AGRICULTURAL POLICY: A LINEAR PROGRAMMING APPLICATION TO GUATEMALA

BY

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

APPENDIX A

LIST OF TABLES (Continued)

APPENDIX B

LIST OF FIGURES

LIST OF ABBREVIATIONS

AID	US Agency for International Development
ANACAFE	National Coffee Association (Asociación Nacional del Café)
BANDEGUA	Guatemalan Banana Exporting Company (Bananera de Guatemala)
BANDESA	National Agricultural Development Bank (Banco Nacional de Desarrollo Agrícola)
CACM	Central American Common Market
CHAC	Mexican Agricultural Model
CNA	National Cotton Council (Consejo Nacional del Algodón)
DGE	Directorate General of Statistics (Dirección General de Estadística)
DIGESA	General Directorate for Agricultural Services (Dirección General de Servicios Agrícolas)
ECID	Center for Central American Integration and Development Studies (Estudios Centroamericanos de Integración y Desarrollo)
FAO	Food and Agricultural Organization
FERTICA	Central American Fertilizer Company (Fertilizantes Centroamericanos)
GDP	Gross Domestic Product
IBRD	International Bank for Reconstruction and Development
IDB	Inter-American Development Bank
ICTA	Institute of Agricultural Science and Technology (Instituto de Ciencia y Technología Agrícola)

LIST OF ABBREVIATIONS (Continued)

IMF	International Monetary Fund
INDECA	National Agricultural Marketing Institute (Instituto Nacional de Comercialización Agrícola)
INTA	National Institute for Agrarian Transformation (Instituto Nacional de Transformación Agraria)
MAYA	Guatemalan Agricultural Model
MOCA	Central American Agricultural Model (Modelo Centroamericano)
SIECA	Secretariat of Central American Economic Integration (Secretaría de Integración Económica Centroamericana)
SGCNPE	National Economic Planning Council (Secretaría General del Consejo Nacional de Planificación Económica)

EQUIVALENCIES AND SYMBOLS

1 quetzal (Q)	=	1 US dollar
1 ton	=	1 metric ton

ha	hectare
kg	kilogram
G	Farm group
---	Close to zero
...	Not available

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This study develops a mathematical programming model of the Guatemalan agricultural sector (MAYA) for the 1976-1977 period and uses it to simulate policy. The main objectives were (a) to determine the optimal pattern of production and show the bias involved when risk-averse behavior is ignored, and (b) to estimate the effects of different policies.

MAYA consists of three subsectors based on farm size and technology, producing 13 annual crops--which could be produced under several techniques and represent 90% of the value of Guatemala's total agricultural production. These subsectors were linked by an objective function and by intersectoral transfers of products and inputs. Crops were either sold directly or transformed. Eighteen final products could be sold in the domestic market or exported.

The basic optimizing market equilibrium formulation of the model assumes that producers are profit maximizers and that consumers' behavior is described by demand functions. This formulation was modified by introducing risk-averse behavior.

To demonstrate the uses of MAYA several experiments were conducted. Supply responses to variations in the prices of maize and cotton were analyzed for selected crops, and technological change was discussed in detail. Another experiment tested the effects of expanding the area planted with cotton in order to increase farmers' incomes and employment. Finally, MAYA was used to obtain schedules of comparative advantage in international trade. The conclusions drawn from these experiments were (a) as product prices increased, farmers tended to adopt higher yielding, more input-intensive techniques which were also riskier; (b) less advanced farmers behaved no differently from the more advanced ones; (c) a policy to increase incomes and promote employment through increased cotton production would only be effective in the short run, as in the long run prices rose cancelling the initial effects; and (d) Guatemalan agriculture is rather competitive in international markets.

The study demonstrated that mathematical programming models can be effective tools for planners in underdeveloped agriculture. Their usefulness could be improved if they were considered within the multilevel framework--maximizing a set of goals subject to a behavioral problem--and if income were explicitly incorporated in their formulation.

CHAPTER I
INTRODUCTION

Agricultural policies in Guatemala have been carried out in a haphazard manner intended to achieve a host of different and often divergent purposes. As is typically the case with less developed countries (LDCs), the agricultural sector is expected to supply food at low prices, increase income levels of the rural population, raise government revenues, provide employment, and generate foreigh exchange. However, the lack of coordination among and within the agencies in charge of executing agricultural policies has prevented the successful implementation of such policies. Policies have primarily been directed toward staple crops, but targets have not been reached. The government is concerned that Guatemala suffers from domestic food shortages, and that agricultural income is, in large part, generated by export crops subject to international price fluctuations. The failure of the Guatemalan authorities to improve the conditions of the sector makes it increasingly necessary to formulate a set of consistent policies.

The traditional approach to agricultural planning in Guatemala has been to arbitrarily set production targets and to estimate the potential income and employment effects through partial and rather superficial analysis. This approach has not permitted an evaluation of the overall behavior of the sector because it disregards substitution effects among products and among inputs (including land and labor).[1] While individual commodity targets may satisfy the production and foreign exchange objectives, they would only simultaneously satisfy an employment or income objective by coincidence. Consequently, benefits and costs of implementing different policies have been improperly evaluated. Effective resource allocation, on the other hand, requires consideration of the substitution effects; that is, a model must allow for certain prices to rise and for others to decline in response to different policies. The sector does not face point demands; it faces demand schedules (Bassoco and Norton, 1975). The position on the schedule should be found through the solution of a resource allocation problem. A model for the whole agricultural sector, thus, is a prerequisite for complete policy planning.

Large scale price exogenous linear programming models have been used extensively by agricultural economists to simulate the impact of farmer plans upon the agricultural sector. These models have taken market prices or quantities as given.[2] When interrelationships between prices and quantities are considered, the problem can be treated as one of spatial and/or intertemporal equilibrium. Samuelson (1952) showed that the problem of spatially separated markets could be solved through the maximization of the net social payoff which rendered competitive equilibrium. Takayama and Judge (1964a, b) proposed a quadratic programming formulation to solve Samuelson's maximand. Using separable programming, Duloy and Norton (1973, 1975) linearized the quadratic

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[1] See, for example, Mellor (1975) and Bassoco and Norton (1975).

[2] See, for example, Heady and Srivastava (1975).

objective function which permitted the use of the simplex alogrithm to solve the problem, whereby the size and scope of problems to be considered were expanded.

The primary objective of this research was to build a linear programming model according to the Duloy and Norton specification for simulating the impact of different policies on key variables in the agricultural sector. Specifically, an attempt was made to estimate direct and cross-price elasticities for a number of crops, to analyze the income and employment effects of expanding cotton production, and to establish comparative advantage in production based on comparative advantage in international trade. The results are limited in that they were generated in the context of the assumptions and model specifications underlying the linear model. The closer these assumptions and model specifications approach the decision environment of agricultural producers, the more valid the results are likely to be. An effort toward achieving greater realism was to introduce risk considerations into the model.

Commodity demand functions are included within the structure of the Guatemalan model (MAYA),[3] hence prices are determined by the interaction of supply and demand. Since relative product and factor prices are the dominant policy instruments in agriculture, this feature of the model permits a wide range of policy experiments. MAYA considers three major groups of farmers who produce 13 crops. Each group is characterized by a technological level. These crops are transformed into 18 final products which are sold domestically or exported.

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[3]MAYA is a name given to the original inhabitants of Guatemala.

To overcome data limitations, MAYA relies heavily on the use of cross-sectional farm level production cost data.

The dissertation is organized as follows: Chapter II gives a brief description of the Guatemalan economy in which the agricultural sector is emphasized. In Chapter III the theoretical background of the model and the inclusion of risk are discussed. The data base of MAYA is explained in Chapter IV. Validation of the model is covered in Chapter V. In Chapter VI various simulation results are presented. The summary, conclusions, and suggestions for further improvement of the model are presented in Chapter VII.

CHAPTER II
OVERVIEW OF THE GUATEMALAN ECONOMY

Guatemala is the largest Central American country with an area of 110,000 square kilometers and a population of 7.2 million in mid-1980. Three quarters of the population live in rural areas. Guatemala has a wide range of climatic conditions, from the tropical northern and coastal areas to the volcanic highlands (Figure 1). Agriculture is diversified and its potential is large especially in the northern part of the country. During the last 15 years Guatemala has been able to diversify its exports (although its major exports are still traditional crops) and achieve rapid industrial growth and a substantially higher level of per capita income. Even so, Guatemala is still primarily an agricultural country.

The economy has been growing rapidly at an annual average of 6.3% in the last 15 years and generally above the Latin American average.[1] The share of agriculture, the most important sector, in GDP has remained at around 28% (Appendix A, Table I). Industry accounts for about 15% (the largest share relative to the other Central American countries) in large part because the country has been a main beneficiary of the Central American Common Market (CACM).

The overall growth of the Guatemalan economy has been highly dependent on the fluctuations of export prices, particularly the price

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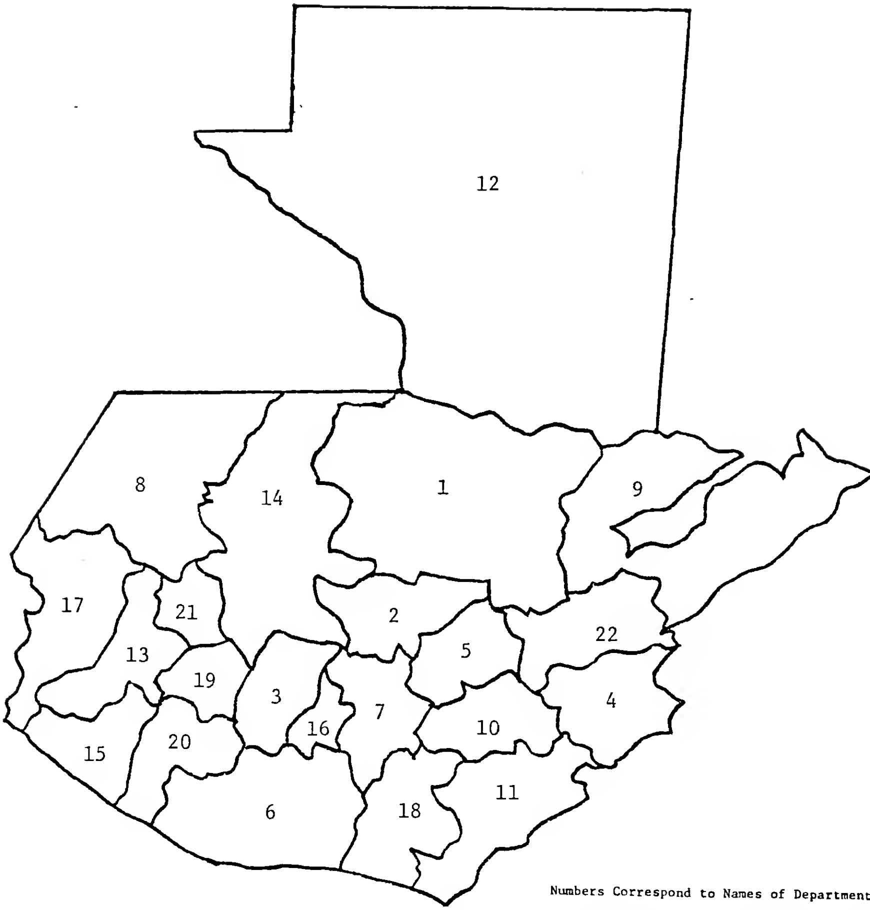
[1]During the period 1965-1976, the annual growth of GDP in Latin America was 4.7% and that of Guatemala, 6.1% (IDB/IBRD/AID, 1977).



Numbers Correspond to Names of Departments:

1	Alta Verapaz	12	Peten
2	Baja Verapaz	13	Quetzaltenango
3	Chimaltenanago	14	El Quiche
4	Chiquimula	15	Retalhuleu
5	El Progreso	16	Sacatapequez
6	Escuintla	17	San Marcos
7	Guatemala	18	Santa Rosa
8	Huehuetenango	19	Solola
9	Izabal	20	Suchitepequez
10	Jalapa	21	Totonicapan
11	Jutiapa	22	Zacapa

Figure 1. Political Map of Guatemala

of coffee. The country has, however, been able to avoid serious balance of payments problems as import growth rates have followed closely those of exports and because the government has curtailed demand through credit restraints.

Over the past 15 years, investment has fluctuated between 12 and 15% of GDP (IBRD, 1978). During the 1960s and early 1970s about 25% of total fixed capital formation took place in manufacturing, much of it because of opportunities opened up by the creation of the CACM. Agricultural investment was, however, about one-third that of industry and deteriorated even further after 1973 (Appendix A, Table II). Although the annual share of banking credit of agriculture was at least 70% that of industry until the mid-1970s, it was used mainly to purchase current inputs rather than for capital investment (Banco de Guatemala, 1980b; IDB/IBRD/AID, 1977). Government lending to agriculture was very limited and gave little support to smaller farmers.

Government consumption has tended to move with GDP, whereas government investment has been much more volatile. During the 1960s the rate of public investment was smaller than that of private investment, whereas the reverse occurred after 1970 due mainly to the implementation of the 1970-1975 Development Plan by the government. Following the earthquake of February 1976, public sector investment almost doubled in real terms as the government took the lead in the reconstruction process (Appendix A, Table III).

During the 1960s and early 1970s domestic prices remained remarkably stable and increased by an average of only 0.3% per year (IMF, 1978). The conservative monetary policies of the government restricted expansion of the money supply, and the openness of the economy allowed imports to rise with export earnings, relieving demand-pull inflationary pressures.

After 1973 Guatemala departed sharply from past patterns of development. In contrast to the previous stable period, consumer prices surged by 10 to 15% each year as a result partly of increased prices of imported inputs after the oil shortage, and partly to the inflation generated by the rapid growth of the money supply resulting from increased export earnings--led by coffee whose price rose by over 35% in 1974 over 1970 (IMF). The resurgence of trade with other CACM countries in 1973 and 1974 generated a surplus of $40 million each year. This surplus combined with a boom in coffee export earnings in 1973 and one in sugar export earnings in 1974 allowed the country to import at a level sufficient to maintain growth, thus avoiding a recession (IBRD).

Contributing to the inflationary pressures was a shortage of basic grains, particularly maize, caused by a shift of areas planted with basic grains toward cotton and sugar production in the South Pacific region. To meet domestic demand, the National Agricultural Marketing Institute (INDECA) was forced to import and sell at prices lower than import cost. In 1974 the government reversed its strategy and took several measures to stimulate production (see below). The favorable crops of 1975 and 1976 (Appendix A, Table IV) helped dampen inflationary pressures, but by the end of 1976, the exceptional demand created by the earthquake reconstruction efforts combined with a massive influx of foreign exchange from coffee and cotton exports pushed the rate back to previous levels. After 1976 moderate government measures to limit the money supply and control the domestic prices of major export commodities have helped control inflation.

During the past 20 years there has been little change in the relative importance of agriculture in Guatemala. It still accounts for about 28% of GDP, about three-fifths of total employment, and over two-thirds of the value of exports. Moreover, savings from export agriculture have provided a large share of investment resources, and much of the industrial expansion of this period has been based on agricultural raw materials (e.g., sugar cane and cattle). During the same period, however, the share of agriculture in the national fixed capital formation has fallen from 15% in the early 1960s to about 8% in the 1970s (IBRD). Limited investment in agriculture is a major cause of lagging productivity in traditional crops and stagnating incomes for small producers. Public investment has concentrated on minor irrigation works, some grain storage facilities, and rural roads.

In an effort to raise the income of small producers and landless agricultural workers, and to secure sufficient production of basic grains, the government has attempted to implement several programs as stated in its development plans. A lack of adequate storage facilities for staple crops by the private sector, leading to marked seasonal price variations, prompted the government to intervene. The government initiated price stabilization programs for staple crops in the early 1960s. It purchased the crops during harvest time at fixed prices, stored them, and sold them during off-peak seasons. But these programs did not produce the expected results because market prices remained above the producer prices set by the government. As a result, grain prices continued to fluctuate (Fletcher et al., 1970).

In the early 1970s, the government reformulated its price stabilization program and initiated a series of measures to promote production within the context of the National Development Plan of 1971-1975. One of the major recommendations of the Plan was to strengthen the public agricultural sector by consolidating existing agencies and establishing new ones under the general authority of the Ministry of Agriculture. A government decree of July 1, 1974 (Diario de Centroamerica, July 1, 1974) made it compulsory for farmers to plant at least 10% of the area in basic grains in plots of 70 hectares or more, made credit through the National Agricultural Development Band (BANDESA) more easily available, announced a prohibition to export grain for the next two years, and raised guaranteed prices by as much as 100% (Appendix A, Table V). Production, however, increased because of higher yields rather than because of expanded areas. INDECA took a more realistic role as a stabilizer of market prices rather than trying to maintain artificially high prices for producers and artificially low prices for consumers. But insufficient and unsuitable government storage facilities and a lack of coordination of the agencies involved have blunted the original intentions. Participation of the government in the market has been about 5%, well below the targeted level of 20% (Appendix A, Table V), and the costs of the price stabilization program during the 1971-1974 period were over $11 million. Prices of staple crops have continued to fluctuate and costs of inputs have increased. Consequently, the area allocated to the production of staple crops decreased. The National Development Plan of 1975-1979 (SGCNPE, 1975) acknowledged that much remained to be accomplished in making the concept of the public agricultural sector a viable one for planning, policy and operational purposes, and reemphasized the need to strengthen its institutions.

The main activities of the government in the agricultural sector are technical assistance and training through the Institute of Agricultural Science and Technology (ICTA) and the General Directorate for Agricultural Services (DIGESA), marketing of basic grains through INDECA, land colonization and distribution through the National Institute for Agrarian Transformation (INTA), and agricultural credit through BANDESA.

Producer organizations, such as the National Coffee Association (ANACAFE) and the National Cotton Council (CNA) which offer marketing and technical assistance to their members, receive partial support from the government. These activities have generally been quite limited and coordination among these organizations has been inadequate because of their autonomous nature.

Another area where the government has intervened is the wheat market. The wheat pricing program started in 1952 and has worked reasonably well because of a high support price made possible by a "bread tax" that transfers income from the urban consumers to wheat growers and millers. The high proportion of imports (60% of domestic consumption) allows the flour mills to maintain a lower average price for flour than would otherwise be possible. This, in turn, allows for a high support price. Self-sufficiency in wheat, however, is not possible because Guatemala produces only soft wheat and would still need to import hard wheat.

The highly skewed distribution of land ownership in Guatemala is a major factor behind the country's unequal distribution of incomes; 7% of the population accounted for 60% of the GDP in the late 1960s (Fletcher et al., 1970). In 1970, 83% of the people in rural Guatemala lived on plots too small (less than 7 hectares) to produce the income needed to support a family without outside employment (Table 1). Within the Central American area, only El Salvador has a higher proportion of people on similar-size plots of land because it is more than three times as densely populated as Guatemala. At the other end of the scale, 80% of Guatemala's agricultural land is held in units larger than 7 hectares, and these farms are owned by only 2% of the farm families. The high concentration of the indigenous population in the Western Highlands accounts for much of the inequality of land distribution, with 26% of the total area and 60% of the population (SGCNPE, 1978a). The situation is made more acute by the fact that the land is rugged and unsuited for cultivation.[2] Erosion of the land and low productivity are common problems. In contrast, the fertile plains of the South Pacific are for the most part held by wealthy owners and dedicated mainly to export crops.

Although an agrarian reform law has existed since the 1950s and the National Institute for Agrarian Transformation (INTA) has existed for nearly as long, negligible progress has been made toward improving the equality of land distribution in Guatemala.

The lack of access to adequate credit at a reasonable cost continues to be a barrier to improved output and productivity, particularly for small farmers. It is unlikely that more than a third of the farmers in Guatemala make regular use of institutional credit even though BANDESA has greatly expanded its operations since 1974. BANDESA now

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[2]Studies have revealed that this land is better suited for forestry (SGCNPE, 1978b).

Table 1. Estimated Land Tenure Pattern in Guatemala, 1970

Size of Holding	Share of Farms or Families		Share of Area	
	(%)	(cum. %)	(%)	(cum. %)
Small	83.3	83.3	12.3	12.3
Landless[a]	26.5	26.5	---	---
Less than 0.7 ha	14.8	41.3	1.0	1.0
0.7 - 4.0 ha	42.0	83.3	11.3	12.3
Medium	14.1	97.4	21.4	33.7
4.0 - 7.0 ha	6.8	90.1	6.3	18.6
7.0 - 35.0 ha	7.3	97.4	15.1	33.7
Large	2.7	100.0	66.3	100.0
35.0 - 350.0 ha	1.4	98.8	23.9	57.6
Over 350.0 ha	0.5	99.2	42.4	100.0
Administrators[a]	0.8	100.0	---	---

[a]Families without land.

SOURCE: IBRD (1978, p. 73).

serves over 80,000 farmers, many of whom are members of cooperatives which receive its funds.

The agricultural sector has played an important part in the earning of foreign exchange. Exports of traditional products (i.e., coffee, cotton, sugar, and bananas) accounted for 60% of the total value of exports during 1970-1977 (Directorate General of Statistics, DGE, 1970-1977). The expansion of production of export crops and favorable conditions in world markets have contributed to this outcome. Export crops, with the exception of coffee (which still uses traditional methods of production), are produced with sophisticated techniques. Coffee exports alone account for 30% of total exports, and the government has encouraged its production by making credit available (Banco de Guatemala, 1976, 1980b).

Although Guatemala has reduced its dependence on coffee exports very substantially, coffee clearly remains the largest single export commodity. Changes in overall export earnings have traditionally been and continue to be very closely linked to changes in the value of Guatemalan coffee exports. Some export diversification as well as favorable movements in the cotton and sugar prices helped dampen the impact of changes in coffee export growth on total export earnings (IMF).

Cotton has been the second most important crop since the 1960s. Production has been stimulated by improved technologies, a growing domestic textile industry, and increasing external demand. Sugar has traditionally been the third largest export product of Guatemala. Production achieved record high levels in 1975, with exceptionally high international prices, and stabilized at pre-1975 levels thereafter

(Banco de Guatemala, 1976, 1980a). Bananas and meat are the remaining major agricultural export products of Guatemala. The policy of BANDEGUA, a subsidiary of Del Monte Corporation and the major exporter of Guatemalan bananas, has been to maintain production for export more or less constant, and in the past few years BANDEGUA has tended to diversify into other fruits such as pineapples and papayas. During the past 15 years increases in meat production reflect increased numbers of animals and hectares of pasture rather than increased productivity per animal or per hectare (IDB/IBRD/AID). The present plan of the government to shift cattle production from the Pacific coast to the northern slopes and lower Peten region should allow the freed lands of the Pacific south to be diverted to cotton and basic grain production.

