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## Integrated Poverty Assessment for Livestock Promotion:
### Technical Reference Handbook

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Draft
January 2004
Not for quotation

## *Acknowledgements*

This handbook provides technical documentation for the analytical methods used to assess economic impacts of livestock promotion in developing countries, with particular reference to poverty alleviation. This work is an integral part of the Pro-Poor Livestock Policy Initiative, an FAO administered program to promote the livelihoods of smallholders in developing countries. The authors are consultants to FAO, working under supervision of Joachim Otte and collaborating with other FAO staff and experts in AGA/FAO. David Roland-Holst is the James Irvine Professor of Economics at Mills College and Directory of the Rural Development Research Consortium at the University of California, Berkeley (dwrh@are.berkeley.edu). Michael Epprecht is an independent consultant on assignment for this project (1). Saule Kazybayeva is a research economist on assignment with FAO (Saule.Kazybayeva@fao.org). The authors would like to thank Joachim Otte, Tim Robinson, Achilles Costales, and other colleagues at FAO for valuable guidance and input, as well as a variety of official and private researchers for facilitating our progress. All opinions expressed below are those of the authors and should not be attributed to their affiliated institutions.

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# 1. INTRODUCTION

It is widely recognized that expanding capacity for livestock production and marketing can be a potent catalyst for rural poverty alleviation in developing countries. Livestock have a variety of characteristics that make them important contributors to sustainable rural development. They are marketable products of scalable household and community production systems, and are generally less vulnerable to perishability and critical harvest timing than many crops. As an agricultural product with relatively high income elasticity, livestock is particularly attractive as a means for rural households to participate in urban-based economic growth. Livestock are also productive assets, contributing directly to output through animal traction and indirectly as a store of wealth for future investment. Finally, they can contribute to soil fertility and recycling of agricultural waste. With these and other advantages in mind, the aid community has consistently promoted livestock, especially among the poorest rural communities, and the FAO's PPLPI program is a prominent multilateral example of this commitment.

In this report, we describe the economic assessment tools developed in the first phase of this project. This technical reference summarizes a variety of analytical approaches that have been unified for evaluating PPLPI, along and in concert with other policy initiatives and changing external conditions. In later work, the methods developed here will be applied to PPLPI hub economies, including Vietnam, Senegal, Uganda, Orissa Province in India, and Peru. Each of these cases and programs has characteristics that make it unique, and each will yield special insights under the proposed analysis. It is hoped, however, that uniform standards for economic assessment will help identify the general properties of the PPLPI program that most effectively contribute to poverty alleviation and sustainable rural development.

# 2. OVERVIEW OF THE IPALP FACILITY

## 2.1. General Motivation and Information Structure

To support it's own and other development programs, PPLPI has undertaken a parallel activity to develop tools for Integrated Poverty Assessment for Livestock Promotion (IPALP), using their own program as a development platform and case study. To improve general understanding about the role of livestock in poverty alleviation, while at the same time strengthening the basis of evidence on how policies can best support pro-poor livestock development, a suite of analytical techniques is being applied across the four hubs of the PPLPI program. Each IPALP study covers four component areas of economic assessment:

### Table 2.1: Schematic Contents for IPALP Reports

- **Analysis of initial macroeconomic conditions**
  This section surveys the recent history of aggregate indicators to set the stage for examination of the more detailed determinant of household welfare.

- **Microeconomic analysis of initial conditions**
  in the individual country, region, etc. This section will provide a systematic survey of existing patterns of household production, employment, asset holding, expenditure and other conditions. The micro results are further divided into three components:
  a. Summary statistics and tables extracted from LSMS survey samples and other detailed data.
  b. To make the micro results on initial conditions more transparent, we include a synoptic atlas of digital maps presenting selected microeconomic results.
  c. To better understand the behavioural basis of household economic activity, we deploy a suite of econometric techniques to model household-level production systems, labor supply, and consumption. These detailed estimates will be focused on elucidating the role of livestock in local production, consumption, markets, and income determination.

- **Dynamic simulation of policies and external economic conditions**
  - with emphasis on the local incidence of these policies.
  These will include, but not be limited to, PPLPI, development strategies, trade policy, WTO accession, market reform, tax policies, etc.

- **Microeconomic assessment of PPLPI and Related Policies**
  - in concert with national and international policies and market forces, to more clearly identify patterns local economic adjustment and, in particular, their implications for poverty alleviation. In this component, a broad spectrum of poverty assessment tools will be implemented.

The basic objective of this approach is to support more technically focused livestock policies with deeper insight into economic conditions, behavior, and market linkages. For PPLPI, Integrated Poverty Assessment (IPA) of this kind can serve as an important evaluation tool both ex ante and ex post. Analysis of initial conditions can improve identification of target groups and anticipate their needs for effective program support and market access. Continuing and ex post economic assessment can strengthen ongoing program implementation and increase effectiveness of future programs.

## 2.2. Empirical Methods

The IPALP methodology itself consists of four generic parts (compare Figure 2.1), as summarized in the following table.

**Table 2.2: Fourfold Structure of IPALP Methodology**

1. **Data development**
   – This includes a comprehensive inventory of data related to the overall economy, including macro and micro information, with particular reference to rural conditions and the livestock sector.

2. **Policy Modeling**
   – Using a highly disaggregated dynamic CGE forecasting model, we will lay out a baseline scenario for growth over the next fifteen years and evaluate a variety of national policy scenarios, including PPLPI, generic development strategies, trade policy, WTO accession, market reform, tax policies, etc.

3. **Living Standards Assessment**
   – Using the microeconomic results obtained from the last two components, we will apply state of the art assessment tools to evaluate the effects of PPLPI and other policies on poverty, inequality, and a variety of living standard and human development indicators.

4. **Digital Mapping**
   – This component also applies in the ex ante micro evaluation, but here we apply digital mapping techniques to the results of our policy simulations. This policy results atlas will provide a transparent set of assessments that can be widely disseminated and compared across case studies regionally and globally.

**Figure 2.1: Four Components of IPALP**

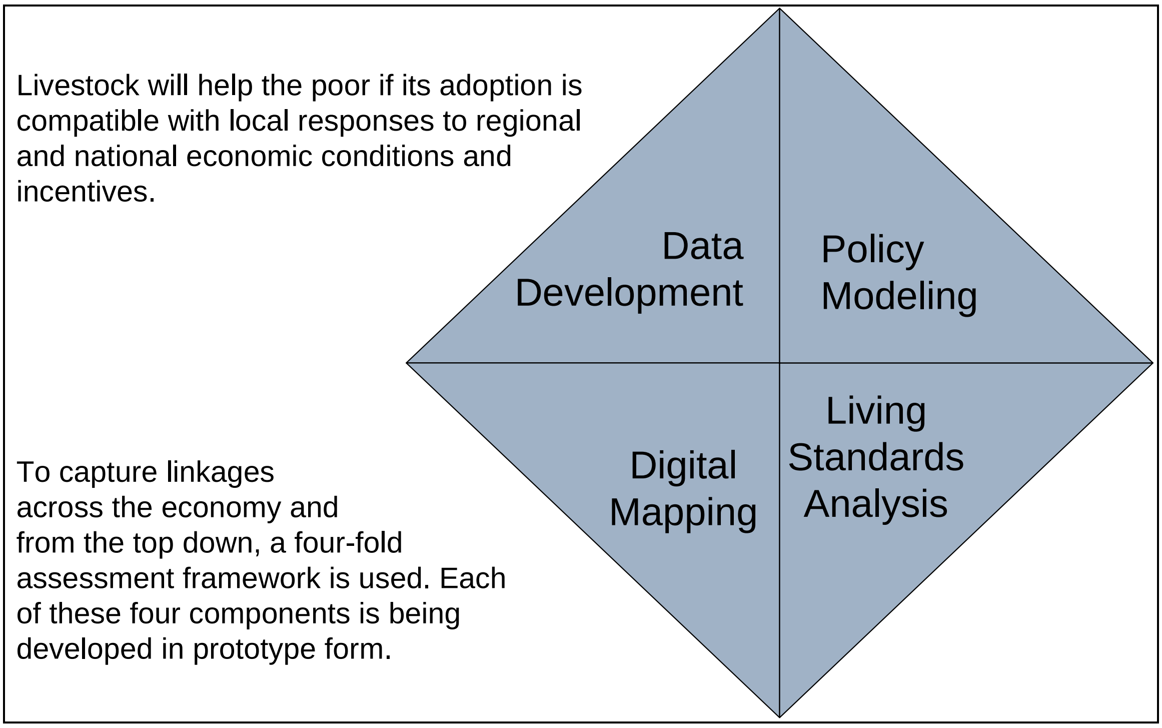
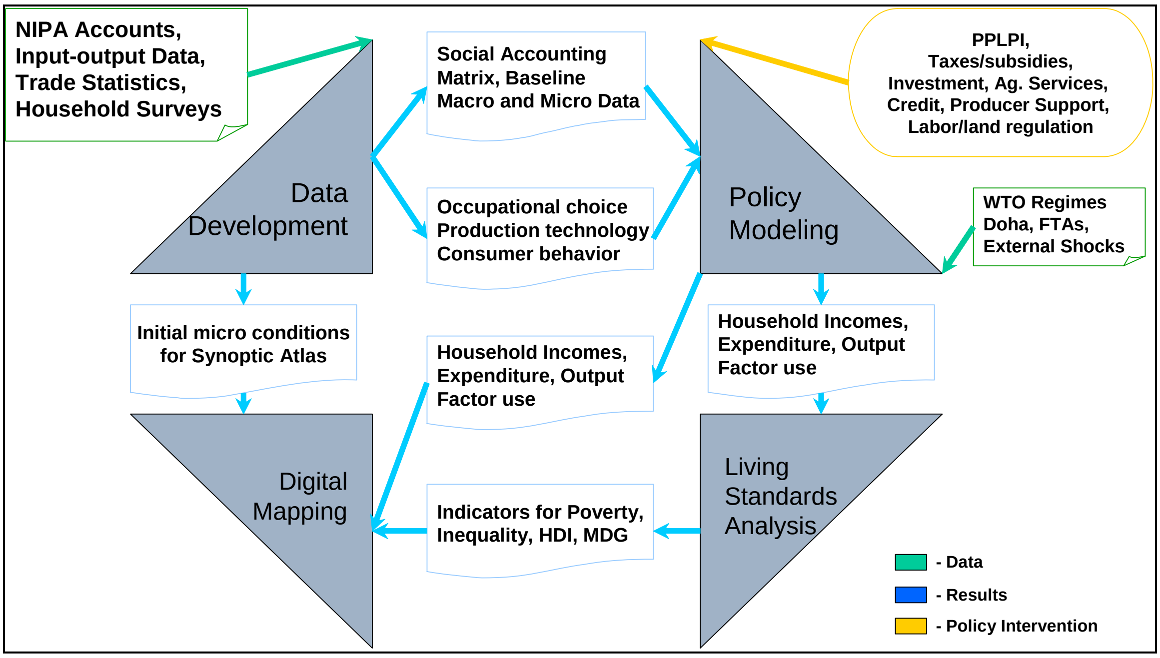



**Figure 3.2: IPALP Flowchart**



### 2.3. Prospective Work Plan

For modern development strategies, economic assessment plays an essential role in effective policy design, implementation, and ex post evaluation. For this reason, we plan to apply IPALP to a representative set of PPLPI cases in an initial phase and then, upon approval, more fully integrate this approach into the larger PPLPI universe.

In the initial phase, we plan to implement IPALP in one or two economies from each PPLPI hub. For each of these, a complete IPALP study will be produced along the lines discussed above. This will then be presented to the Steering Committee and to national stakeholders in a local seminar, accompanied by an IPALP Policy Brief designed for wider dissemination.[1]

If a second phase of IPALP is approved, it is proposed to conduct IPALP studies for several economies within each hub, using the same dissemination model in each case, but followed by hub seminars bringing together PPLPI staff and national stakeholders to present general conclusions. Finally, all this work can be drawn together in a global synthesis study and workshop or symposium (in addition the usual annual reports to the Steering Committee).

## 3. DATA RESOURCES

It is well known that the quality of economic analysis or any other empirical policy support, regardless of its sophistication, relies in an ultimate sense upon the accuracy, timeliness, and relevance of data resources. We are fortunate in modern times that standards for collection and recording of economic data have advanced dramatically. At the aggregate level, the UN sponsored SNA system (UN:1968) has achieved nearly universal comparability of national income and product data, including relatively detailed production information in the form of input-output accounts. These standards have also been adopted and extended in trade statistics, making multilateral reconciliation and comparison much easier (UNCTAD: 1990, Hertel et al: 1998). At more detailed levels, rapid proliferation of Living Standards Measurement Survey (LSMS) data sets has opened new horizons for empirical microeconomics, especially in developing countries where data constraints have been most binding.

The IPALP approach relies on timely and accurate at all levels, from the most aggregate GDP statistics to household expenditure surveys. In this section, we review the main sources and explain how they are adapted for use with our analytical methods.

[1] Policy briefs will summarise the main results and conclusions of each IPALP study in about 10-20 pages of non-technical discussion and descriptive tables and maps.

### 3.1. Household Surveys

Under the auspices of a variety of bilateral and multilateral institutions, as well as from the impetus of national governments and independent researchers, the number of detailed and rigorously sampled household surveys has increased dramatically in recent years. For developing countries in particular, this trend holds new promise for gaining insight into the determinants of living standards and the circumstantial and behavioral conditions that explain initial conditions and invite policy makers to facilitate improvements.

A good example of this trend is the Living Standards Measurement Study (LSMS) system underwritten and propagated by the World Bank. This system and others like it have directly and, through the propagation of standards and distribution of sampling tools, indirectly supported scores of large and small scale surveys around the world. These surveys significantly increase the body of evidence needed to improve our understanding of development generally and poverty in particular, and it is essential for ambitious international policies like PPLPI to leverage these information resources to improve effectiveness.

IPALP strives to do exactly this by recruiting local survey resources in PPLPI countries and incorporating them directly into project assessment. In each case, the extensive micro data already available will be used to sharpen our insights about the economic role of livestock and how PPLPI's direct effects will be dispersed across the local, regional, and national economies.

LSMS resources will vary from country to country, but most of the PPLPI economies have at least one recent nationally representative survey and some have more than one. In all cases, we begin with a comprehensive inventory of micro data of this kind and then apply the IPALP methods to those resources of the most direct relevance and value to the policies at hand.

### 3.2. Social Accounting Matrices

Detailed and rigorous accounting practices always have been at the foundation of sound and sustainable economic policy. A consistent set of real data on the economy is likewise a prerequisite to serious empirical work with economic simulation model. For this reason, a complete general equilibrium modeling facility stands on two legs: a consistent economywide database and modeling methodology. This chapter gives an overview of the accounting conventions used in applied general equilibrium modeling. The discussion below gives general indications about the many sources of data, their unification in the Social Accounting Matrix (SAM) framework, and the numerical and statistical reconciliation procedures which are used. A typical database development project relies on an extensive applied and theoretical literature, and no attempt is made here to give an exhaustive survey.

The three governing criteria for development and maintenance of good economywide data are detail, consistency, and currency. Detail in the context of CGE models refers to industrial and domestic institutional (e.g. household) classification, and to capture this, the database should incorporate input-output accounts and other transactions tables. Economywide consistency is achieved primarily by reconciling the input-output accounting information with the standard National Income and Product Accounts (NIPA) such as those published for the United States. This reconciliation is accomplished and maintained with a SAM tableau, which details economywide transactions between firms, households, government, and other domestic and foreign institutions at a flexible level of disaggregation. This SAM and other components of the database are estimated to a uniform standard that is consistent with observable information in a single base year. As we shall see, two levels of resolution are generally used, one for macroeconomic aggregates and one for more detailed of microeconomic linkages.

The genesis of the SAM approach goes back to the Nobel Laureate Richard Stone's pioneering work on social accounting, and during the past 25 years a variety of formalizations have appeared in the academic literature (see e.g. UN:1964 and Stone: 1981). In essence, the SAM is an economywide accounting device that captures the many interdependencies among sectors and institutions in the economy. As such, the SAM becomes the basis for detailed multiplier analyses that go well beyond more traditional input-output multiplier analysis, and also forms the informational basis for the building and calibration of a variety of applied general equilibrium models. Such models are important analytical tools for policy support. They take explicit account of the importance of price-mediated resource allocation, the hallmark of a market economy, and are therefore well suited to analyze issues such as the impact of liberalization with respect to domestic and international markets.

The type of accounting used here is based on a fundamental principle of economics: for every income or receipt there is a corresponding expenditure or outlay. This principle underlies the double-entry accounting procedures that make up the NIPA accounts. A SAM is a form of single-entry accounting. SAMs also embody the fundamental principle, but they record transactions between accounts in a tableau or matrix format. The number of transactors or accounts constitutes the dimension of the square matrix. By convention, incomes or receipts are shown in the rows of the SAM while expenditures or outlays are shown in the columns. The special merit of SAMs is that they can provide a comprehensive and consistent record of the inter-relationships of an economy at the level of individual production sectors, factors, and general public and foreign institutions. They can be used to disaggregate NIPA accounts, and they can reconcile these with the economy's input-output accounts.

Traditionally, the database for models with sectoral detail was the input-output accounting matrix, which captures industry linkages through flows of intermediate and factor input. Although it provides sectoral disaggregation, an input-output model does not include enough institutional detail to provide a framework for considering the full impact of policy on an economy. Input-output accounts can be extended to capture income and expenditure flows between other institutions, such as households, government, and the rest of the world in a SAM. Indeed, the development of SAMs was motivated in part by the desire for a unified framework that reconciled input-output accounts with NIPA accounts. The SAM thus provides detail and an economywide policy perspective in a consistent accounting framework.

The first SAM was constructed in the 1960s as a part of the Cambridge Growth Project by Sir Richard Stone, Alan Brown, and their associates. The accounts were for the United Kingdom in 1960, and they provided the data base for the Cambridge Growth Model. Since that time, SAMs have been constructed for at least 50 countries and have supported work in input-output analysis, tax-incidence studies, income distribution analysis, sectoral manpower planning, material-balance analysis, and computable general-equilibrium (CGE) modeling. This section introduces the concept of a SAM with macroeconomic emphasis. Next, we consider how the macroeconomic SAM can be disaggregated to provide a data facility for more detailed policy analysis.

### *3.2.1. Macroeconomic SAMs*

From the macroeconomic perspective, a SAM is essentially a double entry representation of the usual macroeconomic accounting identities, and it is used to calibrate the aggregate consistency of the more detailed activity, commodity, factor, and other institutional accounts in the disaggregated SAM. Table 3.1 depicts an open-economy "MacroSAM" with a government sector in terms of the macro accounting identities. Note that in this case intermediate goods are netted out and factor income and transfers are conferred directly to households.[2]

[2] See Reinert and Roland-Holst (1997) for a more extensive introduction to MacroSAMs and SAM estimation.

