmers. The magnitude of transactions costs was estimated using the price section of the LSMS data, using the prices of select goods and services.⁶ It was found that, on average, remote households pay 18.5% higher prices than members of the other household groups.

Table 2 summarizes the household groups. Non-agricultural households are outside the agricultural sector in the sense that they do not engage in crop or livestock production or in agricultural employment. These are a diverse group of households, including skilled and unskilled households, the majority (75%) residing in urban areas. The second group consists of households that report being landless yet engaged in agriculture – either by cultivating crops or by participating in the agricultural labour market. Their share of income originating from farming is relatively low (30%), and their primary income source is off-farm wage labour. Farm households are categorized as follows: small farmers own less than 1 hectare of land, medium-sized own 1–3 hectares, and large farmers own more than 3 hectares.

The share of household income derived from farm activities increases with land ownership. This pattern, also found in other developing countries, may reflect economies of scale and the related fact that farming is an insufficient income source for many small farmers, who therefore must rely on off-farm income sources to secure their livelihood. A higher farm income share in remote than non-remote small farmer households most likely reflects a greater opportunity for non-remote farmers to diversify into non-agricultural income activities.

Table 2: Definition and sample sizes of household groups in the Malawi model

<i>Household category</i>	<i>Defining characteristics</i>	<i>Sample size</i>	<i>farm income share</i>	<i>Average income</i>
1. non-agricultural	Does not cultivate	769	0%	54,854
2. landless agric.	Does not own land, but cultivates or is engaged in agricultural employment	1021	30%	55,331
3. small, non-remote	Owens < 1 ha of land; ≤ 3.5 on remoteness scale	3711	57%	34,727
4. small, remote	Owens < 1 ha of land; > 3.5 on remoteness scale	1063	72%	30,139
5. medium	Owens 1-5 ha of land	4183	73%	44,454
6. large	Owens > 5 ha of land	475	80%	58,428

Note: Average income is based on an annual household income (MWK) estimated by RIGA (Carletto, et al., 2007), with consumption of own farm production valued at consumer prices. 100 MWK is approximately 1 USD.

There are seven goods defined for the Malawi model: maize, rice, other food crops, tobacco, tree crops, livestock products, and a “market good” that cannot be produced on the farm. Maize and rice are treated separately from other food crops, inasmuch as they are the largest grain crops in terms of production volume (FAOSTAT) and are often the targets of agricultural and trade policies. The “other” category is primarily composed of tubers (potatoes and cassava), pulses, and other cereals (millet, sorghum). Tobacco

distance. We then defined as “remote” the communities whose “mean distance quintile” across the twelve distances was above 3.5. The twelve variables were the distances to nearest: asphalt road, bus stop, urban center, local government, daily market, weekly market, post office, telephone, bank, clinic, primary school and secondary school.

⁶ We selected goods and services that are not produced by the rural sector and are unlikely to be subsidized or given away for free by NGO’s. The list includes batteries, cigarettes, beer, detergent, cloth, toothbrushes, and the price of transportation to the nearest local government.

constitutes the annual cash crop and tree crops the permanent cash crops (such as fruits, coffee etc.). The production of each farm good involves labour, physical capital, land, and intermediate inputs (such as seeds and fertilizer).

Further details on how the variables in the Malawi model were defined, how the data were obtained, and how the model was calibrated are presented in Annex 2.

4.3. Simulation of policy changes

To illustrate the potential insights that DEVPEM can provide into differentiated policy impacts within the rural economy, the Malawi model was used to simulate the impacts of three sets of policy shocks:

- A 10% change in price of each major food and cash crop;
- A 10% input subsidy, reflected in a lower price paid by the farmer for purchased inputs;
- The elimination of transaction costs.

In the case of the first two experiments, the price changes are introduced exogenously, and no account is taken of the possible need to pay for these policies from domestic resources.

Table 3 reports the findings from these simulations. For the crop price changes, the table presents for each household the marketed surplus prior to the policy shock (a useful reference when interpreting the effects of each shock), the effect on nominal income, and the effect on welfare. All of these effects reflect interactions among the diverse household groups within the rural economy. The welfare effect was calculated as the (negative of the) income transfer that would be required to maintain each household group at its welfare level prior to the policy change. This transfer, akin to a compensating variation (see Taylor et al. (2009)), is expressed as a percentage of each household group's base income. The table also presents a relative transfer efficiency estimate, which compares the efficiency of alternative policies in terms of generating welfare gains for rural households. It was calculated as the total welfare effect (defined above) divided by the cost of the income transfer implied by each policy.⁷

The first data column in the table presents the total or aggregate effect of each policy on rural households' income and welfare. Rather than the sum of effects across all household groups, this column was computed using a "reduced" version of the model with a single representative household and no transactions costs. This column should thus be read as a more "naive" estimation which ignores the diversity of the rural sector in Malawi. It does, however, consider both the production and consumption aspects of the household economy: it should thus be emphasized that even such aggregate household results are not available from a PEM-type model, in which firms, not households, are the key actors. Columns 2(a-f) report results separately for each of the six household groups. The last column in Table 3 presents the transfer efficiency estimates.

Policy simulation 1: market price support

⁷ It does not, therefore, include the administrative costs associated with financing (e.g., tax collection) or implementing each policy.

The market price support (MPS) experiments simulate, in turn, the rural economy-wide effects of a 10% increase in the price of maize, rice, other staples, tobacco, tree crops, and livestock. In the aggregate, there is striking variation in the nominal income and welfare effects of these policies (Column 1). All nominal income effects are positive; however, they vary from 0.3% (rice) to 6.3% (other food) of household base income. The largest effects are for maize and other food crops. They are the only crops for which the impact exceeds 1% of base income. The welfare effects vary in both magnitude and sign, because they take into account the welfare cost of higher consumption prices, which may outweigh the positive effect of higher nominal income. The welfare effect of an agricultural price increase never exceeds the nominal income effect. The two effects are the same only for goods that rural households produce but do not consume. This effectively is the case for tobacco⁸. The divergence between nominal income and welfare effects is greatest for staples, which constitute a significant share of rural household budgets. For example, the maize MPS raises total nominal income by 1.7% but welfare by only 0.4%, and the MPS for other staples raises nominal income and welfare by 6.3% and 3.9%, respectively.

