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Development of the Analytical Modeling for Analyzing Consumption and Nutritional Impacts of Food and Agricultural Policies in Zambia

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DEVELOPMENT OF THE ANALYTICAL MODELING FOR ANALYZING NUTRITIONAL IMPACTS OF FOOD AND AGRICULTURAL POLICIES IN ZAMBIA

Introduction

Since 1980, the policy environment in Zambia has been characterized by continuous changes in policy. The policy changes have been rather rapid and dramatic in the last few years. It is hard at this point in time to describe the economic policy situation in any definite terms. The policy changes may continue for some time before a definite policy direction emerges.

There are several dimensions to agricultural policy in Zambia. These include policies which work through the price system, policies which directly affect the decision environment of producers and consumers, and policies involving the institutional arrangements used to implement agricultural policies. Several of the agricultural policies can be conveniently classified as production or consumption policy. Policies that come under production policy includes those on producer prices, fertilizer subsidy, production bonus, and interest rates on agricultural production loans. Consumption policies include subsidies of the processing and distribution of maize to consumers. Policies that directly affect the decision environment of producers and consumers include direct government participation in the production and distribution system, such as the creation of government owned organizations to perform specific functions in the agricultural sector, and the provision of service facilities for production and trade. Examples are rural infrastructure, research, and extension services.

Whatever the nature of the policies in question, they have been formulated under a set of well defined national agricultural policy objectives. In the early years following independence, agricultural policy

objectives were narrowly defined. The major agricultural policy objective then was to provide food at low prices to consumers. This has since been broadened and fitted into an overall national program for rural development. The main agricultural policy objectives now include (8):

1. achievement of self-sufficiency in the production of staple food and agricultural raw materials
2. increased production of agricultural commodities with export potential to diversify exports away from copper
3. improvement in infrastructural services related to increased agricultural productivity
4. creation of employment and income opportunities in the agricultural sector to counter rural-urban migration
5. increased contribution of agriculture to the GDP
6. promotion of a more equitable distribution of income, for example, reducing rural-urban income gap through agricultural programs and pricing policies
7. improving nutritional status of the rural population

Although rural nutrition seems to have become a policy objective in its own right, there is little evidence to indicate that agricultural production and pricing policy decisions are made with nutritional considerations in mind. The analytical model presented below is designed to evaluate pricing policy alternatives and generate consumption and nutritional impacts.

Quantitative System--Basic Design

Analytical systems to evaluate agricultural policies in Zambia are conditional on several components. These include the implications of international, national, and local economic events relative to desired policy options. The system must therefore address several components. Starting from

the Zambian economy and working towards the global economic environment implies quantification of basic components associated with agricultural supply, demand, and trade.

Supply in this context would be represented by a planted aggregate statement regarding total acreage. Producer response to economic and government incentives is required for effective statements of potential or desired program policy directions. Since several major commodities are produced in Zambia, cross substitution is also an important consideration. Finally, disaggregation may be necessary over the long term if refinement is desired by region and type operation, i.e., small farmers relative to larger commercial farms.

Demand is associated with food, feed, ending stocks, and trade. Feed use is a minor component of total maize demand, since food use comprises the majority of domestic utilization. Ending carry-over serves as a buffer for production variation, primarily due to weather patterns. Trade becomes the final component to accommodate desired consumption and nutritional levels. If production and stocks are inadequate to support internal use, then imports become necessary.

A quantitative system that provides policy makers with comprehensive statements relative to this total picture is described below. There are ten major components that should be initially discussed in this context.