In summary, prospects for Guatemala's agricultural exports are generally quite good, though efforts could be made to raise productivity, particularly in coffee. Non-export agriculture, however, suffers from fragmented land holdings and low productivity, resulting in inadequate incomes for farmers. This, in large part, stems from a limited ability to analyze agricultural development problems and to formulate appropriate solutions in terms of policies and investment programs. The conditions for agricultural development in the overall context of the Guatemalan economy include some potentially favorable factors. Some balance of these factors could work well for overall economic growth and the development of the country's diversified agriculture. They include (a) increased and more diversified agricultural exports, (b) favorable international prices for export commodities (c) comfortable international reserves, (d) low external debt service ratio and long maturity at low interest, and (e) restrained monetary policy to cope with inflation (AID, 1978). Other factors could be added to the preceding list such as the large untapped natural resources potential, including petroleum and forestry, and strong rural cooperative agreements. These factors appear to offer considerable scope for undertaking medium- and long-range commitments with the goal of increasing output and rural welfare. This goal would require greater participation by the government in such things as increasing credit supply and price regulation. Given the high rate of population growth of nearly 3% per year, it appears, as stated in the Development Plan for 1979-1982, that the only way to increase production levels of basic grains and the incomes of the rural poor is through technological improvement. Policies must be directed to stimulate new technologies and their rate of adaptation without ignoring the adverse effects on employment that they may bring about.

CHAPTER III
THEORETICAL BACKGROUND

Mathematical Programming Models

Traditionally, mathematical programming models have been used in a normative sense, by maximizing a set of goals. Goods are assumed to face infinitely elastic demands, usually justified by the country's price-taker position in international trade. For a large number of products that do not enter international trade, price determination depends on domestic demand. Mathematical programming models can, of course, incorporate product demand functions which yield endogenous prices, thus providing a large degree of generality to the system. As such, these models are used in a descriptive sense to simulate the behavior of a competitive or monopolistic market.

Several authors have tried to provide solutions to Samuelson's (1952) competitive equilibrium formulation. He pointed out that maximization of the net social payoff function (the sum of the consumers' and producers' surplus) led to a competitive equilibrium solution. He used this function to try to solve Enke's (1951) problem of interspatial markets by relating it to the Koopmans-Hitchcock minimum transport cost. He used this artificial magnitude to cast the problem mathematically into a maximizing problem. His suggestions on solutions were, however, iterative procedures.

Fox (1953) proposed an iterative solution for the case of a multi-regional feed grain economy, given estimated parameters of the regional demand functions. Tramel and Seale's (1959) reactive programming and Judge and Wallace's (1958) methods are iterative heuristic methods that solve the product shipments problem with given demands and supplies in each region. Their methods do not formulate the problem as a mathematical programming one with an objective function. Schrader and King (1962) were the first to introduce price responsive demand functions into LP models. Their method maximized producers' revenue and obtained a market clearing solution with iterations.

Takayama and Judge (1946a, b) introduced quadratic programming to solve the regional flows problem under independent linear demand functions. The objective function was specified as the sum of consumers' and producers' surplus and was given a welfare connotation. Iterative solution procedures for the competitive and monopolistic cases are based on Wolf's modified simplex algorithm. Yaron et al. (1965) treated three cases (a) independent demands, (b), interdependent demands with fulfillment of the integrability conditions, and (c) interdependent demands without fulfillment of the integrability conditions. For case (a) they used step-wise approximated demand functions using linear programming. For case (b) they used quadratic programming. For case (c) they used a primal-dual formulation and concluded that the welfare interpretation of the objective function no longer holds, which lends force to satisfying the integrability conditions. They did not, however, present any computations.

Martin (1972) proposed a noniterative equilibrium solution with independent demands. He used a piece-wise linear specification of product demand and factor supply functions. At the same time, similar procedures were being used to build the French national model (Fahri and Varcueil, 1969) and a regional model for the Soviet Union (Mash and Kiselev, 1971). Neither of these, however, considered interdependence in demand.

Interdependence in demand and the specification of a variable that would measure producers' income at endogenous prices were first explored by Duloy and Norton (1973, 1975) when they formulated the programming model for the Mexican economy, CHAC.[1] One advantage of their specification is their use of Miller's (1963) separable programming to approximate nonlinear functions without significantly increasing the number of rows. With this improvement nonlinearities in both the objective function and constraint set could be easily handled.

Incorporating demand functions into planning models, rather than assuming exogenous product prices, allows the model to correspond to a market equilibrium. It also permits an appraisal of the benefits accruing to producers and consumers, and it gives the model greater flexibility in that changes in the input side can take place not only directly through changes in the technology set but also through changes in demand due to relative price changes of given input intensive commodities.

The methodology followed in the present study is that developed by Duloy and Norton. The basic optimizing market equilibrium formulation assumes that producers are profit maximizers and that consumers'

[1]A name which means "Rain God of the Mayas."

behavior is adequately described by a set of demand functions in the space of prices and quantities.

In Duloy and Norton's (1975, pp. 593-594) general model, the demand function was specified as

(1) $$p = f(q, Y),$$

where p is an n x 1 vector of prices, q is an n x 1 vector of quantities, and Y is lagged permanent income. In the unconstrained case, the objective function for the competitive market situation may be written

(2) $$\max_{q} Z = \int_{0}^{q} f(q, Y)\, dq - c(q)$$

where c(q) is an n x 1 vector of total cost functions. Setting the first derivation of Equation (2) with respect to q equal to zero yields the equilibrium conditions of marginal revenue equals marginal cost.

(3) $$p = c'(q)$$

In the constrained resource case the model would include the condition $Aq \leq b$, where A is an m x n matrix of resource coefficients, and b an m x 1 vector of resource availabilities. The Kuhn-Tucker necessary conditions are

(4a) $$\frac{\partial Z^o}{\partial q} = f' - c'(q) - \mu' A \leq 0$$

(4b) $$q^{o\prime} \frac{\partial Z^o}{\partial q} = 0$$

(4c) $$\frac{\partial Z^o}{\partial \mu} = Aq - b \leq 0$$

(4d) $$\mu^{o\prime} \frac{\partial Z^o}{\partial \mu} = 0,$$

where μ is the dual variable vector and the ^{o} superscript means that derivatives and vectors are evaluated at the point of the optimum. Equation (4a) means that marginal profits must be zero or negative. Marginal profits are equal to price minus marginal costs, where the latter have two components; the explicit market costs of inputs, $c'(q)$, and the economic rents which accrue to fixed factors, $\mu'A$. Equation (4b) is the complementary slackness condition, which together with Equation (4a) means that if profits are nonzero the activity is zero, and if the activity level is positive marginal profits are zero. Equation (4c) is the complementary slackness condition for the dual, which with Equation (4d) means that if a resource's shadow price is nonzero its slack is zero and vice versa.

The linear programming formulation for the model described assumes a linear demand function, although this need not be the case, as long as the matrix of demand coefficients is negative semi-definite to insure convexity. Equation (1) may be rewritten as

(5) $$p = a + Bq$$

where a is an n x 1 vector of constants and B is an n x n negative semi-definite matrix of demand coefficients. Y has been dropped since this is a static formulation. Equation (2), the objective function, then becomes in the competitive case[2]

(6) $$\max_q Z = q'(a + .5Bq) - c(q)$$

and the equilibrium conditions

(7) $$p = a + Bq = c'(q).$$

Equation (6) corresponds to Samuelson's net-social-payoff function except for transportation costs which are not included.

Equation (6) can be decomposed into producers' and consumers' surplus[3] (Duloy and Norton, 1975, p. 593)

(8) $$\underline{CS} = .5q'(a - p) = -.5q'Bq$$

(9) $$\underline{PS} = q'p - c(q) = q'(a + Bq) - c(q)$$

Finally, the area under the demand function and the revenue function are respectively, Equations (10) and (11). Both are sketched in Figure 2.

(10) $$W = q'(a + .5Bq)$$

(11) $$R = q'(a + Bq)$$

---

[2] In the monopolistic case, Equation (6) becomes

(6') $$Z^* = q'(a + Bq) - c(q)$$

which yields equilibrium conditions identical to (4a) to (4d), except that the vector p is replaced by the term a + 2 Bq, the vector of marginal revenues

(7') $$a + 2Bq = c'(q),$$

or marginal revenue equals marginal cost.

[3] There has been a long debate over the use of Marshallian surpluses as welfare measures (Mishan, 1960, 1968; Winch, 1965; Burns, 1973), but in the context of sector models the interest is primarily in their use to simulate a market equilibrium and not in their welfare interpretation.

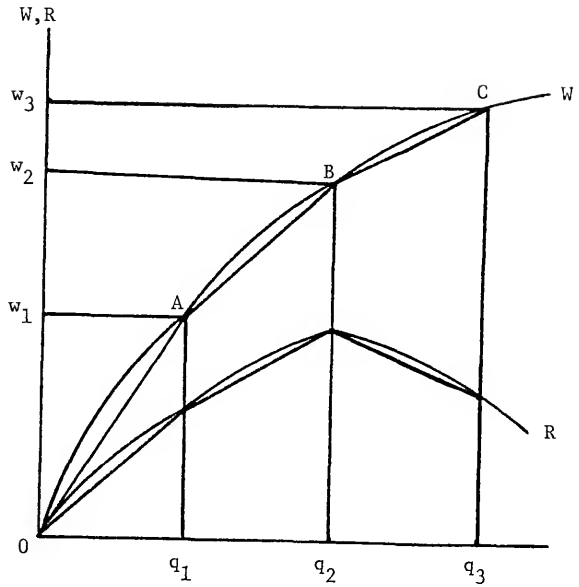

Figure 2. Area under the Demand Equation (W) and Total Revenue Function (R)

The maximum for both the competitive and monopolistic cases involves a quadratic term in q. Two linear approximations have been developed by Duloy and Norton; one based on previous knowledge of B (interdependence in demand) and the other where B is diagonal (separability assumed). In this research only the latter case will be considered.

Let W_j denote the area under the demand curve for product j, then

(12) $$q'(a - .5Bq) = \sum_j W_j . \qquad j = 1, \ldots, n$$

W_j is a quadratic, concave function when plotted against q_j, and since the programming model is a maximization problem, W_j can be approximated by a series of linear steps and conventional LP computer codes can be used to obtain an approximation to the maximum. Duloy and Norton (1973) introduce additional variables, W_{kj}, where k = 1, ..., s, for each W_j; assign upper bounds w_{kj} on q_j over which interval W_{kj} applies; and assign a single value for W_j, say d_{kj}, which approximates W_j over the interval $q_j \leq w_{kj}$. Define q = xy, where x is a vector of aggregate production areas and y is a diagonal matrix of yields. They then suggest that the quadratic term q'(a - .5Bq) be replaced in the maximization problem as follows for the case of product j produced under h (h = 1, ..., t) technologies:

(13) $$\text{Max } -\sum_h c_{hj}\, x_{hj} + \sum_k d_{kj}\, W_{kj}$$

such that

(14) $$-\sum_h c_{hj}\, x_{hj} + \sum_k r_{kj}\, W_{kj} \geq Z$$

(15) $\sum_h y_{hj} x_{hj} - \sum_k w_{kj} W_{kj} \geq 0$

(16) $\sum_k W_{jk} \leq 1.$ $\qquad k = 1, \ldots, s$
$\qquad h = 1, \ldots, t$

This method adds two rows for each product, but permits inclusion of as many W_{kj} activities as desired to increase the accuracy of the approximation. The segmented approximation of W and R for a single product is shown in Table 2.

Because of the concavity of W, no more than two of the W_{kj} selling activities will appear in the solution. It is clear that the approach can be readily extended to the multi-product case. International trade can also be incorporated through well behaved nonlinear import demands and export supplies.

This specification of demand functions is convenient in the analysis of comparative statics solutions from demand rotation. Demand functions can be rotated simply by varying the value of the convexity restriction. The matrices W and R are invariant under this class of transformations. The upward rotation of the demand function is expressed as a proportional lengthening of the segments with prices constant. In Figure 3, D_1D_1 represents the function $p = f(q)$ and D_1D_2 represents $p = f(\lambda q)$, and the slopes of the linearized function W_1 and W_2 are equal for corresponding segments. A similar condition holds for the linearized R function. Thus, the coefficients of the W and R matrices can be expressed as simple multiples of the corresponding quantities. The selling activities of the transformed tableau would be similar to those of Table 2 where all rows except the convexity restriction are multiplied by λ. By dividing

Table 2. LP Tableau for a Single Product

Rows \ Columns	Production Activities	Selling Activities	RHS
	x_{1j} x_{2j} .... x_{tj}	w_{1j} w_{2j} .... w_{sj}	
Objective function	$-c_{1j}$ $-c_{2j}$ .... $-c_{tj}$	d_{1j} d_{2j} .... d_{sj}	max
Income definition	$-c_{1j}$ $-c_{2j}$ .... $-c_{tj}$	r_{1j} r_{2j} .... r_{sj}	$\geq$ Z
Commodity balance	y_{1j} y_{2j} .... y_{tj}	$-w_{1j}$ $-w_{2j}$ .... $-w_{sj}$	$\geq$ 0
Convex combination constraint		1 1 1	$\leq$ 0

where

c_{hj} are the unit costs associated with producing the j^{th} product with the h^{th} technology,

y_{hj} are outputs per unit of the j^{th} production activities using the h^{th} technology,

d_{kj}, r_{kj} are values of w_j and r_j, respectively, corresponding to the associated quantity of the product at the end of the k^{th} interval, and

Z is the producer's net income to factors held fixed in the production process.

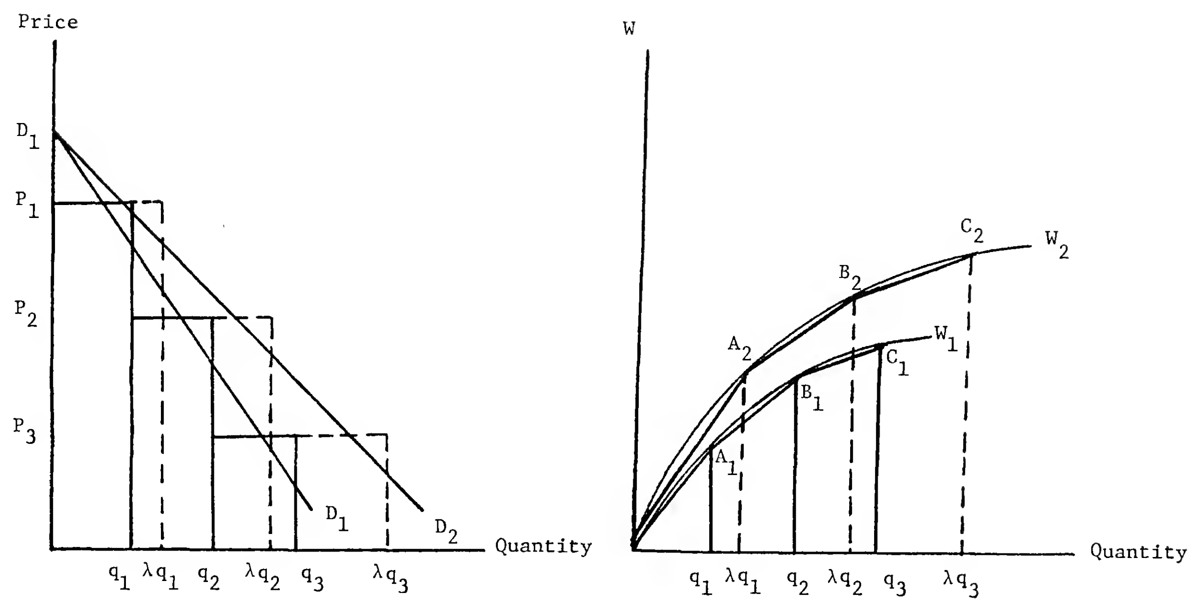

Figure 3. Rotation of the Demand Function and Its Effect on the W Function

all the elements of each activity by λ, the problem with the transformed demand function is reduced to a problem with coefficients in the constraint matrix identical to those before the demand transformation, but with λ replacing unity in the right-hand side of the convex combination constraint.

The underlying assumptions of the aggregate LP model are (a) integrability of product demand and factor supply functions, and (b) a partial equilibrium setting.[4] Integrability refers to conditions in which the matrices of first derivatives of the factor supply and product demand functions must be symmetric. This implies that the cross price effects are equal over all commodity pairs, and also that the effect of income on consumption is identical across all commodities of interest or zero. How restrictive this symmetry condition is depends on whether one is dealing with supply or demand. For the supply functions, the classical assumptions of the theory of production yield this condition. Zusman (1969) notes that, in empirical studies where the supply functions are derived from observed behavior, the symmetry condition is still highly restrictive. In the case of the demand functions, the situation is different; aggregate demand functions satisfy the symmetry condition only if the individual demand functions do. The price derivative of individual demand functions (under constant money income) consists of a symmetric substitution term and an income effect term. For the latter term to also be symmetric it would be necessary that the income elasticity of demand of all commodities be zero. This condition would be only approximately satisfied if the income effect is

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[4]See also McCarl and Spreen (1980).

small relative to the substitution term. This would happen if the goods are closely related in demand, have low income elasticity, and constitute a minor share of the consumer's expenditures. In all other cases the symmetry requirement is not even approximately met. Models that do not require the integrability assumption have, however, been formulated by incorporating price and quantity variables into the primal formulation. The objective function no longer represents the sum of producers' plus consumers' surplus, but rather the excess of consumer expenditure over the sum of factor incomes plus outlays on purchased inputs. The objective function includes a quadratic term, but since it is not derived from an integration process, the symmetry assumption (integrability requirement) may be dropped. The disadvantage of this approach is that it requires a much larger constraint set.

The second assumption of a partial equilibrium setting refers to the fact that the model does not take into account the effect of income generated by the system on the demand function. If the sector modeled is small enough relative to the entire economy, this shortcoming would be unimportant. If, however, the sector considered is large relative to the entire economy, the income it generates would be expected to have a major impact on consumer demand.

Risk Considerations

It has been established that, in general, agriculture is a risky process, especially in LDCs. Several studies[5] support the hypothesis

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[5]See, for example, Behrman (1968), Dillon and Anderson (1971), Francisco and Anderson (1972), Linn et al. (1974), Pomareda and Simmons (1977).

that farmers do behave in risk averse ways. Neglect of risk averse behavior in agricultural planning models had led to overstatements of the output level (usually overspecialized cropping patterns) of risky activities and to overestimates of the value of basic resources.

In modern decision theory, uncertainty is a state of mind in which the individual perceives alternative outcomes to a particular action. Risk, on the other hand, has to do with the degree of uncertainty in a given situation. Some define risk as a measurable probability, for example, as variance. Others define it as the probability that returns will not fall below a given "safe" level. Others, such as John Dillon (in Boussard, 1979) state that one should avoid using the word risk as if it were a definite measure of anything. He feels, though, that one should speak of "risk aversion" without causing confusion.

Two basic traditional approaches for incorporating risk into agricultural programming models have been used: (a) the "theory of games" approach, where the decision maker is supposed to play a game against an unknown opponent called "nature," and (b) the "portfolio selection" approach where risk is taken into account through the objective function. Only the latter approach and its alternative simplified Minimum of Total Absolute Deviations (MOTAD) model will be discussed because of their use in this research.[6]

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[6]Alternative (E - V) models have also been developed, e.g., the "safety first" model proposed by Roy (1952). Its optimizing criterion is

$$\text{Min } P \{ e \leq e_o \},$$

where P represents probability and e_o is a specified level of disaster (risk level). If the distribution of E is fully described by e and σ_e^2, then this criterion is equivalent to

$$\text{Max } \frac{\bar{e} - e_o}{\sigma_e}.$$

The portfolio selection or expected income-associated income variance (E-V) approach, which leads to a quadratic programming formulation, is attributed to Markowitz (1952). His problem was to select an optimal portfolio of stocks solely on an (E-V) criterion such that V is minimum for an associated E under a budget constraint. It is also assumed that the farmer is a risk averter, i.e., faces quadratic iso-utility functions which are convex from above, and the conditions $\frac{\partial E}{\partial V} > 0$, and $\frac{\partial F^2}{\partial V^2} > 0$ hold. Since short-run planning models assume constant overhead costs, the income distribution of a farm plan is totally specified by the total gross margin distribution. For n activities and m resource constraints, the Markowitz's quadratic programming model minimizes expected variance V, subject to expected income and resource availability constraints

(1) Minimize $V = \sum_j \sum_k x_j \, x_k \, \sigma_{jk}$

Baumol (1963), without rejecting Markowitz' approach, used an $(E\text{-}\phi\sigma)$ formulation. The decision maker is assumed to subjectively establish a confidence limit and a floor on expected returns to which the limit is applied. Other approaches which depart from the (E-V) approach, but whose practical usefulness is not questionable are (a) the flexibility constraints approach (Day, 1979), and (b) the focus loss constrained program (FLCP). The first one imposes special constraints to the LP problem. These constraints reflect all the unknown constraints not explicitly taken into account in the analysis but which prevent farmers from changing their year to year plans quickly. The shortcoming of this model is that it does not give very much information on how to choose the level of the bounding constraints. The second approach was developed by Boussard and Petit (1967). The basic assumption is that the expectations of farmers are described by two concepts, (a) the focus of gains (expected gains), and (b) the focus of losses (the most unfavorable outcome). The average gains are maximized subject to the usual constraints of the model and a special focus-loss constraint. The advantage of this model is its ability to be implemented in an ordinary LP framework, whereas its main criticism is its lack of theoretical foundation (Boussard, 1979).

such that

(2) $\quad \sum_j \bar{e}_j x_j \geq E$

(3) $\quad \sum_j a_{ij} x_j \leq b_j \qquad i = 1, \ldots, m \quad j, k = 1, \ldots, n$

(4) $\quad x_j \geq 0,$

where

x_j is the level of the j^{th} activity,

σ_{jk} is the variance of the j^{th} activity when $j = k$, and the covariance of activities j and k when $j \neq k$,

$\bar{e}_j$ is the expected gross margin of the j^{th} activity,

a_{ij} is the amount of the i^{th} resources per unit of the j^{th} activity,

b_i is the i^{th} resource constraint level, and

E is a positive scalar of total expected gross income.

By parameterizing E from zero upward a sequence of solutions is obtained of increasing total gross margins and variance until the highest possible total gross margin is attained. Solutions are obtained for critical changes in the basis such that for the current total margin E, the variance is minimum. These solutions define the efficient (E-V) boundary. The acceptability of any one particular plan on this boundary depends on the farmer's preference determined by his (E-V) utility function. When this function can be measured, a unique farm plan can be rigorously identified which offers the farmer highest utility.

This model has several shortcomings at different theoretical levels. Some ammendments have been proposed in order to improve its significance and its feasibility. From a practical point of view, the necessity of a quadratic programming routine has been cited as a problem, even though several codes have been developed by RAND corporation, IBM, and others. For that reason, a number of approximations of quadratic functions have been proposed. The most general case is the separable programming approach[7] which approximates nonlinear functions in the model at the expense of an enlargement of the initial matrix. The Duloy-Norton approach has many similar features to the separable programming approach. Another drawback of the model is that the variance symmetrically weighs positive and negative deviations from the mean. This would be true only in the exceptional case where the population total gross margin distributions are symmetric. Nevertheless, when income deviations are weighed on a quadratic basis it is not likely that any disutility will be attached to positive income deviations. Thus, using an (E-V) criterion may lead to conservative farm plans. Markowitz (1959) has suggested minimizing the negative semi-variance subject to constraints (2) through (4).

The estimation of the variance-covariance or semi-variance matrices presents some problems. The model requires a priori estimates of the mean gross margins for each activity and the corresponding variances and covariances.