These aggregate results mask the impacts of MPS on individual household groups. In general, one would expect that large marketed-surplus producers will benefit most from MPS for their crop. Households that do not produce the crop and are pure consumers will lose when the market price of the crop increases. This pattern is evident when one compares columns 2(a-f) in Table 3. With only one exception, large and medium commercial farm households benefit from MPS in terms of both nominal income and welfare. With few exceptions, these households also enjoy the largest percentage increases in nominal income and welfare. For example, the 10% MPS for maize raises nominal income and welfare of large commercial farm households by 2.6% and 1.9%, respectively. However, it decreases the welfare of non-farm rural households (-1.8%), small farm households (-0.2%), and remote farm households (-0.7%). The MPS for other staples raises welfare by 5.8% on large commercial farms, 2.5% on small commercial farms, and 1.3% in landless agricultural households. Welfare on non-farm rural households decreases by 3.4%. A MPS for livestock produces a similar pattern, although the impacts tend to be smaller. They range from 0.3% in large commercial farm households to -0.9% in landless agricultural households and -2.4% in non-farm rural households.

⁸ Cigarettes and cigars are industrial products and their purchase enters the model in the category “market good”. Smoking cannot be assimilated to consumption of a self-produced good, as the profits from transformation have leaked out of the rural sector.

Table 3: Policy simulation results from the Malawi DEVPEM

POLICY		(1)	Disaggregated effect by households						(3)	(4)
			(2a)	(2b)	(2c)	(2d)	(2e)	(2f)		
		ALL	Non-Farm Households	Landless Agricultural Households	Small Farm Owners	Remote Farm Owners	Medium Farm Owners	Large Farm Owners	Total Cost of Subsidy	Transfer efficiency
10% increase in price of maize	Marketed Surplus for maize	4551	-1006	-70	-1215	-925	5679	2180		
	Effect on nominal income (%)	1.7%	0	1.9%	1.4%	0.9%	2.0%	2.6%	2791	0.25
	Effect on Welfare (% of income)	0.4%	-1.8%	0.3%	-0.2%	-0.7%	0.9%	1.9%		
10% increase in price of rice	Marketed Surplus for rice	-283	-645	-607	-148	386	776	-10		
	Effect on nominal income (%)	0.3%	0	0.2%	0.3%	0.6%	0.3%	0.1%	454	0.03
	Effect on Welfare (% of income)	0.007%	-1.2%	-0.4%	0.01%	0.4%	0.1%	-0.02%		
10% increase in price of other staples	Marketed Surplus for staples	55232	-1866	-543	7203	3533	40079	7147		
	Effect on nominal income (%)	6.3%	0	4.3%	5.4%	6.3%	7.3%	7.6%	10130	0.59
	Effect on Welfare (% of income)	3.9%	-3.4%	1.3%	2.5%	3.5%	5.3%	5.8%		
10% increase in price of tobacco	Marketed Surplus for tobacco	7629	0	76	1907	1762	3815	229		
	Effect on nominal income (%)	0.6%	0	0.2%	0.6%	1.6%	0.5%	0.2%	968	0.88
	Effect on Welfare (% of income)	0.6%	0	0.2%	0.6%	1.6%	0.5%	0.2%		
10% increase in price of tree crops	Marketed Surplus for tree crops	9141	-509	-532	2497	1119	5154	1413		
	Effect on nominal income (%)	1.3%	0	0.6%	1.6%	1.7%	1.3%	1.6%	2115	0.50
	Effect on Welfare (% of income)	0.7%	-0.9%	-0.2%	0.8%	1.2%	0.7%	1.2%		
10% increase in price of livestock	Marketed Surplus for livestock	-1584	-1329	-1062	-953	11	1425	325		
	Effect on nominal income (%)	0.8%	0	0.7%	0.7%	0.7%	0.9%	0.9%	1287	0.001
	Effect on Welfare (% of income)	-0.004%	-2.4%	-0.9%	-0.1%	0.1%	0.3%	0.3%		
10% decrease in price of crop inputs	Effect on nominal income (%)	3.3%	0	2.4%	2.8%	3.2%	3.8%	4.2%		
	Effect on Welfare (% of income)	3.3%	0	2.4%	2.8%	3.2%	3.8%	4.2%	5442	0.92
10% decrease in price of livestock inputs	Effect on nominal income (%)	0.4%	0	0.5%	0.5%	0.4%	0.4%	0.3%		
	Effect on Welfare (% of income)	0.4%	0	0.5%	0.5%	0.4%	0.4%	0.3%	751	0.86
Removal of transactions costs	Effect on nominal income (%)	NA	0	0.07%	0.02%	7.8%	-0.02%	-0.02%		
	Effect on Welfare (% of income)	NA	0	0.07%	0.02%	5.8%	-0.02%	-0.02%	NA	NA

Policy simulation 2: an input subsidy

Our input subsidy simulations explore the effects of a 10% decrease in the price of intermediate inputs. Input mixes differ between agricultural and livestock production; thus, separate simulations were performed for these two activities. The agricultural input subsidy experiment is of particular interest in light of Malawi's recent fertilizer subsidy policies. An important feature of input subsidies is that they do not produce negative welfare effects via higher consumption costs. Because of this, the percentage changes in nominal income and welfare are the same in input subsidy simulations.