Conceptual Model

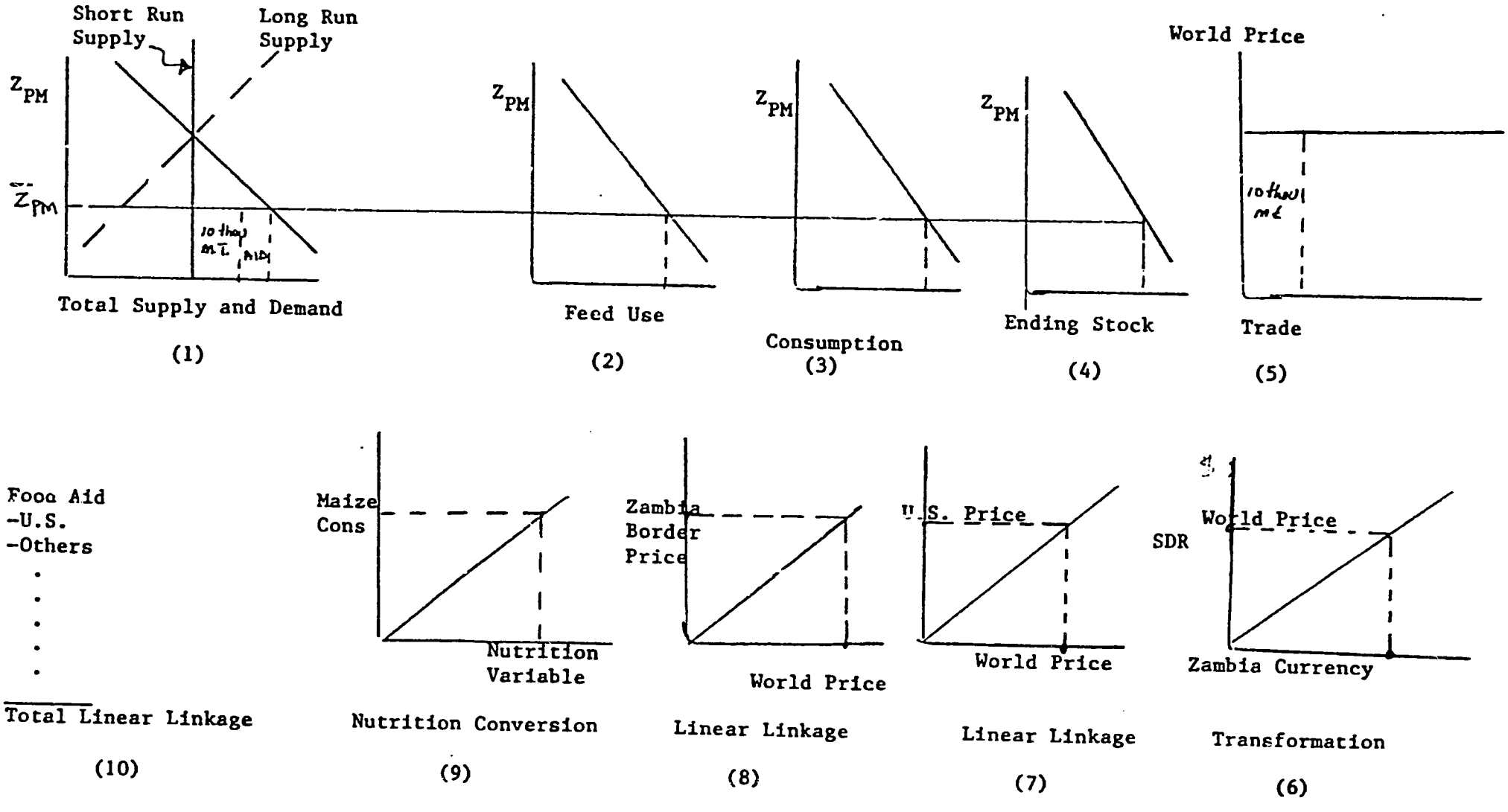
A graphical representation of a model that will serve as a framework for this research activity is given in Figure 1. This approach will accommodate decisions that can be traced through a recursive or simultaneous modeling framework. For example, as long as prices are set internally for the producing and consuming sectors, solutions can be obtained to policy options

POLICY ANALYSIS

Longer Term Implications Based on Economic Elasticities of Supply and Demand

Figure 1

I MAIZE - AGGREGATE - GRAPHICAL EXAMPLE



via the use of a recursive framework. Prices set at the national level imply economic decisions by producers and consumers that may not necessarily equilibrate without modifications from the trade or stock sectors. Therefore, objectives desired under this particular strategy require fairly accurate statements if internal supply and demand are such that differentials can be accommodated via external markets or trade.

Movement towards a market oriented system will require simultaneous solutions relative to supply and internal demand. A desire to operate the economy within a particular price band would necessarily imply stock and trade objectives that are automatically implemented when prices reach boundary points.

The first component, in Figure 1, is the total supply sector. This sector is examined in two parts: an area equation and a yield equation. Initially, area equations are conditioned on supply response elasticities associated with research obtained from the review of developing countries in Central and Eastern Africa. In general, the specifications for area equations are functionally related to the lag price of output relative to inputs, other competitive crops, and lagged area. Yield will be evaluated initially as a function of time.

The second component of consideration is feed use. In Zambia this is a minor component of total demand for maize. However, since livestock are produced on large scale farms, it is likely that some economic analysis can be obtained for this component of the model.