**Table 3.1: An Open-Economy MacroSAM with a Government Sector**

| Receipts | Expenditures 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| 1. Suppliers | - | C | G | I | E | Demand |
| 2. Households | Y | - | - | - | - | Income |
| 3. Government | - | T | - | - | - | Receipts |
| 4. Capital Accnt. | - | $S_h$ | $S_g$ | - | $S_f$ | Savings |
| 5. Rest of World | M | - | - | - | - | Imports |
| Total | Supply | Expenditure | Expenditure | Investment | ROW | |

Additional Variables:

$t_{42} = S_h$ = private savings
$t_{32} = T$ = tax payments
$t_{43} = S_g$ = government savings
$t_{15} = E$ = exports
$t_{45} = S_f$ = foreign savings
$t_{51} = M$ = imports
$t_{13} = G$ = government spending

Accounting Identities:

1. $Y + M = C + G + I + E$ (GNP)
2. $C + T + S_h = Y$ (Income)
3. $G + S_g = T$ (Govt. Budget)
4. $I = S_h + S_g + S_f$ (Saving-Investment)
5. $E + S_f = M$ (Trade Balance)

### 3.2.2. *MacroSAM Construction*

This section described how to actually construct a national MacroSAM. Almost all the necessary aggregated data for such an exercise should be available in published form. In what follows, reference is made to the individual cells in Table 3.2 above, which contains a schematic MacroSAM. It has nine rows and nine columns. Corresponding rows and columns share the same label. For example, row three and column three are both labelled “factors”. In the MacroSAM, entries are in the form of macroeconomic aggregates, and the row/column labels are defined below. The definitions in Table 3.3 are designed so as to provide information on how the SAM is structured and give a sense of how the SAM can be disaggregated to illustrate more economic detail.[3]

In a social accounting matrix (SAM), rows track receipts, while columns track expenditures. Hence, row and column sums represent, respectively, total receipts and total payments by a given account/institution. In the tradition of double entry accounting, row sums must equal column sums. Consider, for example, the second row/column, labelled Commodities. The row sum represents total demand for marketed goods and services in purchaser prices (i.e., producer prices plus a margin to cover trade and transport margins, costs of bringing the commodities from the producer to the consumer), comprised of intermediate demand from activities, private consumption of marketed commodities by households, state consumption, investment demand and exports. Accounting rules dictate that demand for commodities must equal supply, which appears as the Commodities column sum.

Total supply is composed of market sales of commodities by the Activities account, consumption taxes and import tariffs levied by government, as well as imports from the rest of the world (ROW). Marketed production may be either consumed domestically or exported.

[3] For detailed discussion on the methodology of SAM construction, see e.g. Reinert and Roland-Holst (1997). This sub-section also draws upon Arndt et al. (1998).

### Table 3.2: A Schematic MacroSAM

| Receipts | Expenditures | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *1. Activities* | *2. Commodities* | *3. Factors* | *4. Private Households* | *5. Enterprises* | *6. Recurrent State* | *7. Investment Savings* | *8. Rest of World* | *9. Total* |
| *1. Activities* | | Marketed Production | | | | | | | Total Sales |
| *2. Commodities* | Intermediate Consumption | | | Private Consumption | | State Consumption | Investment | Exports | Total Commodity Demand |
| *3. Factors* | Value Added | | | | | | | | Value Added |
| *4. Private Households* | | | Wages, Salaries and Other Benefits | | Distributed Profits and Social Security | Social Security and Other Current Transfers to Households | | Net Foreign Transfers to Households | Private Household Income |
| *5. Enterprises* | | | Gross Profits | | | | | Net Foreign Transfers to Enterprises | Enterprise Income |
| *6. Recurrent State* | Indirect Taxes | Consumption Taxes plus Import Tariffs | Factor Taxes | Income Taxes | Enterprise Income Taxes | | | Net Foreign Transfers to State | State Revenue |
| *7. Investment Savings* | | | | Household Savings | Retained Earnings & Enterprise Savings | State Savings | | Net Capital Inflows (=Foreign Savings) | Total Savings |
| *8. Rest of World* | | Imports | | | | | | | Imports |
| *9. Total* | Total Payments | Total Commodity Supply | Total Factor Payments | Allocation of Private Household Income | Total Enterprise Expenditure | Allocation of State Revenue | Total Investment | Total Foreign Exchange | |

## Table 3.3: Account Definitions for the MacroSAM

| Accounts | SAM Definitions |
|---|---|
| 1. Activities | In the activity row, goods and non-factor services (valued at producer prices) are produced for sale in the commodity market. More than one activity can in principle produce the same commodity. This is so when different technologies are used. For example, rice might be produced by small traditional farmers, requiring limited inputs, and more commercially oriented enterprises that employ greater quantities of inputs thus obtaining higher yields. Hence, the commodity Rice can be produced (in the column) by two activities - one traditional and one modern. This possibility is not allowed for in disaggregating the MacroSAM presented here. |
| 2. Commodities | Commodities are supplied in the column (to the commodity market) by activities in the form of marketed production at producer prices and from the rest of world in the form of imports of goods and non-factor services. Domestic agents demand commodities valued at purchaser prices in the row for intermediate consumption, private consumption, state consumption, and investment. Exports are demanded by the rest of the world. Marketed goods are formed in the commodity column by adding taxes/tariffs to the price of goods supplied from domestic production activities and goods imported from the rest of the world. |
| 3. Factors | Factors typically include labour, capital, and land, but in some cases the necessary data on returns to land are not available. Total payments to factors from productive activities (in the row) comprise value added, whereas the supply of factor inputs enters in the activity column. Factor income is distributed (in the column) as returns to labour and capital in the form of wages, salaries and other benefits, gross profits and factor taxes. |
| 4. Households | In more detailed SAMs, household accounts attempt to capture the characteristics of different policy relevant socio-economic groups of the population. Households differ principally in terms of factor ownership and consumption patterns. Total income (in the row) consists of wages, including other benefits, distributed profits from enterprises, social security payments, and net transfers from abroad. Income is allocated (in the column) to consumption, income taxes and household savings. |
| 5. Enterprises | Enterprises earn profits and receive foreign transfers (in the row). This income is distributed (in the column) to households, withheld as retained earnings or paid as taxes. Enterprises may be public (SOEs), private domestically owned enterprises, or foreign-invested companies. |
| 6. Recurrent State | The state is an institution that levies a variety of taxes to obtain revenue (in the row) and spends a recurrent budget (in the column) on public current and capital expenditure and a diverse set of transfer payments. The difference between recurrent spending and total tax revenue represents state savings. |
| 7. Investment /Savings | The capital account captures the balance between investment (in the column) and total savings (in the row). The latter include household savings, retained earnings, state savings, and net capital inflows (foreign savings) defined below. |
| 8. Rest of World (ROW) | This account reflects the balance between foreign exchange receipts (in the column) for goods, services, remittances, and other international transfers and imports of goods and non-factor services from the rest of the world (in the row). The net capital inflow cell captures in principle the sum of balance of payments entries not appearing elsewhere in the row or column. |
| 9. Total | Sums of columns and rows. Row sums must by definition equal column sums. |

GDP at market prices can be found as the sum of the following cells (referred to as T(i,j) for the entry in row i and column j of table T):

GDP = T(3,1) + T(6,1) + T(6,2), equivalent to value added at factor prices plus indirect taxes (output taxes), import tariffs and consumption taxes.

Alternatively, GDP at market prices may be found as:

GDP = T(2,4) + T(2,6) + T(2,7) + T(2,8) - T(8,2), equivalent to the sum of household and state consumption, investment and exports minus imports.

As discussed further below published data are not completely consistent using these two approaches due to (i) a statistical errors, and (ii) the common practice of adding in all production taxes (i.e., also factor taxes in cell (6,3)) in the value added figure published.[4]

The macroeconomic SAM in Table 3.2 treats exports in a manner that is consistent with the consolidated version of the reduced SNA SAM matrix procedure. Exports could alternatively be extracted from marketed production in the commodities column and placed in the activities row and sold to the rest of the world. Consequently, in this formulation marketed production would only refer to commodities produced by domestic firms and consumed on the domestic market. This is sometimes convenient as the column sum of the commodities account would correspond to total absorption. Comparison of the magnitude of consumption taxes relative to total absorption would also be a simple matter.

However, in the SNA and in the SAM structure employed here, exports are included in the so-called “goods and services” account as commodities adding to demand alongside other cells in the commodity row. Hence, the SNA “goods and services” total does not correspond to a concept of absorption in the domestic economy. In addition, since exports are passed to the rest of world through the commodities accounts, the domestic figures in cell (1,2) refer to total marketed sales of activities at producer prices regardless of whether those sales are destined for domestic or international markets.

The MacroSAM thus obtained provides a consistent set of aggregate consistency totals for the more detailed MicroSAM discussed in the next section. Generally speaking, a MacroSAM should be balanced (i.e. row and column sums made equal) by detailed inspection and judgment regarding individual accounting entries. As we shall see, the vastly larger scale of the MicroSAM makes such inspection prohibitively complex, and recourse must be taken to statistical procedures.

[4] A complete discussion of the economic relationships embodied in a SAM can be found in Pyatt and Round (1985).

### 3.2.3. Microeconomic SAMs

The MacroSAM provides a convenient framework for collection and appraisal of aggregate economic data, it lacks the resolution necessary to understand and favorably influence the determinants of poverty. Although it may be widespread in many developing countries, the experience of poverty is ultimately microeconomic in nature and policies designed to overcome it need to trace incidence to the household level.

**Production Activities and Commodities**

Disaggregation of production activities is generally based on traditional input-output accounts. This choice is partly one of expedience, since these detailed accounts are generally already available. It is also important to conform to existing production accounts, however, if IPALP is to contribute effectively to policy dialogue. Standardized industry classifications are so pervasive in national, regional, and even local economic management (statistics, taxes, regulation, etc.) that political economy is essentially structured by these categories. For these reasons, most micro SAMs maintain full input-output detail in their base data and we conform to this practice in IPALP.

Having said this, traditional SNA production accounting has some important shortcomings in the context of rural development. As we shall argue below in the econometric section, rural households do not closely resemble the neo-classical firm model that underlies these accounts, producing a single output with compensated factors of production. In reality rural households are generally multi-output enterprises that use factors informally and can consume a large fraction of their own output. We shall have more to say about this below, but in developing countries farm households require special treatment, and this is of essential relevance to livestock programs.

**Factors of Production**

Factor aggregation begins with the input-output accounts, usually distinguishing only between labor and capital. To more completely understand links between economic activity and household welfare, we obviously need greater detail in both occupational status and asset ownership. Simply put, economic policies will benefit households if they raise returns to the asset classes associated with them, preferably by direct ownership. For the poor, these assets are usually confined to material factors such as land, unskilled labor, and livestock. Thus if we want to understand income determination we need detailed information about factors of production.

In the case of labor, greater detail can be very useful in revealing labor market dynamics and how the poor find ways to participate in growth outside the farm sector.

**Households**

In the MacroSAM, households are represented by singular aggregates for personal consumption, tax payment, savings, factor and other income, and transfers with respect to the rest of the world. If we are to better understand the microeconomic incidence of policies, this information needs to be disaggregated to a degree that captures essential differences between economic institutions/agents. For the IPALP research agenda, such heterogeneity obviously includes household and per capita income differences, but equally essential are the determinants of these income differences. Such defining characteristics include differences in economic activities, asset/resource holdings, and geographic location.

Most LSMS style surveys have well-defined sections detailing characteristics like this. One important case is consumption expenditures, including expenditures on food, non-food, and durables. In this case, observed consumption vectors for home-produced and marketed goods at commodity aggregations comparable with the input-output tables helps us understand how households are embedded in both net production and consumption. Food and Non-food 'expenditures' on home-produced and marketed goods need to be attributed directly to the different household categories, based on a mapping between the designated SAM households and LSMS survey households. The resulting mapping between the detailed input-output commodities and those of the LSMS then itemize the most important component of final demand, net of subsistence production.

As a practical matter, it is necessary to choose an appropriate level of detail for household categories. Assuming that LSMS data are available, we have considerable discretion about this, with a continuum of aggregation possibilities between the MacroSAM and a fully inclusive implementation of the LSMS sample. At this point, the IPALP facility departs from standards adopted elsewhere in the modeling literature. Generally speaking, there are two established approaches in this context. The first implements a national SAM/CGE approach based on highly aggregated household categories, representing generic dichotomies such as rural/urban, farm/non-farm. At the other extreme is the so-called micro-simulation approach, which incorporates full LSMS samples into a two-stage simulation approach.

Arguments in support of the first approach generally appeal to expedience, yet they lack the resolution necessary to identify detailed welfare incidence. The micro-simulation approach claims to fully utilize available microeconomic information, but in the end only captures a small subset of economic variables endogenously and imputes the rest of the adjustment process in ways that lack transparency and statistical justification.

The IPALP approach strives for a middle way between these two approaches. In essence, we seek a level of statistical detail that is adequate to explain relevance distributional outcomes, but within a unified analytical framework. More aggregated approaches lack the data resolution needed to explication distribution, while traditional micro-macro models lack formal consistency needed to obtain conclusive links between national policies and local impacts.

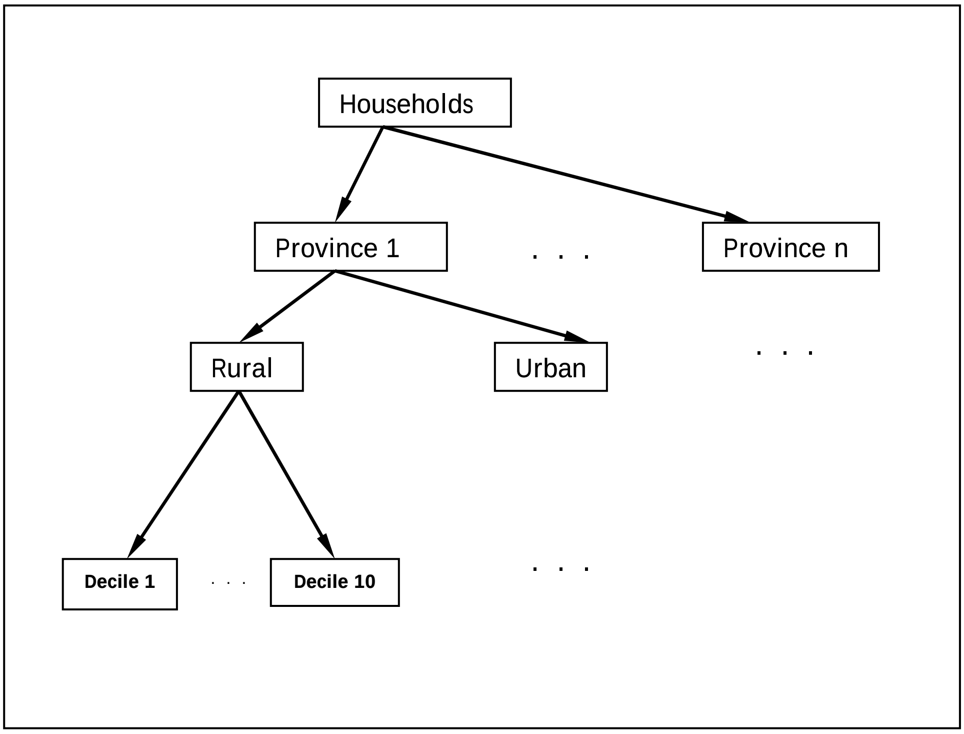
Returning to the issue of household resolution, let us remind ourselves that most LSMS samples have household weights exceeding 1,000. In practice, this means that so-called micro-macro models are using primary household data that represent three orders of magnitude in aggregation. Generally speaking, this sampling resolution may be appropriate for the full sample questionnaire (up to 500 variables), but there is no reason why this level of “aggregation” is optimal for economic modeling. In the latter exercise, we generally focus upon 10-20 endogenous variables. According to our own work with bootstrap and Monte Carlo techniques, most of the variance in distributionally relevant economic variables can be explained with a relatively aggregate representative sample of a given LSMS.

In the case of Vietnam, for example, we found that the 2002 LSMS sample of 60,000 households could be aggregated into less than 1,000 representative households without statistically significant loss of explanatory power among the variables most important to household income and its determination. This includes consideration of geographic factors, which are parting of statistical significance and also of policy important in their own right. In the Vietnamese case, we found that 600 representative households (rural-urban income deciles, by (30) provinces), explained over 95% of the variation in incomes in the full LSMS sample.

Representative aggregation such as this enables us to incorporate detailed households into national modeling specifications, at once reconciling the need for detail with formal consistency in model specification. In practice, the optimal level of representative aggregation will depend upon the other data available and the nature of the policy research at hand. Our experience indicates, however, that the desire for detailed incidence analysis and tractable modeling can be reconciled. The following figure gives a general example of such a representative sampling procedure. Most LSMS samples include household observations across the economy, reflecting diverse locational, demographic, and economic information. Base on our bootstrap studies, we have found that variables associated with general location, rural/urban status, and income decile or quintile are the most influential determinants of economic participation and its consequences for living standards. For this reason, we use a blend of these criteria that depends upon the application at hand. Figure 3.1 presents a schematic for this kind of representative household decomposition. In each empirical case, we will bootstrap the LSMS to determine the optimal level of disaggregation. We know from the outset, however, that economic and locational variable will both play a role. The former are obvious, since they are essential determinants in the economic analysis. The latter must be taken into account for two reasons. Firstly, location is a proxy for much more complex economic variables including asset/resource holdings and distribution margins. Seconding, and at least as importantly, location is an essential component of political economy. In this example, households are averaged by (n) provinces, across deciles of income in rural and urban settings. This example yields a 20n set of representative households, with average characteristics for all other variables (questionnaire items). Simply put, these categories are policy relevant and explain most of the functional differences in economic participation.

In the Vietnamese case already mentioned, this would yield a 20x30=600 household SAM and CGE model. Our statistical analysis indicates that variation among these 600 categories, in response to changes policy and exogenous variables that would affect all households, captures over 95 percent of the variation explained by the full LSMS, and does so within a singular and consistent modeling framework.

**Figure 3.1: Illustration of a Sample Household Disaggregation**



**Other Private Institutions**

In the context of SAM accounting, the main private institutions distinct from households are enterprises. Generally speaking, Enterprises act as an intermediary of financial flows, fiscal incidence, and factor income allocation. In developed countries, most households receive income from non-human factors as these are mediated (i.e. after taxes and expatriated profits) by enterprises. Apart from their role in dispersing income to households, however, enterprises are primarily of interest as targets for non-distortionary taxation.

**Public Institutions**

In addition to the basic fiscal statistics included in NIPA accounts, and the transfer data included in household surveys, it may be desirable to include more detailed information on government balance sheets. This is particularly the case for governments that have extensive foreign borrowing, complex industrial subsidy or enterprise schemes, or incentive based systems of discriminatory taxation.

**Capital Account**

The capital account category encompassed the balance sheets of the entire financial system. Depending upon the degree to which financial transfers, intermediation, or savings flows are important to a given development policy, it may be desirable to disaggregate this account beyond consolidated savings and investment.

If this is desired, a matrix of flow of funds can be inserted into the real SAM by replacing the Capital Account institution, i.e. the column of investments and the row of savings. However, unlike the real SAM data, statistical offices in many countries may not publish complete flow of funds statistics in double entry or matrix format. The data for the construction of the flow-of-fund matrix thus have to be compiled from various sources. First, savings and investments data are derived from the real SAM, which is necessary to guarantee the consistency between the real economy and the financial sector. The assets and liabilities of commercial banks and the monetary authority (i.e., the central bank) are first to be recorded. Next, data on foreign portfolio investments, direct investments, and debts are usually collected from various international publications. Government's equity participation can be represented by the development expenditures of the central government, the data of which are available from the national budget. Finally, the exchange rate data are needed to convert transactions denominated in foreign currency. This can be collected from the IMF's International Financial Statistics.