The 10% crop input subsidy raises nominal income and welfare by 3.3%. This is higher than in any of the MPS experiments except for one (other staples). There is no effect on non-farm rural households, which do not produce crops and thus do not benefit from the input subsidy. The effects for all other household groups are positive, and they vary less than in the MPS experiments. Large holder commercial households benefit most (4.2%), but the range of effects in the other household groups is relatively small, from 2.4% to 3.8%. All of these are smaller than in the MPS experiments with the exception of other staples. For agricultural producer households, the welfare effects of the input subsidy and other-staple MPS experiments are comparable; however, the subsidy does not have a negative consumption-cost effect on non-farm rural households. It can be argued, therefore, that the crop subsidy has the most favourable distributional effects of all of the policies considered in Table 3. An input subsidy for livestock produces positive, equally distributed, but small income and welfare effects, ranging from 0.3% to 0.5%.

The relative efficiency of alternative instruments

The size of each subsidy is calculated as 10% of the estimated value of the output (in the case of a MPS) or of intermediate inputs (in the case of the input subsidy). The relative transfer efficiency (TE) index offers a way to assess the efficiency of these subsidies in terms of generating welfare gains in rural households. An index greater than 1.0 would indicate that the subsidy increases rural household welfare by an amount greater than the subsidy, itself. An index of less than 1.0 implies that the welfare effect is smaller than the size of the subsidy. By this measure, the livestock, rice and maize MPS appear to be inefficient. The TE measure is 0.25 for maize, 0.03 for rice, and zero for livestock. The crop input subsidy, in contrast, has a TE of 0.92. It has the highest welfare effect of any of the subsidies considered. Two other policies, the livestock input subsidy and the tobacco MPS, also have high TEs (0.86 and 0.88, respectively). Their effects on rural household welfare are small compared to the effect of the crop input subsidy, however.

Policy simulation 3: eliminating transaction costs

High transaction costs are a quintessential feature of poor rural economies, particularly for remote farm households. The DEVPEM was designed to explore the ramifications of high transaction costs that create an "output price band" for some household groups. Within this band, a household-specific shadow price replaces the exogenously determined market price as a basis for production and consumption decisions and the household does not participate in the market, producing only for subsistence. The removal of transaction costs (e.g., via the development of marketing infrastructure) directly benefits the remote household group. Its nominal income rises by 7.8% and its welfare by 5.8%. Indirectly, removing transaction costs for the remote group affects other groups by way of their interactions in rural markets, particularly for factors. These indirect effects are positive but small, however, ranging from a .02% loss for large commercial households to a 0.07% gain for the landless agricultural households. These simulation results suggest that reducing transaction costs can create significant benefits for remote households without adversely affecting others in the rural economy.

Figure 3 illustrates the effect of transaction costs on the marketed surplus produced by agricultural households in remote areas. When the market price of maize is sufficiently low (in the figure, less than

approximately 1.7 times the initial or base price of maize), the household participates in the market as a net buyer, despite facing high transaction costs. When the market price is sufficiently high to overcome transaction costs on the producer side, the household participates in the market as a net seller. In between, the household's marketed surplus is zero. Over this subsistence interval, the market price has little effect on the remote household's decision price, as illustrated in

Figure 4.

The removal of transaction costs (e.g., via the development of marketing infrastructure) directly benefits the remote household group. Its nominal income rises by 7.8% and its welfare by 5.8%. Indirectly, removing transaction costs for the remote group affects other groups by way of their interactions in rural markets, particularly for factors. These indirect effects are positive but small, however, ranging from a .02% loss for large commercial households to a 0.07% gain for the landless agricultural households. These simulation results suggest that reducing transaction costs can create significant benefits for remote households without adversely affecting others in the rural economy.

Figure 3: Marketed surplus and the market price in remote rural households

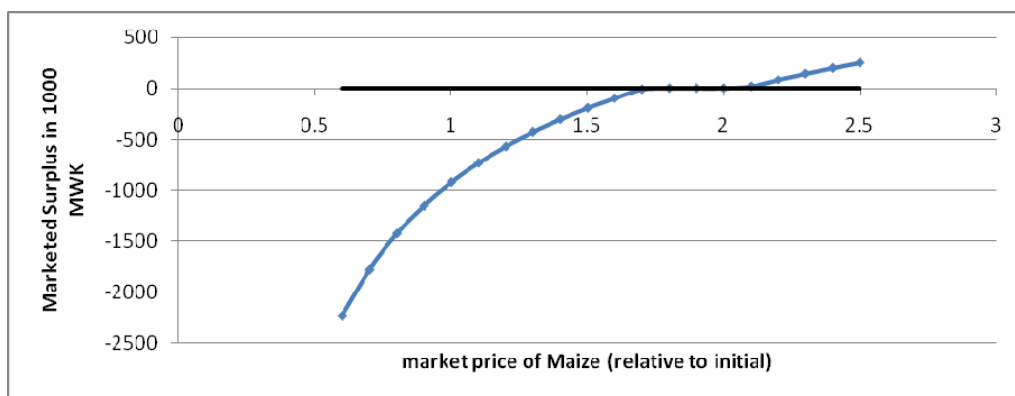
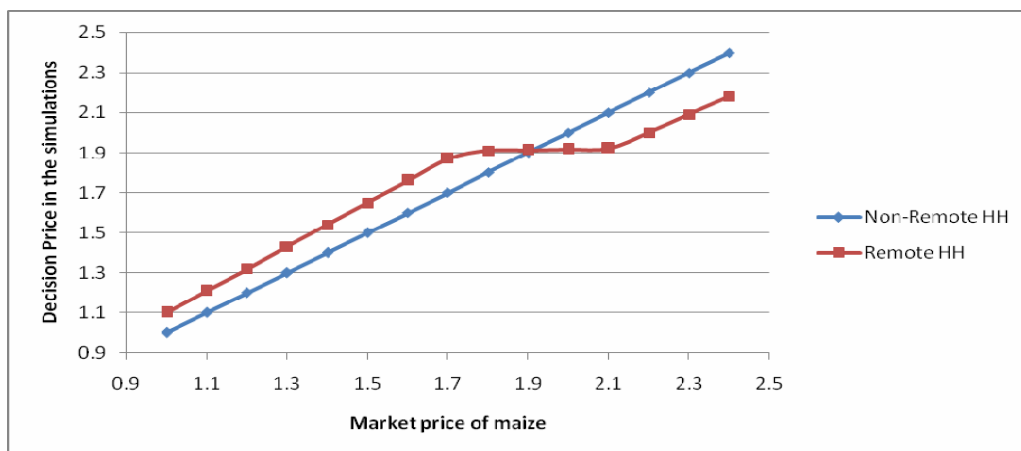