The third component, food consumption, is more significant since it comprises the majority of the domestic utilization of maize. This specification should include the price of maize, income and the price of other nondurables deflated by an appropriate CPI, and population. Desired

nutritional objectives are also associated with this component. Therefore per capita utilization estimates can be transformed into corresponding nutritional statements.

The fourth component of the model is an ending stock equation that would reflect carry-over from year to year. It should be examined relative to prices, current production, and future production.

The fifth component is the foreign excess supply or demand equation facing the country which is perfectly elastic, given the size of Zambia relative to the world trading market. In other words, Zambia can enter the world market and buy or sell as much as the country desires without effecting the world price. For this reason the sixth component, a transformation equation, will be necessary to link the Zambian price to the world market price. Currently, the Zambian currency is devaluing relative to trading partners, which implies that a fixed level of imports brought into the country will require larger and larger amounts of Zambian currency.

The seventh component reflects the linear linkages between the U.S. price and world price. This is derived from the longer term forecast from U.S. models. World price series can be regressed against U.S. price series, as seen in the eighth component and, in turn, linked to the Zambian border price. This is illustrated in part seven and eight in Figure 1.

The ninth component reflects the nutrition conversion matrix, as consumption estimates are obtained relative to overall domestic food demand for Zambian maize or other products. A transformation matrix is used to quantify these measures into corresponding per capita nutritional measures.

Finally, the tenth component represents the amount of food aid that Zambia receives yearly. This important component can be developed in conjunction with the total amount of net trade associated with the Zambian

economy. This aggregate model is the first initial system developed for longer range policy analyses for Zambia. All equations are aggregate and reflect national economic information. It is capable of current policy evaluation and can easily be modified to give indicators for each component under alternative strategies of policy management.

Model Interpretation and Utilization

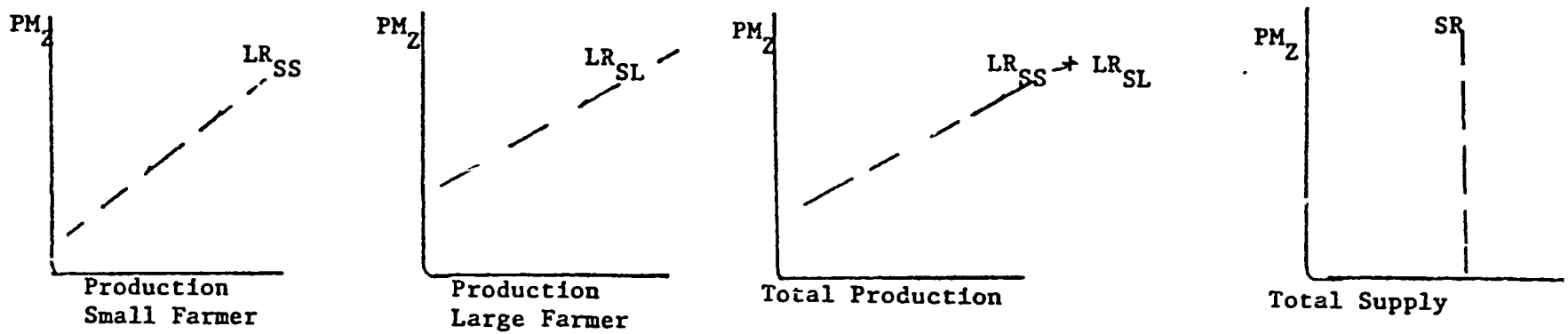
Figure 1 reflects the current situation where Zambia is a net importer. In this particular example, Zambian price PM_z is below the domestic equilibrium price, indicating a gap between supply and demand, requiring imports. Assuming that these imports are about 10 thousand metric tons (part 5, Figure 1) with PL480 or aid type shipments exogenous, then the model should generate the amount of commercial imports necessary to fill the remainder of the gap. The cost of these imports will vary according to the border price generated by components seven and eight, with a corresponding transformation matrix that indicates the exchange differential between the Zambia currency and the world market prices.

The second stage of the model is illustrated in Figure 2. This modification reflects differential production relationships relative to farm size. This differential can be separated into small farm and large farm categories. The large farm category represents large commercial farmers in Zambia. Although they represent a very small proportion of total farmers, they produce a substantial amount of total production for the nation. Given that data can be obtained on these two sectors, supply equations similar to those in Figure 1, section 1 can be estimated to give a total production for the nation as a sum of these two area equations.