**Trade Accounts**

Traditional input-output tables include a single export and import vector to capture trade with an aggregate partner called the Rest of the World (ROW). In many applications, it is desirable to identify origin and destination of trade more specifically, including the possibility of differential taxes/subsidies on this trade. This is particularly important at a time when bilateral and other FTA agreements are proliferating so rapidly. To achieve this, the simple trade accounts must be disaggregated. Some developing countries have such detailed data in customs authorities, but these are rarely in a directly useable form. Fortunately, UNCTAD and other multilateral agencies have achieved a relatively reliable standard with the COMTRADE database, and this is serviceable in most cases. It might also be possible to corroborate this information with the more sophisticated GTAP database (see Hertel et al: 1998), which includes more extensive information on trade barriers.

**Data Inventory**

Each case study will have its own special data characteristics, but there are general categories that should be consulted and represented in any economywide SAM with data resolution sufficient to analyze poverty. The list below is not exhaustive, but represents the generic categories of data that need to be considered in any such exercise.

## Checklist for Primary MicroSAM Data Components

| | Accounts | Description | Sources |
|---|---|---|---|
| 1 | Industry | Input-output tables: use and make tables are needed to capture differences in tax and margin incidence | SNA, ISIC, NAICS classified industry accounts. Maintained by most national statistical bureaus |
| 2 | Gross Output and Value Added | Sectoral statistics, which may differ from the industry accounts if a later year SAM is desired and the Input-output tables need to be updated<br>Value added should be disaggegated by labor and capital at a minimum, and may include depreciation. | Generally maintained annually as part of NIPA. |
| 3 | Trade | Import and Export flows by commodity, including separate account for trade taxes/subsidies and margins | This data is generally maintained by trade ministries, and may or may not include bilateral partner (origin and destination) disaggregation. Alternatively, partner disaggregation from the UN COMTRADE database or possibly GTAP. This is unlikely, however, to be consistent with official government data and we need the latter as a control for the overall domestic accounts |
| 4 | Final Demand | Includes private and public consumption and investment outlays by commodity category, inventory changes may also be included. | These are generally maintained annually at some level of aggregation on an annual basis. Apart from years that input-output tables are created, they may require disaggregation to match the industry accounts for a later year. |
| 5 | National Income and Product Accounts | These correspond to all the macroeconomic aggregates for the reference year, according to UN SNA standards. These supply the basic data to the MacroSAM and act as macro control totals and accounting entries in MicroSAM, including in particular the lower right quadrant of inter-institutional transfers. | NIPA accounts are generally maintained annually at the national level. |
| 6 | Employment | This is not strictly needed for the SAM, but provides an important consistency check for value added disaggregation and in any case is required to implement the CGE model. | Employment statistics are generally maintained by human resource ministries. Sectoral detail needs to conform to industry/commodity aggregation, occupational detail to the household survey extract. |
| 7 | Capital Stock | As with employment, only needed for indirect use with the SAM, but necessary for modeling. This may be available by type of capital (i.e. public, private domestic, private foreign). Factor/profit taxes are also desirable. | This may be available from statistical bureaus, the industry ministry or the central bank. |
| 8 | Household Data | Household data are the main difference between SAM and Input-Output accounts, and they significantly increase the policy relevance of incidence analysis because they capture detailed effects on final consumers and incomes of demographic groups. This data are best derived from very detailed, nationally representative LSMS household survey data. | Generally, we want to define a suitable sub-sample stratification of the household surveys with the dual objectives of parsimony and policy relevance. This must take account of three components: relative income status, functional income determinants, and location.We at least require a rural/urban distinction. While it is not necessary to maintain the whole LSMS sample for direct analysis, it should be available for ex post imputation, mapping extensions, etc. |

### Data Reconciliation

It is apparent from the discussion above that SAMs are intended to achieve a consistent synthesis of related by highly diverse data sources. Compiling these sources into a framework with unified account classifications is the first step, but it then becomes necessary to reconcile the diversity of the underlying entries so they reflect a single, consistent double entry accounting system. Of course such a process entails estimation and its attendant informational compromises, but we are fortunate to have advanced statistical procedures that help us minimize the cost of such losses of precision. Historically, most SAMs and other tabular economic accounts were reconciled by a linear normalization procedure calls the RAS method, developed by Bacharach (1970) and Stone himself (Stone:1980). In this section, we present a more complex but intellectually defensible statistical procedure. The latter method, call Maximum-Entropy Tabular Reconciliation (METR) is the standard we apply to IPALP data. For those who wish to explore the subject further, references are also provided.

### *3.2.4. Statistical MicroSAM Balancing - Maximum Entropy Tabular Reconciliation (METR)*

While the linear reconciliation approach to SAM balancing is intuitive and easy to implement, it lacks any inferential basis, including uncertainty measurements or the capacity to take account of prior information. For this reason, IPALP relies on a more advanced method, termed Maximum Entropy Tabular Reconciliation (METR). This approach originates from the entropy control estimation techniques of information theory (see e.g. Kapur and Kesavan 1992, and Golan et al. 1996) and has been applied to social accounting matrix estimation in e.g. Robinson et al. (1998) and Robinson and El-Said (2000). This section provides a general overview of this reconciliation strategy, but interested readers should consult the literature on this topic before attempting application to large accounting systems.

The entropy technique is a method of solving underdetermined estimation problems. The problem is underdetermined because, for an $n$ x $n$ matrix, we are seeking to identify $n^2$ unknown, non-negative parameters, i.e. the cells of the SAM. However, there are only *2n-1* independent row and column adding-up restrictions. In other words, restrictions must be imposed on the estimation problem so that we have enough information to obtain a unique solution and to provide enough degrees of freedom. The underlying philosophy of entropy estimation is to use *all* and *only* the information available for the problem at hand: the estimation procedure should not ignore any available information nor should it add any false information. [5]

In the case of SAM estimation, 'information' may be the knowledge that there is measurement error concerning the variables, and that some parts of the SAM are known with more certainty than others. There may be a prior in the form a SAM from a previous year, whereby the entropy problem is to estimate a new set of coefficients 'close' to the prior using new information to update it. Furthermore, 'information' could consist of moment constraints on e.g. row and column sums, e.g. the average of the column sums. In addition to the row and column sums, 'information' may also

[5] See Shannon (1948) and Theil (1967), who motivate these statistical ideas from their roots in information theory.

consist of certain economic aggregates such as total value-added, aggregate consumption, investment, government consumption, exports and imports. Such information may be incorporated as linear adding-up restrictions on the relevant elements of the SAM. In addition to equality constraints such as these, information may also be incorporated in the form of inequality constraints placing bounds the mentioned macro aggregates. Finally, one may want to restrict cells that are zero in the prior to remain so also after the entropy balancing procedure.

Following Robinson et al. (2000) and Robinson and El-Said (2000), let the SAM be defined as a matrix T with elements $T_{i,j}$ representing a payment from the column account j to the row account i. As mentioned above, social accounting matrices are consistent accounting frameworks that do not allow leakages. In other words, every row sum in the SAM must equal the corresponding column sum:

(i) $$y_i = \sum_j T_{i,j} = \sum_j T_{j,i}$$

Dividing each cell entry in the matrix by its respective column total generates a matrix of column coefficients A:

$$A_{i,j} = \frac{T_{i,j}}{y_j}$$

It is assumed that the entropy problem starts with a prior, $\bar{A}$, which perhaps is a SAM from a previous year, or as in this case, a raw and unbalanced assembly of the SAM accounting components described in the previous section. $\bar{A}$ represents the starting point from which the cross-entropy balancing procedure departs in deriving the new matrix of coefficients $A^*$. The entropy problem is to find a new set of A coefficients which minimize the so-called Kullback-Leibler (1951) measure of the 'cross entropy' (CE) distance between the prior $\bar{A}$ and the new estimated coefficient matrix $A^*$.

$$\min_{\{A\}} I = \left[ \sum_i \sum_j A_{i,j} \ln \frac{A_{i,j}}{\bar{A}} \right] = \left[ \sum_i \sum_j A_{i,j} \ln A_{i,j} - \sum_i \sum_j A_{i,j} \ln \bar{A} \right]$$

subject to

$$\sum_j A_{i,j} y_i^*$$

$$\sum_j A_{j,i} = 1 \; and \; 0 \le A_{j,i} \le 1$$

Analogous to Walras' Law in general equilibrium theory, note that one equation can be dropped in the second set of constraints: If all but one column and row sum are equal, the last one must also be equal. The solution of the above problem is solved by setting up the Langrangian. The *k* macro aggregates can be added to the set of constraints on the problem above as follows:

$$\sum_i \sum_j G_{i,j}^{(k)} T_{i,j} = \gamma^{(k)}$$

where *G* is an *n* x *n* aggregator matrix with ones for cells that represent the macro constraints and zeros otherwise, and $\gamma$ is the value of the aggregate constraint.

As mentioned above, in the real world one faces economic data measured with error. The cross entropy problem can also be formulated as an 'error-in-variables' system where the independent variables are measured with noise. If, for example, we assume the known column sums are measured with error, the row/column consistency constraint can be written as:

$$y = \bar{x} + e$$

where $y$ is the vector of row sums and $\bar{x}$, the known vector of column sums, is measured with error $e$. The prior estimate of the column sums could be the initial column sums, the average of the initial column and row sums, or e.g. the row sums.

Following Golan et al. (1996) the errors are written as weighted averages of known constants *v*:

$$e_i = \sum_w w_i \bar{v}_{i,w}$$

where *w* is a set of weights that fulfill the following constraints:

$$\sum_w w_{i,w} = 1 \; and \; 0 \le w_{i,w} \le 1$$

In the estimation problem the weights are treated as probabilities to be estimated, and the prior for the error distribution in this case is chosen to be a symmetric distribution around zero with predefined lower and upper bounds, and using either three or five weights. Naturally, not only the column and row sums can be measured with error. The macro aggregates by which we constrain our estimation problem may also be measured with error and so we can operate with two sets of errors with separate weights *w1*'s on the column sum errors, and weights *w2*'s on the macro aggregate errors. The optimization problem in the 'errors-in-variables' formulation is now the problem of finding *A*'s, *w1*'s and *w2*'s that minimize the cross entropy measure including a terms for the error weights:

$$\min_{\{A,w1,w2\}} I = \left[\sum_i \sum_j A_{i,j} \ln A_{i,j} - \sum_i \sum_j A_{i,j} \ln \overline{A}\right] + \left[\sum_i \sum_w w1_{i,w} \ln w1_{i,w} - \sum_i \sum_w w1_{i,w} \ln \overline{w}1_{i,j}\right] + \left[\sum_i \sum_w w2_{i,w} \ln w2_{i,w} - \sum_i \sum_w w2_{i,w} \ln \overline{w}2_{i,j}\right]$$

The cross-entropy measures reflect how much the information we have introduced has moved our solution estimates away from the inconsistent prior, whilst also accounting for the imprecision of the moments assumed to be measured with error. Hence if the information constraints are binding, the distance from the prior will increase. If they are not binding, the cross entropy distance will be zero.

The IPALP application of the cross entropy estimation to a raw and unbalanced MicroSAM uses the 'error-in-specification' formulation described above, and the standard errors for both the column sum and macro aggregate constraints have been set to 1%. The prior for the column sums equal to the average of the initial column and row sums since that there is no *a priori* belief that the one should be more accurate than the other. In addition to the column constraints, a number of macro aggregates have been introduced as constraints on the estimation process. The total value of factor payments is fixed to the aggregate value as specified in the MacroSAM. In other words total GDP at factor costs is constrained to its original value. Furthermore, the foreign trade entries are constrained to their macro aggregates, as are the entries for total private consumption, total government consumption and total investments. Hence also total GDP at market prices and measured from the expenditure side is also bound to the macro figures, taking into account the margin allowed for measurement errors.

For the IPALP approach, we have also developed computer software to implement METR. While RAS methods can be carried out in ordinary spreadsheet applications, METR requires dedicated higher level programming to implement its optimization features.

# 4. ECONOMIC SIMULATION MODELING

As a central component of the IPALP methodology, we use general equilibrium models to shed light on the local impacts of national and international polices, evaluating how these events can be influenced by PPLPI and related development initiatives. In an era of globalization, there is a generally held belief that greater external orientation can confer aggregate growth benefits. Despite this apparent consensus, however, the detailed incidence of trade and growth, among many economywide trends, is not so easy to generalize. Indeed, policies targeted at poverty alleviation in particular need a solid empirical basis to identify the detailed components of the adjustment process.

In today's world, economic linkages are so complex that it is unlikely that policy makers relying on intuition alone will achieve anything approaching optimality. Indeed, much evidence now suggest that indirect effects of many policies outweigh direct effects and, if not adequately understood, can substantially offset or even reverse them. Because of their abilities to capture exactly such linkages, computable general equilibrium (CGE) models have become preferred tools for tracing supply and demand linkages across extended chains of price-directed exchange. Because of their detailed behavioral specification, these models are particularly good at elucidating adjustments in income distribution and economic structure. In this section, we document the basic CGE framework used in all IPALP case studies.

## 4.1. A Prototype Model for Economywide Macro and Micro Assessment

The following sections present a prototype model for the economic model we use to trace linkages between livestock development and the rest of the economy. The prototype has some key features for assessing structural and poverty impacts:

- Labor markets disaggregated by occupation
- Land and capital markets disaggregated by type of capital/land
- A production structure which differentiates the substitutability of different occupation groups, e.g. unskilled labor on the one hand, and skilled labor and capital on the other hand
- Differentiation of production of similar goods (e.g. small and large scale farms, or public versus private production)
- Detailed income distribution
- Intra-household transfers (e.g. urban to rural), transfers from government, and remittances

- Multiple households
- A tiered structure of trade (taking account of both domestic and foreign markets)
- Possibility of influencing export prices
- Internal domestic trade and transport margins
- Various potential factor mobility assumptions

The rest of the document proceeds to describe all of the model details using the standard circular flow description of the economy. It starts with production (*P*), income distribution (*Y*), demand (*D*), trade (*T*), domestic trade and transport margins (*M*), goods market equilibrium (*E*), macro closure (*C*), factor market equilibrium (*F*), macroeconomic identities (*I*), and growth (*G*).

Table 1 describes the indices used in the equations. Note that the model differentiates between production activities, denoted by the index *i*, and commodities, denoted by the index *k*. In many models, the two will overlap exactly. However, this differentiation allows for the same commodity to be produced by one or more sectors, and to differentiate these commodities by source of production. For example, it could be used in a model of economies in transition where commodities produced by the public sector have a different cost structure than commodities produced by the private sector, and the commodities themselves could be differentiated by consumers.[6] Another example, could be small- versus large-scale agricultural producers.

Table 1: Indices used in the model

| | |
|---|---|
| *i* | Production activities |
| *k* | Commodities |
| *l* | Labor skills |
| *ul* | Unskilled labor |
| *sl* | Skilled labor[a] |
| *kt* | Capital types |
| *lt* | Land types |
| *e* | Corporations |
| *h* | Households |
| *f* | Final demand accounts[b] |
| *m* | Trade and transport margin accounts[c] |
| *r* | Trading partners |

*Notes*: a. The unskilled and skilled labor indices, *ul* and *sl*, are subsets of *l*, and their union composes the set indexed by *l*.
b. The standard final demand accounts are '*Gov*' for government current expenditures, '*ZIp*' for private investment, '*ZIg*' for public investment, '*TMG*' for international export of trade and transport services, and '*DST*' for changes in stocks.
c. The standard trade and transport margin accounts are '*D*' for domestic goods, '*M*' for imported goods, and '*X*' for exported goods.

[6] The model allows for perfect substitution, in which case consumers are indifferent regarding who produces the good. An example might be electricity.

## 4.2. Model Equations

### *4.2.1. Production*

Production, like in most CGE models, relies on the substitution relations across factors of production and intermediate goods. The simplest production structure has a single constant-elasticity-of-substitution (CES) relation between capital and labor, with intermediate goods being used in fixed proportion to output. In the production structure described below, there are multiple types of capital, land and labor, and they are combined in a nested-CES structure which is intended to represent the various substitution possibilities across these different factors of production. Typically, intermediate goods will enter in fixed proportion to output, though at the aggregate level, the model allows for a degree of substitutability between aggregate intermediate demand and value added.[7] The decomposition of value added has several components (see *figure* 1 for the a representation of the multiple nests). First, land is assumed to be a substitute for an aggregate capital labor bundle.[8] The latter is then decomposed into unskilled labor on the one hand, and skilled labor cum capital on the other hand. This conforms to recent observations which suggest that capital and skilled labor are complements which can substitute for unskilled labor. The four aggregate factors—unskilled and skilled labor, land and capital, are decomposed by type in a final CES nest.

All sectors are assumed to operate under constant returns to scale and cost optimization. Production in each sector is modeled by a series of nested CES production functions, which are intended to represent the different substitution and complementarity relations across the various inputs in each sector. There are material inputs that generate the input/output table, as well as factor inputs representing value added.

Three different production archetypes are defined in the model—crops, livestock, and all other goods and services. The CES nests of the three archetypes are graphically depicted in Figures 1 through 3. Sectors are differentiated by different input combinations (share parameters) and substitution elasticities within each one of the main production archetypes. The former are largely determined by base year data, and the latter are given values by the modeler.

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7 Deviations from this structure might include isolating some key inputs, for example energy, or agricultural chemicals in the case of crops, and feed in the case of livestock.

8 In some sectors the model also allows for a sector-specific factor of production, for example, coal mining and oil production require reserves which cannot be used for any other activity. In this case, the nesting follows the same general structure as depicted in Figure 1.

The key feature of the crop production structure is the substitution between intensive cropping versus extensive cropping, i.e. between fertilizer and land (see Figure 1).[9] Livestock production captures the important role played by feed versus land, i.e. between ranch-versus range-fed production (see Figure 2).[10] Production in the other sectors more closely matches the traditional role of capital/labor substitution, with energy introduced as an additional factor of production (see Figure 3). Labor can have three different skill levels—unskilled, skilled, and highly skilled. The first two are substitutable and combined in a CES aggregation function as a single labor bundle. Highly skilled labor is combined with capital to form a physical plus human capital bundle.[11]

In each period, the supply of **primary** factors—capital, labor, and land—is usually predetermined.[12] However, the supply of land is assumed to be sensitive to the contemporaneous price of land. Land is assumed to be partially mobile across agricultural sectors. Some of the natural resource sectors also have a sector specific factor whose contemporaneous supply is price sensitive.

The model includes adjustment rigidities. An important feature is the distinction between *old* and *new* capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[13]

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply (zero-profit) conditions in all markets. (A fixed markup has been introduced in the model allowing for assessing the impacts of greater competitiveness.)