In most cases, time series data are used to estimate variance-covariance matrices under the assumption that the dispersion of gains is independent of time. Few empirical studies seem to have been devoted to the verification of this assumption. Errors in estimating the variance-

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[7] See, for instance, Sharpe (1963, 1967) and Thomas et al. (1972).

covariance matrices do shape the final solution of the Markowitz problem. In Thomas et al. (1972) an attempt was made to drop statistically insignificant covariance terms. A number of these were found to be relatively high, and differences between the "significant covariance model" and the "all covariances model" did not exceed 3 to 5% of the optimal activity levels. The significant covariance model yielded lower expected incomes for each permitted level of income variance.

Hazell (1971) suggested the "minimum of total absolute deviations" approach (MOTAD) as an alternative to the (E-V) formulation. This criterion retains most of the desired properties of the latter and is easier to handle computationally. Let c_{hj} ($h = 1, \ldots, s$; $j = 1, \ldots, n$) be the h^{th} observation in a random sample of gross margins of activity j. The sample mean is $g_j = \frac{1}{s} \sum_h c_{hj}$. An unbiased estimator of the population mean absolute income deviation is

$$A = \frac{1}{s} \sum_h \left| \sum_j (c_{hj} - g_j)\, x_j \right| .$$

Using A as a measure of uncertainty, Hazell considers E and A as the crucial parameters in the selection of a farm plan. Efficient (E-A) farm plans are those having minimum mean absolute income deviation for given expected income level E. The (E-A) criterion has an important advantage over the (E-V) criterion in that it leads to a linear programming formulation.

Hazell's model is as follows:

$$\text{Minimize } As = \sum_h y_h$$

such that

$$\sum_j (c_{hj} - g_j)\, x_j + \bar{y}_h \geq 0 \qquad h = 1, \ldots, s$$

$$\sum_j \bar{e}_j\, x_j = E \qquad E \geq 0$$

$$\sum_j a_{ij}\, x_j \leq b_i \qquad i = 1, \ldots, m$$

$$x_j,\ \bar{y}_h \geq 0 \qquad \text{all } h \text{ and } j$$

where $\sum_h y_h$ is the sum of the absolute values of the negative total gross margin deviations around the expected returns based on sample mean gross margins. The efficiency locus is obviously different from the (E-V) locus, but according to Thomson and Hazell (1972), the differences are small enough so as to definitely accept the MOTAD formulation as a reasonable approximation of the (E-V) formulation. They found that for large sample sizes the relative asymptotic efficiency of the estimated mean absolute deviation is 88%. That is, it is 88% as efficient as the estimated standard deviation in estimating the population standard deviation.

Risk can be incorporated into an LP model by simply subtracting the risk term in the objective function and introducing appropriate changes in the constraint set. The general case of the Markowitz criterion will be treated before discussing the MOTAD risk model.

Assuming that farmers behave in a risk-averse way, according to the Markowitz (E-V) criterion, the endogenous price programming formulation can be modified into a risk formulation. The objective function of such a model is

(1) $$\text{Maximize } U = X'Y(A - .5BYX) - C'X - \phi\,(X'\Omega X)$$

where

X is an n x 1 vector of crop area,

Y is an n x n diagonal matrix of average yields,

C is an n x 1 vector of cost coefficients per unit of crop area,

A, B are coefficient matrices of the linear demand structure $P = A - BYX$, where P is expected price and B is assumed to be diagonal with nonnegative elements,

ϕ is an aggregate risk parameter of farmers, and

Ω is an n x n covariance matrix of activity revenues of farmers.

This new objective function is the same as that of the Duloy and Norton model except for the addition of the risk term. The rationale for this function is found in Hazell and Scandizzo (1974). When the risk factor ϕ is set equal to zero, we have the familiar profit maximizing objective function. The effect of ignoring risk-averse behavior depends on the properties of the term $(X'\Omega X)$.

Letting the linear programming constraints be denoted by $DX \leq b$, where D is an m x n matrix of resource requirements and b is an m x 1 vector of resource supplies, the Lagrangian of (1) is then

$$(2) \qquad L = X'Y(A - .5BYX) - C'X - \phi(X'\Omega X) - v'(DX - b),$$

where

v is an m x 1 vector of dual variables.

The solution to this problem is a saddle point, which satisfies the Kuhn-Tucker conditions. The necessary conditions are

(3) $$\frac{\partial L}{\partial x_j} = y_j (a_j - b_j y_j x_j) - c_j - 2\phi \sum_i w_{ij} x_i - \sum_k v_k d_{kj} \leq 0 ,$$

$$i, j = 1, \ldots, n$$
$$k = 1, \ldots, m$$

where the lower case letters denote the elements of the corresponding matrices. Complementary slackness conditions require that (3) holds as an equality for every nonzero x_j in the solution. Thus, from (3) and using the fact that B, the matrix of slopes, is diagonal, we can solve for expected prices, p:

(4) $$p = \frac{1}{y_j} [c_j + \sum_k v_k d_{kj} + 2\phi \sum_i w_{ij} x_i] ,$$

since

$$P_j = a_j - b_j y_j x_j$$

This equation states that for each nonzero activity the expected marginal cost per unit of output must equal expected price. The expected marginal cost is the sum of the expected own marginal cost, $\frac{c_j}{y_j}$, plus expected opportunity costs $\frac{1}{y_j} \sum_k v_k d_{kj}$ for the resources used in activity j, plus a marginal risk factor $\frac{1}{y_j} 2\phi \sum_i w_{ij} x_i$. When risk neutrality is assumed, i.e., $\phi = 0$, as in the deterministic model, this latter term would disappear. The appearance of the risk factor as a marginal cost provides the rationale for the expectation that deterministic models tend to overestimate the supply response of high-risk crops. This is because $\phi \sum_i w_{ij} x_i$ is positive and the marginal cost curve must lie above the marginal cost curve of a risk neutral deterministic model. Crops with large revenue variances and/or whose revenues are positively correlated with those of other crops will have a positive marginal risk term. The converse holds for the case of those crops with small variances, and/or whose revenues are negatively correlated with those of other crops. This will result, under risk behavior, in smaller outputs in the first case and larger ones in the latter (Hazell et al., 1978).

To analyze the effect of risk behavior in the valuation of scarce resources it is helpful to see that since $(X'\Omega X) \geq 0$ in the model objective function, the value of the objective function is smaller than under risk neutrality. The total valuation of resources thus must also be smaller. While it is still possible that some resources increase in value, others must decline by sufficiently large amounts so that, as a whole, farmers would be willing to pay less for their production inputs.

The aggregate risk model as specified in (1) is a quadratic programming problem. Duloy and Norton have shown that the quadratic term $X'Y(A - .5BYX)$ can be linearized (pp. 22-25). Following their methodology, Hazell and Scandizzo (1974) linearized the second term $(X'\Omega X)$ of the risk objective function. They do not, however, linearize the classical variance estimator

$$\text{(1)} \qquad \text{est } (X'\Omega X) = \sum_i \sum_j x_i x_j \left[\frac{1}{T-1} \sum_t (r_{jt} - \bar{r}_j)(r_{it} - \bar{r}_i) \right],$$

but the less efficient variance estimator

$$\text{(2)} \qquad \text{est } (X'\Omega X) = \Delta \left[\frac{1}{T} \sum_t \left| \sum_j (r_{jt} - \bar{r}_j) x_j \right| \right]^2,$$

as suggested by Hazell, where r_{jt} is the t^{th} observation of the revenue of the j^{th} activity x_j, $\bar{r}_j$ is the sample mean revenue for r_j over T years, and $\Delta = \frac{\pi T}{2(T - 1)}$, where π is a constant.

Following Hazell and Scandizzo's methodology, Hazell's MOTAD formulation can be approximated by defining new variables $z_t \geq 0$, for all t, which represent negative deviations in total revenue for all activities so that

$$(3) \qquad 2 \sum_t z_t = \sum_t \left| \sum_j (r_{jt} - \bar{r}_t) x_j \right| .$$

From (2) an estimator, $\hat{s}$, of the population standard deviation can be obtained

$$(4) \qquad \hat{s} = \Delta^{\frac{1}{2}} \frac{2}{T} \sum_t z_t$$

$$= \Delta^{\frac{1}{2}} A .$$

The problem of minimizing $(X'\Omega X)^{\frac{1}{2}}$ is then approximated by

$$\text{Minimize } \phi \hat{s}$$

such that

$$\sum_j (r_{jt} - \bar{r}_j) x_j + z_t \geq 0 \qquad t = 1, \ldots, T$$

$$2 \sum_t z_t - \frac{T}{\Delta^{\frac{1}{2}}} \hat{s} = 0$$

$$x_j, z_t \geq 0 .$$

Figure 4 shows a complete LP tableau which approximates the quadratic programming problem which incorporates this development on risk. In the model ϕ is a coefficient to be parametrically programmed.

Areas for Further Improvement

Mathematical programming models could be improved if they were considered in the context of multi-level programming and if income were explicitly incorporated.

Multi-level Programming

In a market economy most economic policy problems can be decomposed into two related subproblems, (a) the behavioral problem of forecasting (describing) the economy's (or sector's) response to policy changes, and (b) the policy (normative) problem of choosing among possible alternatives. Mathematical programming deals only with the maximization of the behavioral objective function.

Higher level decision makers usually manipulate policy variables (e.g., tax rates, the size of the budget deficit) in order to influence a set of impact variables (e.g., employment level, rate of inflation), and decentralized decision makers control behavioral variables (e.g., private investment) in the light of the levels of the policy variables. Candler and Norton (1977) formally define this area of investigation as "multi-level programming." Candler and Townsley (1979) attempted to develop algorithms for the multi-level problem solution.

Multi-level programming assumes that the product possibilities open to decentralized decision makers and the rules governing their choice of variables under their control are known, and that the policy makers

	CONSTRAINT	Production Activities x_1 x_2 .... x_n	Activities to Linearize Area under Demand Functions w_{11} ... w_{s1} w_{12} ... w_{s2} .... w_{1n} ... w_{sn}	Negative Deviation Activities z_1 z_2 ... z_T	Population Income Deviation Estimator $\hat{\sigma}$	RHS
1	Objective Function	$-c_1$ $-c_2$ .... $-c_n$	d_{11} ... d_{s1} d_{12} ... d_{s2} .... d_{1n} ... d_{sn}		$-\phi$	Max.
18	Commodity Balance Rows	y_1 y_2 .... y_n	$-w_{11}$ ... $-w_{s1}$ $-w_{12}$ ... $-w_{s2}$ .... $-w_{1n}$ ... $-w_{sn}$			≥ 0
12	Convex Combination Constraints		1 ... 1 1 ... 1 .... 1 ... 1			≤ 1
174	Resource Constraints	A Matrix				$\leq b$
30	Revenue Constraint	$r_{11} - \bar{r}_1$ $r_{21} - \bar{r}_2$ .... $r_{n1} - \bar{r}_n$ ⋮ ⋮ ⋮ $r_{1T} - \bar{r}_1$ $r_{2T} - \bar{r}_2$ .... $r_{nT} - \bar{r}_n$		1 1 1		≥ 0
3	Z Identity			2 2 ... 2	-1000 [illegible]	= 0
	No. Columns	52	185	30	3	

Figure 4. Linearized Programming Problem with Risk

objectives are also known. Little attention has, however, been given to the definition of policy objectives, partly due to the fact that investigators have limited themselves to presenting policy makers a set of alternatives (e.g., different product prices or investment levels) based on their models and partly because of the difficulty of defining these objectives.

In the two-level case, Candler and Norton state the multi-level problem as follows: find vector $x = x_0, x_1, x_2)$ such that

(1) $$f_2 = \max_{x_2} (c_2' x_2)$$

such that

(2) $$f_1 = \max_{x_1 | x_2} (c_1' x_1)$$

(3) $$A_{11} x_1 + A_{12} x_2 \leq b$$

(4) $$-I x_0 + A_{21} x_1 + A_{22} x_2 = 0$$

(5) $$x \geq 0$$

where

x_0, x_1, x_2	are vectors of impact, behavioral, and policy variables, respectively,
f_2	is the policy makers' objective function,
f_1	is the behavioral objective function,
A_{11}	is the matrix of resource requirements,
A_{12}	expresses the effect of the policy variables on resource availability,
b	is the level of available resources prior to policy intervention,

A_{21} is a matrix of the effects of the behavioral variables x_1 on the impact variables, and

A_{22} expresses the direct effects of the policy variables x_2 on the impact variables x_0 (often this matrix is zero and policies would have to achieve their impacts directly).

For a given level of x_2, (2) to (5) define an LP problem. However, (1) to (5) is a multi-level problem. Because it implies multiple levels of optimization, multi-level programming is a generalization of mathematical programming. Since (1) through (5) is a two-level example, there are two objective functions, (a) a "policy objective function" which defines preferences at the aggregate level, and (b) a "behavioral objective function" which drives the normative model to yield the kind of market equilibrium that is felt to be most realistic. There are also three feasible sets corresponding to each type of variable: (a) the policy instrument set, (b) the feasible behavioral set which, for any given set of policy instrument values, constrains the values to be taken by the behavioral variables, and (c) the feasible policy set which is an implicit feasible set for the impact variables--for example, given the possible subsidy rates, the feasible policy range states the boundaries for possible values of impact variables such as employment and output growth. The frontier of the feasible policy set is the policy behavioral frontier. The size of the feasible policy set depends on the size of the policy instrument and behavioral sets, and on the nature of the behavioral objective function.

Candler and Norton maintain that the frontier of the feasible policy set normally lies very much interior to the corresponding technological (production possibilities) frontier, even in the absence of market distortions. Parameterization of the policy objective function, without recognition of a behavioral function will trace out points on the technological frontier, but this solution is not of interest to policy makers. The authors illustrate the use of multi-level programming for the case of the Northwest Mexican agriculture and show that, for a given set of policies, the policy behavioral frontier lies much interior to the production possibilities frontier, and the behavioral optimum, undisturbed by policy actions, lies interior to the policy behavioral frontier. Consequently, gains in the impact variables could be achieved with an appropriate policy mix. And, solving only a behavioral programming model without concern for a wide range of policy choices may not be very realistic.

Incorporating Income

A second area where mathematical programming models could be improved is the incorporation of income effects in their formulation. An increase in yields, for example, may have important shift effects on food demand, with farm family food demands increasing as their incomes rise, and nonfarm family demands increasing, partly in response to lower prices (a movement down the demand function), but also in response to income increases arising from the multiplier effects of increased incomes (a rightward shift of demand).

A proper treatment of these income effects in agricultural models has not yet been developed. In 1967 Yaron developed a programming model into which the demand functions for the final outputs and the income generated by the system are endogenously incorporated. He established a lagged relationship between demand and income and set up a two-period version of the model to show that the competitive equilibrium interpretation still holds. However, he made initial income exogenous, thus leaving out any effects on income of variations in the endogenous prices and quantities of the model. Thus, as he pointed out, the approach is limited to cases where the portion of the economy represented by the model is small. Regarding LP solutions he used iterative procedures. Norton and Scandizzo (1977) developed a procedure for obtaining general equilibrium solutions for economy-wide models in the LP format so that the computational power of the simplex solution algorithm could be exploited. The LP framework can be adapted to the nongeneral equilibrium cases.[8] Their static general equilibrium model assumes that there exists a maximization problem whose solution is a general equilibrium solution in prices, quantities, and incomes; demand is now a function of prices and incomes. The quadratic programming formulation exploits the Cournot and Engel aggregation conditions to make endogenous the process of income formation in the computation of competitive equilibrium. The assumption underlying the formulation is that consumers behave according to an aggregate inverse demand function of the type

$$(1) \qquad \underset{n,1}{P} = \underset{n,1}{A} - \underset{n,n}{B}\,\underset{n,1}{X} + \underset{n,1}{\phi}\,\underset{1,1}{y}$$

$$(2) \qquad y \geq P'X,$$

where P is a price vector, A > 0, B is a nonsingular symmetric matrix of demand coefficients, X is quantities demanded, and y is income. Their model is as follows:

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[8] Some work in this direction is being undertaken by the World Bank.

(3) $\max_{X,Q} \; X'(A - .5BX) - C'Q$

such that

(4) $X'\phi \leq 1$

(5) $DQ - b \leq 0$

(6) $X - Z \leq 0$

(7) $X,Q \geq 0$

where C' are the costs of all primary factors which are available in infinitely elastic supply, Q is quantity supplied, and function (3) is the sum of consumers' and producers' surplus over all product markets. Inequality (4) is the Engle aggregation obtained by differentiating (2) with respect to income and assuming that consumers are on their budget lines; (5) are aggregate resource constraints; and (6) expresses the requirement that quantities demanded cannot exceed quantities produced. The motivation behind the introduction of (4) is not the assumption of utility maximization by individual consumers, but rather the requirement that the Engel aggregation must hold in the aggregate for the equilibrium solution. Norton and Scandizzo (1977) show that a model specified in this way yields the static market equilibrium conditions and can be linearized with some transformations using log-derivative variables. An added advantage of their formulation is that the Engel aggregation conditions, (4), imply compensated quantity changes. This condition then guarantees that utility is held constant by an appropriate change in prices. Their model, then, maximizes the sum of the areas under the compensated demand functions, overcoming the limitations of consumer surplus analysis and its dependence on the assumption of constant marginal utility of income. It also overcomes the problem of integrability, which requires that the matrix of first derivatives in the demand function, B, be quasi-negative definite, and also symmetric, and the cross price effects of the demand functions do not need to be symmetric.

Empirical Applications: Supply Response

Several approaches have been used to estimate supply response in agriculture. The most common are the linear programming and econometric approaches. Linear programming is appealing because it permits consideration of several products and inputs in the decision-making process. Linear programming also has an advantage in less developed countries where time-series data are unavailable but cross-sectional data may be obtained. A brief discussion of the literature on supply response is presented in this section, and an analysis of the supply response estimation with MAYA is presented in Chapter V.

Estimating the supply responsiveness of agricultural commodities is both difficult and important. Supply elasticities are useful in showing how producers are likely to react to higher output and input prices, and can give planners a basis for setting output prices to meet production targets. In general, the extent of responsiveness measures the ability of producers to adjust production to changing economic conditions confronting them in a dynamic economy.

Most of the research on supply analysis has concentrated on the development of a one-commodity supply function with little regard to the influence of other commodity prices. According to Shumway and Chang (1977) conceptual and empirical problems remain in understanding own-price effects as well as cross-price effects; moreover, the number of both econometric and LP studies is limited. Perhaps the most important econometric study where direct and cross-price supply relations were estimated is that of Gruen et al. (1968). In that study the elasticities for six commodities were reported. Perhaps the most important LP study on supply response is the Southern Farm Management Research Committee's (1966) study of cotton supply in 17 regions in the U.S. It estimates the impact of price changes of cotton on its own supply and on the supply of substitute crops, tobacco, peanuts, and rice.

Nerlove and Bachman (1960) outlined the setting of supply analysis and summarized models which derive optimum supply from production functions and from linear programming. They found that linear programming was seemingly a sound analytical approach for comprehensive estimation of direct and cross-price effects. Interaction between alternative production activities is captured in the analysis. The authors criticized the time-series approach in that it takes only a few variables into account, and substitutability and complementarity among products and inputs could not be adequately measured. Furthermore, historic data do not always give good inferences for the future. Looking to the future, the authors mention serious gaps in the theory of aggregation and adjustment.

Other studies show that the LP estimates are unreliable. Wipf and Bawden (1969) evaluated the descriptive and predictive reliability of production function estimates. They derived firm-level supply functions from production functions for a variety of agricultural products and farm types. Supply elasticities and profit maximizing outputs were computed from these, and comparisons were made with actual output and with elasticities estimated from regression results of alternatively specified forms of production functions. They wanted to see if realistic supply functions could be derived from statistically fitted production functions according to the notion that a firm's supply curve is that portion of marginal cost above average cost. They found that these empirical estimates were not reliable. Their output prediction did not exhibit a consistent magnitude or direction of bias but ranged from slight underestimates to extreme overestimates--the latter being most frequent.

Quance and Tweeten (1971) compared the results of positivistic (time series) studies with those of conditionally normative studies[9] for cotton, wheat, feed grain, and livestock. They found that LP models provide somewhat realistic long-term elasticity estimates for commodities characterized by well defined resource constraints. They believed that their predictions were good for wheat, average for cotton, and poor for livestock. The LP results showed more realistic regional shares of production (based on comparative advantage), but not so realistic absolute levels of these shares or of supply elasticities. The LP supply functions exhibited an "inverted lazy-S" shape, rising steeply at very low prices where the commodity is not profitable, becoming more elastic at higher prices as commodities become competitive, and finally, becoming steeply sloped when resources become constraining and diminishing returns is experienced. Their results showed that supply

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[9]In the sense that linear programming estimation is based on the norm "what would be" if producers followed the profit norm.

elasticities are not at all constant, and supply functions are not straight lines as assumed by regression analysis. The authors cautioned against constant slope regression estimates, especially when examining policy impacts that fall outside the range of experience reflected in past data.

From Wipf and Bawden's and Quance and Tweeten's findings it is apparent that both regression and LP estimates differ. It is not apparent which one is more reliable. Shumway and Chang (1977) estimated direct supply elasticities for 15 vegetable and field crops in California using regression analysis, and both direct and cross-price elasticities with LP analysis. They compared the reliability of both methods according to three criteria. First, they compared long-run LP direct supply elasticities for each commodity (group) at the average 1961-1965 output levels and lagged representative crop prices for 1960-1964 with regression elasticities for the same period computed by imposing certain efficiency conditions for acceptability. The authors found a high degree of comparability for individual crops. Secondly, they used the LP derived parameters as prior information in time-series regressions to predict 1974 and 1975 supply levels and found that this procedure did not significantly reduce the accuracy of those equations. Finally, they used LP estimated cross-price parameters in time-series regressions. This procedure neither improved nor worsened the regression estimates. Their findings do provide direct contrast to previous studies. The authors suggested that LP estimates could be substantially improved if the model specification better reflected the real world behavior of producers. These estimates could be used to improve econometric models where the latter are also appropriate.[10] The introduction of endogenous prices and of risk into linear programming models should add to the realism of supply estimates.

Positive estimates have certain advantages. Where available and where the structure of the economy has not markedly changed, these estimates would give accurate predictions. Problems can arise, however, if one or more of the statistical assumptions are violated, e.g., high correlations among independent variables, aggregation errors, measurement errors, omission of variables, or incorrect specification of the relationship.

Errors can also arise when estimating LP supply functions. Stoval (1966) considers three sources of error, (a) the specification error (errors in technical coefficients, resource restrictions, or in product and input prices), (b) the sampling error (when the distribution of the model's parameters over all firms is unknown but estimated by sampling techniques), and (c) the aggregation error (in finding the representative farm). Programming estimates are also limited in that they are based on the profit maximizing goal and pure competition assumptions. Profit maximization may not be the only goal of producers. Risk considerations are also important in their decision making process. Thus, the closer these assumptions reflect the decision environment of producers, the more accurate one would expect the estimates to be. Linear programming models permit simulation of the effects of exogenous policies not experienced in the past--hence, not available from

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[10] Sharpless (1969) also emphasizes the importance of combining linear programming with time-series studies of the rate at which farmers adjust under given circumstances.

positivistic models. Furthermore, as stated earlier, they permit the analysis of supply response to LDCs, where time-series data are often of poor quality or nonexistent.