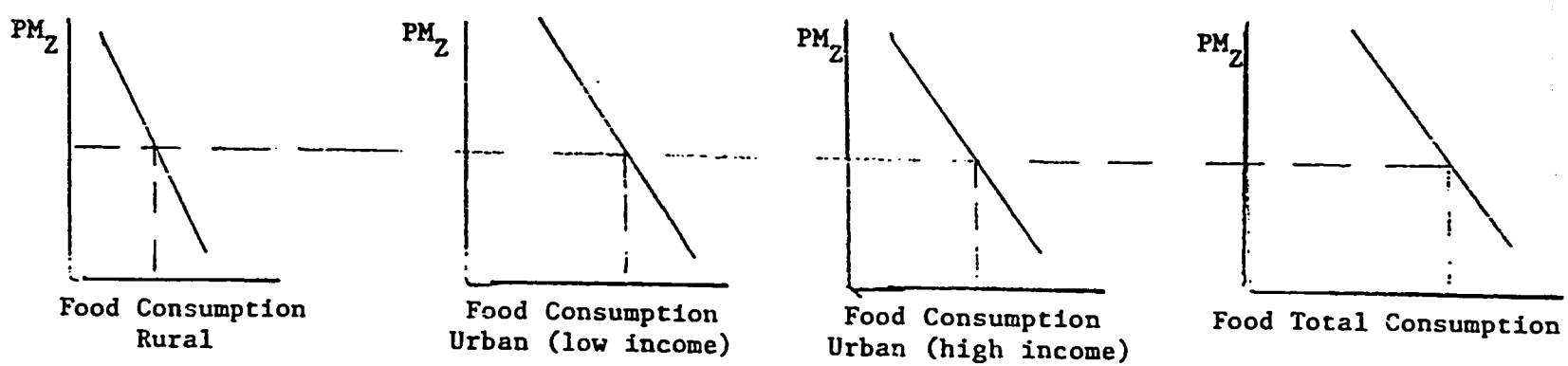
A second component is associated with the decomposition of the consumption or the aggregate-consumption equation. This second round of analyses is concentrated in three areas: (1) food consumption and nutrition for the rural population, (2) for the urban lower-income population, and

FIGURE 2

I(a) MAIZE - AGGREGATE - GRAPHICAL EXAMPLE



3(a)



(3) for the urban higher-income population. Finally, the model can be developed or conditioned in such a way that a third longer term research component could be introduced that reflects the regional economics associated with supply and demand for the major districts of Zambia. In this event, each region would have a production equation for the small and large farm section and the sum of all regions would be the total supply for the country (Figure 3). Similarly (part 3b of Figure 3), consumption equations for each region, rural and urban would be estimated in order to give a complete analysis of the supply and demand, simultaneously determined to cross all regions in the country.

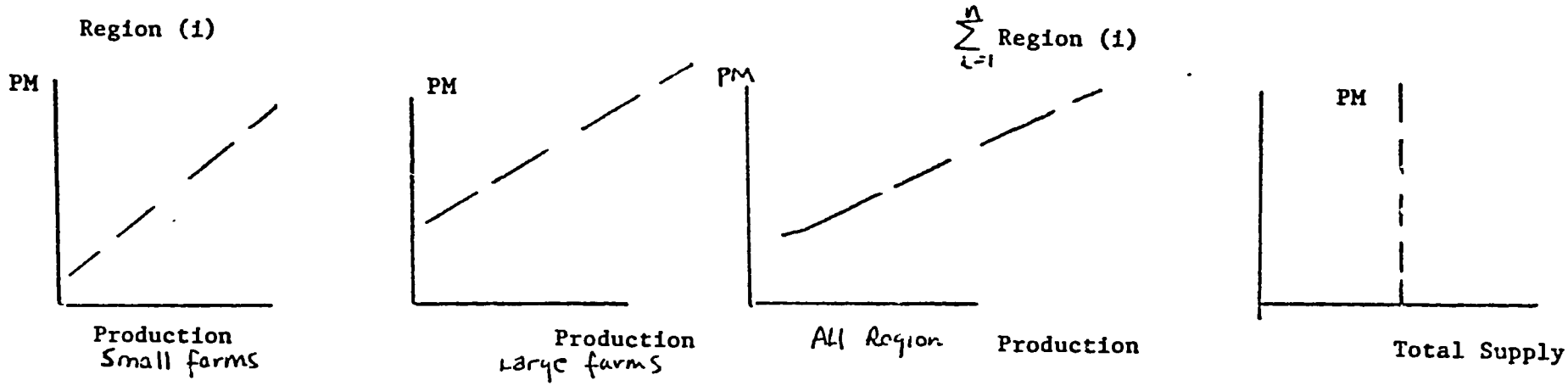
General Model Specifications

As indicated in the above section, there are several market activities that must be specified, estimated, and solved in a simultaneous or recursive system in order to capture the basic structure of the agricultural industry. In livestock there are retail markets, wholesale markets, and farm supply. The grains industry, as indicated, is composed of three major sectors--domestic supply, domestic demand, and export or import demands. These markets are imbedded in the overall general economy, thus reacting to national and international shifts in income, inflation rates, energy prices, exchange rates, interest rates, etc. These several, but distinct, areas of economic theory are discussed in the next section to lay groundwork for general equation specification.