Figure 4: Decision prices of remote and market-integrated agricultural households



5. Conclusions and next steps

DEVPEM is being developed as a companion to the OECD-country PEM as a tool for policy evaluation in developing countries, in which agricultural production is carried out by heterogeneous households and where market transaction costs potentially play an important role in shaping policy impacts. The models are similar in that they depict the impacts of agricultural policies on incomes over the short to medium term. However, there are important differences between the two models. In structural terms, one might view the PEM as being effectively a special case of DEVPEM, in which production is carried out not by households but, rather, by a single aggregate or representative firm, and in which transaction costs are negligible.

The modelling work for this project is still at the development stage, but the preliminary results for Malawi indicate that agricultural policies may have fundamentally different impacts on incomes in low income countries to those obtained in developed OECD countries. As in OECD countries, market price support is likely to be an ineffective instrument for raising the incomes of farm households, albeit for different reasons. In the PEM, market price support is ineffective because a significant share of the benefits “leaks” to non-farm factor owners (input suppliers and land owners). In the DEVPEM prototype for Malawi, market price support is similarly ineffective, not because of these leakages (farm households supply relatively more of their own inputs to production) but because farm households consume a significant share of what they produce. Indeed, net food deficit farm households could lose from higher food prices, if their production response is sufficiently limited. In the case of input subsidies, there are *a priori* reasons for believing that such measures could have a superior transfer efficiency to those obtained in OECD countries, again because farmers tend mostly to supply their own factors to the farm operation, so there less scope for leakages to other agents. Of course, high transfer efficiency is not by itself enough to justify the use of input subsidies. As discussed in Part I, a range of factors need to be considered, beyond an instrument’s immediate impact on short term incomes. Nevertheless, the possibility that a large share of the benefits of input subsidies could be retained by the farm household is significant to that broader discussion. Finally, the prototype model suggests that policies to reduce transaction costs can have important benefits for households whose market interactions are impeded by those costs.

In the near future, we plan to extend the modelling work in two directions. In the first place there is a need to refine the prototype model by considering a number of factors that were discussed at the PEM expert meeting in September, and were considered to be potentially important. For example, it was considered important to address the possibility that food prices are determined endogenously in the rural economy. Another issue raised was that seasonal cash constraints may affect farmers’ responses to changes in market prices. Aside from developing the model structure to accommodate such possibilities, it will also be important to provide a more detailed interpretation of the results, including a mapping onto measures of poverty, inequality and food security. Further consideration will also be given to the manner in which policies are implemented and how they are financed, as well as a wider range of policy experiments. Once the prototype model is fully developed, a series of country models will be constructed, as noted in Section 4, with a view to describing how structural differences between developing countries can affect the distribution of policy impacts.

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Annex 1. Solution of the model

To solve for the first order conditions of the model, we first define the Lagrangian of the joint utility and profit-maximization problem of the household:

$$\begin{aligned}
L = & \prod_{i \in I^-} (C_i - c_i)^{\alpha_i} - \sum_{i \in I} \mu_i \left(C_i + Q_i^s + \sum_{j \in I^-} Q_{ji}^f - E_i - \left[\sum_{k \in I} b_{ik} (Q_{ik}^f)^\beta \right]^{1/\beta} - Q_i^b \right) \\
& - \lambda \left(\sum_{i \in I^-} (p_i^m + t_i^b) Q_i^b - \sum_{i \in I^-} (p_i^m - t_i^s) Q_i^s \right) \\
& - \xi \left(\left(\sum_{i \in I^-} \gamma_i (Q_{iT}^f)^\rho \right)^{1/\rho} - E_T \right)
\end{aligned} \tag{26}$$

Differentiating the Lagrangian yields the following first-order conditions:

$$\frac{\partial L}{\partial C_i} = \alpha_i \frac{U}{(C_i - c_i)} - \mu_i = 0 \tag{27}$$

$$\frac{\partial L}{\partial Q_{ik}} = \mu_i \left[\sum_k b_{ik} (Q_{ik}^f)^\beta \right]^{\frac{1}{\beta}-1} b_{ik} (Q_{ik}^f)^{\beta-1} - \mu_k = 0, \quad \text{for } k \neq T \tag{28}$$

$$\frac{\partial L}{\partial Q_{iT}} = \mu_i \left[\sum_k b_{ik} (Q_{ik}^f)^\beta \right]^{\frac{1}{\beta}-1} b_{iT} (Q_{iT}^f)^{\beta-1} - \xi \left(\sum_l \gamma_l (Q_{iT}^f)^\rho \right)^{\frac{1}{\rho}-1} \times \gamma_i (Q_{iT}^f)^{\rho-1} = 0 \tag{29}$$

$$\frac{\partial L}{\partial Q_i^b} = \mu_i - \lambda(p_i^m + t_i^b) \leq 0; \quad Q_i^b \geq 0; \quad Q_i^b \times (\mu_i - \lambda(p_i^m + t_i^b)) = 0 \tag{30}$$

$$\frac{\partial L}{\partial Q_i^s} = \lambda(p_i^m - t_i^s) - \mu_i \leq 0; \quad Q_i^s \geq 0; \quad Q_i^s \times (\lambda(p_i^m - t_i^s) - \mu_i) = 0 \tag{31}$$

$$\frac{\partial L}{\partial \lambda} = \sum_{i=1}^N (p_i^m + t_i^b) Q_i^b - \sum_{i=1}^N (p_i^m - t_i^s) Q_i^s = 0 \tag{32}$$

$$\frac{\partial L}{\partial \mu_i} = E_i + Q_i + Q_i^b - C_i - Q_i^s - \sum_{j=1}^N Q_{ji}^f = 0 \tag{33}$$

$$\frac{\partial L}{\partial \xi} = \left(\sum_l \gamma_l (Q_{iT}^f)^\rho \right)^{\frac{1}{\rho}} - E_T = 0 \tag{34}$$