The theory of supply response based on the linear programming assumptions is well known. Most of the research on supply response at the firm level or at the industry level has been based on the fixed-price assumption of classical linear programming. On the aggregate level, this assumption does not hold. When production is large, prices are the result of the interaction of supply and demand. Hence, even if the individual producer is a price taker, on the aggregate, product prices cannot be given ex-ante. Aggregating firm supply functions has been the usual approach to arrive at sector-wide or industry supply functions.[11]

The first econometric studies to consider supply and demand simultaneously were those by Powel and Gruen (1968) and by Gruen et al. (1968), where direct and cross-price elasticities were calculated.

Interaction of supply and demand was considered by Hall et al. (1968) to simulate competitive equilibrium for six products in 144 producing regions and nine consuming regions in the United States using quadratic programming. At the time of their writing they did not report results on the estimation of supply functions. Several studies of supply response at the sector level have used LP models with endogenous prices--the Duloy and Norton approach. Using the agricultural model CHAC, Bassoco and Norton (1975) analyzed the aggregate response of the

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[11]The limitations of this approach are discussed in Nerlove and Bachman (1960), Sharpless (1969), and Egbert and Kim (1975).

Mexican agricultural sector from 1968-1976. Short-run and long-run elasticities were estimated from supply functions derived by shifting the demand function. The extent of the shift in demand was based on certain assumptions regarding annual GNP growth, the rate of increase of factor endowments, the rate of technological growth (rate of change in yields per hectare), and the rate of change in export bounds. Condos et al. (1974) developed a four region agricultural model of Tunisia which has been used to analyze the implications of achieving a self-sufficiency objective. Pomareda and Simmons (1977) analyzed the competitive position of northwest Mexico, Guatemala, and Florida in the U.S. winter market for fresh vegetables. The model included annual crops and vegetables in three regions in Mexico and two regions in Guatemala. The authors included four types of labor, various planting dates, monthly yields and use of land and irrigation water, and monthly demands in the U.S. and Mexico. Risk was introduced by means of absolute deviations matrices and a risk aversion parameter. This model has been used to analyze the supply response of alternative policies such as changes in the U.S. demand, changes in the tariff structure, adoption of new technologies in Guatemala, and increasing wages in Mexico. Cappi et al. (1978) used the MOCA model for Central America[12] to estimate direct and cross-price elasticities for four grains.

The Aggregative Programming Model of Australian Agriculture (Monypenny, 1975) was developed as a vehicle for obtaining guidelines to the micro and macro implications of changes in policy instruments. This model incorporates risk and considers nonirrigated short-cycle crops,

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[12]This experiment was done only with the Costa Rican model.

pasture, and livestock activities. This model includes special activities to account for yearly cash-flows, maximum borrowing constraints, and allocations of cash for taxes and family consumption.

The research done on the reliability of supply response estimates in agriculture does not reveal that the LP approach is less reliable than the econometric approach. Previous tests on this reliability used fixed-prices for products and did not include risk. Inclusion of demand functions and risk should improve the estimates. Even though both approaches present difficulties due to their assumptions, mathematical programming models which include risk offer a potential tool for improving the supply estimates. The most important strength of the LP approach is that it can simulate the effects of exogenous forces and policies for which historical observations are not available.

CHAPTER IV
THE LP MODEL OF GUATEMALA

The Guatemala LP model MAYA is structured like the CHAC-type models. In MAYA the agricultural sector is disaggregated into three subsectors according to farm size and technology. Group 1 includes subsistence farms primarily in the Guatemalan Highland, Group 2 farms are engaged in small-scale marketing primarily in the eastern half of the country, and Group 3 farms are engaged in commercial agriculture and are located in the South Pacific region. These subsectors are linked by the objective function and by intersectoral transfers of products and inputs.

MAYA was adapted from previous partial models of Guatemala's agricultural sector and contains data for 1976-1977. Input-output coefficients for Group 1 were obtained partly from raw data from a farm-level survey of Guatemala (AID, 1975) which includes only basic grains, and partly from tabulated data of an LP model for the Highlands (see ECID/SIECA, 1980), the data of which are also based on the survey. Although the data from the survey is for 1973, a comparison with data from ICTA surveys revealed that, in most cases, it was still valid for 1976-1977. Input-output coefficients for Groups 2 and 3 were adapted from (a) a fixed-demand, risk LP model for the South Pacific region (see Pomareda and Samayoa, 1978), which includes mostly export crops, some grains, and the livestock sector; (b) a country model of Guatemala which is part of a simplified, no-risk, CHAC-family model (MOCA) for Central American agriculture that links five country models through international trade activities (see Cappi et al., 1978); and (c) farm budgets kept on a daily basis by the Institute of Science and Agricultural Technology at several experimental areas scattered throughout the country, and which concentrate mainly on basic grains and other staples (ICTA, 1976, 1977, 1978, 1979).

Although MAYA is more inclusive than the models mentioned, it is still not a complete model of the agricultural sector. It includes only the 13 most important annual crops and excludes the livestock sector. Approximately 90% of the value of total agricultural production is accounted for in the model. Figure 5 gives an overview of MAYA and Appendix A, Table VI a complete listing of the variables included. Activities (columns) are classified into five major groups--production and transformation activities, input supply, product demand, foreign trade, and national accounts. The signs of the coefficients are indicated. The matrix shows that basic inputs enter into the production process as governed by the input balance rows and the resource availability restrictions. Crops are either sold directly or transformed. Both are sold to the domestic market or exported. Imports are included to complete the demand and supply process.

Specification of the Production and Transformation Block

Production Groups

Group 1 producers are subsistence farmers with landholdings of less than 10 hectares and a low level of technology who produce mainly staple crops. Yields are low and labor is supplied by family members. Some surplus produce is sold during market days or along the road. This type

	ROWS \ COLUMNS		Production and Transformation						Input Purchases												
			Group 1		Group 2		Group 3		Inputs Group 1				Inputs Groups 2 & 3				Credit		Mules		
			Prof.	Transf.	Prod.	Transf.	Prod.	Transf.	Fert's.	Chem's.	Seeds	Mach.	Fert's.	Chem's.	Seeds	Mach.	G2 & G3	G1	G1	G2	G3
1	Objective Function								-c1 ... -ci	-1 ... -1	-r1 ... -r1	-m1	-c1 ... -c4	-1 ... -1	-r1 ... -r4	-m2	-c, -c, -c	-c1	-a1	-a2	-a3
1	Revenue																				
3	National Accounts																				
13	National Product Balances			- -		- -		- -													
12	Convexity Restrictions																				
72	National Labor Constraints																				
6	Labor Income																				
9	Input Balances Group 1	Fertilizers	+ +						F_1												
		Chemicals	+ +							-1000 ... -1000											
		Seeds	+ +								-1000 ... -1000										
		Credit							+ ... +	+ ... +	+ ... +	+						-1			
53	Group 1 Farms	Income		+ +																	
		Product Balances	- -	1000 ... -1000																	
		Labor	+ +																		
		Machinery	+ +									-1									
		Land	+ +																		
		Draft Animals	+ +																		
27	Input Balances Groups 2 & 3	Fertilizers			+ +		+ +						F_2						-1		
		Chemicals			+ +		+ +							-1000 ... -1000							
		Seeds			+ +		+ +								-1000 ... -1000						
		Machinery			+ +		+ +									-1	-1-1-1				
		Credit											+ ... +	+ ... +	+ ... +	+					
46	Group 2 Farms	Income				+ +															
		Product Balances			- -	1000 ... -1000															
		Labor			+ +																
		Land			+ +																
		Draft Animals			+ +															-1	
42	Group 3 Farms	Income						+ +													
		Product Balances					- -	1000 ... -1000													
		Labor					+ +														
		Land					+ +														
		Draft Animals					+ +														-1
292	Bounds																				

75 39

Figure 5. Overview of the MAYA Model[a]

[a]Does not include risk (see Figure 4).

[b]A detailed labor matrix is shown in Figure 6.

Labor[b]											Demand		International Trade			National Accounts								
Group 1		Group 2		Group 3				Total								Income								
Fam	Hired	Fam	Hired	Reg.	[illegible]	[illegible]	[illegible]	G1	G2	G3	Estimated Demands	Fixed	Imps. R.O.W	Exps.	Imps. C.A.	G1	G2	G3	Labor	Fx. Exch.	Trans.	Tar.	Total Income	RHS
$-w_1$	$-w_2$	$-w_3$	$-w_4$	$-w_4$	$-w_5$	$-w_6$	$-w_7$				++..........++	+ ... +	- ... -	+ ... +	- ... -						-1	-1		MAX
											++..........++	+ ... +	- ... -	+ ... +	- ... -								-1	≥ 0
													M_1	X	M_2	1	1	1	1 ... 1	-1	-1	-1		≤ 0
											1 ... 1 ... 1	1 ... 1	-I	I	-I									≤ 0
											1 ... 1 ... 1													≤ 1
I	I	I	I	I	I	I	I																	$\leq \bar{L}$
. .		. .	. .	. ...	. ...	. ...	. ...												-I					≤ 0
																								≤ 0
																								≤ 0
																								≤ 0
																								≤ 0
																-1								≤ 0
																								≤ 0
-I	-I							-1																≤ 0
																								$\leq MA_1$
																								$\leq \ell_1$
																								$\leq a_1$
																								≤ 0
																								≤ 0
																								≤ 0
																								$\leq MA_2$
																								≤ 0
																	-1							≤ 0
																								≤ 0
		-I	-I						-1															≤ 0
																								$\leq \ell_2$
																								$\leq a_2$
																		-1						≤ 0
																								≤ 0
				-I	-I	-I	-I			-1														≤ 0
																								$\leq \ell_3$
																								$\leq a_3$
							b_2						m_1	x	m_2									

99 190 13 14 310

EXPLANATION OF SYMBOLS

F_1, F_2	fertilizer matrices	R.O.W.	rest of the world	C.A.	Central America	Tar.	total tariffs
f, s, m, c, e	cost coefficients of fertilizers, seeds, machinery, credit, and draft animals, respectively	Imps.	Imports	Fx. Exch.	foreign exchange	w	vectors of wage coefficients
		Exps.	Exports	Trans.	total transformation differentials	M, X	import and export matrices

Figure 5. Extended

of farm is found in the Guatemalan Highland. One important feature of the producers in this group is that they migrate to the coastal area during the harvest season, and thus becomes part of the labor force of Group 3. Income generated through migration is an important component of the total income of this group.

Group 2 producers are small-scale farmers with landholdings of between 10 and 60 hectares who are increasingly adopting modern technologies. They typically hold part of the production for their own consumption and for animal feed and market the remainder. The labor force is made up of family members although some outside labor may be hired. This type of farm is characteristic of the eastern half of the country where 90% of the sesame, 50% of the beans and maize, 70% of the rice, 30% of the coffee, and 40% of the domestically consumed bananas are produced.

Group 3 producers are engaged in commercial agriculture in landholdings greater than 60 hectares and with relatively advanced technology. They produce export crops, viz., cotton, sugarcane, coffee, and bananas, and most of the grain marketed in the capital. These farms are found only in the South Pacific region and produce 95% of the sugarcane, 60% of the coffee, 34% of the rice, 25% of the maize, and all of the cotton produced in Guatemala. From the point of view of agricultural production and employment, this region is the most important of the country.

Groups 1, 2, and 3 account, respectively, for roughly 10%, 30%, and 60% of the total value of agricultural production.

Production Technologies

Sixteen technologies have been specified according to whether labor is used alone, combined with draft animals and/or machinery and according to the proportion of total variable costs that make up intermediate inputs, viz., fertilizers, chemicals, and improved seeds.[1] In Table 3 four basic ways of combining labor, machinery, and draft animals are shown. Each of these can be associated with a given level of intermediate input use. Codes used appear in parentheses.

This classification is somewhat arbitrary and does not necessarily represent the usual practices of farmers because changes in prices of products and inputs influence farmers' decisions on the combination of inputs to use from one crop cycle to the other. Production of a given crop in each of the three groups of farmers may take place under any of these possibilities. For example, rice is produced in Group 3 with technologies D1 and D2 with yields of 2275 and 2800 kilograms per hectare, respectively, whereas in Group 2 it is produced with technology C1 with a yield of 2242 kilograms per hectare.

Transformation Activities

The model includes transformation activities in order to make it more complete. Transformation coefficients take into account the extraction rates of raw products into final products and waste in marketing the crop. For example, in the case of rice, farm yield is specified for paddy, while demand is specified for polished rice. The extraction rate

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[1] A similar specification was used in Pomareda and Samayoa (1978).

Table 3. Capitalize: Intermediate Inputs as Percent of Variable Costs, Technological Possibilities in MAYA

Basic Technology	Intermediate Inputs as Percent of Variable Costs	Technological Possibilities
(A) labor	(1) 0 - 24	(A1), (A2), (A3), (A4)
(B) labor and draft animals	(2) 25 - 49	(B1), (B2), (B3), (B4)
(C) labor, draft animals and machinery	(3) 50 - 74	(C1), (C2), (C3), (C4)
(D) labor and machinery	(4) 75 - 100	(D1), (D2), (D3), (D4)

of rice is 65%, for bran, 8%, and waste is 4% (SIECA/FAO, 1974). Therefore, from every ton of paddy produced, 64.3% polished rice and 7.6% bran are obtained. For some crops such as beans and maize, which are consumed without transformation, only the waste coefficient applies. Account has also been taken of a "transformation differential" which is the price of the final product multiplied by the transformation coefficient less the producer price of the raw product. For example, in the case of rice the transformation differential is Q.087/kg = .96 [(.67 x .463) + (.08 x .079)] - .217, where .96 is 1 less the waste rate, .463 is the price per kilogram of polished rice, .079 is the price per kilogram of bran, and .217 is the farm-gate price of paddy. The transformation coefficients and differentials as used in MAYA for the three groups are shown in Appendix A, Table VII. Differences in the figures for the same product between groups are due to different producer prices.

Specification of Inputs

Two types of inputs are used in MAYA, (a) inputs supplied at the regional level (viz., land, labor, machinery, and draft animals), which are assumed to be perfectly inelastic and are specified on a monthly basis; and (b) inputs supplied at the national level (viz., fertilizers, chemicals, seeds, and credit), which are assumed to be perfectly elastic. Farmers from Group 1 receive special treatment by the government in the form of subsidized credit and easier access to seeds and fertilizer. Farmers in Groups 2 and 3 are assumed to compete for inputs primarily because of lack of disaggregated data.

Labor

The treatment of the labor market in the LP model is a difficult task. In a country where dualism in agriculture exists, with family labor making up a large proportion of the labor force and where migrations occur during certain months of the year, two problems arise: (a) how to value family labor (treated under input prices), and (b) how to define the limits of the supply of labor. Figure 6 shows a structure of the labor market and brings out the hiring patterns of the three groups. The labor force of Groups 1 and 2 is made up mainly of family labor and, to a lesser extent, of hired labor from adjacent rural and urban areas. On commercial farms four kinds of field labor are used, (a) resident laborers who are given housing, (b) wage laborers from the area, (c) migrant workers from the Highland (who contribute up to 60% of the total labor force during harvest time), and (d) migrant workers from Group 2. An upper bound was set on the supply of migrants from Group 2 equal to 10% of the labor force in Group 3 in order to allow the model to hire migrants from the Highland at a higher cost, which is the case during harvest time.

The data on labor used in MAYA are projected figures based on the 1973 Population Census. The economically active population in 1976 by departments was 1,911,313. Table 4 shows the distribution by group.

Labor constraints have been estimated subject to several considerations such as the contribution of family labor and the availability of urban labor for agriculture. Total labor force was thus adjusted to exclude labor employed in livestock and in other crops not considered in

		Production in Group 1	Production in Group 2	Production in Group 3	Group 1 Family	Group 1 Hired	Group 2 Family	Group 2 Hired	Group 3 Resident	Group 3 Regional	Group 3 Migrant G1	Group 3 Migrant G2	Total Group 1	Total Group 2	Total Group 3	RHS
Objective function					$-.3c_1 \cdots -.3c_1$	$-c_1 \cdots\cdots -c_1$	$-.3c_2 \cdots -.3c_2$	$-c_2 \cdots\cdots -c_2$	$-c_3 \cdots\cdots -c_3$	$-c_4 \cdots\cdots -c_4$	$-c_5 \cdots\cdots -c_5$	$-c_6 \cdots\cdots -c_6$				
Labor Income						$w_1 \cdots\cdots w_1$		$w_2 \cdots\cdots w_2$	$w_3 \cdots\cdots w_3$	$w_4 \cdots\cdots w_4$	$w_3 \cdots\cdots w_3$	$w_4 \cdots\cdots w_4$				≥ 0
Labor Supply Group 1	Family				1 1 ... 1						1 1 ... 1					$\leq F_1$
	Hired					1 1 ... 1										$\leq H_1$
Labor Supply Group 2	Family						1 1 ... 1					1 1 ... 1				$\leq F_2$
	Hired							1 1 ... 1								$\leq H_2$
Labor Supply Group 3	Resident								1 1 ... 1							$\leq R_{13}$
	Regional									1 1 ... 1						$\leq R_{23}$
Requirements Group 1		+ +			-1 -1 ... -1	-1 -1 ... -1										≤ 0
	Total	+ +											-1			
Requirements Group 2			+ +				-1 -1 ... -1	-1 -1 ... -1								≤ 0
	Total		+ +											-1		
Requirements Group 3				+ +					-1 -1 ... -1	-1 -1 ... -1	-1 -1 ... -1	-1 -1 ... -1				≤ 0
	Total			+ +											-1	
Bounds												$k_1 \cdots k_{12}$				

Figure 6. Labor Market in MAYA

Table 4. Economically Active Population in Guatemala by Category and in Agriculture, by Group, 1976[a]

Group and Labor Type	Category			Total	Percent in Agriculture	Total in Agriculture
	Contracted	Self-Employed	Non-wage Family Workers			
Group 1						
rural	100,043	189,080	75,057	364,180	80	291,344
urban	46,972	44,717	9,742	101,431	30	30,429
Group 2						
rural	206,756	268,119	88,175	563,050	82	461,701
urban	361,412	139,705	16,810	517,927	20	103,585
Group 3						
rural	143,391	74,955	23,365	241,711	85	205,454
urban	63,655	31,138	3,449	98,242	28	27,508
TOTAL				1,886,541		1,120,021

[a]Employers are excluded since this study is interested in hired and family labor only.

SOURCE: SGCNEE (1978a).

the model[2] as well as to account for absenteeism and idleness. In MAYA self-employed workers (family heads and adults) are assumed to provide 100% of their time, whereas nonwage family members are assumed to contribute only 60% of adult-equivalent work. Hired labor in Groups 1 and 2 is assumed to be made up of rural and urban contracted labor in each group. Resident labor in large farms is assumed to be made up of 70% of the family labor force of Group 3. Temporal labor is provided by wage laborers (both rural and urban) from the region. It was assumed that only males migrate for temporal work in agriculture. Labor restrictions expressed in full-time adult equivalent workers are shown in Table 5 and in thousands of work-days per month in Appendix A, Table VIII.

Other Inputs

The land input coefficient was one, implying the use of an entire hectare. An exception is made at the beginning of the cropping cycle when preparation of the land would not tie it up for a full month. Preparation of the land with draft animals may require a full month, whereas preparation with machinery may require less than a month. This time savings is important when double cropping is feasible. The restrictions on land were set equal to the area planted with the crops considered in each group. The alternative of using the total land area owned by each group of producers would have understated the restrictions when two crops are grown per year. Ideally, idle land with a potential

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[2]Labor employed in livestock activities accounts for 15, 25, and 20% of the agricultural labor force in Groups 1, 2, and 3, respectively. A further reduction of 10% was made to account for employment in crops not included in the model.

Table 5. Labor Restrictions in MAYA

Labor Category	Group 1	Group 2	Group 3
	(Adult-equivalent workers)		
Residents			32,604
Temporal			
Family labor	120,100	203,100	
Hired labor	66,400	185,800	
TOTAL	186,500	388,900	92,404

for growing annual crops should be included; however, due to lack of data this could not be done.

Machinery requirements were standardized for a tractor of 60 HP and were expressed in hours of tractor use. The total number of tractors available in 1976 was calculated from the total imports since 1967. During this period 8,847 were imported, 5% of which were assumed to be available to producers in Group 1.[3] A maximum of 180 hours of use per month per tractor was assumed.

The technical coefficients for fertilizer in Group 1 were expressed in terms of kilograms of urea and kilograms of "other fertilizers." In Groups 2 and 3 the technical coefficients express nutrient requirements in terms of kilograms of nitrogen, phosphorus, and potassium (N, P, K). Nutrient supplies, however, were expressed in kilograms of fertilizer, i.e., simple and complex formulas with the model selecting the best combination.

Four types of chemicals were specified (viz., soil insecticides, foliage, insecticides, herbicides, and fungicides), and their coefficients were expressed in quetzales per hectare. Coefficients for local and/or improved seeds were expressed in kilograms per hectare. Farmers were assumed to use available credit to purchase seeds, fertilizers, and chemicals.

Input Prices

Input prices used in the model are reported in Table 6. Input prices in MAYA are market prices and include wages which vary over

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[3]The Agricultural Census of 1964 reports this figure and it is taken to be still valid.

Table 6. MAYA Input Prices

Input	Unit	Group 1	Group 2	Group 3
			(Quetzales per unit)	
Labor[a]	day	0.40	2.20	2.20
Machinery	hour	5.00[b]	2.29	2.29
Draft animals	day	1.54	1.20	1.20
Fertilizers				
ammonium nitrate	ton		154.00	154.00
ammonium sulphate	ton		120.00	120.00
urea	ton	153.00	173.00	173.00
diammonium phosphate	ton		236.00	236.00
(20-20-0)	ton		180.00	180.00
(12-24-12)	ton		188.00	188.00
(15-15-15)	ton		181.00	181.00
(16-20-0)	ton		168.00	168.00
other fertilizers	ton	168.00		
soil insecticides	Q	1.00	1.00	1.00
foliage insecticides	Q		1.00	1.00
herbicides	Q		1.00	1.00
fungicides	Q		1.00	1.00
other chemicals	Q	1.00		
Improved seeds				
maize	ton	510.00	840.00	840.00
rice	ton		600.00	600.00
sorghum[c]	ton		350.00	350.00
wheat	ton	380.00	380.00	
potatoes	ton	330.00		
sugarcane	ton			30.00
coffee	ton		4,500.00	4,500.00
cotton[c]	ton			550.00
lemon grass tea[c]	ton			6.00
Credit	Q	.05	.08 - .12	.08 - .12

[a]The wage for Group 1 is the reservation wage. The market wage is Q 1.40. Wages for Groups 2 and 3 are market wages.

[b]Price of rented machinery.

[c]Only the 1973 prices of seeds for sorghum, cotton, and lemon grass tea were available.

SOURCES: BANDESA, FERTICA, DIGESA, and Banco de Guatemala.

farm groups. Prices for land were endogenously determined. The problem of how to account for family labor in the objective function depends on its opportunity cost. If one assumes that labor could be employed elsewhere, its price in the objective function would be the wage received. This potential wage, called the reservation wage, is lower than the market wage because labor would then be abundant and jobs still scarce resulting in a fall of the current market wage.[4] This reservation wage was set at 30% of the market wage in the model.