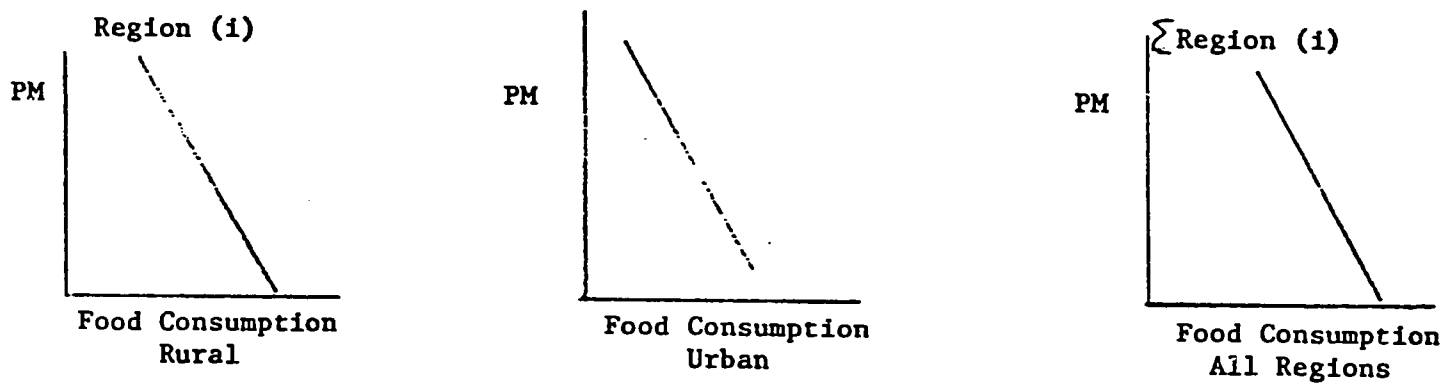
Within each commodity model are final or intermediate demands, supply, and product stocks components. In addition there are technical conversion relations, inventory accounting equations, and supply-demand identities. Each of these equation forms will be discussed in turn. A generalized grains-livestock model is presented in the Appendix. This type of model

FIGURE 3

I(b) MAIZE - REGIONAL - GRAPHICAL EXAMPLE



3(b)



specification is specialized here to fit the conceptual model for the Zambia maize sector presented in the previous section.

Production

The first component of production is area harvested. Because major differences in behavioral characteristics are expected to exist between large commercial farms and small subsistance farms, there are separate area response functions for these. Area planted is expected to depend on product prices of the crop and competing crops, input costs, and government policies. If policies are only in the form of product and import price intervention, there will be no separate policy variables.

(1) $AREA1 = f_1(PRICES, COST, POLICY)$ Large Farm Area

(2) $AREA2 = f_2(PRICES, COST, POLICY)$ Small Farm Area

Yield is expected to respond to changes in inputs that occur as product and fertilizer prices vary. Again, the response of large and small farms is expected to differ. Weather effects are, of course, very important but will be captured primarily in the stochastic disturbance of the yield function.

(3) $YIELD1 = f_3(PRICE, FERTILIZER)$ Large Farm Yield

(4) $YIELD2 = f_4(PRICE\ FERTILIZER)$ Small Farm Yield

Production is merely area harvested times yield per hectare.

(5) $PRODUCTION = AREA1 * YIELD1 + AREA2 * YIELD2$

Utilization

The main component of maize utilization in Zambia is human consumption. This is specified as a per capita retail demand influenced by prices of maize,

prices of competing foods, and income per capita. Due to different dietary patterns of these groups, consumption is disaggregated into rural, urban high income, and urban low income components. Total human consumption is then the per capita consumption of each group times the population in each group.

(6) $CONSPN_i = g_i(PRICES, INCOME_i)$ i = rural, urban high income, urban low income

(7) $CONSUMPTION = \sum_i CONSPN_i * POPULATION_i$

Feed use of maize is now a minor component of utilization in Zambia but is included for completeness. The livestock sector is taken as an exogenous factor in the model at this stage, and feed use is related to livestock numbers and feed prices.