These first order conditions lead to a solvable system of equations, which we derive below. We first need to define the notion of shadow price (until now absent from the model) and spell out the constraints on decision-making prices. Let us define

$$p_i = \frac{\mu_i}{\lambda}, \quad \text{for } i \neq T \tag{35}$$

which we will call the household shadow price of good i . This then lets us re-write equations (30) and (31) as:

$$\begin{cases} p_i \leq p_i^m + t_i^b \\ p_i^m - t_i^s \leq p_i \\ Q_i^b (p_i - (p_i^m + t_i^b)) = 0 \\ Q_i^s (p_i - (p_i^m - t_i^s)) = 0 \\ Q_i^s \geq 0, Q_i^b \leq 0 \end{cases} \quad (36)$$

We then turn to the consumption side of the household economy. Using the definition of shadow prices and equation (27) yields:

$$C_i - c_i = \frac{\alpha_i \frac{U}{\lambda}}{p_i} \quad (37)$$

which, when multiplied by p_i and summed over i , yields:

$$\sum_I p_i (C_i - c_i) = \sum_I \alpha_i \frac{U}{\lambda} = \frac{U}{\lambda} \quad (38)$$

Let us define $y = \frac{U}{\lambda} + \sum_I p_i c_i$. Then:

$$\sum_I p_i (C_i) = y \quad (39)$$

where y can be interpreted as the shadow income of the household, that is, the shadow value (in money units) of household consumption (whether bought on the market or self-provided).⁹ We will later show that it is also equal to the shadow value of the household's assets. This definition of y also allows us to write the demand function in the usual form used for linear expenditure systems:

$$C_i = \frac{\alpha_i}{p_i} \left(y - \sum_{j \in I} p_j c_j \right) + c_i \quad (40)$$

Having defined consumption demands, we now turn to the production side of the household economy. We first derive the optimal use of factors in production functions. Rather than explicitly writing out factor demands, it is common practice when using constant elasticity functional forms to work with relative factor ratios. Using equation (28) for two different factors k and l used in the production of good i we can write the optimality condition in terms of factor ratios in the production of good i :

⁹ The Lagrangian multiplier on the full-income constraint, λ , might be viewed as an exchange rate converting income currency (e.g., dollars) into welfare currency (utils). Dividing U by λ thus converts utility into the income currency, i.e., into what we call the shadow income. This shadow income is identical to full income when the prices of all goods are exogenous to the household. A similar approach appears in Holden et al.(1999).

$$\frac{Q_{ik}^f}{Q_{il}^f} = \left(\frac{\mu_k b_{il}}{\mu_l b_{ik}} \right)^{\frac{1}{\beta-1}} = \left(\frac{p_k b_{il}}{p_l b_{ik}} \right)^{\frac{1}{\beta-1}}, \quad k \neq T, l \neq T \quad (41)$$

Land is excluded from this condition, since we have not defined the notion of price for land, for which there is no market. To derive an equivalent factor ratio condition for optimal land use, let us take a closer look at the left-most term of equation (29), but replacing μ_i in terms of p_i :

$$p_i \left[\sum_k b_{ik} (Q_{ik}^f)^\beta \right]^{\frac{1}{\beta}-1} b_{iT} (Q_{iT}^f)^{\beta-1} = \frac{1}{\lambda} \times \xi \left(\sum_l \gamma_l (Q_{il}^f)^\rho \right)^{\frac{1}{\rho}-1} \times \gamma_i (Q_{iT}^f)^{\rho-1} \quad (42)$$

The left-hand term is the marginal value product of land in the production of good i , in other words the “shadow rent” of land used as a factor in this production process. Let us therefore define r_{iT} as that left-hand term:

$$r_{iT} = p_i \left[\sum_k b_{ik} (Q_{ik}^f)^\beta \right]^{\frac{1}{\beta}-1} b_{iT} (Q_{iT}^f)^{\beta-1} \quad (43)$$

This definition allows us to write an optimality condition for land use similar to equation (41), obtained in a very similar way. Dividing equation (28) by equation (29) yields:

$$\frac{b_{ik} (Q_{ik}^f)^{\beta-1}}{b_{iT} (Q_{iT}^f)^{\beta-1}} = \frac{\mu_k}{\xi \left(\sum_l \gamma_l (Q_{il}^f)^\rho \right)^{\frac{1}{\rho}-1} \times \gamma_i (Q_{iT}^f)^{\rho-1}} = \frac{p_k}{r_{iT}} \quad (44)$$

where the second equality follows from dividing by λ and using the optimality condition (42). The optimality condition for factor use when one of the factors is land can thus be written:

$$\frac{Q_{ik}^f}{Q_{iT}^f} = \left(\frac{p_k b_{iT}}{r_{iT} b_{ik}} \right)^{\frac{1}{\beta-1}} \quad (45)$$

Note that if this equation is true for all goods i and all factors k , the condition in equation (41) is rendered redundant, because it follows directly from this one: By writing equation (45) for factors k and l then dividing one by the other, we obtain equation (41).