### *4.2.2. Top-level nest and producer price*

The top-level nest has output, *XP*, produced as a combination of value added, *VA*, and an aggregate demand for goods and non-factor services, *ND*. In most cases, the substitution elasticity will be assumed to be zero, in which case the top-level CES nest is a fixed-coefficient Leontief production function. Equations (P-1) and (P-2) represent the optimal demand conditions for the generic CES production function, where *PND* is the price of the *ND* bundle, *PVA* is the aggregate price of value added, *PX* is the unit cost of production, and $\sigma^p$ is the substitution elasticity. If the latter is zero, both *ND* and *VA* are used in fixed proportions to output, irrespective of relative prices. Equation (P-3) represents the unit cost function, *PX*. It is derived from the CES dual price formula. The model assumes constant-returns-to-scale and perfect competition in all sectors. Hence, the producer price, *PP*, is equal to the unit cost, adjusted for a producer tax/subsidy, $\tau^p$, equation (P-4).

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9 In the original GTAP data set, the fertilizer sector is identified with the crop sector, i.e. chemicals, rubber, and plastics.

10 Feed is represented by three agricultural commodities in the base data set: wheat, other grains, and oil seeds.

11 The level of highly skilled capital is user-determined in the current version of the model.

12 Capital supply in each period is somewhat influenced by the level of contemporaneous investment if the gap size between periods is greater than 1.

13 For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium price to be determined by the model (see Fullerton, 1983).

$$ND_i = \alpha_i^{nd}\left(\frac{PX_i}{PND_i}\right)^{\sigma_i^p} XP_i \tag{P-1}$$

$$VA_i = \alpha_i^{va}\left(\frac{PX_i}{PVA_i}\right)^{\sigma_i^p} XP_i \tag{P-2}$$

$$PX_i = \left[\alpha_i^{nd} PND_i^{1-\sigma_i^p} + \alpha_i^{va} PVA_i^{1-\sigma_i^p}\right]^{1/(1-\sigma_i^p)} \tag{P-3}$$

$$PP_i = \left(1+\tau_i^p\right) PX_i \tag{P-4}$$

### 4.2.3. Second-level production nests

The second-level nest has two branches. The first decomposes aggregate intermediate demand, *ND*, into sectoral demand for goods and services, *XAp*. The model explicitly assumes a Leontief structure. Thus equation (P-5) describes the demand for good *k* by sector *j*, where the coefficient *a* represents the proportion between *XAp* and *ND*. The price of the *ND* bundle, *PND*, is the weighted average of the price of goods and services, *PA*, using the technology coefficients as weights, equation (P-6). The so-called Armington price is multiplied by a sector and commodity specific indirect tax, $\tau^{cp}$.

$$XAp_{k,j} = a_{k,j} ND_j \tag{P-5}$$

$$PND_j = \sum_k a_{k,j}\left(1+\tau_{k,j}^{cp}\right) PA_k \tag{P-6}$$

The second branch decomposes the aggregate value added bundle, *VA*, into three components: aggregate demand for capital and labor, *KL*, aggregate land demand, $TT^d$, and a sector-specific resource, *NR*,[14] see equations (P-7) through (P-9). The relevant component prices are *PKL*, *PTT* and *PR*, respectively, and the substitution elasticity is given by $\sigma^v$. Equation (P-9) allows for the possibility of factor productivity changes as represented by the $\lambda$ parameter. The price of value added, *PVA*, is the CES aggregation of the three component prices, as defined by equation (P-10).

[14] The latter will typically be zero in most sectors.

$$KL_i = \alpha_i^{kl} \left( \frac{PVA_i}{PKL_i} \right)^{\sigma_i^v} VA_i \qquad \text{(P-7)}$$

$$TT_i^d = \alpha_i^{tt} \left( \frac{PVA_i}{PTT_i} \right)^{\sigma_i^v} VA_i \qquad \text{(P-8)}$$

$$NR_i^d = \alpha_i^{nr} \left( \lambda_i^{nr} \right)^{\sigma_i^v - 1} \left( \frac{PVA_i}{PR_i} \right)^{\sigma_i^v} VA_i \qquad \text{(P-9)}$$

$$PVA_i = \left[ \alpha_i^{kl} PKL_i^{1-\sigma_i^v} + \alpha_i^{tt} PTT_i^{1-\sigma_i^v} + \alpha_i^{nr} \left( \frac{PR_i}{\lambda_i^{nr}} \right)^{1-\sigma_i^v} \right]^{1/(1-\sigma_i^v)} \qquad \text{(P-10)}$$

## *4.2.4. Third-level production nest*

The third-level nest decomposes the aggregate capital-labor bundle, *KL*, into two components. The first is the aggregate demand for unskilled labor, *UL*, with an associated price of *PUL*. The second is a bundle composed of skilled labor and capital, *KSK*, with a price of *PKSK*. Equations (P-11) and (P-12) reflect the standard CES optimality conditions for the demand for these two components, with a substitution elasticity given by $\sigma^{kl}$. The price of capital-labor bundle, *PKL*, is defined in equation (P-13).

$$UL_i = \alpha_i^{u} \left( \frac{PKL_i}{PUL_i} \right)^{\sigma_i^{kl}} KL_i \qquad \text{(P-11)}$$

$$KSK_i = \alpha_i^{ksk} \left( \frac{PKL_i}{PKSK_i} \right)^{\sigma_i^{kl}} KL_i \qquad \text{(P-12)}$$

$$PKL_i = \left[ \alpha_i^{u} PUL_i^{1-\sigma_i^{kl}} + \alpha_i^{ksk} PKSK_i^{1-\sigma_i^{kl}} \right]^{1/(1-\sigma_i^{kl})} \qquad \text{(P-13)}$$

## *4.2.5. Fourth-level production nest*

The fourth-level nest decomposes the capital-skilled labor bundle into a capital component, $KT^d$, and a skilled labor component, *SKL*. Equations (P-14) and (P-15) represent the optimality conditions where the relevant component prices are *PKT* and *PSKL*, and the substitution elasticity is given by $\sigma^{ks}$. Equation (P-16) determines the price of the *KSK* bundle, *PKSK*.

$$SKL_i = \alpha_i^s \left( \frac{PKSK_i}{PSKL_i} \right)^{\sigma_i^{ks}} KSK_i \qquad \text{(P-14)}$$

$$KT_i^d = \alpha_i^{kt} \left( \frac{PKSK_i}{PKT_i} \right)^{\sigma_i^{ks}} KSK_i \qquad \text{(P-15)}$$

$$PKSK_i = \left[ \alpha_i^s PSKL_i^{1-\sigma_i^{ks}} + \alpha_i^{kt} PKT_i^{1-\sigma_i^{ks}} \right]^{1/(1-\sigma_i^{ks})} \qquad \text{(P-16)}$$

### 4.2.6. Demand for labor by sector and skill

Equations (P-17) and (P-18) decompose the demands for aggregate unskilled and skilled labor, respectively, across their different components. The variable $L^d$ represents labor demand in sector *i* for labor of skill level *l*. The relevant wage is given by *W* which is allowed to be both sector and skill-specific. The respective cross-skill substitution elasticities are $\sigma^u$ and $\sigma^s$. Both equations (P-17) and (P-18) incorporate sector and skill specific labor productivity, represented by the variable $\lambda^l$. The aggregate unskilled and skilled price indices are determined in equations (P-19) and (P-20), respectively *PUL* and *PSKL*.

$$L_{i,ul}^d = \alpha_{i,ul}^l \left( \lambda_{i,ul}^l \right)^{\sigma_i^u - 1} \left( \frac{PUL_i}{W_{i,ul}} \right)^{\sigma_i^u} UL_i \qquad \text{for } ul \in \{\text{Unskilled labor}\} \qquad \text{(P-17)}$$

$$L_{i,sl}^d = \alpha_{i,sl}^l \left( \lambda_{i,sl}^l \right)^{\sigma_i^s - 1} \left( \frac{PSKL_i}{W_{i,sl}} \right)^{\sigma_i^s} SKL_i \qquad \text{for } sl \in \{\text{Skilled labor}\} \qquad \text{(P-18)}$$

$$PUL_i = \left[ \sum_{ul \in \{\text{Unskilled labor}\}} \alpha_{i,ul}^l \left( \frac{W_{i,ul}}{\lambda_{i,ul}^l} \right)^{1-\sigma_i^u} \right]^{1/(1-\sigma_i^u)} \qquad \text{(P-19)}$$

$$PSKL_i = \left[ \sum_{sl \in \{\text{Skilled labor}\}} \alpha_{i,sl}^l \left( \frac{W_{i,sl}}{\lambda_{i,sl}^l} \right)^{1-\sigma_i^s} \right]^{1/(1-\sigma_i^s)} \qquad \text{(P-20)}$$

### 4.2.7. Demand for capital and land across types

The aggregate land and capital bundles, $KT^d$ and $TT^d$ respectively, are disaggregated across types, leading to type- and sector-specific capital and land demand, $K^d$ and $T^d$. The decomposition is represented in equations (P-21) and (P-23), where the respective prices are *R* and *PT* which are both type- and sector-specific. The equations also incorporate productivity factors. Equations (P-22) and (P-24) represent the price indices for aggregate capital and land, respectively *PKT* and *PTT*.

$$K_{i,kt}^d = \alpha_{i,kt}^k \left(\lambda_{i,kt}^k\right)^{\sigma_i^k - 1} \left(\frac{PKT_i}{R_{i,kt}}\right)^{\sigma_i^k} KT_i^d \quad \text{(P-21)}$$

$$PKT_i = \left[\sum_{kt} \alpha_{i,kt}^k \left(\frac{R_{i,kt}}{\lambda_{i,kt}^k}\right)^{1-\sigma_i^k}\right]^{1/(1-\sigma_i^k)} \quad \text{(P-22)}$$

$$T_{i,lt}^d = \alpha_{i,lt}^t \left(\lambda_{i,lt}^t\right)^{\sigma_i^t - 1} \left(\frac{PTT_i}{PT_{i,lt}}\right)^{\sigma_i^t} TT_i^d \quad \text{(P-23)}$$

$$PTT_i = \left[\sum_{lt} \alpha_{i,lt}^k \left(\frac{PT_{i,lt}}{\lambda_{i,lt}^k}\right)^{1-\sigma_i^t}\right]^{1/(1-\sigma_i^t)} \quad \text{(P-24)}$$

### 4.2.8. Commodity aggregation

Each activity produces a single commodity, *XP*, indexed by *i*. Consumption goods, indexed by *k*, are a combination of one or more produced goods. Aggregate domestic supply of good *k*, *X*, is a CES combination of one or more produced goods *i*. In many cases, the CES aggregate is of a single commodity, i.e. there is a one-to-one mapping between a consumed good and its relevant production. There are cases, however, where it is useful to have consumed goods be an aggregation of produced goods, for example when combining similar goods with different production characteristics (e.g. public versus private, commercial versus small-scale, etc.) Equation (P-25) represents the optimality condition of the aggregation of produced goods into commodities. The producer price is *PP*, and the price of the aggregate supply is *P*. The degree of substitutability across produced commodities is $\sigma^c$. Equation (P-26) determines the aggregate supply price, *P*. The model allows for perfect substitutability, in which case the law of one price holds and the produced commodities are simply aggregated to form aggregate output.[15]

$$\begin{cases} XP_i = \alpha_{i,k}^c \left(\frac{P_k}{PP_i}\right)^{\sigma_k^c} X_k & \text{if} \quad \sigma_k^c \neq \infty \\ PP_i = P_k & \text{if} \quad \sigma_k^c = \infty \end{cases} \quad \text{(P-25)}$$

$$\begin{cases} P_k = \left[\sum_{i \in K} \alpha_{i,k}^c PP_i^{1-\sigma_k^c}\right]^{1/(1-\sigma_k^c)} & \text{if} \quad \sigma_k^c \neq \infty \\ X_k = \sum_{i \in K} XP_i & \text{if} \quad \sigma_k^c = \infty \end{cases} \quad \text{(P-26)}$$

15 Electricity is a good example of a homogeneous output but which could be produced by very different production technologies, e.g. hydro-electric, nuclear, thermal, etc.

## 4.3. Income distribution

The prototype model has a rich menu of income distribution channels—factor income and intra-household, government and foreign transfers (i.e. remittances). The prototype also includes corporations used as a pass-through account for channeling operating surplus.

### 4.3.1. *Factor income*

There are four broad factors—a sector specific resource, land, labor and capital—the latter three which can be sub-divided into various types. Equations (Y-1) through (Y-3) determine aggregate net-income from labor, *LY*, capital, *KY*, and land, *TY*, each indexed by its sub-types. The fourth equation determines aggregate income from the sector-specific resource. These are net incomes because the model incorporates factor taxes designated by $\tau^{fl}$, $\tau^{fk}$, $\tau^{ft}$ and $\tau^{fr}$ respectively.[16]

$$LY_l = \sum_i \frac{W_{i,l} L^d_{i,l}}{1+\tau^{fl}_{i,l}} \qquad \text{(Y-1)}$$

$$KY_{kt} = \sum_i \frac{R_{i,kt} K^d_{i,kt}}{1+\tau^{fk}_{i,kt}} \qquad \text{(Y-2)}$$

$$TY_{lt} = \sum_i \frac{PT_{i,lt} T^d_{i,lt}}{1+\tau^{ft}_{i,lt}} \qquad \text{(Y-3)}$$

$$RY = \sum_i \frac{PR_i R^d_i}{1+\tau^{fr}_i} \qquad \text{(Y-4)}$$

### 4.3.2. *Distribution of profits*

All of labor, land and sector-specific factor income is allocated directly to households.[17] Profits (aggregated with income from the sector-specific resouce), on the other hand, are distributed to three broad accounts, enterprises, households, and the rest of the world (ROW). Equation (Y-5) determines the level of profits distributed to enterprises, $TR^E$. Equation (Y-6) represents the level of profits distributed directly to households, $TR^H$. And, equation (Y-7) determines the level of factor income distributed abroad, $TR^W$. Note that the three share parameters, $\varphi^E$, $\varphi^H$, and $\varphi^W$ sum to unity.

[16] The factor taxes are type- and sector-specific. Note as well that the relevant factor prices represent the perceived cost to employers, not the perceived remuneration of workers.
[17] Depending on the structure of the final SAM, land and or income from the sector-specific resource may also pass through corporate accounts.

$$TR^{E}_{k,kt} = \varphi^{E}_{k,kt} KY_{kt} \quad \text{(Y-5)}$$

$$TR^{H}_{k,kt} = \varphi^{H}_{k,kt} KY_{kt} \quad \text{(Y-6)}$$

$$TR^{W}_{k,kt} = \varphi^{W}_{k,kt} KY_{kt} \quad \text{(Y-7)}$$

### *4.3.3. Corporate income*

Corporate income, $TR^E$, is split into four accounts. First, the government receives its share through the corporate income tax, $\kappa^c$. The residual is split into three: retained earnings, and income distributed to households and the rest of the world. Equation (Y-8) determines corporate income of enterprise *e*, *CY*. It is the sum, over possible capital types, of shares of distributed profits (to corporations).[18] Equation (Y-9) determines retained earnings, i.e. corporate savings, $S^c$, where the rate of retained earnings is given by $s^c$. Equations (Y-10) and (Y-11) determine the overall transfers to households and to ROW. Note that the two share parameters, $\varphi^H$ and $\varphi^W$, and the retained earnings rate, $s^c$, sum to unity.

$$CY_e = \sum_{kt} \varphi^{e}_{kt,e} TR^{E}_{k,kt} \quad \text{(Y-8)}$$

$$S^c_e = s^c_e \left(1 - \kappa^c_e\right) CY_e \quad \text{(Y-9)}$$

$$TR^{H}_{c,e} = \varphi^{H}_{c,e} \left(1 - \kappa^c_e\right) CY_e \quad \text{(Y-10)}$$

$$TR^{W}_{c,e} = \varphi^{W}_{c,e} \left(1 - \kappa^c_e\right) CY_e \quad \text{(Y-11)}$$

### *4.3.4. Household income*

Aggregate household income, *YH*, is composed of eight elements: labor, land and sector-specific factor remuneration, distributed capital income and corporate profits, transfers from government and households, and foreign remittances, equation (Y-12).[19] Government transfers, in the standard closure, are fixed in real terms and are multiplied by an appropriate price index to preserve model homogeneity. Remittances, are fixed in international currency terms, and are multiplied by the exchange rate, *ER*, to convert them into local currency terms.[20]

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18 The share parameters, $\varphi^e$, sum to unity.

19 All share parameters within the summation signs sum to unity.

20 *ER* measures the value of local currency in terms of the international currency.

$$YH_h = \underbrace{\sum_l \varphi_{l,l}^h LY_l}_{\text{Labor}} + \underbrace{\sum_{kt} \varphi_{kt,h}^h TR_{k,kt}^H}_{\text{Capital}} + \underbrace{\sum_{lt} \varphi_{lt,h}^h TY_{lt}}_{\text{Land}} + \underbrace{\varphi_{nr,h}^h RY}_{\text{Sector-specific factor}}$$
$$+ \underbrace{\sum_e \varphi_{e,h}^h TR_{c,e}^H}_{\text{Enterprise}} + \underbrace{PLEV.TR_{g,h}^h}_{\text{Transfers from government}} + \underbrace{\sum_{h'} TR_{h,h'}^h}_{\text{Intra-household transfers}} + \underbrace{ER \sum_r TR_{r,h}^h}_{\text{Foreign remittances}} \qquad \text{(Y-12)}$$

$$YD_h = \left(1 - \lambda^h \kappa_h^h\right) YH_h - TR_h^H \qquad \text{(Y-13)}$$

$$TR_h^H = \varphi_{h,h}^H \left(1 - \lambda^h \kappa_h^h\right) YH_h \qquad \text{(Y-14)}$$

$$TR_{h,h'}^h = \varphi_{h,h'}^h TR_h^H \qquad \text{(Y-15)}$$

$$TR_{h,r}^w = \varphi_{h,r}^w TR_h^H \qquad \text{(Y-16)}$$

Disposable income, *YD*, is equal to after-tax income, less household transfers, equation (Y-13), where the household tax rate is $\kappa^h$. It is multiplied by an adjustment factor, $\lambda^h$, which is used for model closure. In the standard closure, government savings (or deficit), is held fixed, and the household tax schedule adjusts (uniformly) to achieve the given government fiscal balance. In other words, under this closure rule, the relative tax rates across households remain constant.[21] Aggregate household transfers, $TR^H$, is a share of after tax income, equation (Y-14). This is transferred to individual households and abroad, respectively $TR^h$ and $TR^w$, using constant share equations, (Y-15) and (Y-16).