(8) $FEED = f_5(PRICES, LIVESTOCK)$

An ending stocks component is proposed for the model, though data may be very inadequate. The private stocks component is specified as a function of price and production, and government stocks is exogenous. If private stocks data are not found, only government stocks will appear here.

(9) $STOCKS = f_6(PRICES, PRODUCTION) + GOVERNMENT\ STOCKS$

Price Determination

Since the Zambia maize trade is small relative to the world market, it can be assumed that imports or exports by Zambia will not significantly influence world market prices. Thus, the maize price in Zambia can be specified as the border price plus (minus) any government subsidy (tax) on imports. The border price is the world price converted to Zambia currency units and adjusted for transport costs to the border.

(10) PRICE = WORLD PRICE * EXCHANGE RATE + TRANSPORTATION + SUBSIDY

Trade

Given that prices are determined by the world market and government intervention policies, trade is the residual from the domestic production and use. Since Zambia is currently a maize importer, this is expressed in the form of net imports. Some of this is provided under food aid programs, so the remainder is denoted as commercial imports.

(11) NET IMPORTS = CONSUMPTION + FEED + STOCKS - PRODUCTION - lag(STOCKS)

(12) COMMERCIAL IMPORTS = NET IMPORTS - FOOD AID

Nutrient Conversion

The nutrient intake of the three population groups is computed with standard nutrient conversion factors so that changes in policy can be traced through to nutrient impacts.

(13) $NUTRIENTS_{ij} = \Sigma_j \; CONSPN_{ij}$ $\qquad$ j = calories, protein

Data Requirements and Analysis

Elasticities of Maize Supply and Demand

Limited availability of data may preclude the estimation of economic relationships for the key components of the Zambian model. Therefore, a thorough review of the literature on similar research will be utilized to fill in key components of the supply and demand elasticities for the crop sector. Direct crop elasticities will provide the quantitative component for the first initial pass at a longer term assessment. The numbers in Table 1 are used as references and do not indicate a consensus of the review process, but are indicative of the type of direct and cross elasticities necessary for this evaluation process.

Table 1. Easticities (maize supply and demand)*

	Price	Income	Livestock Units	Inputs	Competitive Price
Area	0.2	-	-	-0.2	-0.15
Feed	-1.2	-	1.0	-	0.5
Food Cons	-1.0	1.5	-	-	0.3
Stocks	-1.5	-	-	-	-
Exports	∞	-	-	-	-
Imports	∞	-	-	-	-

*Numbers in tables are given as examples and will be modified according to research review and quantitative analysis.

Supply, Use, and Economic Data

--Major commodities (table on micro-computer). Data to be collected for this project will be on an annual basis and include major agricultural components.

- Commodity detail:
  - maize
  - wheat
  - rice
  - sorghum and millet
  - tobacco
  - groundnuts
  - beef
  - poultry
  - soybeans
  - sunflowers
- National
  - Small farmers--percent of production (crops and livestock)
  - Large farmers--percent of production (crops and livestock)
- Regional
  - Small farmers--percent of production (crops and livestock)
  - Large farmers--percent of production (crops and livestock)

--Inputs (tables on micro-computer)

- All data necessary to give per hectare variable cost of production per commodity type:
  - national series
  - regional series

- Historical series of major input cost and or amounts of inputs subsidized by the government.

--Economic and other data

- population
- income
- fuel
- interest
- exchange rate
- retail prices of major commodities
- nominal GDP
- real GDP
- wage rates
- deficit
- employment
- inflation measures
- U.S. price
- world price
- border price
- wholesale price index

Projection and Policy Analysis

The analyses are to be conducted in the following sequences.

1. Estimate prices, either set by policy or from a reduced form price equation derived from elasticities similar to Table 1.
2. Estimate domestic production
3. Estimate domestic demand and carry-over.
4. Set imports or exports as the residual.

5. Estimate border price relative to the link between U.S. and world prices.
6. Estimate import price to reflect border price modified for exchange rates and transportation cost.
7. Calculate total supply and use quantities and government outlays.
8. Evaluate impacts of changes in pricing policies.

Nutritional Impact Analysis

Transform consumption estimates and impacts into aggregate nutritional estimates. Explore additional data for enriching nutritional estimates from census data. This section will be dependent upon the development of and the information necessary to generate a transformation matrix that reflects the nutritional components associated with the production of each major commodity estimated in the analyses.