Prices for other inputs in Groups 2 and 3 were as follows: (a) fertilizer prices were expressed in thousand quetzales per ton of a given formula, (b) chemicals were expressed in quetzales and their prices in the objective function were unity, (c) coefficients for machinery were total costs per hour of operating and maintaining a tractor of 60 HP assuming a useful life of 10,000 hours over a period of 10 years,[5] and (d) credit was available to farmers in Groups 2 and 3 at interest rates of 12, 10, and 8% for short, medium, and long term credit, respectively. Credit to Group 1 farmers was assumed to be subsidized by BANDESA at a fixed rate of 5%.

The Specification of Demand and Product Prices

Demands are specified at the national level for 18 final products. Demand functions for 12 of these products were estimated. The remaining six products (including export bananas which are only sold abroad) were

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[4]See, for example, Bassoco and Norton (1975) and Candler and Pamareda (1977).

[5]Machinery in Group 1 is assumed to be rented.

assumed to sell at fixed prices. At present, no comprehensive study is available from which one could derive demand functions. To estimate the demand functions the procedure used for the Central American model (MOCA) was followed. Price elasticities were derived from expenditure elasticities previously estimated.[6]

The method used to estimate price elasticities is the one suggested by Frisch (1959) according to which price elasticities can be estimated once income elasticities, expenditure weights, and the value of the money flexibility coefficient--the elasticity of the marginal utility of income with respect total income--are known. The basic assumption behind Frisch's approach is that there is "want independence" (i.e., the marginal utility of good i depends only on its own quantity) among groups of commodities.[7] Estimation of the Frisch coefficient for Guatemala is based on the findings of De Janvry et al. (1972) and of Lluch and Williams (1977) on the relationship of the value of the Frisch coefficient and per capita income. De Janvry et al. estimated values of $\tilde{w}$ from income and price elasticities of demand for food in various countries of various income levels; regressed these values on real per capita income; and obtained the following relation:

$$(1) \qquad \log_e(-\tilde{w}) = 1.591 - .5205 \log_e y/p,$$

where $\tilde{w}$ is the money flexibility coefficient, y is per capita income, and p is the price level. This equation was found to be statistically significant and consistent with Frisch's conjecture that $\tilde{w}$ increases as

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[6] See SIECA/FAO (1974, Volume II).

[7] This assumption may not be realistic for very disaggregated commodity groups. See also footnote 9.

the level of income decreases. The same authors obtained $\tilde{w}$ from the estimation of the parameters of cardinal utility functions and from systems of demand equations where the assumption of additivity was made. They surveyed the literature of values of $\tilde{w}$ estimated using this approach and calculated the following regression equation:

$$(2) \qquad \log_e (-\tilde{w}) = 1.7595 - .5127 \log_e y/p.$$

Lluch and Williams used time-series data on income and expenditures for 14 countries with a broad range of incomes and four levels of commodity aggregation, and obtained the following regression equation:

$$(3) \qquad \log_{10} (-\tilde{w}) = 1.434 - .331 \log_{10} Y,$$

where Y is per capita GNP in 1969 dollars.

These three equations were applied to Guatemalan income data. Values for $\tilde{w}$ were obtained for four income strata, corresponding to 50, 30, 15, and 5% of the population, and for the average income level. The results obtained were consistent with the theory and do not differ notably between equations. Therefore, the average of all three values of $\tilde{w}$ obtained for the average income level (-2.0) was used in the calculation of price elasticities.[8]

Frisch's equation for estimating the price elasticity of commodity i is

$$(4) \qquad \eta_i = -E_i \left(a_i - \frac{1 - a_i E_i}{\tilde{w}}\right),$$

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[8]More traditional farmers have larger values of $\tilde{w}$ because of their lower incomes; consequently, their direct price elasticities would be smaller, which reflects fewer alternative crops and technologies than larger farmers.

where η_i is the price elasticity, E_i is the income elasticity, and a_i is the expenditure weight of commodity i. Since previous estimates of the E_is were available, and $\tilde{w}$ and the a_is could be estimated, this equation was used to calculate direct price elasticities.[9] Given income elasticities and the consequent estimated direct price elasticities are reported in Table 7.

The approach used to estimate demand functions is crude but has been used for lack of better information. The analysis assumes a linear

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[9]When the "want-independence" assumption is dropped, it can be shown that the direct-price elasticities estimated by Equation (4) would be biased. Frisch's equation for estimating cross-price elasticities is

$$(1) \qquad \eta_{ik} = -E_i \, a_k \left(1 - \frac{E_k}{\tilde{w}}\right). \qquad \begin{array}{l} i = 1, \ldots, n \\ k = 1, \ldots, n \\ i \neq k \end{array}$$

From Cournot's aggregation it follows that direct elasticities can be calculated by (2)

$$(2) \qquad \eta_{kk} = \left[\sum_i a_i \, \eta_{ik} - \sum_{i \neq k} a_i \, \eta_{ik}\right] / \, a_k \, .$$

By (1) we can write η_{kk} as

$$(3) \qquad \eta_{kk} = \left\{ - \sum_i a_i \left[E_i \, a_k \left(1 - \frac{E_k}{\tilde{w}}\right)\right] - \sum_{i \neq k} a_i \, \eta_{ik} \right\} / \, a_k$$

$$= - \left(1 - \frac{E_k}{\tilde{w}}\right) - \sum_{i \neq k} a_i \, \eta_{ik} / \, a_k \, ,$$

by virtue of Engel's aggregation.

Equation (4) can also be written as

$$\eta_i = -E_i \, a_i \left(1 + \frac{E_i}{\tilde{w}}\right) + \frac{E_i}{\tilde{w}} \, .$$

The first term is clearly smaller than in (3). The second term is negative (since $\tilde{w}$ is negative), whereas that of (3) can take either sign. The bias of (4) thus cannot be known a priori.

Calculation of direct elasticities according to (3) does require, however, previous knowledge of cross elasticities which are, usually, not available in developing countries.

Table 7. Given Income Elasticities and Calculated Price Elasticities Using Frisch's Method

Product	Given Income Elasticity, E_i	Direct Price Elasticity, η_i
Maize	0.4	-0.231
Rice	0.6	-0.302
Sorghum	...	-0.300
Wheat flour	0.6	-0.312
Beans	0.4	-0.208
Potatoes	0.5	-0.252
Cassava	0.2	-0.100
Bananas	0.3	-0.155
Sugar	0.5	-0.260
Cotton fiber	...	-0.300
Coffee	0.5	-0.267
Vegetable oil	0.8	-0.408

SOURCE: Income elasticities are estimated for 1965 and taken from SIECA/FAO (1974, Vol. II).

demand function of the form

(5) $$Q = \alpha - \beta P.$$

The price elasticity of demand is

(6) $$\eta = \frac{P}{Q}\frac{dQ}{dP} = \beta\frac{P}{Q},$$

and the slope and intercept parameters are

(7) $$\beta = \eta\frac{Q}{P}$$

(8) $$\alpha = Q + \beta P,$$

where Q is the observed quantity consumed, by definition equal to per capita consumption times population, and P is the observed price. Appendix A, Table IX reports the demand equations as incorporated into MAYA.

Demand functions were then broken down into at least 12 segments. The extreme values correspond to the observed price ± 60 to 100%. The area under the demand curve and the revenue function were then calculated given the estimated parameters.

The incorporation of demand structures permits specification of competitive and monopolistic market forms. For simulation purposes with MAYA, the competitive market form was assumed since, with a few possible exceptions in the export crops, no producer can influence the market price through production decisions. The optimization feature of the model is not used in a normative sense, to maximize some goal set, but rather in a descriptive sense, to simulate the behavior of the competitive market. In the model the sum of the Marshallian surpluses for each product's market is maximized, except in the case of those products whose prices are assumed to be exogenous.

Since the observed data on prices and quantities refer only to market data, the Marshallian surpluses in MAYA pertain only to the marketed surpluses. In Guatemala not all the quantity of maize and beans consumed is bought in the market. Many producers satisfy their consumption needs first before selling the remainder. In MAYA this was represented by subtracting farm-family requirements of those two crops from total production to arrive at the marketed surplus. Data on home retentions are available by district. It was further assumed that if a farmer meets his consumption requirements through market purchase, he must pay an opportunity cost equal to the difference between the farm gate price and the market price.

In MAYA national demand curves pass through a point representing observed prices and quantities. Information on some product prices on a regional basis is available from the statistical office, but information on production on a regional basis is incomplete. Therefore, it was not possible to estimate a weighted average of consumer prices, and the prices used were simple averages. Export and import prices were exogenous to the model under the assumption that Guatemala is a price taker in international trade. Prices of exports were fob prices. Import prices were adjusted for transportation costs and were measured in Guatemala City. Domestic and international prices used in MAYA are shown in Table 8.

Table 8. Domestic, Import, and Export Prices in MAYA

Product	Consumer Price	Export Price	Import Prices	
			Third Countries	Central America
		(Quetzales per ton)		
Maize	168.0		158.0	157.0
Beans	476.0		566.0	460.0
Sorghum	145.0			145.0
Rice	463.0		384.0	427.0
Wheat flour	430.0		223.0[a]	
Potatoes	220.0	260.0		
Cassava	153.0			
Bran	79.0			
Sugar	242.0	340.0		
Molasses	90.0			
Lump Molasses	300.0			
Coffee (ground)	3060.0			
Coffee (beans)		2040.0		
Bananas (domestic consumption)	225.0			
Bananas (export)		151.0		
Cotton fiber	1140.0	1162.0		
Cottonseed cake	87.0			
Lemon grass tea	3370.0			
Vegetable oil	940.0			

[a]Price of wheat grain.

SOURCES: DGE (1978), CNA, and Banco de Guatemala.

The Risk Matrix

The risk matrix was built as shown in Figure 4 (p. 41), with the variant that it consists of three blocks; each corresponding to one group. The available data on revenue variations were 10-year time-series of prices for each of Guatemala's 22 departments, from which series on a par group basis were obtained (see Appendix A, Tablw X), and on yields at the national level (Appendix A, Table IV). To derive per hectare revenue series by technology per crop (single cropped or in association), yields for each technology were assumed to hold a constant relation to national yields, equal to the ratio between the technology yield and the average of national yields for 1975-1977. After detrending the revenue series by linear regressions the matrices of deviations were calculated for each group.

CHAPTER V
MODEL VALIDATION AND RESULTS

MAYA was designed to model actual 1976-1977 behavior of the Guatemalan agricultural sector. Before using it for policy analysis, its predicting ability was tested. There are no formal analytical tests for validating a large scale LP model. Validation or verification of LP models has been examined by several researchers. Nugent (1970) explored the feasibility of validation tests of programming models. In his work with a multi-sector, multi-time period model of the Greek economy, he gave three reasons why a model may not perfectly simulate the actual economy: (a) there may be errors of specification in the model's constraint set, (b) the underlying market structure may be incorrectly represented numerically in the model, and (c) a programming model optimizes a particular objective function, whereas the real world may optimize several "micro" objective functions. To test the first two distortions, Kutcher (1979) proposed two tests for the Pacifico model of the Mexican northwest--a capacity test which forced the model to produce at least the base period quantities and sell at base period prices, and a competitive market assumption test by further redefining the objective function to a cost minimization version and analyzing shadow prices of the minimum output constraints. On the demand side, Kutcher tested the model assuming perfectly elastic demand (price taker assumption), and then assuming downward sloping demands. An analysis of activity levels and shadow prices revealed that the latter version was perferred.

Rodriguez (1978) did similar validation tests with an agricultural model for the Philippines. The basic validation tests used in most planning models involve analyzing how well the model solution simulates the base period situation, (a) whether the model can produce the base period demand quantity, (b) how well the model replicates the base period quantity (whether price equals marginal cost), and (c) how well the model replicates base period quantities with prices fixed at base period values. The validation tests which have been used generally relate to aggregate results. This is most likely because results from an aggregate model generally do not compare well to disaggregate regional production patterns (McCarl and Spreen, 1980).

In validating MAYA the average absolute deviation criterion was used to check how closely the model predicts consumer prices, volume of production, and areas planted. The fact that MAYA does not reflect the actual levels of prices and quantities on a group basis, as closely as it does on the aggregate, does not discredit its usefulness in predicting the general behavior at the group level. Before showing the results, a number of validation issues need to be mentioned.

All of the parameters in MAYA were agronomic coefficients from published surveys, farm budgets kept on a daily basis, previous partial models, and government publications. The competitive market structure was used on the assumption that it accurately describes the behavior of Guatemalan farmers. Two modifications were, nevertheless, introduced to make the model more realistic. First, Groups 1 and 2 farmers were permitted to choose between keeping a minimum amount of maize and beans for family consumption at home at farm-gate prices or buying them at a higher price that takes into account an acceptable buying-selling margin.

This is equivalent to shifting the price axis to the right. The demand function for these two products, then, only reflects the demand for the marketed surplus by the nonfarm population. Second, risk was introduced to explain observed behavior more realistically.

An important question in validating the Guatemalan model was what to validate the base-period solution against. How confident can one be of the base-period data? With regards to product and area levels, large discrepancies were often encountered in published documents where the source of the data was the same. An effort was then made to use the data believed to be most reliable based on the opinion of experienced authorities.

To recapitulate, the basic conditions under which the model was solved for the base period were as follows:

(a) Each producer group had a limited amount of land equal to the average of the area planted during 1976 and 1977.

(b) Most crops were produced under different technologies.

(c) Labor-use constraints were specified monthly by group.

(d) The areas planted with coffee and export bananas were restricted.

(e) Inputs supplied at the regional level were fixed and those supplied at the national level were available in infinitely elastic supplies.

(f) Commodity demand functions were specified at the national level.

(g) Upper bounds were set on imports from and exports to the rest of the world (except on exports of cotton), as well as on imports from other Central American countries.

The model was solved under these conditions and its predictive ability was tested against actual base-period data. In the absence of any empirical data from which to estimate the risk parameters ϕ, the basic procedure followed was to search through post-optimality techniques the values of ϕ for each group which best described the base-period prices. Research done by Pomareda and Simmons (1975), Hazell and Scandizzo (1977), Dillon and Scandizzo (1979), and Pomareda and Samayoa (1978) indicate that values of between .5 and 2.0 best describe the level of risk aversion in Brazil, Central America, and Mexico. These studies also reveal that smaller, less sophisticated farmers are more risk averse. Based on these studies, the assumption was made that the value of the risk parameter ϕ differed by .75 between Groups 1 and 2, and by .5 between Groups 2 and 3. It was found that the set of ϕ values (2.0, 1.25, .75) for Groups 1, 2, and 3, respectively, performed best. These values represent risk aversion at the aggregate group level.

Solving the model for different sets of ϕ values provides direct information about the effects of different levels of risk aversion on equilibrium prices and quantities, for quantifying the actual values of ϕ. Table 9 reports the result of different sets of ϕ values on domestic equilibrium prices. The prices of maize, beans, sorghum, sugar, lump molasses, potatoes, and vegetable oils tended to rise with increases in ϕ, which indicates that there are corresponding reductions in the quantities produced for the domestic market. On the other hand, the prices of rice, wheat flour, cassava, and export bananas decreased as ϕ increased, indicating that production of these crops for the domestic market would increase as producers become more risk averse. The prices of cotton fiber, bananas for domestic consumption, and lemon grass tea

Table 9. Price Response to Different Values of ϕ

Product	Actual	Risk Levels[a]			
		0-0-0	1.5-.75-.25	2-1.25-.75	2.5-1.75-1.25
		(Quetzales per ton)			
Maize	168	143	157	159	159
Beans	476	357	445	498	558
Sorghum	145	108	128	144	159
Rice	463	412	403	385	363
Wheat flour	430	453	418	415	411
Potatoes	220	169	193	201	210
Cassava	153	117	116	114	112
Bran	79	79	79	79	79
Coffee	3060	2472	2474	2474	2474
Sugar	242	218	227	240	255
Molasses	90	90	90	90	90
Lump molasses	300	275	285	301	317
Cotton fiber	1140	1261	1261	1261	1261
Cottonseed cake	87	87	87	87	87
Bananas (export)	151	113	111	110	108
Bananas (domestic consumption)	225	234	237	235	233
Lemon grass tea	3370	3370	3370	3370	3370
Vegetable oil	940	813	831	842	850
m.a.d.[b]		70.7	60.7	57.8	64.1

[a]The first, second, and third values correspond, respectively, to groups of farmers G1, G2, and G3.

[b]m.a.d. is the mean absolute deviation of the solution value with respect to the actual value.

showed little or no response to risk. The results on quantities are shown in detail in Table 10.

The first columns of Tables 9 and 10 show the base-year values (1976-1977 averages) of prices and quantities. By comparing the model solution for different values of risk with the base-year values, we have a basis for selecting the best-fitting values of ϕ. Clearly, the solution corresponding to risk neutrality ($\phi = 0$) is unsatisfactory. There is a definite improvement in both prices and quantity fits as ϕ increases, but it deteriorates again as the values reach 2.5, 1.75, and 1.25. These results are better visualized at the group level in Appendix A, Tables XI and XII. In selecting the set of ϕ values it is more appropriate to concentrate on the commodity prices because the market structure of the model can only be expected to work best at the demand level. The last row of Table 9 reports the sample mean absolute deviation, m.a.d., of the price fits and demonstrates the superiority of the risk set (2.0, 1.25, .75). The results suggest a useful definition of riskiness in crop production which takes into account intercrop relationships. High (low) risk crops can be defined as those where production decreases (increases) as producers become more risk averse, whereas risk neutral crops are those whose production is unaffected by ϕ. Thus, it can be concluded that introduction of risk averse behavior in MAYA improves its predictive power compared to the more common assumption of risk neutrality.

The results of this section suggest that the model solution is improved with the incorporation of risk and that the risk set (2.0, 1.25, .75) most closely represents the real world situation. This risk set was selected as the basis for further policy simulations.

Table 10. Quantity Response to Different Values of ϕ

Product	Actual	Risk Levels[a]			
		0-0-0	1.5-.75-.25	2-1.25-.75	2.5-1.75-1.25
		(Quetzales per ton)			
Maize	850	905	896	851	852
Beans	97	103	100	92	89
Sorghum	51	59	55	54	47
Rice (paddy)	26	27	27	27	27
Wheat	57	55	57	57	57
Potatoes	63	66	65	65	64
Cassava	10	8	8	8	8
Bran	...	31	32	32	32
Coffee	469	431	431	431	431
Sugarcane	5705	6042	6042	5705	5651
Molasses	216	205	205	203	201
Lump molasses	...	21	21	---	---
Cotton (raw)	326	309	310	316	318
Cottonseed cake	...	79	79	80	81
Bananas (export)	336	348	348	348	348
Bananas (domestic consumption)	194	194	194	194	194
Lemon grass tea	4	---	---	---	---
Vegetable oil	27	28	28	28	28

[a]The first, second, and third values correspond, respectively, to groups G1, G2, and G3.

CHAPTER VI
EMPIRICAL TESTING

One of the important uses of LP models is to obtain insights into supply response, a fundamental question of production theory. MAYA was built using cross-section microeconomic data and behavioral assumptions which appropriately define the conditions for supply response to different policies. The purpose of the results presented in this chapter is not to provide concrete recommendations to policy makers, but rather to present some issues and broad qualitative results of the Guatemalan agriculture, using MAYA. In this chapter direct and cross-price elasticities for selected crops and the supply response to changes in the price of maize and cotton are explored in detail. The effect of risk on supply response and some comparative advantage calculations are also presented.

Estimation of Supply Elasticities

Supply elasticities are estimated for six products--maize, beans, rice, sorghum, wheat, and cotton. These products were selected because their input data in the model are more complete and are believed to be more reliable. The results of this estimation for maize and cotton are explored in detail in following sections. The supply response functions obtained are, given the static formulation of the model, "equilibrium short-run" functions; equilibrium in the sense that the points along a given function are implicit intersections of supply and demand, after all adjustments are allowed to work themselves out; and short-run because investment and technology remain fixed. These response functions, then, are not the traditional supply functions since, when the price of one product is varied, the prices of all other products are also allowed to vary.

The procedure for tracing out the functions consists of rotating the product demand functions rightward, one at a time by varying the right-hand side value of the convex combination constraint (see Chapter III). Following this procedure, supply response schedules of maize, other grains, and cotton were calculated as reported in Table 11. Figures 7 and 8 portray these results graphically. Increased production of maize due to higher prices took place at the expense of decreases in the production of other crops. Since the demand for other products was held constant, resources were reallocated away from these crops into maize; the prices of these crops thus tended to rise in all cases except in the case of cotton[1] whose domestic price remained constant, and beans whose production increased because of double cropping with maize. Similar results were obtained when the international price of cotton was gradually increased as in Table 12. Expanded production of both crops thus draws resources away from others, and as production of the latter declines, their prices tend to rise unless they are complements in consumption.

It is evident from these results that the elasticity of supply is not at all constant.

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[1]See footnote 4 on page 99.