This would complete the description of the production side of the economy if there was a perfectly elastic supply of all factors in our model. Land use, however, is constrained on the supply side by the CET land supply function. Using equation (29) for the use of the land factor in the production of two different goods i and j , we can write an optimality condition for the ratio of different land uses:

$$\frac{\mu_i \left[\sum_k b_{ik} (Q_{ik}^f)^\beta \right]^{\frac{1}{\beta}-1} b_{iT} (Q_{iT}^f)^{\beta-1}}{\mu_j \left[\sum_k b_{jk} (Q_{jk}^f)^\beta \right]^{\frac{1}{\beta}-1} b_{jT} (Q_{jT}^f)^{\beta-1}} = \frac{\gamma_i Q_{iT}^{\rho-1}}{\gamma_j Q_{jT}^{\rho-1}} \quad (46)$$

This translates into a simple condition on the ratio of land shadow rents:

$$\frac{r_{iT}}{r_{jT}} = \frac{\gamma_i Q_{iT}^{\rho-1}}{\gamma_j Q_{jT}^{\rho-1}} \quad (47)$$

The final step tying the production and consumption sides together is to derive the “shadow income” equation. Let us use equation (33) multiplied by p_i and summed over i . Equation (32) allows simplifying the quantities bought and sold away to obtain:

$$\sum_I p_i E_i + \sum_I p_i Q_i - y - \sum_{i \in I} p_i \sum_{j \in I} Q_{ji}^f = 0 \quad (48)$$

But from equation (41), which we multiply by p_i and sum over j and i , and from the fact that the beta coefficients sum to one, we can write

$$\sum_{i \in I} p_i \sum_{j \in I} Q_{ji}^f = \sum_{i \in I} p_i \sum_{j \in I} \frac{p_j \beta_{ji}}{p_i} \times Q_j = \sum_I p_j Q_j \times 1 \quad (49)$$

Using this fact, we can further simplify (48) to:

$$\sum_I p_i E_i = y \quad (50)$$

Equation (50) defines the “shadow income” of the household as the value of all endowments evaluated at shadow prices.

We have thus completed the derivation of the system of equations fully describing the solution to our model. The complete set of first order conditions is summarized in Table A1.

Table A1: DEVPEM variables and equations

Sets and parameters	Variables	Number of variables
<i>Sets</i>	Q_i quantities produced	$N-1$
$i (=k), N$ goods and factors	Q_{ik}^f input of k into production of i .	$N(N-1)$
<i>Parameters</i>	Q_i^s, Q_i^b quantities sold or bought	$2N-2$
p_i^m market prices, $i \neq T$	C_i quantities consumed	$N-1$
t_i^s additive sales transaction cost	p_i shadow price, $i \neq T$	$N-1$
t_i^b additive purchase transaction cost	r_{iT} shadow rent	$N-1$
E_i initial endowments (fixed in the case of land)	y shadow income	1
<i>Function parameters</i>	Total number of variables:	$(5 + N)N-5$
α_i exponent in consumption function		
β_i exponent in production function		
γ_i CET share parameters		
ρ CET exponent		

Equations	Domain restrictions	Number of equations	Description
<i>Price bounds and complementary slackness</i>			
$\begin{cases} p_i \leq p_i^m + t_i^b \\ p_i^m - t_i^s \leq p_i \\ Q_i^b (p_i - (p_i^m + t_i^b)) = 0 \\ Q_i^s (p_i - (p_i^m - t_i^s)) = 0 \end{cases}$	$i \neq T$	$2N-2$	Price bands
<i>Consumption block</i>			
$C_i = \frac{\alpha_i}{p_i} \left(y - \sum_j p_j c_j \right) + c_i$	$i \neq T$	$N-1$	Demands
$\sum_T p_i E_i = y$		1	Shadow income
<i>Production block</i>			
$Q_i = \left[\sum_{k=1}^N b_{ik} (Q_{ik}^f)^\beta \right]^{1/\beta}$	$i \neq T$	$N-1$	Production function
$\frac{Q_{ik}^f}{Q_{iT}^f} = \left(\frac{p_k b_{iT}}{r_{iT} b_{ik}} \right)^{\frac{1}{\beta-1}}$		$N(N-1)$	Factor demand ratios
<i>Land Supply Block</i>			
$\left(\sum_{i \in I} \gamma_i (Q_{iT}^f)^\rho \right)^{1/\rho} = E_T$		1	CET land supply
$\frac{r_{iT}}{r_{jT}} = \frac{\gamma_i Q_{iT}^{\rho-1}}{\gamma_j Q_{jT}^{\rho-1}}$	$i \neq T, j \neq T$	$N-2$ (excluding redundancies)	CET optimality condition
<i>Market Constraints</i>			
$E_i + Q_i + Q_i^b - C_i - Q_i^s - \sum_{j=1}^N Q_{ji}^f = 0$	$i \neq T$	$N-1$	Market clearing
$Q_i^b \geq 0; Q_i^s \geq 0$			
Total number of equations:		$(5+N)N-5$	

Annex 2. Data sources and construction of variables for the Malawi prototype model

This Annex briefly explains how the variables used in the Malawi simulations were defined. The two data sources are the 2004 Malawi Integrated Household Survey, processed by the RIGA team at FAO and FAOSTAT. The former data set is referred to below as “RIGA data”.