APPENDIX

Generalized Grains-Livestock Model

Livestock Components

Notational Convention for Livestock Components

y and y' are output commodities

x is an input (e.g., feed) commodity

Ny is the number of y slaughtered

Qy is quantity of y

K is a capital stock variable (e.g., breeding herds)

ESY is the ending stock of commodity y

DPIC is per capita disposable personal income

POP is population

WR is the wage rate in the processing industry

Py and Py' are the prices of y and y'

Pyr and Pyf are the prices of y at retail and at the farm

Pk is the price of the capital input (e.g., breeding heifers)

Px is the price of x

Retail Demand Equations

The retail demand equations are in per capita terms and contain income and prices of both substitute and complement goods. The form of the retail demand equation is:

$$\frac{Qy}{POP} = f(Pyr,\ Py'r,\ DPIC). \tag{1}$$

The partial derivative with respect to the first argument is negative and for the second is positive if y' substitutes for y and negative if they are complements. The partial derivative with respect to income is positive unless the good is an inferior one. All prices and income are nominal variables. Equations of this form describe the retail demand of beef, pork, poultry, and veal. The quantity variable in these equations is typically the civilian

disappearance variable--the final quantity consumer. This equation is often specified in a price dependent form.

Farm Demand Equations

The farm demand equation relates numbers of animals slaughtered to the retail prices, the farm price, and process wage rates. This is a derived demand equation in which the wage rate and farm price of live animals are input prices, the retail price of meat is the output price, and the slaughter number measures the amount of the input demands. The specification is:

$$Ny = f\left(\frac{Pyf}{Pyr}, \frac{WR}{Pyr}\right). \tag{2}$$

The partial derivative with respect to both arguments should be negative. There is no direct income effect, since that is transmitted through the retail price variable. This relationship is often specified in price dependent form and is the means to generate the prices of sows, barrows and gilts, fed cattle, feeder cattle, nonfed cattle, and slaughter calves.

Investment Demand Equations

The livestock industry has the characteristic that the output of the production process can also augment the capital stock for that production process. The investment demand equations are quantity-dependent, with the capital stock, capital price, and product and other input prices as independent variables. The functional form (recall that investment is the time rate of change in the capital stocks) is:

$$\frac{dK}{dt} = f\left(K, Pk, \frac{Py}{Px}\right). \tag{3}$$

The partial derivatives with respect to the first two arguments should be negative and, with respect to the third, positive. The larger the capital

stock and the higher the price of the capital good, the less investment (replacement) should occur. A relatively higher product price should increase investment.

This equation characterizes sow slaughter (disinvestment), pigs for breeding, nonfed beef cow slaughter (disinvestment), and beef heifers for breeding. In the equations where it occurs, Px is the feed price variable. Pk and Py may be the same variable but with different time subscripts. This also is a derived demand equation--derived from the farm production process which provides animals for slaughter. On the disinvestment side of this relationship, the equation explains the supply of lower quality (nonfed) slaughter animals.

Farm Supply Equations

The output of the production process is a function of the level of the capital stock and the price of the output relative to the price of the variable inputs. This is of the form:

$$Ny = f(K, Pyf/Px). \tag{4}$$

Both partial derivatives are expected to be positive. Here, the breeding herd is the capital stock, feed is the variable input, and animals for slaughter are the output. This equation describes the pig crop, barrow and gilt slaughter, beef heifer and steer slaughter, fed beef heifer and steer slaughter, and calf crop and veal production relationships.

Retail Supply Equations

The supply into the retail market is the result of a production process which converts live animals into meat using labor and fixed capital. Because aggregate slaughter numbers are largely determined prior to the packing plant

decision process, this supply equation contains the quantity of live animals rather than the price of the live animals. In particular, the form of this equation is:

(5) $$Qy = f(Ny, Pyr/WR).$$

The dairy sector has several retail products which are produced from a homogeneous input (milk). The model differentiates between and among them. This is in contrast with, for example, the homogeneous output of beef from the differentiated inputs (fed steers versus cull cows).

In addition, a number of other relations in the model simply convert quantities from one form into another unaffected by price. Mathematically, they are the form:

(6) $$Qy^* = f(Qy).$$

These proportionately convert numbers of live animals to dead ones and calculate the average carcass weights. The equations in this group include calf and other cattle losses, calf slaughter and average weight of fed and nonfed cattle slaughter.

Product Stocks Equation

The ending stocks of the commodity are related to the beginning stocks and the per capita production. This relates changes in stocks to the excess of current stocks over an "equilibrium" level and per capita production over some "average". For a continuously produced product like beef, the role of such stocks is more of a transaction demand than speculative. This is of the form:

(7) $$ESY_t = f(ESY_{t-1}, \frac{Qy}{POP}),$$ or in continuous time

(7a) $$\frac{dESY}{dt} = f(ESY, \frac{Qy}{POP}).$$

The partial derivatives of f in equation (7a) are negative with respect to stocks and positive with respect to per capita supplies.