Table 11. Supply and Price Response to Variations in the Price of Maize as Estimated with MAYA

Maize		Beans		Sorghum		Wheat		Rice		Cotton	
Price	Volume	Price	Volume	Price	Volume	Price	Volume	Price	Volume	Price	Volume
(Prices in quetzales per ton, volume in thousand tons)											
109.0	747.6	509.3	90.4	125.0	55.3	361.0	62.6	358.0	27.4	1261.0	319.5
124.0	807.9	508.0	90.4	128.0	53.7	363.0	59.8	368.0	27.4	1261.0	316.5
142.5	845.4	502.9	90.4	138.0	53.7	403.2	59.8	374.6	27.4	1261.0	313.8
159.3	850.6	498.0	92.0	144.0	53.7	414.5	56.6	385.6	27.4	1261.0	316.1
165.0	872.8	494.6	92.0	146.0	48.9	418.0	56.6	389.2	27.4	1261.0	313.7
180.0	913.6	494.0	92.0	153.0	47.3	428.0	56.6	392.1	27.4	1261.0	313.8
209.0	951.8	493.0	92.0	175.6	33.4	453.0	55.2	406.5	27.4	1261.0	299.2

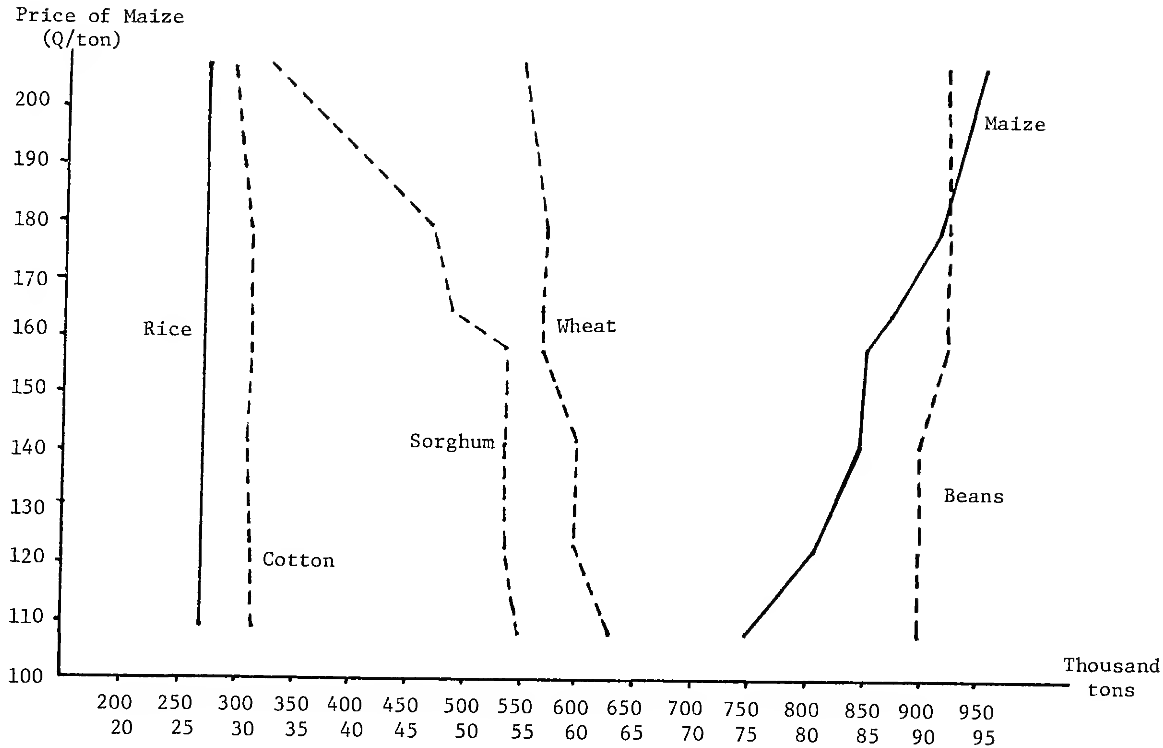

Figure 7. Supply Response to Variations in the Price of Maize as Estimated with MAYA

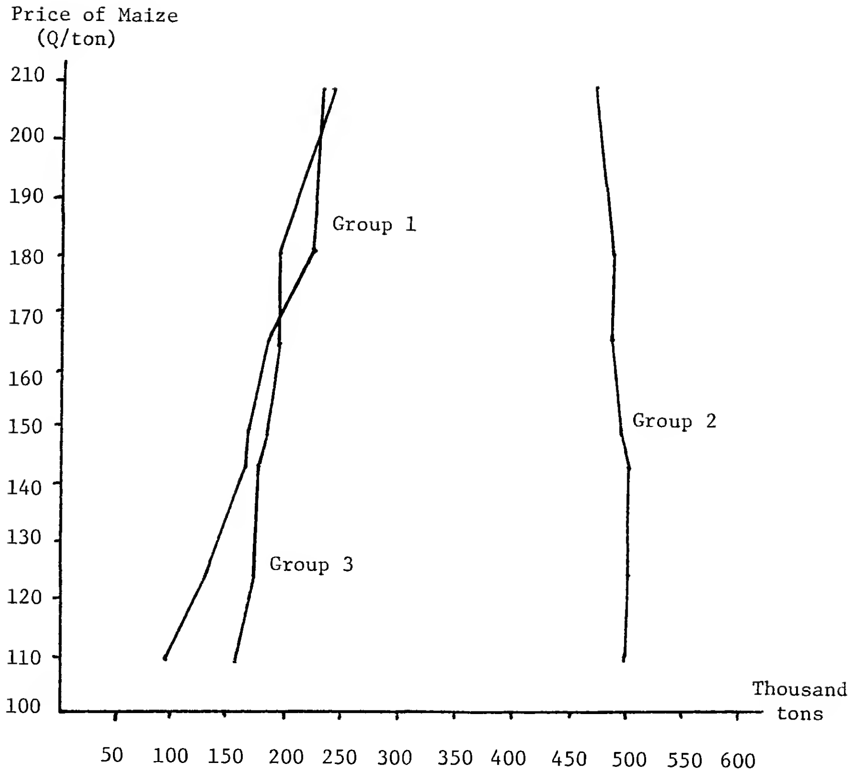

Figure 8. Maize Supply Response by Group as Estimated with MAYA

Table 12. Supply and Price Response to Variations in the Export Price of Cotton as Estimated with MAYA

Cotton			Maize		Beans		Sorghum		Wheat		Rice	
Export Price	Domestic Price	Volume	Price	Volume	Price	Volume	Price	Volume	Price	Volume	Price	Volume
(Prices in quetzales per ton, volume in thousand tons)												
798	904	56.6	122	929	468	91	105	58	339	48	300	29
912	1016	263.1	154	903	469	92	132	55	391	55	325	28
1026	1127	310.9	159	850	492	92	140	54	413	57	355	28
1140	1261	316.1	159	851	498	92	144	54	414	57	386	28
1254	1338	320.6	159	848	508	90	145	49	417	57	402	28
1368	1436	320.9	159	848	521	90	147	49	421	57	423	27
1482	1530	325.6	159	853	533	90	149	49	425	57	444	16
1596	1622	325.7	159	854	545	90	151	47	428	57	465	16
1710	1712	337.7	159	539	556	90	157	47	431	57	485	15

Direct and cross-price elasticities for the six products selected were calculated taking as reference the highest and lowest production recorded between 1970 and 1977 (Table 13). These points are only approximate limits since by rotating the demand we are controlling demand shifts not output shifts. It is, therefore, not possible to find exact reference quantities. It may be seen from Figure 9 that the arc elasticity of supply between points a and b can be calculated ex-post as follows:

$$\varepsilon = \frac{(q_2 - q_1)/(q_2 + q_1)}{(p_2 - p_1)/(p_2 + p_1)} .$$

The direct price elasticities in Table 13 are reasonable in view of previous econometric studies of less developed countries.[2] The cross-price elasticities show that some crops were more likely to drop in production than others when prices of competing crops were raised. Sorghum, for example, is more responsive in a negative direction to an increase in the price of maize. Since maize, cotton, and rice compete for resources in the more productive Group 3, an increase in the price of rice caused a decrease in both area and volume of production of maize and cotton--the estimated cross-price output elasticity of maize is -1.038 and that of cotton is -1.664. The increase in cotton production also took place at the expense of sharp decreases in the rice producing areas (a cross-price elasticity of -1.003). Cotton is a very profitable crop in Guatemala, and cotton responsiveness to maize price change is only -.104, wherease maize responsiveness to cotton price change

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[2]See, for example, Askari and Cummings (1977).

Table 13. Arc Elasticities of Supply of Selected Products[a] as Computed from Estimates Obtained with MAYA

Price Change for	Quantity Response of					
	Maize	Beans	Sorghum	Rice	Wheat	Cotton
Maize	0.619	0.030	-0.785	0	-0.199	-0.104
Beans	0.135	4.975	0	0	0	-0.322
Sorghum	-1.821	0	65.189	0	0	-0.452
Rice	-1.038	0	0	33.746	0	-1.664
Wheat	-0.177	0	0	0	4.078	-0.014
Cotton	-0.193	-0.037	-0.247	-1.003	0.059	0.408

[a]In calculating the direct and cross-price elasticities of maize and beans, only the marketed quantities of both commodities were taken into account. Total elasticities are smaller.

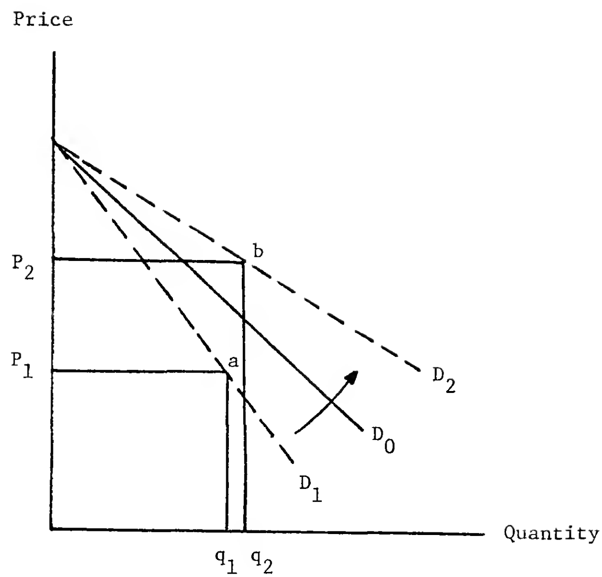

Figure 9. Hypothetical Graph Showing Response Associated with the Increasing Slope of the Demand Function

is -.193. The cross-price elasticities between maize and beans, as expected, are positive since they are mostly double cropped. The size of the elasticities of these two crops appear to be small when taken for the country as a whole; they conceal, however, important changes which take place at the group level. An analysis of the elasticities at the group level would be of more interest to policy makers. Table 14 reports the direct and cross-price elasticites for maize and beans by group. The own-price elasticities of maize for small, medium, and large farmers are, respectively, 3.18, -.10, and 1.07, whereas the average for the country is .62. The own price elasticity of beans is .51 for Group 1, and 4.98 for Group 2, whereas the average elasticity for all groups is 4.98. The high price elasticity of maize of Group 1 indicates that small farmers are much more responsive to changes in the price of maize than are medium and large farmers.

Direct and cross-price elasticities for maize and beans have expected magnitudes and signs in Groups 1 and 3. Maize price elasticities--direct and cross-price--for Group 2, although small, are unexpectedly negative. Moreover, the direct price elasticity of beans for Group 2 has the expected sign but the cross-price elasticity of maize, -.15, is negative. Group 2 farmers grow one-third of maize and one-half of beans in association. Since maize and beans are complements in consumption one would expect that an increase in the price of one of them would produce increments in the production of both crops. In the next section it will be shown that competition for resources between Groups 2 and 3 is responsible for these results.

Table 14. Arc Elasticities for Maize and Beans as Computed from Estimates Obtained with MAYA, by Group

Price Change for	Quantity Response of					
	Maize	Beans	Sorghum	Rice	Wheat	Cotton
Maize						
G1	3.180	0.711	0	0	-0.200	0
G2	-0.100	-0.100	3.180	0	0	0
G3	1.068	0	-0.785	0	0	-0.104
Beans						
G1	0.268	0.506	0	0	0	0
G2	-0.154	4.976	0	0	0	0
G3	0.885	0	0	0	0	-0.322

Supply Response to Changes in the Price of Maize

Tracing the supply curve by shifting the demand permits an overview of the technological change and crop substitution that takes place at the group level. In Table 15 and Appendix A, Table XIII, it is shown that an increase in maize output in Group 1 takes place through increases in area and yields. At a price of Q 209 per ton single-crop maize is grown with more input-intensive, higher-yielding technologies A4 and D2.

Maize output in Group 2 declined slightly. Output in this group is the sum of that from a single-cropped technology and technologies associated with beans and sesame--each showing a different behavior. The area planted with maize-beans declined sharply from 56,200 to 4,300 hectares, whereas that planted with maize-sesame increased from 18,800 to 26,300 hectares. The area planted with single-cropped maize increased by one-fourth as more and more farmers switched to lower yielding technology B3. Total area planted with maize (single-cropped and in association) increased by 3.1%. Group 3 farmers respond to the price rise by planting more maize with higher-yielding technology D1. Maize production becomes quite profitable in Group 3 and is substituted for export cotton and sorghum (cross-price elasticities are -1.04 and -.785, respectively). There is, clearly, a great competition for resources between Groups 2 and 3,[3] with the latter benefitting from the price rise because of their more efficient use of resources. In Group 2 sorghum

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[3]As indicated in Chapter IV, in MAYA Groups 2 and 3 compete for intermediate inputs.

Table 15. Production, Yield, and Employment Response to Variations in the Price of Maize as Estimated with MAYA, by Group

Farm Group and Crop	Price of Maize per Ton in Quetzales						
	109.0	124.0	142.5	159.3	165.0	180.0	209.0
	(Production in thousand tons)						
Group 1							
maize	98.0	132.1	167.3	168.6	187.0	226.4	236.7
beans	15.4	19.6	22.0	23.0	22.4	20.6	20.7
wheat	62.6	59.8	59.8	56.6	56.6	56.6	55.2
Group 2							
maize	496.6	502.6	500.3	496.4	492.5	491.2	476.1
beans	75.0	70.8	68.4	69.1	69.6	71.4	71.3
rice	27.4	27.4	27.4	27.4	27.4	27.4	27.4
sorghum							12.3
Group 3							
maize	153.0	173.2	177.8	185.6	193.3	196.0	239.0
sorghum	55.3	55.3	53.7	53.7	48.9	47.3	33.4
cotton	319.5	316.5	313.8	316.1	313.7	313.8	299.2
	(Yield in kilograms per hectare)						
Group 1							
maize	1227	1233	1245	1242	1254	1275	1324
beans	393	393	393	393	393	393	393
wheat	1540	1404	1371	1388	1388	1388	1396
Group 2							
maize	1848	1785	1780	1763	1750	1745	1724
beans	593	610	669	674	723	711	712
rice	2242	2242	2242	2242	2242	2242	2242
sorghum							3000
Group 3							
maize	2040	2132	2151	2162	2212	2221	2320
sorghum	2900	2900	2900	2900	2900	2900	2900
cotton	3194	3194	3194	3194	3194	3194	3194
	(Employment in thousand man-days)						
Group 1	10,878	13,982	16,739	16,507	18,048	21,366	21,178
Group 2	43,373	42,936	41,856	41,833	41,429	41,797	41,960
Group 3	32,171	32,272	32,233	32,002	31,974	31,963	31,782

production benefits from these crop areas and input substitutions (with a cross-price elasticity of 3.18). It is also interesting to note that the area planted with single-cropped beans increased by 37%. This result seems to indicate that as the price of maize rises and resources become scarce, farmers in Group 2 are willing to take more risk and prefer to grow single-cropped beans, a high risk activity, rather than to grow associated maize-beans, a less risky activity. Total area response function for maize and beans, and group yield response functions for maize are shown in Figures 10 and 11, respectively.

Similar results were obtained when the price of beans was allowed to vary. The signs of the elasticities of Group 1 are positive, as expected, and the magnitudes are reasonable (Table 14). The direct price elasticity of beans of Group 2 has the expected sign, but the cross-price elasticity of maize, -.15, is negative. Again, there is competition for resources with Group 3. More maize is produced by Group 3 (the cross-price elasticity is .88) even at the expense of cotton production.

Appendix A, Table XIV shows the degree of input use, yield, and risk[4] of the technologies of interest for each group of farmers. This table and Appendix A, Table XII indicate that, in general, higher prices motivate farmers to adopt more input-intensive, higher-yielding techniques which are also riskier. Thus, Group 1 farmers plant larger areas of single-cropped maize and of associated maize-beans. Group 2 farmers, on the other hand, plant smaller areas of associated maize-beans

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[4]Risk is represented by the sum of absolute deviations of total returns per hectare from the fitted regression over a 10-year period.

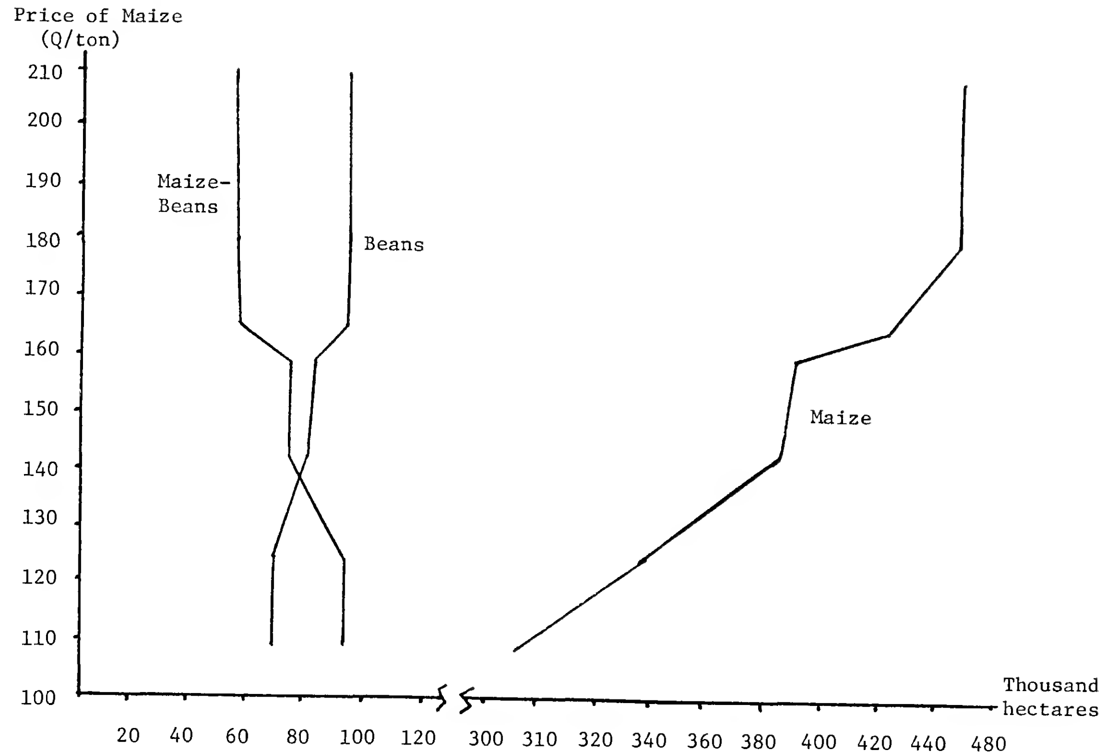

Figure 10. Total Area Response of Maize, Beans, and Associated Maize and Beans to Variations in Price of Maize Using Estimates Obtained with MAYA

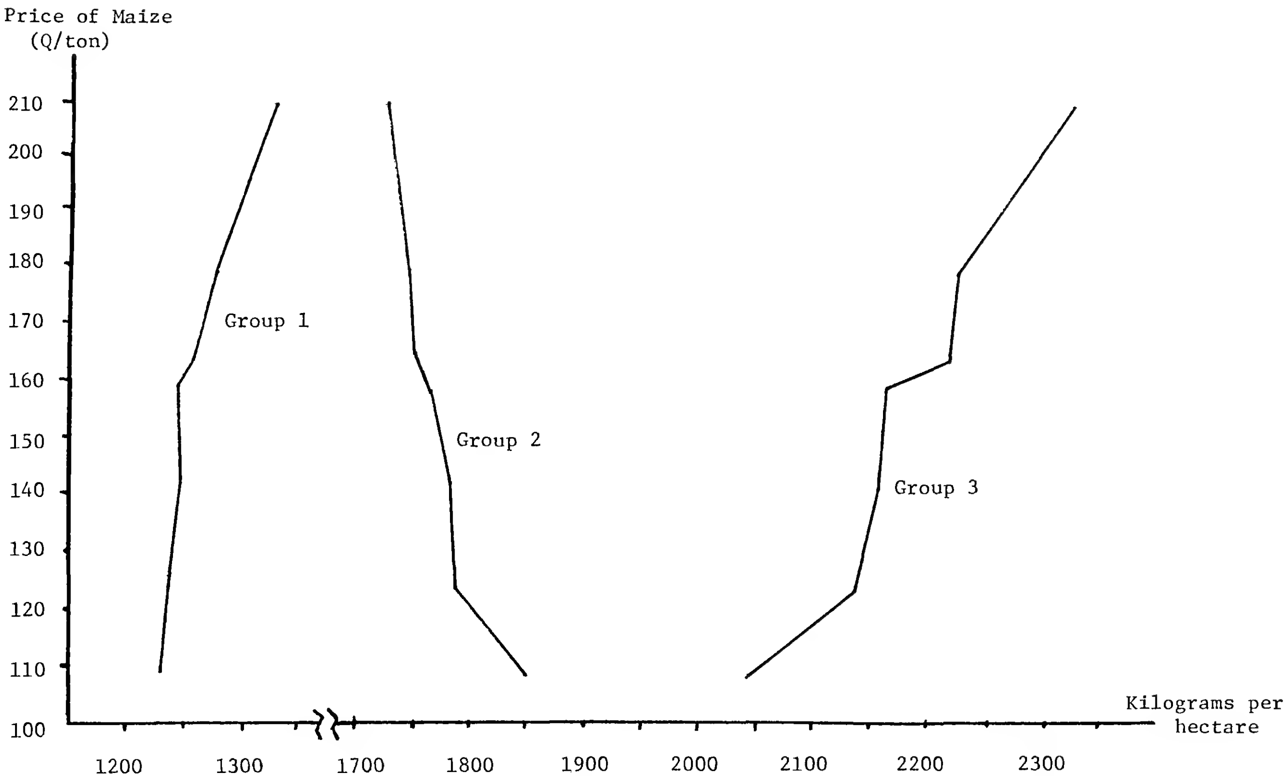

Figure 11. Maize Yield Response to Variations in Its Own Price, by Group Using Estimates Obtained with MAYA

(initially adapted to avoid risk), and larger areas of intercropped maize-sesame, and of beans alone (a more risky activity). Group 3 farmers grow only single-cropped maize and respond positively to price increases; their risk taking behavior is evident as they quickly adopt more advanced and more risky technologies.

Another area affected by the foregoing price policy was employment. On the one hand, an increase in the price of maize brought about technological improvement which is labor reducing. On the other hand, an increase in areas planted is labor creating. Overall employment increased by 9.8% as the price increased from Q109 to Q209 per ton. Table 15 reports that employment in Groups 2 and 3 decreased by 3.3 and 1.2%, respectively, whereas employment in Group 1 almost doubled mainly due to large increases in areas planted. This result is interesting given the serious problem of employment in agriculture.

Supply Response to Changes in the Price of Cotton

To trace the supply function for cotton the same procedure of shifting the demand function around its intercept, as explained earlier, was followed with the additional assumption that exogenous international prices also increase.[5] The domestic consumption of cotton grew at average annual rates of 9.4% from 1959 to 1973 (IDB/IBRD/AID, 1977), and of 9.0% from 1973 to 1977 (Banco de Guatemala, 1979). During 1974-1977 average annual consumption accounted for 11% of total production.

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[5] With international prices unchanged, rotation of the demand curve around its intercept yields a perfectly elastic domestic supply. This is explained by the small domestic demand relative to international demand.

International prices of cotton experienced an upward trend after 1973, and Guatemalan export prices reflect that trend. For purposes of calculating supply elasticities and of tracing supply response functions, it was assumed that export prices varied in increments of 10% of the 1975-1977 price of Q1140 per ton (as assumed in the model), within the range -20% to +30% of this price. At the same time, domestic demand was assumed to change by 9.5% of the equilibrium quantity with each export price change. The idea was to reflect the trend in domestic demand and, at the same time, the situation that prevailed from 1973 to 1977 when export prices varied within the range considered. The assumed price changes imply smaller domestic demands coupled with lower international prices, which in general would not necessarily hold true.

A domestic and an export supply function were obtained (Figure 12). The domestic supply function is very inelastic since domestic consumptions is a small fraction of total supply. The export supply function exhibits some interesting features. Its shape resembles an inverted lazy-S; at low prices it is quite elastic, and at higher prices it becomes more and more inelastic as resources become constraining. The most restricting resource is credit which is assumed fixed in the model. It was interesting to find that an increase in credit of 5% was fully allocated to cotton, and the consequent increase in production was greater than the credit increase in percentage terms. This result shows that the supply elasticity with respect to credit is greater than one. This finding should be of interest to policy makers in formulating a credit policy.