## 4.4. Domestic final demand

Domestic final demand is composed of two broad agents—households and other domestic final demand. The model incorporates multiple households. Household demand has a uniform specification, however, with household-specific expenditure parameters. The other domestic final demand categories, in the standard model, include government current expenditures, *Gov*, private and public investment expenditures, *ZIp* and *ZIg*, exports of international trade and transport services, *TMG*, and changes in stocks, *DST*. The other domestic final demand categories, indexed by *f*, are also assumed to have a uniform expenditure function, but with agent-specific expenditure parameters. Demand at the top-level, reflects demand for the Armington good. The latter are added up across all activities in the economy and split into domestic and import components at the national level.[22]

### *4.4.1. Household expenditures*

Households have a tiered demand structure, see figure 2. At the top-level, households save a constant share of disposable income, with the savings rate given by $s^h$. At the next level, residual

[21] An alternative would be to use an additive factor, which would adjust the average tax rates, not the marginal tax rates.
[22] There are few SAMs, which would allow for agent-specific Armington behavior.

income is allocated across goods and services, *XAc*, using the linear expenditure system (LES).[23] Equation (D-1) represents the LES demand function. Household consumption is the sum of two components. The first, $\theta$, is referred to as the subsistence minimum. The second is a share of real supernumerary income. Supernumerary income is equal to residual disposable income, subtracting savings and aggregate expenditures on the subsistence minima from disposable income. The next level, undertaken at the national level, is the decomposition of Armington demand, *XAc*, into its domestic and import components, see below. Equation (D-2) determines household saving, $S^h$, by residual. The consumer price index, *CPI*, is defined in equation (D-3). Note that the consumer price is equal to the economy-wide Armington price, *PA*, multiplied by a household and commodity specific ad valorem tax, $\tau^{cc}$.

$$XAc_{k,h} = \theta_{k,h} + \frac{\mu_{k,h}}{(1+\tau^{cc}_{k,h})PA_k}\left((1-s^h_h)YD_h - \sum_{k'}(1+\tau^{cc}_{k',h})PA_{k'}\theta_{k'}\right) \quad \text{(D-1)}$$

$$S^h_h = YD_h - \sum_k (1+\tau^{cc}_{k,h})PA_k XAc_{k,h} \quad \text{(D-2)}$$

$$CPI_h = \frac{\sum_k (1+\tau^{cc}_{k,h})PA_k XAc_{k,h,0}}{\sum_k (1+\tau^{cc}_{k,h,0})PA_{k,0} XAc_{k,h,0}} \quad \text{(D-3)}$$

### 4.4.2. Other domestic demand accounts

The other domestic final demand accounts all use a CES expenditure function (with the option of having fixed volume or value expenditure shares with an elasticity of 0 or 1, respectively). Equation (D-4) determines the expenditure share on goods and services, *XAf*. Equation (D-5) defines the expenditure price index, *PF*. And equation (D-6) defines the value of expenditures, *YF*. Model closure is discussed below.

$$XAf_{k,f} = \alpha^f_{k,f}\left(\frac{PF_f}{(1+\tau^{cf}_{k,f})PA_k}\right)^{\sigma^f_f} XF_f \qquad \text{for } f \in \{\text{Other final demand}\} \quad \text{(D-4)}$$

$$PF_f = \left[\sum_k \alpha^f_f \left((1+\tau^{cf}_{k,f})PA_k\right)^{1-\sigma^f_f}\right]^{1/(1-\sigma^f_f)} \qquad \text{for } f \in \{\text{Other final demand}\} \quad \text{(D-5)}$$

$$YF_f = PF_f XF_f \qquad \text{for } f \in \{\text{Other final demand}\} \quad \text{(D-6)}$$

[23] This class of models often uses the so-called extended linear expenditure system, which integrates household savings directly in the utility function. However, this can create calibration problems for households without savings.

## 4.5. Trade equations

This section discusses the modeling of trade. There are three sections—import demand, and export supply and demand. The first two use a tiered structure. Import demand is decomposed in two steps. The top tier disaggregates aggregate Armington demand into two components—demand for the domestically produced good and aggregate import demand. At the second tier, the aggregate import demand is allocated across trading partners. Both of these tiers assume that goods indexed by *k* are differentiated by region of origin, i.e. the so-called Armington assumption. A CES specification is used to model the degree of substitutability across regions of origin. The level of the elasticities will often be determined by the level of aggregation. Finely defined goods, such as wheat, would typically have a higher elasticity than more broadly defined goods, such as clothing. At the same time, non-price barriers may also inhibit the degree of substitutability, for example prohibitive transport barriers (inexistent or few transmission lines for electricity), or product and safety standards. Export supply is similarly modeled using a two-tiered constant-elasticity-of-transformation specification. This permits imperfect supply responses to changes in relative prices. Finally, the small-country assumption is relaxed for exports with the incorporation of export demand functions.

### 4.5.1. Top-level Armington nest

National demand for the Armington good, *XA*, is the sum of Armington demand over all domestic agents: intermediate demand, household and other domestic final demand, and demand generated by the internal trade and transport sector, *XAmg*, equation (T-1). Aggregate Armington demand is then allocated between domestic and import goods using a nested CES structure. Equation (T-2) represents demand for the domestically produced good, $XD^d$, where the top-level Armington elasticity is given by $\sigma^m$. Note that the price of the domestic good is equal to the producer price, *PD*, adjusted by the internal trade and transport margin, $\tau^{mg}$. Demand for aggregate imports, *XMT*, is determined in equation (T-3). The price of aggregate imports is given by *PMT*.[24] The Armington price, *PA*, is defined in equation (T-4), using the familiar CES dual price aggregation formula.

$$XA_k = \sum_j XAp_{k,j} + \sum_h XAc_{k,h} + \sum_f XAf_{k,f} + \sum_m \sum_{k'} XAmg_{k,k',m} \tag{T-1}$$

$$XD_k^d = \alpha_k^d \left( \frac{PA_k}{(1+\tau_{k,D}^{mg})\, PD_k} \right)^{\sigma_k^m} XA_k \tag{T-2}$$

$$XMT_k = \alpha_k^m \left( \frac{PA_k}{PMT_k} \right)^{\sigma_k^m} XA_k \tag{T-3}$$

[24] It includes the trade and transport margins, sales tax, and import tariffs.

$$PA_k = \left[ \alpha_k^d \left( (1+\tau_{k,D}^{mg})\ PD_k \right)^{1-\sigma_k^m} + \alpha_k^m PMT_k^{1-\sigma_k^m} \right]^{1/(1-\sigma_k^m)} \qquad \text{(T-4)}$$

### 4.5.2. Second-level Armington nest

At the second level, aggregate import demand, *XMT*, is allocated across trading partners using a CES specification. Equation (T-5) defines the domestic price of imports, *PM*.[25] It is equal to the world price (in international currency), *WPM*, multiplied by the exchange rate, and adjusted for by the import tariff, $\tau^m$, i.e. *PM* represents the port-price of imports, tariff-inclusive. The tariff rate is both sector- and region of origin-specific. Equation (T-6) represents the import of commodity *k* from region *r*, *XM*, where the inter-regional substitution elasticity is given by $\sigma^w$. The relevant consumer price includes the internal trade and transport margin, $\tau^{mg}$. The aggregate price of imports, *PMT*, is defined in equation (T-7).

$$PM_{k,r} = ER.WPM_{k,r}(1+\tau_{k,r}^m) \qquad \text{(T-5)}$$

$$XM_{k,r} = \alpha_{k,r}^w \left( \frac{PMT_k}{(1+\tau_{k,M}^{mg})\ PM_{k,r}} \right)^{\sigma_k^w} XMT_k \qquad \text{(T-6)}$$

$$PMT_k = \left[ \sum_r \alpha_{k,r}^w \left( (1+\tau_{k,M}^{mg})\ PM_{k,r} \right)^{1-\sigma_k^w} \right]^{1/(1-\sigma_k^w)} \qquad \text{(T-7)}$$

### 4.5.3. Top-level CET nest

Domestic production is allocated across markets using a nested CET specification. At the top nest, producers allocate production between the domestic market and aggregate exports. At the second nest, aggregate exports are allocated across trading partners. The model allows for perfect transformation, i.e. producers perceive no difference across markets. In this case, the law-of-one-price holds. Equation (T-8) represents the link between the domestic producer price, *PE*, and the world price, *WPE*. Export prices are both sector- and region-specific. The FOB price, *WPE*, includes domestic trade and transport margins, $\tau^{mg}$[26], as well as export taxes/subsidies, $\tau^e$. Equations (T-9) and (T-10) represent the CET optimality conditions. The first determines the share of domestic supply, *X*, allocated to the domestic market, $XD^s$. The second determines the supply of aggregate exports, *XET*. *PET* represents the price of aggregate export supply. The transformation elasticity is given by $\sigma^x$. The model allows for perfect transformation. In this case, the optimal supply conditions are replaced by the law-of-one price conditions. Equation (T-11) represents the CET aggregation function. In the case of finite transformation, it is replaced with its equivalent, the CET dual price

[25] *PM* and *WPM* are indexed by both commodity, *k*, and trading partner, *r*.
[26] Note that the domestic trade and transport margins are differentiated for three different goods: domestically produced goods sold to the domestic market, exported goods, and imported goods.

aggregation function. In the case of infinite transformation, the primal aggregation function is used, where the two components are summed together since there is no product differentiation.

$$PE_{k,r}\left(1+\tau^{mg}_{k,X}\right)\left(1+\tau^{e}_{k,r}\right)=ER.WPE_{k,r} \qquad \text{(T-8)}$$

$$\begin{cases} XD^s_k=\gamma^d_k\left(\dfrac{PD_k}{P_k}\right)^{\sigma^x_k}X_k & \text{if} \quad \sigma^x_k\neq\infty \\ PD_k=P_k & \text{if} \quad \sigma^x_k=\infty \end{cases} \qquad \text{(T-9)}$$

$$\begin{cases} XET_k=\gamma^e_k\left(\dfrac{PET_k}{P_k}\right)^{\sigma^x_k}X_k & \text{if} \quad \sigma^x_k\neq\infty \\ PET_k=P_k & \text{if} \quad \sigma^x_k=\infty \end{cases} \qquad \text{(T-10)}$$

$$\begin{cases} P_k=\left[\gamma^d_k PD_k^{1+\sigma^x_k}+\gamma^e_k PET_k^{1+\sigma^x_k}\right]^{1/(1+\sigma^x_k)} & \text{if} \quad \sigma^x_k\neq\infty \\ X_k=XD^s_k+XET_k & \text{if} \quad \sigma^x_k=\infty \end{cases} \qquad \text{(T-11)}$$

### 4.5.4. Second-level CET nest

The second-level CET nest allocates aggregate export supply, *XET*, across the various export markets, *XE*. Equation (T-12) represents the optimal allocation decision, where $\sigma^z$ is the transformation elasticity. Equation (T-13) represents the CET aggregation function, where again, the CET dual price formula is used to determine the aggregate export price, *PET*. As above, the model allows the transformation elasticity to be infinite.

$$\begin{cases} XE_{k,r}=\gamma^x_{k,r}\left(\dfrac{PE_{k,r}}{PET_k}\right)^{\sigma^z_k}XET_k & \text{if} \quad \sigma^z_k\neq\infty \\ PE_{k,r}=PET_k & \text{if} \quad \sigma^z_k=\infty \end{cases} \qquad \text{(T-12)}$$

$$\begin{cases} PET_k=\left[\sum_r \gamma^x_{k,r}PE_{k,r}^{1+\sigma^z_k}\right]^{1/(1+\sigma^z_k)} & \text{if} \quad \sigma^z_k\neq\infty \\ XET_k=\sum_r XE_{k,r} & \text{if} \quad \sigma^z_k=\infty \end{cases} \qquad \text{(T-13)}$$

### 4.5.5. Export demand

Export, *ED*, demand is specified using a constant elasticity function, equation (T-14). If the elasticity, $\eta^e$, is finite, demand decreases as the international price of exports, *WPE*, increases. The numerator contains an exogenous export price competitive index. If the latter increases relative to the domestic export price, market share of the domestic exporter would increase. The model allows for infinite demand elasticity. This represents the small-country assumption. In this case, the domestic price of exports (in international currency units) is constant. If the two CET elasticities are likewise infinite, then the domestic producer price is also equal to the world price of exports (adjusted for taxes and trade and transportation margins).

$$\begin{cases} ED_{k,r} = \alpha^e_{k,r}\left(\dfrac{\overline{WPE}_{k,r}}{WPE_{k,r}}\right)^{\eta^e_{k,r}} & \text{if} \quad \eta^e_{k,r} \neq \infty \\ WPE_{k,r} = \overline{WPE}_{k,r} & \text{if} \quad \eta^e_{k,r} = \infty \end{cases} \qquad \text{(T-14)}$$

## 4.6. Domestic trade and transportation margins

The marketing of each good—domestic, imports, and exports—is associated with a commodity specific trade margin.[27] Equations (M-1) through (M-3) define the revenues associated with the domestic trade and transport margins. Domestically produced goods sold domestically generate $Y^{mg}_{.,D}$. Imported goods generate $Y^{mg}_{.,M}$. And exported goods generate $Y^{mg}_{.,X}$. Equation (M-4) defines the volume of margin services. The production of the trade and transport services follows a Leontief technology. Equation (M-5) defines the demand for goods and services. In other words, to deliver commodity *k*' (in either sector *D*, *M*, or *X*) requires an input from commodity *k*, the level of which is fixed in proportions to the overall volume of delivering commodity *k*' in the economy, $XT^{mg}_{k'}$. Equation (M-6) is the expenditure deflator, $PT^{mg}_{k'}$, for individual trade margin activities.

$$YT^{mg}_{k,D} = \tau^{mg}_{k,D} PD_k XD^d_k \qquad \text{(M-1)}$$

$$YT^{mg}_{k,M} = \sum_r \tau^{mg}_{k,M} PM_{k,r} XM_{k,r} \qquad \text{(M-2)}$$

$$YT^{mg}_{k,X} = \sum_r \tau^{mg}_{k,X} PE_{k,r} XE_{k,r} \qquad \text{(M-3)}$$

$$XT^{mg}_{k,m} = YT^{mg}_{k,m} / PT^{mg}_{k,m} \qquad \text{(M-4)}$$

$$XAmg_{k,k',m} = \alpha^{mg}_{k,k',m} XT^{mg}_{k',m} \qquad \text{(M-5)}$$

$$PT^{mg}_{k',m} = \sum_k \alpha^{mg}_{k,k',m} PA_k \qquad \text{(M-6)}$$

27 The model does not include international trade and transport margins. A change in the latter could be simulated by a change in the relevant world price index, *WPM* or $\overline{WPE}$.

## 4.7. Goods market equilibrium

There are three fundamental commodities in the model—domestic goods sold domestically, imports (by region of origin), and exports (by region of destination). All other goods are bundles (i.e. are defined using an aggregation function) and do not require supply/demand balance. The small-country assumption holds for imports, and therefore any import demand can be met by the rest of the world with no impact on the price of imports. Therefore, there is no explicit supply/demand equation for imports.[28] Equation (E-1) represents equilibrium on the domestic goods market, and essentially determines, *PD*, the producer price of the domestic good. Equation (E-2) defines the equilibrium condition on the export market. With a finite export demand elasticity, the equation determines *WPE*, the world price of exports. With an infinite export demand elasticity, the equation trivially equates export demand to the given export supply.

$$XD_k^d = XD_k^s \tag{E-1}$$

$$ED_{k,r} = XE_{k,r} \tag{E-2}$$

## 4.8. Macro closure

Macro closure involves determining the exogenous macro elements of the model. The standard closure rules are the following:

- Government fiscal balance is exogenous, achieved with an endogenous direct tax schedule
- Private investment is endogenous and is driven by available savings
- The volume of government current and investment expenditures is exogenous
- The volume of demand for international trade and transport services is exogenous
- The volume of stock changes is exogenous
- The trade balance (i.e. capital flows) is exogenous. The real exchange rate equilibrates the balance of payments.

These are further detailed below.

### *4.8.1. Government accounts*

Equation (C-1) defines total government revenues, *GY*. There are 10 components: revenues from the production tax, sales tax, import tax, export tax, land, capital and wage tax, corporate and household direct taxes, and transfers from the rest of the world. Equation (C-2) defines the government's current expenditures, *GEXP*. It is the sum of three components: expenditures on goods

[28] One could rather easily add an import supply equation and an equilibrium condition.

and services, transfers to households, and transfers to ROW. Government savings (on current operations), $S^g$, is defined in equation (C-3), as the difference between revenues and current expenditures. Real government savings, *RSg*, is defined in equation (C-4). It is this latter which essentially determines the level of direct household taxation since *RSg* is exogenous in the standard closure.

$$\begin{aligned} GY = {} & \underbrace{\sum_k \sum_j \tau^{cp}_{k,j} PA_k XAp_{k,j}}_{\text{Sales tax on intermediate demand}} + \underbrace{\sum_k \sum_h \tau^{cc}_{k,h} PA_k XAc_{k,h}}_{\text{Sales tax on household demand}} + \underbrace{\sum_k \sum_f \tau^{cf}_{k,f} PA_k XAf_{k,f}}_{\text{Sales tax on other final demand}} \\ & + \underbrace{ER \sum_k \sum_r \tau^m_{k,r} WPM_{k,r} XM_{k,r}}_{\text{Import tariff revenues}} + \underbrace{\sum_k \sum_r \tau^e_{k,r} (1+\tau^{mg}_{k,X}) PE_{k,r} XE_{k,r}}_{\text{Export tax revenues}} \\ & + \underbrace{\sum_{lt} \sum_i \frac{\tau^{ft}_{i,lt} PT_{i,lt} T^d_{i,lt}}{1+\tau^{ft}_{i,lt}}}_{\text{Land tax}} + \underbrace{\sum_{kt} \sum_i \frac{\tau^{fk}_{i,kt} R_{i,kt} K^d_{i,kt}}{1+\tau^{fk}_{i,kt}}}_{\text{Capital tax}} + \underbrace{\sum_l \sum_i \frac{\tau^{fl}_{i,l} W_{i,l} L^d_{i,l}}{1+\tau^{fl}_{i,l}}}_{\text{Wage tax}} + \underbrace{\sum_i \frac{\tau^{fr}_i PR_i NR^d_i}{1+\tau^{fr}_i}}_{\text{Resource tax}} \\ & + \underbrace{\sum_i \tau^p_i PX_i XP_i}_{\text{Production tax}} + \underbrace{\sum_e \kappa^c_e CY_e}_{\text{Corporate tax}} + \underbrace{\lambda^h \sum_h \kappa^h_h YH_h}_{\text{Income tax}} + \underbrace{ER \sum_r TR^g_{W,r}}_{\text{Transfers from ROW}} \end{aligned} \quad \text{(C-1)}$$

$$GEXP = YF_{Gov} + PLEV \sum_h TR^H_{g,h} + ER \sum_r TR^W_{g,r} \quad \text{(C-2)}$$

$$S^g = GY - GEXP \quad \text{(C-3)}$$

$$RSg = S^g / PLEV \quad \text{(C-4)}$$

### 4.8.2. *Investment and macro closure*

Equation (C-5) defines the investment savings balance. In the standard closure, it determines the level of private investment since public investment and stock changes are exogenous. These three components are financed by aggregate savings defined over corporations, households, and the government, and adjusted by foreign savings. The latter is fixed (in international currency terms). Equations (C-6) through (C-9) define the exogenous volumes of public current and investment expenditures, exports of international trade and transport services and stock changes. The aggregate price level, *PLEV*, is the average absorption (Armington) price, equation (C-10). Equation (C-11) represents the balance of payments (in international currency terms). It can be shown to be redundant, and is dropped from the model specification.

$$YF_{ZIp} + YF_{ZIg} + YF_{DST} = \sum_e S_e^c + \sum_h S_h^h + S^g + ER.\sum_r S_r^f \qquad \text{(C-5)}$$

$$XF_{Gov} = \overline{XF}_{Gov} \qquad \text{(C-6)}$$

$$XF_{ZIg} = \overline{XF}_{ZIg} \qquad \text{(C-7)}$$

$$XF_{TMG} = \overline{XF}_{TMG} \qquad \text{(C-8)}$$

$$XF_{DST} = \overline{XF}_{DST} \qquad \text{(C-9)}$$

$$PLEV = \frac{\sum_k PA_k XA_{k,0}}{\sum_k PA_{k,0} XA_{k,0}} \qquad \text{(C-10)}$$

$$\begin{aligned} BoP \; = \; & \sum_r \sum_k WPE_{k,r} XE_{k,r} + YF_{TMG} + \sum_h TR_{W,h}^h + TR_W^g + S^f \\ - \; & \sum_r \sum_k WPM_{k,r} XM_{k,r} - \frac{\sum_{kt} TR_{k,kt}^W + \sum_e TR_{c,e}^W + \sum_h TR_h^w}{ER} - TR_g^W \\ \equiv \; & 0 \end{aligned} \qquad \text{(C-11)}$$

## 4.9. Factor market equilibrium

The following sections describe the standard factor market equilibrium conditions.[29]

### *4.9.1. Labor markets*

Labor markets are assumed to clear. Equation (F-1) sets aggregate demand, by skill-level, to aggregate supply, $L^s$. This equation determines the equilibrium wage, $W^e$.[30] Equation (F-2) equates sectoral wages to the equilibrium wage, i.e. the model assumes uniform wages across sectors.[31]

$$L_l^s = \sum_i L_{i.l}^d \qquad \text{(F-1)}$$

$$W_{i,l} = W_l^e \qquad \text{(F-2)}$$

[29] More detailed analysis may require more market segmentation, e.g. rural versus urban labor markets, though so of this segmentation can be picked up by the data itself.
[30] Market structure can emulate perfect market segmentation by an appropriate definition of labor skills. For example, unskilled rural labor can assume to be only employed in rural sectors, whereas unskilled urban labor is only employed in urban sectors. Perfect market segmentation, as modeled here, does not allow for migration.
[31] Quite a few alternatives could be used allowing for sector-specific wages, for example union wage bargaining models, efficiency wages, etc.