Inventory Accounting Equations

The capital stock variables, such as breeding herds, are accounted for by simply adding (integrating out) all the individual investment items. Mathematically, this takes the form:

(8) $$K(t) = K(0) + \frac{dK}{dt}\, dt$$

This process is represented in the equations for breeding and market hog inventories and beef cow inventory.

Market Clearing Identities

The remaining equations in the livestock model express the market clearing supply-demand identities for each commodity. These incorporate imports, exports, and military consumption into the retail sector and equate numbers produced with numbers processed. These equations impose the condition that supply equals demand, which forces the model to find a market clearing price.

Crop Equations

The crop sector of a cross-commodity forecasting system consists of a demand side which is differentiated by source of demand, a supply side whose key elements are acreage response and yield, and a market clearing identity which determines the farm level price.

Notational Convention for Crops Components

QFEED is quantity of feed demand

QFOOD is quantity of nonfeed demand

QSTK is ending stocks

PLANT is area planted for the next crop

QEXP is quantity of net exports

GSTK is government stocks

QP is production

CPI is price index for nondurables less food

Pxf and Px'f are farm prices of inputs

Pyf is farm price of livestock

Ny is the number of y slaughtered

Feed Demand Equations

One use of grains and oilseeds is to feed livestock. The demand for this purpose is, by consequence, a derived demand. The quantity of each grain (or soybean meal) consumed by livestock is a function of livestock numbers, livestock prices, their own price, and prices of competing feeds. These relationships are homogeneous in all price variables and must represent the units of livestock fed, rather than pounds of meat produced. The mathematical form of the feed demand equations is:

$$QFEED = f(Pxf/Pyf,\ Px'f/Pyf,\ Ny). \tag{9}$$

The crushing demand for soybeans is included in the table of feed demands since it also is a derived demand.

Food Demand Equations

The food usage of grains and soybean oil is most analogous to the retail demand for livestock products. It is often specified on a per capita basis and is affected by consumer income, inflation, and competing product prices. The entire food processing sector is not explicitly modeled. Instead, the food demand is related to farm prices for the commodity and competing commodities, consumer incomes per capita, and the CPI for nonfood commodities other than durables. In particular, the form of the equation is:

$$\frac{QFOOD}{POP} = f(Px/CPI,\ Px'/CPI,\ DPIC/CPI). \tag{10}$$

Export Demand or Import Supply Equations

The export demand (import supply) for grains and oilseeds is an excess demand (supply) concept. Whatever factors affect foreign supply and use, also affect the levels of demand for exports when appropriately transposed from the major importing regions. Similarly, for an importer, the factors affecting foreign supplies and use affect the levels of foreign supplies available for import at any given price. Policy instruments like the European threshold price for corn, Japanese resale price for wheat, and USSR net grain imports also affect foreign demands and supplies.

Domestic prices need to be converted to the prices in the foreign market to incorporate the exchange rate effect and link domestic prices to those that influence foreign demands or supplies.

Crop Inventory Demand

The inventory demand for U.S. crops is separated into components owned by the government and those owned by private agents. The private stocks demand is an accelerator-type model which incorporates both transactions and speculative components. The speculative demand can incorporate rational

expectations arguments to represent the expected price at which the grain can be sold at a later time. Current farm price is the acquisition cost for new inventories. Production for the current marketing year captures the transactions component of demand, and the beginning stocks (lagged dependent variable) represents the accelerator. The area planted for next year's harvest and the current level of ending government stocks are sometimes used as simple representations of expected future price. In mathematical terms:

$$QSTK = f(\text{lag}(QSTK), QP, Px, PLANT, GSTK). \tag{11}$$

The government stocks holdings may be modeled as functions of program provisions or related to some government decision rule.

Production Response Equations

In each case, the planted area response is related to the relative prices of the own and major competing crop products. The effect of government programs is measured by including program provisions as explanatory variables.

The yield per acre for each crop is estimated outside the simultaneous solution process of the commodity market model, drawing on weather variables and economic factors, including acreage planted (or harvested) and crop and fertilizer prices.

Market Clearing Identity

The market clearing condition requires that supply equals demand and generates the market clearing price. It takes the form:

$$QP + \text{lag}(QSTK) + \text{lag}(GSTK) = QFEED + QFOOD + QEXP + QSTK + GSTK \tag{12}$$

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