Table 16 shows direct and cross-price elasticities of cotton by farm group. The direct price elasticity of cotton of .41 seems

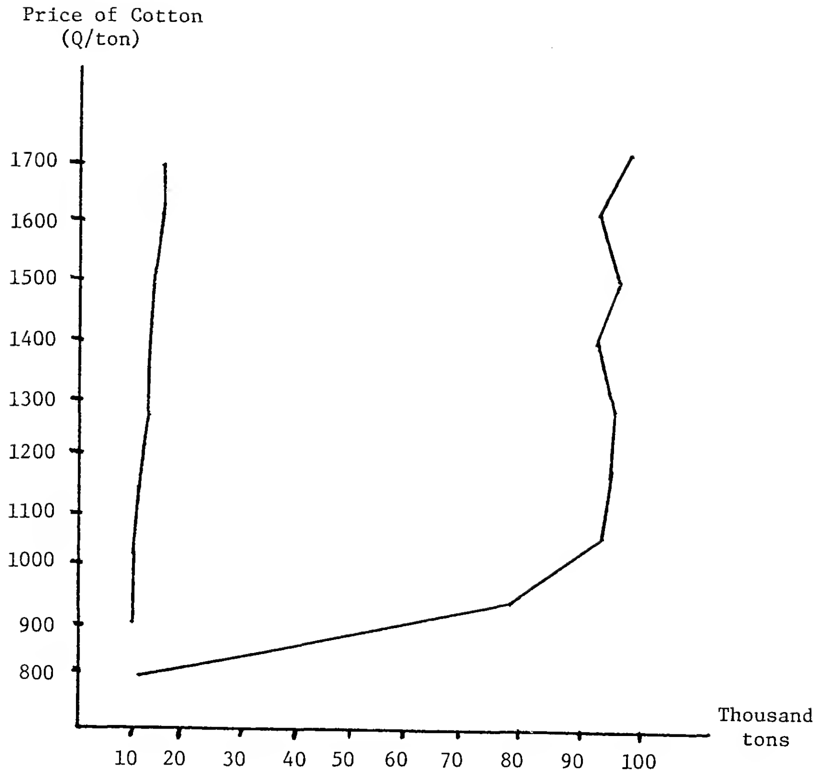

Figure 12. Supply Response Functions for Cotton as Estimated with MAYA

Table 16. Arc Elasticities of Supply of Cotton as Estimated with MAYA, by Group

Price Change for	Quantity Response of					
	Cotton	Maize	Beans	Sorghum	Rice	Wheat
Country	0.408	-0.193	-0.037	-0.247	-1.003	0.059
Group 1	0	-0.548	-0.628	0	0	0.059
Group 2	0	0.227	0.187	0	-1.556	0
Group 3	0.408	-1.095	0	-0.258	0	0

reasonable when compared to results of studies by Quance and Tweeten (1971) and Tweeten and Quance (1969), which revealed a supply elasticity of .3 to .4 for the U.S. and of .3 for the world excluding the U.S. and communist countries. The cross-price elasticity of maize in Group 3 is -1.09 which implies that maize growers are the most affected by an increase in cotton prices; and Table 17 reports that the area planted with maize in Group 3 decreased by 21%. The cross-price elasticity of maize for Group 1, -.55, is relatively large as labor is scarce because migration into cotton production is intensified. Group 2 farmers benefit directly from these area reductions. Because farmers in Group 2 compete with those of Group 3 for intermediate inputs, as less maize is produced by Group 3, some of the resources formerly used to produce maize on large farms are shifted to maize production on medium-sized farms. It is interesting to note that maize area decreased on Group 2 farms and, at the same time, more maize was produced. This occurred both due to the adoption of more input-intensive, riskier technologies of maize and to increased production of maize associated with beans. Production of beans by Group 2 farmers remained rather stable, whereas rice production decreased. The shadow price of cotton for the domestic market is also reported in Table 17 and is always greater than the export price. This result makes sense in view of the nature of the maximization of the model; more exports are preferred because this adds foreign exchange and export takes to producer surplus. The discrepancy between domestic and export prices becomes smaller as the latter increases. This may be due to the fact that the tax rate was allowed to increase with higher export prices.

Table 17. Area, Production, and Domestic Price Response to Variations in the Export Price of Cotton as Estimated with MAYA, by Group

Farm Group and Crop	Price of Cotton per Ton in Quetzales							
	912	1026	1140	1254	1368	1482	1596	1710
	(Area in thousand hectares)							
Group 1								
maize	81	79	77	76	76	78	78	78
maize-beans	72	59	58	57	57	56	56	53
wheat	40	41	41	41	41	41	41	41
Group 2								
maize	243	264	249	226	226	232	232	182
beans	88	94	85	68	68	69	69	36
maize-beans	---	1	18	43	43	43	43	100
rice	13	12	12	12	12	7	7	4
Group 3								
cotton	82	97	99	100	100	102	102	106
maize	97	84	85	85	85	84	84	77
sorghum	19	19	19	17	17	17	16	16
	(Production in thousand tons)							
Group 1								
maize	189	171	169	166	166	167	166	163
beans	28	23	23	23	23	22	22	21
wheat	55	57	57	57	57	57	57	57
Group 2								
maize	476	499	496	496	497	505	505	523
beans	64	69	69	68	68	68	68	70
rice	28	27	27	27	27	16	16	10
Group 3								
cotton	263	311	316	321	321	326	326	338
maize	238	181	186	186	186	181	183	153
sorghum	55	54	54	49	49	49	47	47
	(Shadow price in quetzales per ton)							
	1016	1127	1261	1338	1436	1530	1622	1712

Effects of Expanding the Cotton Area

Cotton is the second largest export commodity in Guatemala after coffee. It contributed 20% of the foreign exchange earnings of agricultural exports during 1975 to 1977. Spurred by attractive world prices, production and exports of cotton in Guatemala started in the 1950s despite unsettled political conditions. Following a phenomenal rise during the early 1960s, cotton area and production trended lower in the late 1960s. During 1960-1961 the area planted was only 26,000 hectares, it reached a peak of 115,000 hectares in 1965-1966, and declined sharply to 80,000 hectares in 1968-1969 (Harness and Pugh, 1970). The decline in cotton production followed lower prices in foreign markets, some increase in production costs, especially pest control, and difficulty in maintaining yields. This trend reversed itself in the 1970s with more favorable international prices. In 1975 the area planted with cotton reached 110,000 hectares which was again close to the peak level of 1965-1966. The adoption of new techniques and effective plague control also contributed to this outcome. The rapid upsurge of prices and the consequent expansion of areas caused the Ministry of Agriculture to intervene by fixing the area planted to protect smaller producers from being displaced by the larger ones, and by fixing the quantities to be sold in the domestic market.

Despite the competition of artificial fibers, world demand for cotton shows an upward trend. International demand for Guatemalan cotton was estimated to grow at an average of 1.6%, and domestic demand at an average of 7.3% for the period 1980 to 1985 (IDB/IBRD/AID, 1977).

Cotton farming in Guatemala is dominated by large scale commercial enterprises. Some farming operations combine cotton and cattle. Generally speaking, a farmer who obtains high yields with reasonable efficiency finds cotton much more profitable than most alternative crops. From the stand point of land availability there is no close competition among commercial crops. One reason for this is that land is still relatively plentiful although there is considerable expense in clearing and developing it. Another reason for the lack of competition among the chief commercial crops is different growing requirements--for example, cotton is grown in the lowlands, sugar cane usually at slightly higher elevations, and coffee in the highlands. However, there are some overlapping labor needs between these crops, especially during harvest time. Major enterprises most likely to continue to compete with cotton for investment capital and management are cattle, bananas, and sugar cane. More recently, tropical fruits and essential oil crops such as lemmon grass and citronella have shown to be potential competitors of cotton.

Like coffee and sugar cane, cotton production is a highly labor intensive crop. The supply of unskilled laborers, especially migratory workers, has been inadequate especially during harvest time since often the harvest season of all three crops overlap. However, increases in wages coupled with increasing export prices have alleviated this problem in the short run.

Migratory labor mainly from the Guatemalan Highlands make up about 60% of the total labor employed during harvest time in export crops. Since the Guatemalan government has emphasized the need to improve the economic conditions of small and medium-size farmers, it should be of particular interest to policy makers to analyze the impact of policies aimed at promoting exports on incomes and employment of these groups. MAYA was used to simulate an 8%[6] increase in the cotton area. Results on labor supply response are shown in Table 18. Total labor use increased by 1.4%. The reduction in migrant labor from Group 2 was more than compensated by an increase in migrant labor from Group 1. Both family and hired labor use decreased in Group 1, whereas in Group 2, family labor decreased and hired labor increased. Figure 13 portrays the total labor use in Group 3 on a monthly basis. The seasonality of labor is immediately apparent. More labor was hired during December and January, the cotton harvest period, and less labor was hired during April to June, the sugar cane harvest period. Indeed, the sugar cane area decreased by 1,200 hectares and production decreased by 107,500 tons (Table 19).

Maize and sorghum area and production decreased in Group 3. In Group 2 the area for single-cropped maize and for beans decreased, whereas that planted with maize-beans increased. This change resulted in an overall increase in the production of maize from 496,400 to 528,800 tons--due partly to adoption of higher yielding technologies and partly to the increase in the area planted with maize associated with beans. Total cropped area, however, decreased by 9%. Total area planted decreased by 4.4% in Group 1 because both the area planted with maize and that planted with maize-beans decreased as labor is in short supply.

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[6]The area authorized for cotton production increased by 25% from 1973 to 1979, with great yearly fluctuations. The 8% increase assumed is an arbitrary magnitude.

Table 18. Labor Supply Response to an 8% Increase in Cotton Area as Estimated with MAYA, by Group

Labor by Category	Basic Solution	8% Area Increase	% Change
	(Thousand man-days)		
Group 1 Labor			
family	14,869	14,441	-2.9
hired	1,617	1,407	-13.0
Group 2 Labor			
family	37,238	36,793	-1.2
hired	4,522	6,401	41.6
Group 3 Labor			
Group 1 migrants	6,455	7,158	10.9
Group 2 migrants	2,873	2,684	-7.0
regional	22,674	22,627	-0.2
Total Labor	90,247	91,511	1.4

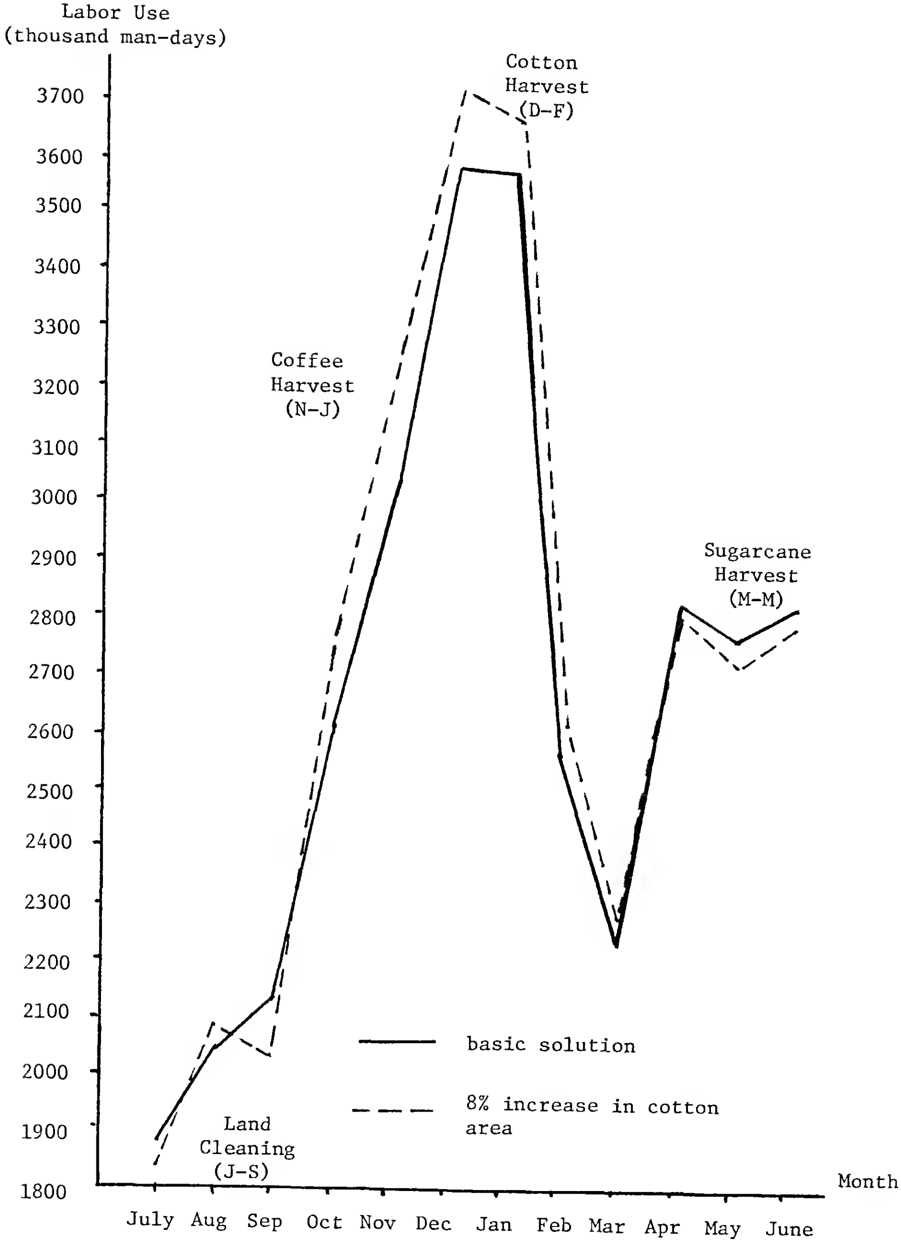

Figure 13. Monthly Distribution of Labor Use in Group 3 with Base Solution and with an 8% Increase in Cotton Area as Estimated with MAYA

Table 19. Area and Production Response to an 8% Increase in Cotton Area as Estimated with MAYA, by Group

Farm Group and Crop	Basic Solution		8% Area Increase	
	Area	Production	Area	Production
	(Area in thousand hectares, production in thousand tons)			
Group 1				
maize	77.3	168.6	75.5	159.3
beans	---	23.0	---	14.3
maize-beans	58.4		52.2	
other	45.8		45.8	
Group 2				
maize	249.1	496.4	185.3	528.8
beans	84.7	69.1	29.9	52.2
maize-beans	17.8		104.8	
other	153.1		129.9	
Group 3				
cotton	99.0	316.1	106.9	341.4
maize	85.0	185.5	75.0	153.0
sorghum	18.5	53.7	15.4	44.6
sugarcane	62.7	5705.2	61.5	5597.7
other	121.3		127.2	

The welfare effects of a policy aimed at increasing cotton productions, employment, and incomes of farmers through an increase in the area planted with cotton are shown in Table 20. Such a policy was effective in raising producers income in Group 3, hired-labor income in Group 2, migrant-labor income, and foreign exchange earnings.[7] Producers income of farmers in Groups 1 and 2, however, decreased and agricultural prices rose by 6%. The latter occurred mainly because of higher consumer prices of those crops whose production diminished as a consequence of this policy--e.g., sorghum, beans, and sugar.[8] Producers' welfare, measured by producers' surplus, increased by 24%, whereas total welfare (the sum of consumers' and producers' surpluses) decreased by .3%.

Although the magnitudes of the results presented in Table 20 may not be realistic, they are, at least, indicative of the likely effects of controlling the expansion of the area planted with cotton in order to benefit small farmers.

A very important implication for planning of this policy, as well as of others aimed at achieving given targets of production, is that trade-offs in consumption and production cannot be ignored and must, therefore, be properly evaluated. The supply response analysis of the last two sections showed that farmers react to price stimuli in

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[7]Foreign exchange earnings increased by Q 5.1 million. Additional earnings from cotton exports alone amounted to Q 9.7 million. The difference of Q 4.6 million account for foreign exchange foregone by importing additional quantities of maize, rice, and sorghum, whose production declined since resources were drawn away from these activities into cotton.

[8]Sugar exports remained constant but domestic supply decreased.

Table 20. Welfare Indicators in the Base Period and After an 8% Increase in Cotton Area as Estimated with MAYA

Indicator	Basic Solution	8% Area Increase	% Change
	(Millions of quetzales)		
Producers Income			
Group 1	41.26	39.02	-5.7
Group 2	101.65	98.42	-3.3
Group 3	271.58	276.44	1.8
Hired-labor Income			
Group 1	2.26	1.97	-14.7
Group 2	7.69	10.88	41.5
Group 3	71.42	72.53	1.4
Group 1 migrants	(14.85)	(16.46)	10.8
Other	(56.57)	(56.07)	-0.1
Balance of Trade in Agriculture	501.81	506.93	1.0
Producers' Surplus	89.53	111.07	24.1
Objective Function Value	934.18	931.45	0.3
Consumer Price Index in Agriculture	100.00	105.97	6.0

accordance with their attitudes toward risk. Their ability to adopt new technologies and the availability of resources influence their cropping patterns. Moreover, on the consumption side, product prices are determined by the interaction of supply and demand. Appropriate evaluation of substitution effects in production and consumption should thus contribute to effective policy making.

Effect of Risk on Supply Response

In Chapter III it was shown that the introduction of risk into an LP model leads to different levels of production and prices than those obtained with no risk. In this section an attempt was made to explore the slope and location of the supply function for selected crops with and without risk. Since prices are endogenous supply, functions are not derived by changing a given price ceteris paribus but by allowing other prices to change also. Thus, the functions obtained must be considered as total supply response relationships. Supply response functions derived in this manner are portrayed in Figures 14A to 14F for six crops. The points on these functions are numbered so that points 1, 2, etc., correspond to the same demand shift under risk[9] and under risk neutrality. The end points represent low and high production levels observed during 1970 to 1977. Contiguous points represent a 10% shift in demand except in the case of sorghum and rice whose demands were shifted by 20% intervals.

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[9]The risk set (2.0, 1.25, .75) for Groups 1, 2, and 3, respectively, was assumed.

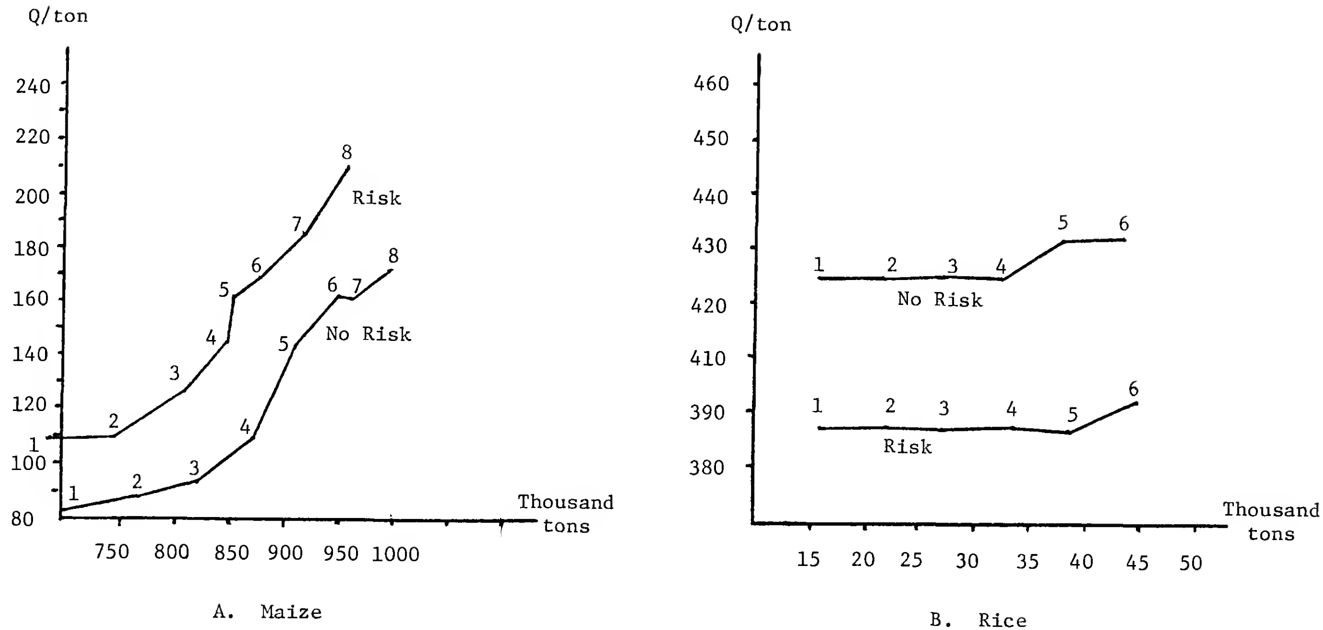


Figure 14. Supply Response Functions with and without Risk Using Estimates Obtained with MAYA

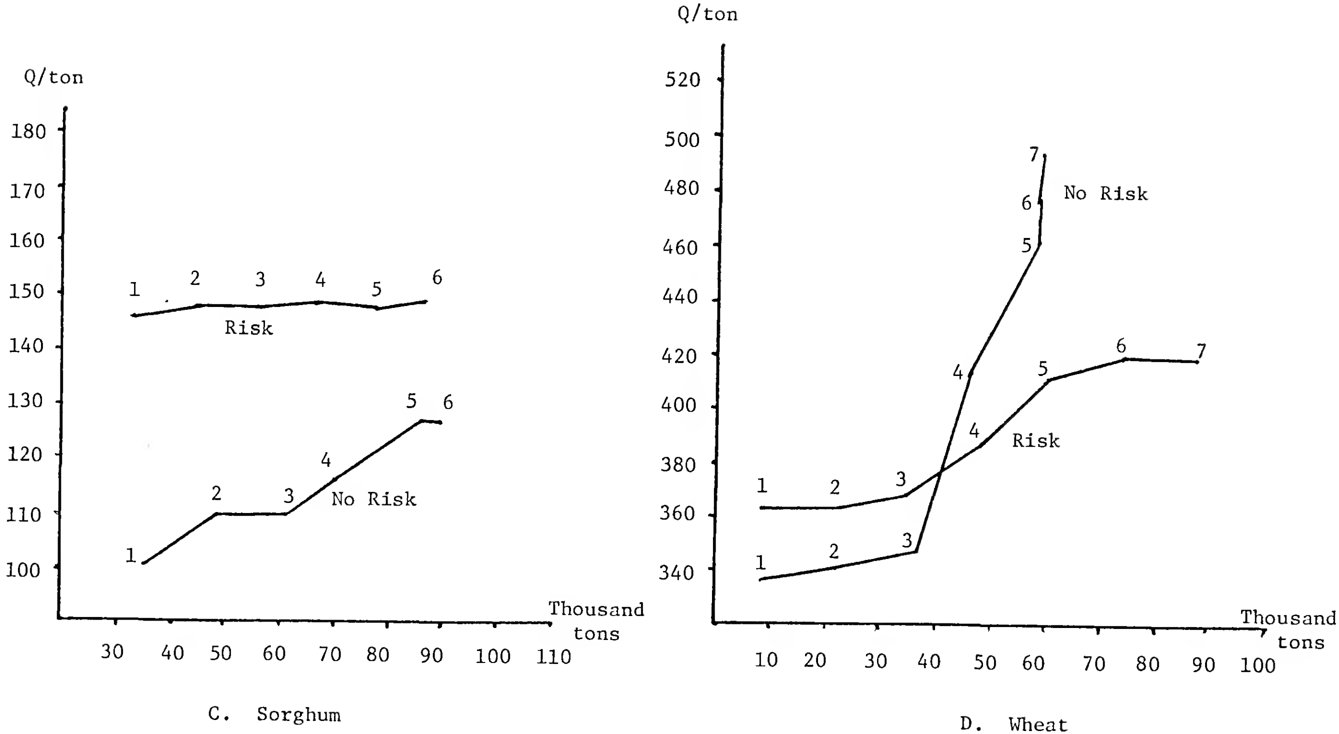
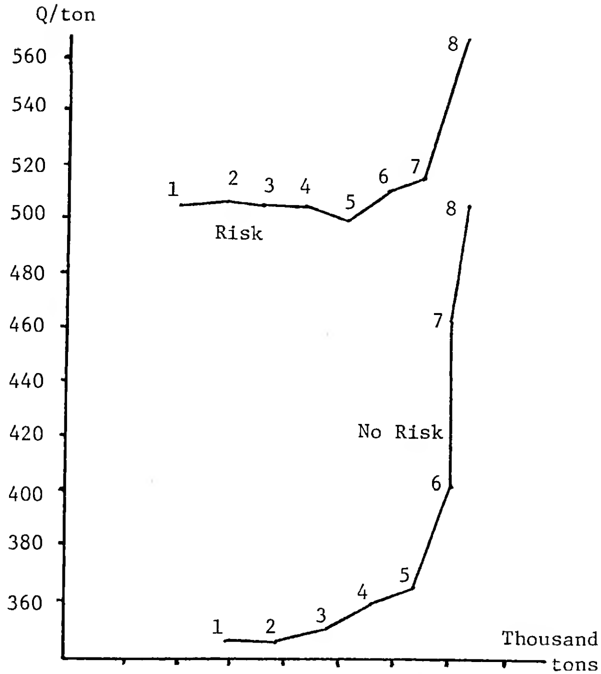
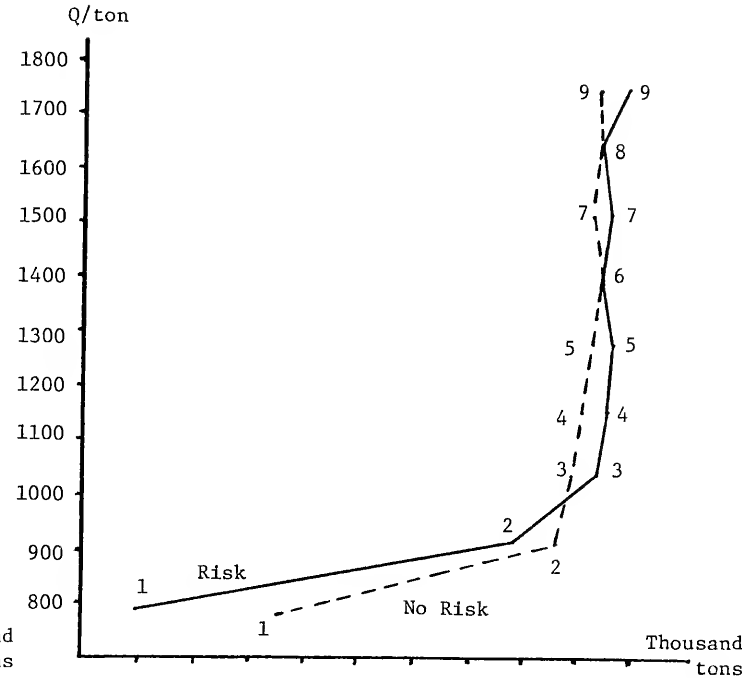