### 4.9.2. *Capital market*

Equilibrium on the capital market allows for both limiting cases—perfect capital mobility and perfect capital immobility, or any intermediate case. Aggregate capital, $K^s$, is allocated across sectors and type according to a nested CET system. At the top-level, the aggregate investor allocates capital across types, according to relative rates of return. Equation (F-3) determines the optimal supply decision, where $TK^s$ is the supply of capital of type *kt*, with an average return of *PTK*. *PK* is the aggregate rate-of-return to capital. If the supply elasticity is infinite, the law-of-one-price holds. Equation (F-4) represents the top-level aggregation function, replaced by the CET dual price function in the case of a finite transformation elasticity. Perfect capital mobility is represented by setting $\omega^{kt}$ to infinity. Perfect immobility is modeled by setting the transformation elasticity to 0.

$$\begin{cases} TK_{kt}^{s} = \gamma_{kt}^{tks}\left(\dfrac{PTK_{kt}}{PK}\right)^{\omega^{kt}} K^{s} & \text{if} \quad \omega^{kt} \neq \infty \\ PTK_{kt} = PK & \text{if} \quad \omega^{kt} = \infty \end{cases} \qquad \text{(F-3)}$$

$$\begin{cases} PK = \left[\sum_{kt} \gamma_{kt}^{tks} PTK_{kt}^{1+\omega^{kt}}\right]^{1/(1+\omega^{kt})} & \text{if} \quad \omega^{kt} \neq \infty \\ K^{s} = \sum_{kt} TK_{kt}^{s} & \text{if} \quad \omega^{kt} = \infty \end{cases} \qquad \text{(F-4)}$$

At the second level, capital by type, $TK^s$, is allocated across sectors using another CET function. Equation (F-5) determines the optimal allocation of capital of type *kt* to sector *i*, $K^s$, where the transformation elasticity is $\omega^k$. Equation (F-6) represents the CET aggregation function. The equilibrium return to capital, *R*, is determined by equation capital supply to demand, equation (F-7).[32]

$$\begin{cases} K_{i,kt}^{s} = \gamma_{i,kt}^{k}\left(\dfrac{R_{i,kt}}{PTK_{kt}}\right)^{\omega^{k}} TK_{kt}^{s} & \text{if} \quad \omega^{k} \neq \infty \\ R_{i,kt} = PTK_{kt} & \text{if} \quad \omega^{k} = \infty \end{cases} \qquad \text{(F-5)}$$

$$\begin{cases} PTK_{kt} = \left[\sum_{i} \gamma_{i,kt}^{k} R_{i,kt}^{1+\omega^{k}}\right]^{1/(1+\omega^{k})} & \text{if} \quad \omega^{k} \neq \infty \\ TK_{kt} = \sum_{i} K_{i,kt}^{s} & \text{if} \quad \omega^{k} = \infty \end{cases} \qquad \text{(F-6)}$$

$$K_{i,kt}^{d} = K_{i,kt}^{d} \qquad \text{(F-7)}$$

32 If the transformation elasticity is infinite, equation (F-5) determines the sector- and type-specific rate of return using the law-of-one price, and equation (F-7) trivially sets capital supply equal to capital demand.

### 4.9.3. Land market

Land market equilibrium is specified in an analogous way to the capital market with a tiered CET supply system. The first tier allocates total land across types. This could have a zero transformation elasticity if for example land used for rice production could not be used to produce other commodities. Their respective prices are *PLAND* and $PTT^s$.

$$\begin{cases} TT_{lt}^{s} = \gamma_{lt}^{tts}\left(\dfrac{PTT_{lt}^{s}}{PLAND}\right)^{\omega^{tl}} LAND & \text{if} \quad \omega^{tl} \neq \infty \\ PTT_{lt}^{s} = PLAND & \text{if} \quad \omega^{tl} = \infty \end{cases} \tag{F-8}$$

$$\begin{cases} PLAND = \left[\sum_{lt} \gamma_{lt}^{tts}\left(PTT_{cl}^{s}\right)^{1+\omega^{tl}}\right]^{1/(1+\omega^{tl})} & \text{if} \quad \omega^{tl} \neq \infty \\ LAND = \sum_{lt} TT_{lt}^{s} & \text{if} \quad \omega^{tl} = \infty \end{cases} \tag{F-9}$$

Equations (F-10) and (F-11) determine the optimality conditions at the second and final tier, determining land supply (by type and) by sector of use. Land market equilibrium is represented by equation (F-12).

$$\begin{cases} T_{i,lt}^{s} = \gamma_{i,lt}^{t}\left(\dfrac{PT_{i,lt}}{PTT_{lt}^{s}}\right)^{\omega_{lt}^{t}} TT_{lt}^{s} & \text{if} \quad \omega_{lt}^{t} \neq \infty \\ PT_{i,lt} = PTT_{lt}^{s} & \text{if} \quad \omega_{lt}^{t} = \infty \end{cases} \tag{F-10}$$

$$\begin{cases} PTT_{lt}^{s} = \left[\sum_{i} \gamma_{i,lt}^{t} PT_{i,lt}^{1+\omega^{t}}\right]^{1/(1+\omega_{lt}^{t})} & \text{if} \quad \omega_{lt}^{t} \neq \infty \\ TT_{lt}^{s} = \sum_{i} T_{i,lt}^{s} & \text{if} \quad \omega_{lt}^{t} = \infty \end{cases} \tag{F-11}$$

$$T_{i,lt}^{s} = T_{i,lt}^{d} \tag{F-12}$$

### 4.9.4. Natural resource market

The market for natural resources differs from the others in the sense that there is no inter-sectoral mobility, i.e. this is a sector specific resource. There is therefore a sector specific supply curve (eventually flat).[33] Equation (F-13) describes the sector-specific supply function, or $NR^s$. Equation (F-14) then determines the equilibrium price, *PR*.

[33] More realistic models allow for kinked supply curves. It is typically easier to take resources out of production than to bring them online—the latter requiring new investments and/or new

$$\begin{cases} NR_i^s = \gamma_i^{nr}\left(\dfrac{PR_i}{PLEV}\right)^{\omega^{nr}} & \text{if} \quad \omega^{nr} \neq \infty \\ PR_i = PLEV.PR_{i,0} & \text{if} \quad \omega^{nr} = \infty \end{cases} \qquad \text{(F-13)}$$

$$NR_i^d = NR_i^s \qquad \text{(F-14)}$$

## 4.10. Macroeconomic identities

The macroeconomic identities are not normally needed for the model specification, i.e. they could be calculated at the end of a simulation. In the case of dynamic scenarios, one or more of them could be used to calibrate dynamic parameters to a given set of exogenous assumptions. For example, the growth of GDP could be made exogenous. In this case, a growth parameter, typically a productivity factor, would be endogenous and set to target the given growth path of GDP.

Equations (I-1) and (I-2) define nominal and real GDP, respectively, at market prices. Equation (I-3) is the GDP at market price deflator. Similarly, equations (I-4) and (I-5) define nominal and real GDP at factor cost. Note that real GDP at factor cost is evaluated in efficiency units.[34] Equation (I-6) defines the GDP at factor cost deflator.

$$\begin{aligned} GDPMP \; = \; & \sum_k \sum_h (1+\tau_{k,h}^{cc}) PA_k XAc_{k,h} + \sum_k \sum_f (1+\tau_{k,f}^{cf}) PA_k XAf_{k,f} \\ + \; & ER \sum_k \sum_r WPE_{k,r} XE_{k,r} - \sum_k \sum_r PM_{k,r}(1+\tau_{k,M}^{mg})\, XM_{k,r} \end{aligned} \qquad \text{(I-1)}$$

$$\begin{aligned} RGDPMP \; = \; & \sum_k \sum_h (1+\tau_{k,c,0}^{cc}) PA_{k,0} XAc_{k,h} + \sum_k \sum_f (1+\tau_{k,f,0}^{cf}) PA_{k,0} XAf_{k,f} \\ + \; & ER_0 \sum_k \sum_r WPE_{k,r,0} XE_{k,r} - \sum_k \sum_r PM_{k,r,0}(1+\tau_{k,M,0}^{mg})\, XM_{k,r} \end{aligned} \qquad \text{(I-2)}$$

$$PGDPMP = GDPGMP / RGDPMP \qquad \text{(I-3)}$$

$$GDPFC = \sum_l \sum_i W_{i,l} L_{i,l}^d + \sum_{kt} \sum_i R_{i,kt} K_{i,kt}^d + \sum_{lt} \sum_i PT_{i,lt} T_{i,lt}^d + \sum_i PR_i NR_i^d \qquad \text{(I-4)}$$

$$\begin{aligned} RGDPFC \; = \; & \sum_l \sum_i W_{i,l,0} \lambda_{i,l}^l L_{i,l}^d + \sum_{kt} \sum_i R_{i,kt,0} \lambda_{i,kt}^k K_{i,kt}^d \\ + \; & \sum_{lt} \sum_i PT_{i,lt,0} \lambda_{i,lt}^t T_{i,lt}^d + \sum_i PR_{i,0} \lambda_i^r NR_i^d \end{aligned} \qquad \text{(I-5)}$$

$$PGDPFC = GDPGFC / RGDPFC \qquad \text{(I-6)}$$

exploration. Thus a so-called down supply elasticity would be higher than a so-called up supply elasticity.

[34] So is nominal GDP at factor cost, but the efficiency factors cancel out in the equation since the nominal wage is divided by the efficiency factor to derive the efficiency wage.

### 4.11. Growth equations

In a simple dynamic framework, equation (G-1) defines the growth rate of GDP at market price. Equation (G-2) determines the growth rate of labor productivity. The growth rate has two components, a uniform factor applied in all sectors to all types of labor, gl, and a sector- and skill-specific factor, xl. In defining a baseline, the growth rate of GDP is exogenous. In this case, equation (G-1) is used to calibrate the gl parameter. In policy simulations, gl is given, and equation (G-1) defines the growth rate of GDP. Other elements of simple dynamics include exogenous growth of labor supply, exogenous growth rates of capital and land productivity (typically 0), and investment driven capital accumulation, equation (G-3).[35]

$$RGDPMP = (1 + g^{y})\ RGDPMP_{-1} \tag{G-1}$$

$$\lambda^{l}_{ip,l} = (1 + \gamma^{l} + \chi^{l}_{ip,l})\ \lambda^{l}_{ip,l,-1} \tag{G-2}$$

$$K^{s} = (1 - \delta)K^{s}_{-1} + XF_{ZIp,-1} \tag{G-3}$$

[35] Note that public investment, in this version of the model, has no impact on production technology.

**Figure 1: Nested structure of production**

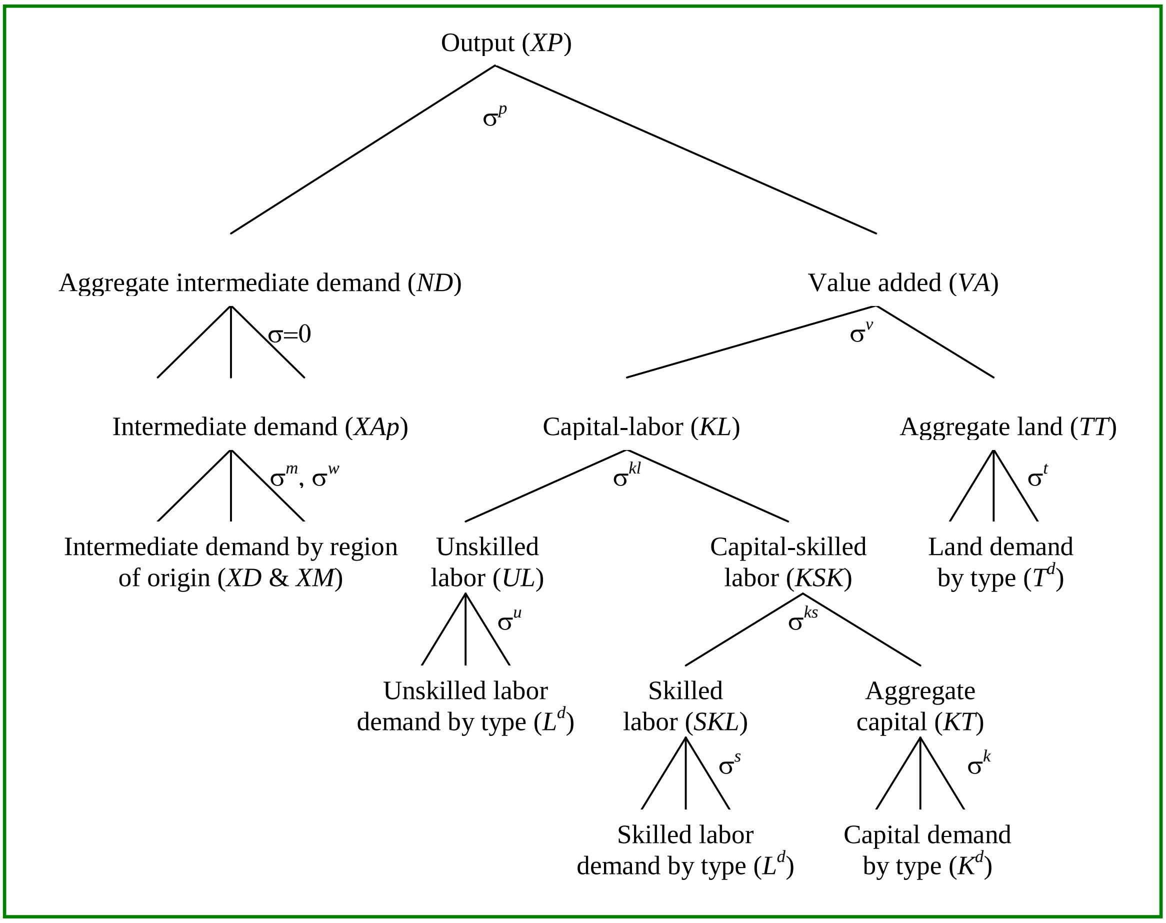
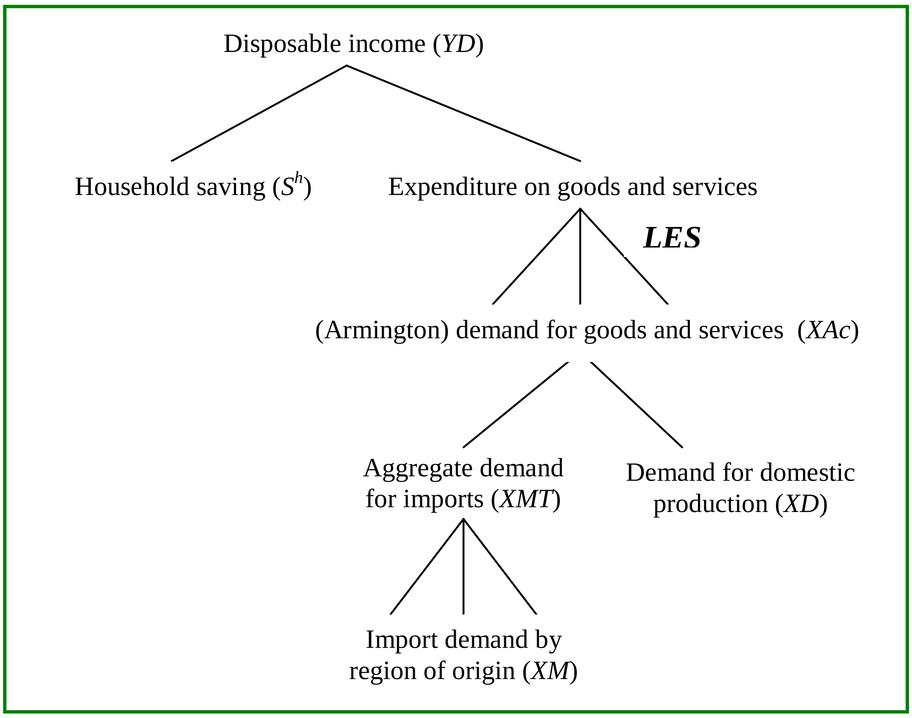


**Figure 2: Nested structure of consumer demand**



# 5. ECONOMETRIC ESTIMATION

As the previous sections have made clear, IPALP relies on a data intensive research strategy using economic models with high levels of institutional detail. To achieve the most productive synthesis of these extensive datasets and relatively complex simulation models, we rely on a combination of traditional calibration and direct econometric estimation of the underlying behavioral relationships. Calibration is generally a simple matter of fitting economic share parameters (e.g. input-output coefficients) to the baseline equations. To capture more complex interactions, however, we need a variety of functional forms that are best estimated directly from local data resources. This is particularly the case for households, and even more so for the rural poor, whose responses and welfare are the focal point of IPALP. By more rigorous modeling of household level production systems, agricultural marketing, and labor use at home and elsewhere, we can better identify household income opportunities and the role of livestock in local production and markets. In this section, we review our approach to three of the most important behavioral components of the model, household production responses, labor supply, and consumption.