To obtain the information needed in the SAM described in Table 1, we needed to define a) adequate household groups, b) product categories, c) value of production, d) consumption, e) expenditure on input in production, and f) household income by source. FAOSTAT was used to obtain information on total value of production and consumption of each good category. The RIGA data were used to obtain all other information. The construction of each of these components is described below.

a) Household groups

As described in section 4, six household groups were defined, based on land ownership, production, and remoteness to markets. Category 1 does not cultivate, yet households in this category may own land. Category 2 does not own land but is engaged in cultivation either by renting land or by working on a farm. Category 3 and 4 (small landowners) both have less than 1 hectare of land. The difference between the two is their “remoteness” to markets. We defined a remoteness indicator based on 12 community variables in the Malawi survey (see footnote 6). For each variable, communities were divided into quintiles, with the 5th quintile containing the most “remote” communities. A community was defined as remote if its “average quintile” was above 3.5. Thus, households in category 4 all reside in communities defined as remote. Households in category 5 (medium land owners) own more than 1 but less than 5 hectares of land, and large land owners own 5 hectares or more.

b) Product categories

Agricultural goods were defined to fit four types of land use: Food crops, annual cash crops, tree crops, and livestock products. Among food crops, we distinguish between maize (local maize, composite maize, and hybrid maize), rice, and other crops (all other food crops listed in rain-fed and dry-season cultivation in the agricultural modules of the survey). Annual cash crops are tobacco in the case of Malawi, and tree crops consist of all crops in the tree crop production module of the survey, including fruits, tea, and coffee. The livestock product category includes all meat, dairy products, and all other livestock by-products.

c) Value of production

The total value of production of each product category was obtained from data on quantity and producer prices from FAOSTAT. To distribute the aggregate production value among the household groups, we used production shares derived from the RIGA data (Table A2). These shares were then multiplied by the aggregate FAOSTAT production value to assign total value of production for each household group.

d) Value of consumption

The value of consumption of each product category for each household group was estimated analogously to the production values. Using FAOSTAT, we multiplied consumption in tonnes by producer prices to get total consumption value of each good. Consumption shares per household group were estimated based on consumption information in the RIGA data (Table A1).

Table A2: Production and consumption shares per household group

	1. non-agricultural	2. landless agric.	3. small, non-remote	4. small, remote	5. medium	6. large	Total
<i>Production shares</i>							
Maize	0.00	0.06	0.19	0.03	0.55	0.17	1.00
Rice	0.00	0.01	0.24	0.12	0.57	0.05	1.00
Other food crops	0.00	0.03	0.17	0.06	0.53	0.21	1.00
Tobacco	0.00	0.01	0.25	0.21	0.50	0.03	1.00
Tree crops	0.00	0.01	0.22	0.19	0.47	0.11	1.00
Livestock	0.00	0.06	0.22	0.07	0.55	0.10	1.00
<i>Consumption shares</i>							
Maize	0.05	0.09	0.31	0.10	0.41	0.04	1.00
Rice	0.16	0.16	0.27	0.05	0.33	0.03	1.00
Other food crops	0.05	0.09	0.31	0.08	0.41	0.06	1.00
Tobacco	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Tree crops	0.05	0.09	0.34	0.07	0.40	0.05	1.00
Livestock	0.11	0.14	0.27	0.06	0.37	0.06	1.00

e) *Value of inputs in production*

The biggest challenge in deriving variables for the SAM was to estimate the cost of each factor used in farm production, for each product and each household category. We defined five inputs – own labour, physical capital, land, hired labour, and intermediate inputs. We treated the first three as household endowments, which means that utilization of any of these factors is an implicit cost to the household. Hired labour and purchases of intermediate inputs (seeds and fertilizer), on the other hand, are explicit costs. There is some information available in the RIGA data on explicit costs, but all implicit costs needed to be estimated. We assume zero economic profit in production of each good, such that,

$$TR_i = TC_i = TIC_i + TEC_i,$$

where TR_i denotes total revenue in production of good i , and TC denotes total costs, as the sum of implicit costs (TIC) and explicit costs (TEC). This means that the net revenue (total revenue minus explicit costs) is equal to implicit costs. To derive implicit cost shares for own labour, capital, and land, we used the following identity:

$$TIC = r_L Q_L + r_K Q_K + r_T Q_T,$$

where Q_L , Q_K , and Q_T denote quantities of own labour, capital, and land, respectively, and r_L , r_K , and r_T denote the respective shadow prices. Own labour's cost share, then, is

$$s_L = r_L Q_L / TR,$$

with capital's and land's cost shares, s_K and s_T , defined analogously. While the shadow prices are unobserved, we have some information in the RIGA data on net revenue (and hence TIC), and the quantities of each factor endowment, Q_L , Q_K , and Q_T . We estimated the following linear regression through the origin to obtain shadow price estimates:

$$TIC = b_L Q_L + b_K Q_K + b_T Q_T + e$$

where the b 's denote coefficients to be estimated and e denotes the error term. This regression was estimated for each product category and for each household group. Information on input utilization, however, is not available on crop level in the RIGA data. We therefore used single-crop farmers as the sample for each crop-specific regression, with the assumption that multi-cropping farms use the same production technology mono-croppers.

The estimated cost shares for labour, capital, and land in crop production were defined as:

$$\hat{s}_L = \hat{b}_L Q_L / \hat{TIC} \times (TIC / TR)$$

$$\hat{s}_K = \hat{b}_K Q_K / \hat{TIC} \times (TIC / TR)$$

$$\hat{s}_T = (1 - \hat{s}_L - \hat{s}_K) \times (TIC / TR)$$

where “hats” indicate estimates.

Cost shares for hired labour (HL) and intermediate inputs (IN) were defined as:

$$s_{HL} = (1 - s_L - s_K - s_T) * (\text{expenditure on hired labour} / TEC)$$

and

$$s_{IN} = 1 - s_L - s_K - s_T - s_{HL}.$$

For livestock production, we only assumed three inputs: capital, land and one variable input. The cost share of the land and capital inputs (implicit cost share) was defined as the ratio of net revenue to total revenue. For lack of better information, the cost shares of land and capital were assumed to be equal. The cost share of the variable inputs was defined as the residual share. Table A3 gives an overview of these cost shares.

f) Household income

In order to derive an estimate of aggregate household income for each household group that is comparable with the production and consumption values derived from FAOSTAT, we used the following relationship:

$$\text{Total household income} = \text{agprod}_{\text{FAOSTAT}} * (\text{agnet/aggross})_{\text{RIGA}} * (1 / \text{agshare}_{\text{RIGA}}),$$

where agprod is the value of the household group's total agricultural production derived from FAOSTAT, (agnet/aggross) is the average ratio of net to gross agricultural incomes according to RIGA data and agshare is the share of agricultural income in total household income according to RIGA data. Subscripts were added to indicate data source.