## 5.1. Production Response

Traditional economywide models have generally failed to recognize that agricultural production in developing countries bears little resemblance to a neoclassical/leontief specification of production. In this framework, a single representative production activity (for each agricultural product or sector) combines constant share inputs with factors of production recruited from national labor, capital and (sometimes) land markets. This activity then maximizes profits and some portion of its factor income accrues to rural households who make their expenditure decisions independently.

In reality, most rural households in the developing world are combined production and consumption units. Their factors largely belong to them and a significant part of their output is retained for own consumption. Although evidence indicates that even remote households are aware of local market signals, more remote areas exhibit higher levels of self-sufficiency. This may be partly because of price biases such as those described above, or because of other behavioural characteristics. The consequence in any case is that more careful specification of rural household behavior is needed to model their supply and input use responses.

While we make no pretence to definitive treatment of this, we believe that joint specification of production and consumption can shed important light on rural economic participation, particularly household decisions in response to changing prices and emergent market opportunities. Economywide CGE models use (combined Leontief and CES) industrial technology at the sectoral level, which bears little resemblance to the microeconomics of household production decisions. Standard micro-simulation techniques, including all the antecedents to our approach, have relied on human capital based specification of household profits. While these components are important to wealth determination, household agricultural technologies are in fact very dependent on the quantity and quality of non-human factors and inputs, and this needs to be estimated more directly.

Households are assumed to be characterized by the representative attribute vectors $x_i$ drawn from the VHLSS. This means the sample is stratified into household categories representing a discrete partition of each component in $x_i$ as defined in the previous section. With the characteristics come econometrically estimated functions for significant behavioural relationships, including consumption, household production, and labor supply. Consumption is calibrated to a standard ELES form, whereas we model household production with two alternative specifications. and production arising from a household profit function. For calibrating consumption, we assume households divide output between own use and the market. To calibrate production, we are fortunate to have estimates of both types of household production in the SAM. Activities with no own production in the base data will be assumed to be produced by standard neoclassical enterprises.

Where data are available on own production for market, we want to specify, estimate, and implement household productions at the micro level and aggregate them consistently with the macro data. At the micro level, the production function F() of equation 4.2 above is estimated using a flexible functional form representing a multi-input, multi-output production technology.[36] In particular, consider a production unit using variable inputs $x \in R^n$ available at prices $w \in R^n$, together with a quasi-fixed input $H \in R$ to produce outputs $y \in R^m$ for sale at given prices $p \in R^m$. Define the (m+n)x1 vector q' = (p w) and the corresponding quantity vector u' = (-y x), and suppose that the producer adjusts variable inputs and outputs to maximize profit $\pi$ = py – wx = qu. With this specification, we can consider the variable profit function given by

$$\pi(p,w,H) = max_{y,x} \{py - wx \mid (x,y,H) \in T\}$$

where $T \subset R^{n+m+1}$ is a well behaved production possibility set. For practical estimation, we use duality relationships to obtain a generalized profit function of the Generalized Leontief (GL) form

$$\pi(q,H) = \sum_{i=1}^{m+n} \sum_{j=1}^{m+n} \alpha_{ij} q_i^{1/2} q_j^{1/2} + \sum_{l=1}^{m+n} \alpha_{lH} q_l H^{1/2}, \ \alpha_{ij} = \alpha_{ji}$$

which in turn extends to a CET-CES-GL[37] form for profit maximizing outputs and input demands given by

[36] Here we follow a long list of contributions, including Gorman (1968), Diewert (1973), MacFadden (1978), and most recently Behrman et al (1989). The approach currently under development could be extended to include non-homogeneous inputs, as described in an annex below, but this was infeasible in the present timetable.
[37] This extended acronym stands for Constant Elasticity of Transformation (in output), Constant Elasticity of Substitution (between inputs) and Generalized Leontief (also between inputs).

$$u^i(q,H) = \alpha_{ii} q_i^{\varepsilon-1} \left( \sum_{j=1}^{m+n} \alpha_{ii} q_i^{\varepsilon} \right)^{\frac{1-\varepsilon}{\varepsilon}} + \sum_{j \neq 1}^{m+n} \alpha_{ij} q_i^{1/2} q_j^{1/2} + \alpha_{iH} q_i H^{1/2}, \ i = 1, ..., m+n$$

This reduced for yields both outputs $u^i(q,H) = y^i(q,H)$ and inputs $u^i(q,H) = -x^i(q,H)$. For econometric estimation, we implement this functional form at the lth household level in the kth province as follows:

$$u_{il} = \mu_{ik} + f_{il}(q_{lk,} H_l; \alpha_i) + v_{il}$$

where

n = Cereals, Livestock, OthAg

m = Labor, Livestock, OthInputs

H = Land

Formally, we estimate equation (4.9) with a nonlinear generalized least squares estimator $\alpha = \{\alpha_i\}$ which is the solution to

$$\inf_{\alpha} \{[u - \mu - f(q,H;\alpha)]' \Psi^{-1} [u - \mu - f(q,H;\alpha)]\}$$

where $\Psi$ is based on the nonlinear least squares residuals from estimates of the system $u_{il}$ above.[38]

## 5.2. Labor Supply

The second primary channel for improving rural incomes is the labor market, which can provide cash employment for farm residents locally and, if they are willing to migrate, regionally, nationally, and even internationally. In developing countries, off-farm employment, including distant migration, is a primary means for rural households to participate in urban-centered growth stemming from external liberalization and other national reforms. Direct local earnings are important and many rural communities exhibit complex markets for off-farm employment, including both cash and in-kind compensation. Generally speaking, however, the primary driver of rising living standards in this channel is remittances from workers who migrate to regional or national urban markets. Not only does this migration provide rural households with access to more dynamic economic growth trends, but cash remittances overcome many obstacles to local capital accumulation, investment, and

[38] This estimation has presented extreme difficulty until recently because of the prevalence of limit observations (zero inputs or outputs) in the sample. To control for these censored observations, as well as to allow for a general heteroscedastic structure, we are using the unconditional variances (based on both limit and non-limit observations) as a second order Taylor series approximation based on the consistent nonlinear least squares residuals. This procedure has ameliorated estimation problems for the majority of provinces, and we are currently refining if further to cover the others. Complete results will be forthcoming.

enterprise development. These new sources of savings also reduce the vulnerability of rural households to economic shocks and thereby reduce their relative risk aversion, promoting adoption of new practices and other forms of entrepreneurial risk taking. This latter category surely includes livestock development.

Finally, we have seen in the previous section that complex links exist between labor income and livestock. In particular, it appears from the econometric analysis that remittances are strongly associated with emergence into marketable livestock production. Conversely, increasing livestock holdings and income can liberate household members to move to off-farm employment. Animal traction to some extent substitutes directly for labor, and livestock's many contributions to farm income and productivity free workers indirectly.

All in all, the labor-livestock link is a two-way street, and policies to promote livestock development should be grounded in a better understanding of the ways in which household allocate labor across its alternative uses. We do precisely this with the econometric component of IPALP, using detailed occupational choice models such as the examples calibrated for NMR in the annexes. Ultimately, these are intended for use in micro-simulation, where we model individual household responses to external policies and events. For PPLPI, the immediate objective is to develop smallholder livestock capacity. The ultimate objective, however, is poverty alleviation, and between the two is a complex chain of household responses, with many indirect linkages that can cumulatively outweigh the direct ones. For example, more marketable livestock may raise farm income by a certain amount. If this enterprise change permits household members to work in the formal sector, the resulting income effect could be much greater. Conversely, migrant remittances may be used for complementary investments which multiply the gains from direct livestock assistance. In any case, more effective livestock assistance can benefit from a better understanding of linkages between itself and the two main channels of rural income generation.

To better understand this important microeconomic behavior, we use LSMS survey data to formally estimate labor supply. Consider a given household h which can supply k varieties of labor (occupational classes in the SAM accounts). For an individual household, the problem is to maximize income

$$\max \sum_{i=1}^{k} w_i L_{hi}$$

subject to

$$L_h = \left[ \sum_{i=1}^{n} \alpha_{hi} \lambda_{hi} L_{hi}^{\nu} \right]^{1/\nu}$$

where $L_{hi}$ represents labor supplied to market *i* at wage $w_i$, and $L_h$ is aggregate supply for household h. We also want to discriminate between $\alpha_{hi}$ , a standard calibrated share parameter, and $\lambda_{hi}$ , which represents a "technology" of labor supply, such as education or training. The relevant reduced forms are then given by:

$$w_h = \left[ \sum_i \alpha_{hi} \lambda_{hi} w_{hi}^{1+\omega} \right]^{1/(1+\omega)}$$

$$L_{hi} = \alpha_{hi} \lambda_{hi} \left( \frac{w_{hi}}{w_h} \right)^{\omega} L_h$$

where we have the following relation between the CET transformation elasticity and the primal and dual share parameters:

$$\omega = \frac{1}{\nu - 1} \Leftrightarrow \nu = \frac{\omega + 1}{\omega}$$

and

$$\omega > 0$$

$$\gamma_{hi} = g_i^{-\omega} \Leftrightarrow g_i = \gamma_{hi}^{-1/\omega}$$

where $\gamma_{hi} = \alpha_{hi} \lambda_{hi}$. The parameter $\omega$ is the transformation elasticity which is either estimated econometrically or designated by the user. The other parameters can be calibrated using the base year values for the variables and the transformation elasticity. Typically in the model implementation there is no need for the CET primal exponent $\nu$, nor the primal share parameters, the $\alpha_{hi}$. When we ignore technology ($\lambda_{hi}$ =0), and simply want to calibrate $\gamma_i$ from the initial employment data, this is readily done by inverting the first order conditions as

$$\gamma_i = \left( \frac{L_{hi,0}}{L_{h,0}} \right) \left( \frac{w_0}{w_{hi,0}} \right)^{\omega}$$

If we are to capture the real heterogeneity of household labor responses, however, these equations need to be estimated directly from micro data such as the LSMS. We are currently experimenting with a number of CET specifications for this purpose, and will implement the most efficacious one in the IPALP studies.

### 5.3. Expenditure Behavior

In the standard specification of the CGE model, household consumption and savings behavior are determined jointly as the outcome from maximizing a utility function, using the Extended Linear Expenditure System (ELES). For a given household and a single commodity (i), this results in the following equations:

$$XAc_i = \theta_i + \frac{\mu_i}{PAc_i} \left( Y - \sum_j \theta_j PAc_j \right) = \theta_i + \frac{\mu_i Y^*}{PAc_i}$$

$$\theta_i = \eta_i + \omega(Xh_i)$$

$$\theta_i = \eta_i + \omega(q_{ik,} Hi_i)$$

$$S^h = \left(1 - \sum_i \mu_i\right) Y^* = Y - \sum_i PAc_i XAc_i$$

where *Y* is total disposable income, *XAc* is consumer demand (at the Armington level), *PAc* is the vector of consumer prices, and $S^h$ is household saving. Consumer demand is the sum of two components, a subsistence and own-produced minimum (or floor consumption), $\theta$, and a share, $\mu$, of committed expenditures (or supernumerary income), $Y^*$, defined as residual income after aggregate expenditures on the subsistence minima. The minimum $\theta$ is in turn a combination of a true subsistence minimum and CET share of own-output allocated to household consumption. The latter are determined endogenously in response to varying prices and wages. For households with own production, the intercept of this function is $\eta$, meaning that own needs are met before market goods are purchased.

This functional form is normally calibrated to aggregate consumption data when the model is implemented, but we are currently experimenting with direct econometric estimation at the provincial level. Results will be forthcoming, and these will shed more detailed light on rural consumption patterns and cost of living determinants. Meanwhile, however, simulations can be undertaken with the calibrated version.

Note that by assumption, the floor savings level is 0, and that savings is determined in nominal terms. For the purposes of welfare evaluation, the consumer price level is used as a proxy for the 'price' of savings. Savings can be regarded as claims to a future bundle of consumption goods with the expected price given by the current consumption price index.

# 6. MEASURING POVERTY AND OTHER LIVING STANDARD IMPACTS

Significant progress has been made in recent years on methods for ex post analysis of income distribution and poverty. The advent of decomposable measures has inspired an extensive analytical literature and a broad spectrum of practical measurement tools.[39] In this project, we exploit that literature and link it explicitly to the modeling framework, enabling a wide range of scenario analysis with endogenously determined distribution and incidence measures. There is precedent for this approach in more aggregated context, but the present effort seeks to capture more detailed institutional characteristics and market segmentation.[40]

In the IPALP approach, we want to elucidate incidence by exploiting new work on measures of poverty and income distribution. At the same time, we hope to extend these contributions by incorporating the novel features of our own modeling approach. In particular, the CGE model is intended to capture the process by which national level policies (e.g. livestock promotion, WTO accession, etc.) transmits economic effects across the national economy and, in particular, to microeconomic institutions. Detailed model results, including modeling of labor supply and production that give detailed information about induced adjustments in factor and product markets. Finally, we want to present a set of incidence measures that incorporate broader considerations such as those reflects in the UN Human Development Indices (HDI) and Millennium Development Goal (MDG) measures. Moreover, these measures are endogenous to the model, allowing them to vary directly from scenario to scenario rather than post-processing them.[41]

By applying established measures to new microeconomic incidence results, we hope to improve general understanding about the determinants of human welfare, particularly among the rural poor who are the primary targets of the PPLPI initiative. By extending these measures to encompass a broader spectrum of structural features and welfare characteristics, we want to advance the same objective but also contribute to poverty research generally.

## 6.1. Generalized Poverty and Inequality Measures

Two of generalized entropy measures of inequality (Theil: 1967),

[39] See e.g. Bourguignon:1979, Foster et al:1984, and Kanbur:1984, followed by many contributions including Ravaillion (examples follow) and others.

[40] See e.g. Datt et al (2003).

[41] Several attempts have been made to assess CGE scenarios with ex post poverty and inequality measures. In addition to the present exercise, only one, a new manuscript by Ravallion and Lokshin (2004), link the two approaches directly.

1. $GE(0) = \frac{1}{W}\sum w_i \log\frac{y_i}{\bar{y}}$, the mean log deviation, where $y_i$ is income of household i, $w_i$ is their sample weight, and W is the total population, and

2. $GE(1) = \frac{1}{W}\sum w_i \frac{y_i}{\bar{y}}\log\frac{y_i}{\bar{y}}$, the Theil index of inequality

We also include the traditional index of inequality,

3. $Gini = \frac{W+1}{W-1} - \frac{2}{W(W-1)\bar{y}}\sum w_i y_i\left[\rho_i + 0.5(w_i - 1)\right]$ where $\rho_{i+1} = \rho_i + w_i$

Finally, three versions of the poverty index popularized by Foster, Greer, and Thorbecke (1984), i.e. $P\alpha = \frac{1}{N}\sum_{i=1}^{N}\max\left[0,\left(\frac{z-y_i}{z}\right)^{\alpha}\right]$ with defined poverty line $z_i$.

4. P0 = Headcount incidence of poverty
5. P1 = Depth of poverty
6. P2 = Severity of poverty

In addition to these traditional measures of poverty and inequality, we will implement a suite of livings standards indicators that have more recently emerged in the development policy literature. These include the United Nations Human Development Indicators (HDI) and a subset of the Millennium Development Goals (MDGs). In each case, these measures will be localized to the economy and target group under consideration and made endogenous to the policy simulations. In this way, we can use a variety of internationally accepted metrics for evaluating PPLPI and related policy initiatives.

### 6.2. Human Development Indicators

### 6.3. Millennium Development Goals

The Millennium Development Goals (MDGs) are a set of development indicators endorsed unanimously by the UN General Assembly in its 2000 Millennium Declaration (a complete list is given in an annex below). A number of these indicators are relevant to both the capacity to produce and benefits derived from livestock. As has been emphasized in flagship FAO publications (FAO:2004), these indicators are of immediate relevance to food security and therefore implicate the livestock directly in multilateral policy dialogue and development goal setting. Thus it would be desirable to incorporate these into the IPALP assessment indicators.

# 7. DIGITAL MAPPING OF ECONOMIC CONDITIONS

Digital mapping techniques are revolutionizing the empirical assessment of all kinds of data. In economics, mapping has demonstrated its ability to sharpen insights from empirical analysis and dramatically enlarge the audience for applied policy analysis. Mapping not only makes ex ante economic assessment more intuitive and compelling, but can contribute in essential ways to it makes can make essential contributions to policy implementation and effectiveness. From a political economy perspective, policy makers need to clearly identify stakeholders who will be positively and adversely affected, recruiting the former to support the policy and anticipating the adjustment needs of the latter. Because it facilitates more general understanding and dissemination of policy results, mapping can play a critical role in promoting development strategies like PPLPI.

For these reasons, digital mapping is one of the mainstays of IPALP, providing a geographic "window" to the economic assessment results we obtain from the economic datasets and models. Generally speaking, mapping results are developed and presented in two ways: as a local atlas of baseline economic conditions and as a geographic representation of policy simulation results. In this section, we summarize the basic approach and present a few examples.

## 7.1. A Synoptic Atlas of Rural Poverty, Market Participation, and Asset Ownership

The IPALP approach is focused on a relatively specific set of policies and issues, and our application of mapping techniques is scaled to this research agenda. For that reason, the baseline mapping activity for IPALP represents only a synoptic atlas of each case, including primary characteristics of the rural poor and their economic activities. For all cases in the IPALP project, we strive to present a minimum set of maps covering essential initial conditions. This should include, but need not be limited to, the following:

**Reference IPALP Map Portfolio**

1. Geographical Overview
   - 1.1 Transportation network
   - 1.2 Relief

2. General Demographic Characteristics
   - 2.1 Population density or Population distributions
   - 2.2 Population 5 years of age and younger
   - 2.3 Population 65 years of age and older
   - 2.4 Dependency Ratio ((2.2+2.3)/Total)
   - 2.5 Average household size persons per household

3. Literacy and Education
   - 3.1 Literate population 15 years of age and older

4. Economic Activities
   - 4.1 Economically active population 15 years of age and older
   - 4.2 Unemployed population 15 years of age and older

5. Ethnicity and Religion
   - 5.1 Ethnicity

6. Living Conditions
   - 6.1 Average living space per capita
   - 6.2 Percent of households with access to clean water
   - 6.3 Households with electricity

7. Poverty and Accessibility
   - 7.1 Incidence of poverty
   - 7.2 Access to main urban areas

## 7.2. Mapping Policy Outcomes

While the synoptic atlas provides a revealing overview of existing economic conditions, the main objective of IPALP is to provide ex ante insight about the effects of actual or prospective economic policies, PPLPI being the primary example of this. To extend our insights in this way, we the primary assessment tools, economic models, with the descriptive facility provided by digital mapping. There are many ways of doing this, and our result mapping methods are still a work in progress. In this section, we summarize the general principles of the approach and present a few examples.

The primary outputs of IPALP's economic modeling are direct economic variables and indicators of human welfare. The former include detailed information on income, employment, production, consumption, while the latter include all the composite poverty, inequality, and human development indexes discussed above. Our results mapping approach will present these in a comparative manner, indicating graphically how the relevant indicators have changed as a result of policy or policies.

### *7.2.1. Mapping Methodology*

Geographic visualization of data within GIS is a powerful tool with the ability to analyze and display large amounts of data in an easy to read output format, supporting so the process of transforming data to information and to knowledge that is accessible also to a non-specialist audience such as e.g. policy-makers. IPALP is aiming at making best possible use of this tool to support the communication of potential alternative outcomes of policy adjustments in the livestock sector.

While the ability of current computing technology drastically increased the potentials of geovisualisation, basic conventions on cartographic visualization to convey the maximum amount of information through the maps, however, need to be considered. The conceptualization of socioeconomic phenomena as objects in spatial representation shall hereafter be explored, and basic mapping conventions relevant to the spatial visualization of socioeconomic outcome scenarios will be discussed.

Spatial representations in a GIS are always abstractions of selected aspects of a real world situation, where, in our case, socioeconomic attribute data are being linked to spatial objects for representation. Gatrell (1991) defined such spatial objects as entities with both a spatial location and geographically independent attribute characteristics. Such abstractions imply the importance of the questions about what exactly shall be represented, and for what purpose, and consequently, also about who makes those decisions. The high relevance of these issues particularly in its application to socioeconomic aspects shall be illustrated with a spatial visualization of the geographic distribution of poverty in Vietnam taken from Minot, Baulch, and Epprecht, (2003), as depicted in Fig. XXX: while both maps are based on the same estimates of commune-level poverty, each of them appears to indicate the location of geographical 'hotspots of poverty' in exact opposite places than the other map does. While the 'cause' of this apparent contradiction obviously lies in the underlying uneven population distribution, the example illustrated the importance of decisions on what shall be visualized, and for what purpose: Shall ‘poverty density’ be mapped to identify ‘poor people’, or do we want to identify ‘poor areas’ though a geographic depiction of ‘poverty rates’?

While socioeconomic phenomena vary across space, their exact ‘value’ can typically not be measured and attributed to an exact location. It is generally not clear to what exact spatial unit they relate to. This implies the important question about how a particular socioeconomic data set shall be geo-referenced, that is, with what spatial entity it shall be associated. While the variety of socioeconomic phenomena is virtually unlimited, there is only a rather limited choice of spatial objects to which they can be related to.

This difficulty to exactly geo-reference each individual record means that indirect referencing in one way or another it is always necessary. This is usually done as aggregates of the individual records by, and linked to geographic areas such as administrative entities. While the administrative unit is often the areal unit (meaning the unit of geographic coverage or area) for which socioeconomic data is reported, visual representation of such data at administrative level might not always be without limitations. Unwin (1981) notes that the administrative unit as the spatial object for geo-referencing socioeconomic data is problematic because such geographic units are basically imposed rather than natural units, whereas the social phenomena might not at all be related to the location of the administrative boundaries.

Besides, the use of such aggregated data leads to problems known as ecological fallacy (Blalock 1964), where observed relationships between two variables at one level of aggregation are not valid at another level of aggregation. Furthermore, and related to the problem of ecological fallacy, spatial visualization of socioeconomic phenomena is also subject to problems of scale, and to what is known as the modifiable areal unit problem (MAUP): Aggregation of socioeconomic data to, and visualization of those aggregates at different levels of administration, for instance, may result in varying pictures of the ‘reality’ provided by the different maps. An example of that phenomenon related to geographic scale issues can for instance be found in Minot, Baulch, and Epprecht, (2003), where the geographic depiction of poverty rates at provincial level implies only moderate poverty rates in large parts of the country, while the depiction of those poverty rates at commune level reveal that in fact high poverty rates persist in many parts of the country, which were not necessarily identified as poor areas in the province-level map. Related to the scale issue is the above mentioned MAUP, extensively discussed e.g. in Openshaw and Taylor (1981) and Openshaw (1984). This problem has been known well before the development of modern GIS, and describes the implications of alternative choices of areal units for aggregation, or zoning and geo-referencing of data. A famous example of MAUP was dubbed ‘gerrymandering’ (e.g. Bivand 1998), referring to the deliberate redesigning of administrative units to benefit a particular political party, making reference to the re-districting of the state of Massachusetts in 1812 by the state’s governor E. Gerry in such a way as to benefit the Republican Party with respect to the number of representatives of the state that were sent to the House of Representatives.

While the above mentioned illustrates potential technical, conceptual, and possibly ethical difficulties, its main implication is the considerable responsibility of users to fully apprehend the implications of a chosen mapping approach, which inherently always represents a socioeconomic reality only selectively. While there is generally not only one “correct” mapping approach, it is important to carefully consider the respective nature of the data, and the purpose of the visual spatial representation when choosing a mapping method.

For the purpose of our results mapping component, thematic maps, i.e. graphic visualization of attribute data in space (as opposed to topographic maps, showing how objects are distributed in space, where special attention is given to the accurate representation of proportional relationships between objects), will form the basis. Different types of thematic maps have evolved over the years, each of them individually appropriate for specific types of information. Typically, five types of thematic maps can be differentiated:

1. Dot maps: In dot maps, each dot represents an equal number or quantity of the attribute that is being displayed. Geographic distributions and relative densities of absolute numbers such as populations of something can meaningfully be represented with dot maps. The dots are typically distributed randomly within the enumeration area (e.g. the province) for which the attribute exists. For an example of a typical application of dot mapping see e.g. the “poverty density map” in Minot, Baulch, and Epprecht, (2003).

2. Choropleth maps: In choropleth maps, the entire area is divided into discrete regions such as administrative entities, for which the attribute data exist. Political administrative maps are typical examples, where each country or province is depicted in a distinctive color, and colors change along the boundaries only. Though this can fallaciously imply some sort of uniformity within each entity, and sharp changes right along the borders, choropleth maps are frequently used for depicting socioeconomic data per administrative unit. Choropleth maps typically depict *relative* numbers (e.g. population density). For an example on typical choropleth maps see e.g. Epprecht and Heinimann (2004).

3. Isarithmic maps: Isarithmic maps represent trends in continuous data through lines of equal values. Typical examples include meteorological maps of atmospheric pressure (isobars) or temperature (isotherms) and elevation maps depicting contour lines of equal elevation. It is not common for socioeconomic data to be depicted as isarithmic maps.

4. Symbol maps: On symbol maps, the attributes are represented with symbols (e.g. circles) of varying size according to the respective attribute value. A special case of symbol maps is the graph map, where statistical graphs are used to show the attribute values of multiple attributes in space. The Digital Atlas of California is an example for the use of symbol maps

for a geographic depiction socioeconomic data (Bowen, 2000), while an application of graph maps is provided e.g. in Minot, *et al* (2004).

5. Trend surfaces: Trend surface maps depicting continuous surfaces as a raster grid are used for visualizing individual values for hypothetically any point in space. Such surfaces are generally obtained either through remotely sensed data (e.g. elevation data), modeled data such as for instance 'accessibility' to certain services (see e.g. Epprecht and Heinimann, 2004), or through interpolation of attribute data of measurement points (e.g. air pollution).

Furthermore, recent advances in desktop GIS applications and geo-computation brought about increased exploration into new ways of analytical dynamic geographic visualization such as 3D visualizations, video animation, etc.[42]

IPALP's result mapping component envisages various levels of spatial representation: geographic visualization of socioeconomic attribute data at administrative (province) level, discriminating between urban and rural areas, differentiated by income group, and as changes over time and in terms of alternative outcomes. Different forms of representation shall be used to maximize visualization of the results and alternative outcomes.

Choropleth thematic maps will represent the basis for the result mapping, and the results will be mapped at province level. Since many of the urban areas in the country are too small to distinctively be visible on national maps, depicting the urban-rural discrimination on two separate province-level choropleth maps appears appropriate. Visualization of the differentiation according to income level shall be achieved through separated parallel mapping of individual income quintiles, depicting the results for different income groups on a series of maps displayed parallel to each other. Similarly, the geographic visualization of alternative outcomes shall be achieved through a series of maps including *status quo* and potential different outcomes depending on the different policy adjustments.

Several methodological extensions to these outlined basic mapping approaches shall be explored: While choropleth mapping on administrative unit can give a good visual representation of the spatial distribution of the mapped phenomenon, this phenomenon might not, as mentioned earlier, be much related to the actual geographic shape of an administrative unit on which the data is mapped. Dasymetric mapping techniques can be used to delineate more appropriate areas on which the data can be mapped. Dasymetric mapping is basically an extension to choropleth mapping, whereas ancillary data is used to delineate potentially more meaningful boundaries of the spatial object associated with the attribute data to be mapped.

Furthermore, in order to 'combine' the two dimensions of 'income' and 'alternative outcomes', the potentials of 3D mapping shall be explored: The different income groups will be mapped separately on parallel displayed maps,  whereas the changes in outcome of alternative scenarios shall be

[42] Slocum (2004) provides a good and comprehensive overview of different types of maps and their usage.

visualized in these maps in z direction. Lastly, geo-visualization using GIF animated maps to visualize changes resulting from alternative scenarios can be envisaged for electronic visualization and dissemination.

The resolution of results mapping of course depends on resolution of the results, which in turn depends on all the data disaggregation issues raised in previous sections. At a minimum, we should recall the need to maintain detail at the provincial level, discriminating between rural and urban households, and identifying deciles or quintiles of income distribution. This resolution is the extent of our direct economic estimation. Beyond this, more detail can be imputed by two means. The first is small area estimation, a new and rapidly growing area combining mapping and econometric methods. In addition, we can also use spatial methods to impute more detail into maps of policy results.[43] Since IPALP is rooted in economic analysis, however, this approach needs to be motivated explicitly in terms of economic behavior.

Small area estimation is a statistical method that synthesizes survey and census data and imputes economic characteristics to geographically small areas such as communes and districts. From original applications to detailed population imputation in the U.S, it was applied to estimate other demographic and economic variables such as income, cropping patterns, and adjustment factors for census weighting schemes (Ghosh and Rao,1994).

In developing countries, small area estimation is being applied extensively and intensively, from poverty studies to analysis of agricultural biotech adoption. In the former context, household or community welfare indexes are regressed on a set of variables common to the census and the LSMS or other survey. The coefficients thus obtained are then used to impute the (dependent) economic variables across the more detailed census sample. Examples include Bigman et al. (2000) for Burkina Faso, and Bigman and Fofack (2000b) for India. Vietnam has so far two poverty maps, one based on the community level data method (Minot,2000), and the other based on the individual level (Minot and Baulch, 2003).

The household level approach was first applied to Ecuador (Hentschel et al., 2000). Elbers, Lanjouw and Lanjouw (ELL) rigorously studied the statistical models underlying this approach and proposed a variety of estimation strategies (Elbers et al., 2000, 2003) that have been applied elsewhere. Alderman et al. (2002) study the case in South Africa and find that the income from the census data provides only a weak proxy for the average income or poverty rates at either the provincial level or at lower levels of aggregation. Demombynes et al. (2002) compared the experience of poverty mapping from Ecuador, Madagascar and South Africa. In Asia, Fujii (2003) made the first application of these techniques in Cambodia.

Elbers et al. (2002) have also demonstrated how to decompose inequality estimates into progressively more disaggregated spatial units. Their results for three countries, Ecuador, Madagascar, and Mozambique, suggest that, even at a very high level of spatial disaggregation, the

[43] See Davis (2002) for a survey of various imputation methods.

contribution to overall inequality of within-community inequality remains high. Elbers et al (2001) use a large sample data instead of the census. Fujii et al. (2002) applied the ELL approach to the nutritional status of children under five.

Small area estimation enriches the mapping approach by more intensively using demographic and other data resources, but it still presents only a static picture of the conditions under consideration. In particular, policy makers can assess initial conditions in great detail, but currently lack the ability to evaluate detailed composition of hypothetical shocks or alternative responses. Linking the mapping techniques described above our CGE simulation model enables the IPALP approach to trace out the actual effects of policies before they are implemented.

# 8. CONCLUSIONS

This report summarizes work in progress to develop empirical tools for Integrated Poverty Assessment of Livestock Promotion (IPALP). By using a broad spectrum of analytical tools for economic evaluation of PPLPI, we can gain greater insight into livestock's contributions to rural household welfare, improve effectiveness of policy implementation, and provide a broader context for public and private recognition of the program's achievements.

As a supporting activity, IPALP recognizes the significance of livestock promotion in a constellation of economic activities linking rural households to a wider economic universe. Livestock policy can decisively influence microeconomic opportunities and decisions, and likewise other economic events and behavior will influence household responses to livestock initiatives. An integrated approach to assessment is needed to identify such chains of influence and make sure that this form of assistance achieves its fullest potential.

The IPALP method elucidates these issues from two perspectives: a comprehensive evaluation of initial (macro and micro) conditions and simulation analysis of scenarios for PPLPI and related policy options to improve those conditions for target populations. Using a combination of intensive data analysis and advanced methods of economic modeling and digital mapping, the result is a practical road map of economic conditions and development options that is designed for direct policy support and extensive dissemination. By making both the initial conditions of the poor and the potential of livestock policy more widely understood, we hope to advance not only the goals of PPLPI, but the agenda for poverty alleviation generally. The unmet needs of world's rural poor majority require better development policies, and better research support will help achieve this.

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## Annex 1 – Human Development Indicators

The HDI is a summary measure of human development. It measures the average achievements in a country in three basic dimensions of human development:

- A long and healthy life, as measured by life expectancy at birth.
- Knowledge, as measured by the adult literacy rate (with two-thirds weight) and the combined primary, secondary and tertiary gross enrolment ratio (with one-third weight).
- A decent standard of living, as measured by GDP per capita (PPP US$).

Before the HDI itself is calculated, an index needs to be created for each of these dimensions. To calculate these dimension indices —the life expectancy, education and GDP indices—minimum and maximum values (goalposts) are chosen for each underlying indicator.

## Annex 2 - Millenium Development Goals

Following consultations among international agencies, including the World Bank, the IMF, the OECD, and the specialized agencies of the United Nations, the Millennium Development Goals were incorporated into the Millennium Declaration, adopted unanimously by the General Assembly in 2000. The goals and performance indicators for them are listed below, each with linked text in each case to a World Bank internet site that explains the MDGs in greater detail.

### Goal 1 Eradicate extreme poverty and hunger

Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than $1 a day

1. Proportion of population below $1 (PPP) a day [a]
    - 1a. Poverty headcount ratio (percentage of population below national poverty line)
2. Poverty gap ratio *(incidence x depth of poverty)*
3. Share of poorest quintile in national consumption

Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger

4. Prevalence of underweight in children (under five years of age)
5. Proportion of population below minimum level of dietary energy consumption

### Goal 2 Achieve universal primary education

Target 3: Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling

6. Net enrollment ratio in primary education
7. Proportion of pupils starting grade 1 who reach grade 5 [b]
    - Primary completion rate
8. Literacy rate of 15 to 24-year-olds

### Goal 3 Promote gender equality and empower women

Target 4: Eliminate gender disparity in primary and secondary education preferably by 2005 and in all levels of education no later than 2015

9. Ratio of girls to boys in primary, secondary, and tertiary education
10. Ratio of literate women to men ages 15- to 24
11. Share of women in wage employment in the nonagricultural sector
12. Proportion of seats held by women in national parliament

### Goal 4 Reduce child mortality

Target 5: Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate

13. Under-five mortality rate
14. Infant mortality rate
15. Proportion of one-year-old children immunized against measles

**Goal 5 Improve maternal health**

Target 6: Reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio

16. Maternal mortality ratio
17. Proportion of births attended by skilled health personnel

**Goal 6 Combat HIV/AIDS, malaria, and other diseases**

Target 7: Have halted by 2015 and begun to reverse the spread of HIV/AIDS

18. HIV prevalence among pregnant women ages 15- to 24
19. Condom use rate of the contraceptive prevalence rate [c]
    - o Condom use at last high-risk sex
    - o Percentage of 15-24-year-olds with comprehensive correct knowledge of HIV/AIDS [d]
    - o Contraceptive prevalence rate
20. Ratio of school attendance of orphans to school attendance on non-orphans ages 10-14

Target 8: Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases

21. Prevalence and death rates associated with malaria
22. Proportion of population in malaria-risk areas using effective malaria prevention and treatment measures [e]
23. Prevalence and death rates associated with tuberculosis
24. Proportion of tuberculosis cases detected and cured under directly observed treatment short course (DOTS)

**Goal 7 Ensure environmental sustainability**

Target 9: Integrate the principles of sustainable development into country policies and program and reverse the loss of environmental resources

25. Proportion of land area covered by forest
26. Ratio of area protected to maintain biological diversity to surface area
27. Energy use (kilograms of oil equivalent) per $1 GDP (PPP)
28. Carbon dioxide emissions (per capita) and consumption of ozone-depleting chlorofluorocarbons (ODP tons)
29. Proportion of population using solid fuels

Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation

30. Proportion of population with sustainable access to an improved water source, urban and rural
31. Proportion of population with access to improved sanitation, urban and rural

Target 11: Have achieved, by 2020, a significant improvement in the lives of at least 100 million slum dwellers

32. Proportion of households with with access to secure tenure

## Goal 8 Develop a global partnership for development

Target 12: Develop further an open, rule-based, predictable, nondiscriminatory trading and financial system (includes a commitment to good governance, development, and poverty reduction—both nationally and internationally)[44]

**Official development assistance**

33. Net ODA total and to the least developed countries, as a percentage of OECD/DAC donors' gross national income
34. Proportion of bilateral, sector-allocable ODA of OECD/DAC donors for basic social services (basic education, primary health care, nutrition, safe water, and sanitation)
35. Proportion of bilateral official development assistance ODA of OECD/DAC donors that is untied
36. ODA received in landlocked countries as proportion of their gross national incomes
37. ODA received in small island developing states as proportion of their gross national incomes

Target 13: Address the special needs of the least developed countries (includes tariff-and quota-free access for exports enhanced program of debt relief for HIPC and cancellation of official bilateral debt, and more generous ODA for countries committed to poverty reduction)

Target 14: Address the special needs of landlocked countries and small island developing states (through the Program of Action for the Sustainable Development of Small Island Developing States and 22nd General Assembly provisions)

**Market access**

38. Proportion of total developed country imports (by value and excluding arms) from developing countries and from least developed countries, admitted free of duty
39. Average tariffs imposed by developed countries on agricultural products and textiles and clothing from developing countries
40. Agricultural support estimate for OECD countries as a percentage of their gross domestic product
41. Proportion of ODA provided to help build trade capacity

Target 15: Deal comprehensively with the debt problems of developing countries through national and international measures in order to make debt sustainable in the long term

**Debt sustainability**

42. Total number of countries that have reached their HIPC decision points and number that have reached their HIPC completion points (cumulative)
43. Debt relief committed under HIPC initiative
44. Debt service as a percentage of exports of goods and services

Target 16: In cooperation with developing countries, develop and implement strategies for decent and productive work for youth

Target 17: In cooperation with pharmaceutical companies, provide access to affordable, essential drugs in developing countries

Target 18: In cooperation with the private sector, make available the benefits of new technologies, especially information and communications

[44] Some of the indicators listed below will be monitored separately for the least developed countries, Africa, landlocked countries, and small island developing states.

**Other**

45. Unemployment rate of 15- to 24-year-olds, male and female and total [f]
46. Proportion of population with access to affordable, essential drugs on a sustainable basis
47. Telephone lines and cellular subscribers per 100 population
48. Personal computers/internet users per 100 population