To estimate the value of consumption of non-farm products (“market goods”), we assumed that total household income equals total household expenditure and that non-farm consumption is the difference between household income and agricultural consumption. Table A4 shows shares of income spent on each good for each household group.

Table A3: Input cost shares

	All farmers	2. landless agric.	3. small, non-remote	4. small, remote	5. medium	6. large
<i>Maize</i>						
Own labour	0.14	0.02	0.00	0.04	0.06	0.18
Physical capital	0.44	0.32	0.15	0.40	0.03	0.31
Land	0.07	0.29	0.52	0.43	0.50	0.11
Hired labour	0.09	0.09	0.07	0.02	0.11	0.11
Intermediate inputs	0.26	0.28	0.26	0.11	0.30	0.28
<i>Rice</i>						
Own labour	0.37	0.37	0.38	0.28	0.23	0.30
Physical capital	0.41	0.07	0.08	0.11	0.10	0.47
Land	0.03	0.38	0.37	0.44	0.46	0.02
Hired labour	0.06	0.08	0.07	0.06	0.05	0.05
Intermediate inputs	0.13	0.09	0.09	0.11	0.17	0.17
<i>Other food crops</i>						
Own labour	0.24	0.10	0.10	0.08	0.18	0.22
Physical capital	0.31	0.21	0.21	0.06	0.09	0.31
Land	0.05	0.27	0.27	0.57	0.34	0.07
Hired labour	0.07	0.07	0.07	0.04	0.07	0.04
Intermediate inputs	0.33	0.35	0.35	0.25	0.32	0.36
<i>Tobacco</i>						
Own labour	0.17	0.11	0.15	0.06	0.06	0.13
Physical capital	0.27	0.20	0.10	0.20	0.20	0.26
Land	0.09	0.24	0.31	0.26	0.26	0.12
Hired labour	0.05	0.04	0.04	0.05	0.05	0.05
Intermediate inputs	0.43	0.41	0.40	0.42	0.42	0.44
<i>Tree crops</i>						
Own labour	0.12	0.06	0.16	0.20	0.12	0.16
Physical capital	0.49	0.34	0.21	0.31	0.03	0.42
Land	0.02	0.32	0.51	0.13	0.43	0.02
Hired labour	0.04	0.02	0.02	0.02	0.07	0.07
Intermediate inputs	0.33	0.26	0.10	0.34	0.36	0.33
<i>Livestock</i>						
Capital	0.20	0.135	0.175	0.215	0.255	0.335
Land	0.20	0.135	0.175	0.215	0.255	0.335
Intermediate inputs	0.60	0.73	0.65	0.57	0.49	0.33

Table A4: Household budget shares

	1. non- agricultural	2. landless agric.	3. small, non-remote	4. small, remote	5. medium	6. large
<i>Expenditure shares</i>						
Maize	..	0.14	0.15	0.15	0.09	0.03
Rice	..	0.05	0.03	0.02	0.02	0.00
Other food crops	..	0.26	0.28	0.22	0.16	0.08
Tobacco	..	0.00	0.00	0.00	0.00	0.00
Tree crops	..	0.07	0.08	0.05	0.04	0.02
Livestock	..	0.13	0.08	0.05	0.05	0.03
Non-farm goods	..	0.34	0.37	0.52	0.64	0.84
<i>Total</i>	..	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>	<i>1.00</i>

Table A5: DEVPEM data requirements

<i>Variable category</i>	<i>Information needed</i>	<i>Purpose</i>	<i>Source</i>
1. Household types	Land ownership, household education, and/or remoteness to markets	“Exogenous” (fixed) household characteristics that can distinguish between 4-6 household groups and capture heterogeneity in responses to shocks.	RIGA
2. Value of total production	National production of: a) the two or three most important food crops b) residual food crops c) annual cash crops (e.g. tobacco or entire group of crops) d) permanent cash crops (tree crops) e) livestock products	National aggregate production information is used to estimate each household group’s total production of each crop. The product categories are defined to capture different types of land use.	FAOSTAT
3. Value of total consumption	National consumption of items (a) – (e)	To estimate each household group’s total consumption of each crop.	FAOSTAT
4. Production shares	The share of each household group’s production of each product defined above	Multiplied by national production of each good, these will provide the value of production of each good, for each household category.	RIGA
5. Consumption shares	The share of each household group’s consumption of each product defined above	Multiplied by national consumption of each good, these will provide the value of consumption of each good, for each household category.	RIGA
6. Input cost shares	For each product defined, explicit or implicit costs of: a) labour b) capital c) land d) intermediate inputs (e.g. seeds and fertilizer)	Assuming zero economic profits, the cost shares provide costs of each input when multiplied by total agricultural gross revenue. Implicit costs are unobserved and need to be estimated with regression analysis based on input quantities or on some other method. (Number of inputs may vary between products.)	RIGA
7. Household income shares:	Share of total income for: a) net and gross farm production b) agricultural wage income c) non-agricultural income	Given the information on total agricultural production, an estimate of total household income can be derived that is consistent with the consumption and production values defined above. Non-farm income is then estimated using the corresponding income share. Assuming zero saving, total income equals total consumption. Consumption of market (non-farm) goods is given by the difference between estimated total income and total consumption on agricultural goods. If relevant, additional income sources may be defined (e.g. migrant remittances).	RIGA