Figure 14. Continued



E. Beans



F. Cotton Exports

Figure 14. Continued

The supply functions are all upward sloping. Production increased less than proportionally with demand, causing prices to increase. Wheat, beans, and cotton supplies show a rather inelastic portion at higher prices. Clearly, there is keen competition for resources from other crops in the model. In some cases risk affected the slopes of the functions and, in most cases, it shifted their location. It caused the supplies of maize, sorghum, and beans to shift up and to the left, which means that lower quantities are produced at higher prices. Taken as a whole, cotton is risk neutral. Wheat presents an interesting case; it appeared to be a risky crop at low prices and became less risky and more elastic in the price range Q 383 to Q 414. In contrast the supply response function of rice, a low risk crop, shifted down when risk averse behavior was introduced. The analysis indicates that the bias of ignoring the risk averse behavior in planning models could be significant.

Comparative Advantage

Comparative advantage in international trade has been quantified in terms of Bruno's (1965, 1972) domestic resource cost (DRC) or exchange cost measure--i.e., the level of production costs in quetzales required to earn a dollar of foreign exchange via exports. This concept can also be used in the case of imports to measure the gains to Guatemala from additional units of imports in order to save a dollar of foreign exchange via import substitution.

The numerator of the domestic resource cost formulation is the opportunity cost of an additional unit of production, and the denominator is the net foreign exchange earned (in the case of exports) or saved (in the case of imports).

Since the LP solution directly provides a measure of opportunity costs, it is a straight forward matter to calculate the domestic resource costs (the numerator of the DRC) of exports and imports. For the present study it is desirable to know the exchange costs of incremental exports and imports from the existing levels and, therefore, for this experiment all exports and imports were upper bounded at the 1976 to 1977 levels. For imports from the Central American countries governed by international agreements, these bounds were set equal to those quantities. In the case of exports of a given product, the domestic resource cost, excluding profits but including the "normal" returns to land and labor, was found by subtracting the export bound shadow price (representing the amount of producer's excess profits per incremental unit exported) from the exogenous export price (Bassoco and Norton, 1979). Normal factor returns refer to the rates of return accruing from production for sale in domestic markets. The procedure followed in the case of imports is essentially the same except that in this case this measure can also be interpreted as the (potential) domestic resource savings of not importing one additional unit.

The shadow price column, shown in Table 21, represents the marginal profits (when positive), or losses (when negative), for export and import crops, respectively. A distinction between imports from the Central American countries, which are tariff exempt, was made. To obtain a measure of the exchange cost the DRC is simply divided by the export or import price. By comparing this cost with the prevailing exchange rate, a ranking of crops according to the degree of comparative

Table 21. Profitability of Selected Products in International Trade as Estimated with MAYA

Product	Actual Volume Traded	Export or Import Bound	Export or Import Price	Shadow Price	Marginal Cost of Production
(Volumes and bounds in thousand tons, prices and costs in quetzales per ton)					
Exports					
Sugar	314.0	314.0	314.0	105.2	234.8
Bananas	302.4	302.4	151.0	81.7	69.3
Cotton	91.7	110.0	1162.0	0.0	1162.0
Coffee	130.0	130.0	2040.0	39.7	2000.3
Potatoes	24.0	24.0	260.0	94.8	165.2
Imports from Third Countries					
Maize	40.3	60.0	-158.0	0.0	-158.0
Beans	0.0	2.0	-566.0	-120.0	-686.0
Rice	0.0	5.5	-384.0	-47.9	-431.9
Wheat	74.0	74.0	-223.0	71.1	-151.9
Imports from C.A.					
Maize	8.0	8.0	-157.0	2.3	-154.7
Beans	6.0	6.0	-460.0	38.0	-422.0
Rice	0.0	1.0	-427.0	-41.5	-468.5
Sorghum	0.0	4.5	-145.0	-1.2	-146.2

advantage in international trade is possible; that is, in order of the marginal domestic cost of earning a dollar in exports (or import substitution). Crops whose exchange cost in quetzales is greater than the exchange rate in quetzales per dollar would require subsidies for additional exports (import substitution) at the margin. The exchange costs calculated in this manner are given in Table 22. The average of the exchange costs weighted by the proportion of the value of exports during 1976 to 1977 for all crops exported turned out to be Q .88 per dollar (12% less than the official exchange rate), for imports from third countries Q .84 per dollar, and for imports from Central American countries Q .96 per dollar. These figures indicate that Guatemalan export agriculture is quite competitive in world markets. It also means that export crops could have been taxed up to 12% without becoming unprofitable. Imports from third countries appear to be more favorable than imports from other Central American countries. Guatemala would certainly be better off importing wheat from third countries than producing it domestically.

These results provide a basis for establishing the relative comparative advantage on a group basis. Group 3 is clearly better off than Groups 1 and 2 since export crops, which are mostly produced by Group 3 farmers, are very profitable in international markets.

Table 22. Ranking of Products According to Exchange Cost Calculations Using Estimates Obtained with MAYA

Product	% of Production	Value (million Q)	Exchange cost[a]	Rank
		Exports		
Bananas	100.0	45.66	0.46	1
Potatoes	44.5	6.24	0.64	2
Sugar	64.8	106.76	0.69	3
Coffee	84.5	265.20	0.98	4
Cotton	88.0	127.82	1.00	5
		Imports from Third Countries		
Wheat	137.0	16.50	0.68	1
Maize	13.1	9.48	1.00	2
Rice	33.0	2.11	1.12	3
Beans	2.9	1.13	1.21	4
		Imports from C.A.		
Beans	8.8	2.76	0.92	1
Maize	1.8	1.26	0.99	2
Sorghum	9.7	0.65	1.01	3
Rice	9.9	0.43	1.10	4

[a]The exchange cost in quetzales is equal to the marginal cost of production over the export or import price of Table 21. The exchange rate is 1 quetzal = 1 US dollar.

CHAPTER VII
SUMMARY AND CONCLUSIONS

Summary

The purpose of this research was to build a mathematical programming model for the agricultural sector of Guatemala which could be used to simulate the consequences of different policies. The basic optimizing market equilibrium formulation of the model assumed that producers are profit maximizers and that consumers' behavior is described by a set of demand functions in the space of prices and quantities. This assumption implies that prices are endogenously determined by the intersection of the demand and supply schedules and is, thus, more realistic than the fixed-demand assumption of traditional mathematical programming models. The model formulated in this manner was modified by adding the assumption that producers behave in a risk averse manner.

MAYA modelled three subsectors of agriculture according to farm size and technology--subsistence, small-scale marketing, and commercial agriculture--which produce 13 annual crops representing about 90% of the total value of agricultural production during 1976-1977. These crops could be transformed into 18 final products which could be sold directly in the domestic market or exported.

Some of the data sources of MAYA included (a) the South Pacific regional model of Guatemala which is a risk model but assumes fixed demands, and (b) the Central American model, MOCA, made up of five country-models which assumes downward sloping demands but no risk. Conceptually, thus, MAYA is a much improved, more inclusive version of previous partial models of the Guatemalan agricultural sector because of its more realistic theoretical assumptions and because it covers a wider range of products. Market equilibrium models can be useful for policy analysis in that they define an equilibrium, toward which the market system tends, conditional upon specific policy instrument values. Several different equilibria of this type were obtained with MAYA in order to compare the relative impetus given to the economy by alternative policy actions. The introduction of assumptions about producers' decision rules and consumers' behavior may, however, also increase the scope of errors in specification and estimation.

To demonstrate the uses to which the Guatemalan model MAYA can be put, several experiments were conducted. Supply response to variations in the prices of maize and cotton was analyzed by rotating their respective demand functions around the intercept to trace out the supply. Matrices of direct and cross price elasticities for six major crops (viz., maize, beans, rice, wheat, sorghum, and cotton) were estimated and the results were interpreted. Technological change resulting from these price variations was also analyzed in detail at the subsector level. Another experiment was done to evaluate the results of a policy designed to increase incomes and employment of small and landless farmers through an increase in the area planted with cotton. The extent of the bias involved when risk averse behavior is ignored was also evaluated by tracing out risk and no-risk supply functions. Finally, MAYA was used to obtain schedules of comparative advantage in production. Export and import products were ranked according to their degree of comparative advantage in international trade.

Conclusions

In this study it has been demonstrated that the responsiveness of farmers to changes in the price of a given commodity are dictated by the availability of resources, particularly land and family labor, employment possibilities outside the farm, choice of crops and techniques, relative product prices, and uncertainty of product prices and yields. The study emphasized the importance of the yield and area components of output elasticity in evaluating supply response. This approach is relevant in underdeveloped agriculture where land and family labor are scarce. It has been shown that increases in maize and cotton production take place through increases in areas and yields--intensifying the use of inputs such as chemicals, seeds, and machinery. In general, in response to price increases, farmers tended to adopt higher yielding, more input intensive techniques which are also riskier. The less advanced farmers behaved no differently from the more advanced ones. This result supports Behrman's (1968) findings that farmers in underdeveloped agriculture respond quickly and efficiently to relative price changes. Another consequence of policies desinged to increase production of a given commodity is that the prices of those commodities whose production is not increased tend to rise as inputs are drawn away from those products toward those whose production increases. It was found that a policy to increase incomes and employment of small farmers through an increase in the area planted with cotton could be effective in the short run. In the long run, there are adverse effects caused by an increase in the price level which could cancel out the initial favorable results unless other policies designed to alleviate or present this price increase were implemented.

Different methods to measure supply response, i.e., econometric analysis, linear programming, and production functions, have been discussed in the literature. The results of this study support Shumway and Chang's (1977) prediction that linear programming can be an effective tool for simulating the behavior of farmers if downward sloping demand functions as well as risk-averse behavior are explicitly introduced into the analysis.

It has been demonstrated that the descriptive performance of agricultural planning models can be considerably improved by introducing risk-averse behavior, even when based on Hazell's (1971) MOTAD model which yields results 88% as efficient as those which use unbiased estimators of the variance-covariance matrix in the Markowitz's (1952) portfolio selection approach of quadratic programming. Estimates of risk aversion coefficients were obtained at aggregate levels using post-optimality techniques of linear programming. Finally, it has been shown that biases in estimates of supply response and resource valuation may be quite significant in planning models which ignore risk-averse behavior.

Areas for Further Research

Much improvement still remains to be done to increase the usefulness of MAYA. Livestock activities as well as tree crops production activities need to be incorporated. Regarding the actual data base, some improvement needs to be introduced through field work in the area of export crops, particularly sugarcane and coffee for which insufficient data were available.

There are some areas in which the methodology of market equilibrium programming model is, in general, deficient. Two topics which are usually ignored are land tenure systems and factor markets. Apart from the Kutcher-Scandizzo (1976) and Ferreira (1978) studies of northeast Brazil, there has been no attempt to capture the influence of land tenure considerations in the specification of a mathematical programming objective function. Factor prices are, generally, not as specified endogenous in sector models. Different kinds of land and labor need to be specified. Some work in this direction has been done by Hazell (1979).

The usefulness of mathematical programming models could further be improved if they were considered within the multi-level framework and if income was explicitly incorporated in their formulation. The descriptive nature of mathematical programming models restricts their use within the more broad policy context. Even though a policy objective function is sometimes attached to the constraint set of the descriptive problem, it should be clear that such a model does not represent completely either the policy problem or the descriptive problem. In most cases optimization of the objective function given by the sum of producers' plus consumers' surpluses need not be "the optimum" policy. Mathematical programming when used to simulate the behavior of markets for single products and complete sectors, particularly in agriculture, deals only with the maximization of a behavioral function.

Insofar as MAYA does not go beyond solving the behavioral sub-problem of multi-level programming, its results should be interpreted within the limitations and assumptions of mathematical programming. It also means that a solution nearer real world optimality could be found by formulating the model within the multi-level programming framework. Several policy options can be considered to arrive at more realistic solutions. Some of the policy variables directly affecting agriculture, which the Guatemalan authorities control, are import quotas, import and export taxation, credit, and interest rates. With these variables they can influence the level of foreign exchange, farm incomes, employment, and GNP growth. In the international trade sector, for example, it could be of interest to maximize the level of foreign exchange subject to given levels of import and export taxation and agricultural credit. Another objective may be to maximize small farmers' incomes and employment levels subject to given levels of credit, interest rates, and volume of trade. Formulating MAYA in the multi-level programming framework would, thus, permit a more realistic representation of the policy making process, which could be quite useful for planners.

The second shortcoming of mathematical programming models is that their partial nature ignores income effects which act to shift consumer demands under different policies. If the sector modelled is small enough, ignoring income effects should be unimportant. But if the sector is relatively large, the income it generates must necessarily influence demand patterns. Given that the agricultural sector of Guatemala represents one-third of GNP, income effects are very likely to play a role in the demand for agricultural commodities. Thus, the incorporation of income into the model would add to the realism of the results.

APPENDICES

APPENDIX A
STATISTICAL TABLES

Table I. Gross Domestic Product and Trade in Guatemala by Selected Sectors, 1965-1978

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
	(Millions of 1958 quetzales)													
GDP at market prices	1355	1430	1489	1619	1696	1793	1893	2032	2169	2308	2353	2532	2738	2879
Agriculture	389	408	408	452	463	490	524	575	605	644	660	692	723	744
Mfg. industry	191	211	228	255	273	283	303	320	346	362	356	394	435	466
Construction	25	27	29	28	29	28	28	34	41	38	44	83	90	89
Private services[a]	79	83	86	90	94	98	106	114	123	1232	1258	1330	1447	1531
	(Percent)													
GDP at market prices	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Agriculture	28.7	28.5	27.4	27.9	27.2	27.3	27.7	28.3	27.9	29.7	28.1	27.3	26.5	25.8
Mfg. industry	14.1	14.7	15.3	15.7	16.1	15.8	16.0	15.7	15.9	15.7	15.1	15.5	15.9	16.2
Construction	1.8	1.9	1.9	1.7	1.7	1.6	1.5	1.7	1.9	1.6	1.9	3.3	3.3	3.1
Private services	5.8	5.8	5.8	5.6	5.5	5.5	5.6	5.6	5.7	53.4	53.4	52.6	52.9	53.2
	(Millions of quetzales)													
Total exports	186	226	198	227	255	290	283	327	442	582	641	760	1160	1092
Agriculture (percent)	158 (85)	187 (83)	144 (73)	166 (73)	187 (73)	204 (70)	199 (70)	233 (71)	303 (69)	391 (68)	434 (70)	409 (54)	782 (67)	722 (66)
Total imports	229	208	247	249	250	284	303	324	427	700	732	838	1052	1280
Agriculture (percent)	27 (12)	41 (20)	33 (13)	29 (11)	26 (10)	32 (11)	31 (10)	30 (10)	36 (8)	58 (7)	70 (9)	52 (6)	65 (6)	100 (8)

[a]After 1973, total services.

SOURCES: Banco de Guatemala; FAO, Trade Yearbook.

Table II. Gross Fixed Capital Formation in Guatemala by Sector, 1969-1978

Economic Sector	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
	(Millions of quetzales)									
Agriculture[a]	19	20	22	26	31	45	55	68	...	...
machinery and equipment	9	9	11	13	16	25	32	42	...	...
improvements	10	11	11	13	15	20	23	26	32	38
Industry[a]	63	71	70	74	96	137	164	297	...	...
Transport and communications	22	28	41	29	41	56	86	114	...	...
Public works	41	43	44	55	77	102	90	134	197	217
Other private construction	27	28	27	23	32	50	54	114	144	165
Other investment[b]	59	49	60	66	80	101	104	125	...	...
Total	231	239	264	273	357	491	553	852	1016	1195

[a]Includes capital investment by the public sector.

[b]Includes only locally produced capital goods.

SOURCE: Banco de Guatemala.

Table III. Gross Domestic Product of Guatemala by Expenditure Category at Current and Constant Prices, 1967-1979

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
					(Millions of current quetzales)								
Consumption	1290	1364	1493	1647	1731	1843	2201	2677	3125	3693	4481	5110	5909
Private	1177	1248	1357	1496	1592	1686	2034	2470	2875	3396	4127	4675	5434
Government	113	116	136	151	139	157	167	207	250	297	354	435	475
Gross domestic investment	188	244	210	244	285	255	352	588	587	866	1099	1313	1296
Private	148	177	176	193	206	205	269	375	452	690	790	956	944
Government	44	44	55	45	57	67	87	93	118	210	249	262	320
Change in stocks	-4	23	-21	6	22	-17	-4	120	17	-34	60	95	32
Gross domestix expenditure	1478	1608	1703	1891	2016	2098	2553	3265	3712	4559	5580	6423	7205
Exports (inc. services)	236	270	305	354	343	397	537	708	792	942	1340	1304	1474
Imports (inc. services)	284	297	299	338	371	389	519	811	858	1204	1439	1655	1793
Current account	-48	-27	6	16	-28	8	18	-103	-66	-262	-99	-351	-319
Gross domestic product	1430	1581	1709	1907	1988	2106	2571	3162	3646	4347	5481	6072	6886
					(Millions of 1975 quetzales)								
Consumption	813	876	929	1128	1172	1231	1681	2366	3125	4136	5825	7001	8804
Private	742	801	844	1025	1078	1126	1554	2183	2875	3803	3803	5365	6405
Government	71	75	85	103	94	105	127	183	250	333	460	596	708
Gross domestic investment	118	157	131	167	193	170	269	520	587	970	1429	1798	1932
Private	93	114	109	132	139	137	206	331	452	773	1027	1310	1407
Government	28	28	34	31	39	45	66	82	118	235	324	358	477
Change in stocks	-3	15	-12	4	15	-12	-3	107	17	-38	78	130	48
Gross domestic expenditure	931	1033	1059	1295	1365	1401	1951	2886	3712	5106	7254	8799	10736
Exports (inc. services)	149	173	190	242	232	265	410	626	792	1055	1742	1786	2196
Imports (inc. services)	179	191	186	321	251	260	397	717	858	1348	1871	2267	2671
Current account	-30	-18	4	11	-19	5	13	91	-66	-293	-129	-481	-476
Gross domestic product	901	1015	1063	1306	1346	1406	1964	2795	3646	4813	7125	8318	10261

SOURCE: IMF (1980), and Banco de Guatemala (1980b).

Table IV. Guatemalan Agricultural Statistics by Selected Crops, 1968-1978

Product	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
	(Area in thousand hectares, yield in kilograms per hectare, volume in thousand tons)													
Coffee														
Area	237	237	237	237	237	224	255	245	244	248	248	248	248	248
Yield	1645	1385	1425	1425	1552	1701	1700	1700	886	2028	2025	1784	1698	1717
Volume of production	126	106	109	108	119	123	141	134	149	163	162	143	147	149
Exports	96	109	81	94	100	95	100	111	115	121	136	119	133	132
Domestic consumption[a]	31	-3	28	14	19	28	41	23	34	42	27	24	11	17
Cotton														
Area	100	84	90	97	76	74	70	87	89	103	111	84	99	128
Yield	2334	2281	2367	2150	2004	2143	3286	3114	3569	3571	2917	3535	4128	3413
Volume of production	233	192	212	207	152	56	80	95	111	129	105	124	139	143
Exports	64	82	57	65	73	50	48	74	98	126	98	93	123	128
Domestic consumption[a]	169	110	155	142	78	6	33	21	13	3	7	30	15	15
Sugar[b]														
Area	33	36	37	34	36	36	49	40	40	45	55	70	69	57
Yield	5466	5979	6148	5760	6259	6250	5493	7290	7311	7494	7613	7633	7244	6938
Volume of production	180	215	228	195	226	224	268	293	294	340	421	531	502	392
Exports	32	52	61	56	50	57	70	103	126	134	204	339	279	159
Domestic consumption	148	163	167	138	176	166	198	190	168	206	218	192	223	233

Table IV. Continued

Product	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
	(Area in thousand hectares, yield in kilograms per hectare, volume in thousand tons)													
Bananas														
Area	2	3	2	4	4	4	5	5	5	5	5	5	5	5
Yield[c]	17	26	30	40	43	39	58	62	60	74	64	75	63	70
Volume of production	41	74	52	151	157	166	277	310	308	377	321	387	334	372
Export	34	63	44	127	145	157	236	271	263	299	240	303	283	386
Domestic consumption	7	12	8	24	12	166	41	39	45	78	80	84	52	86
Maize														
Area	676	659	697	691	735	662	660	742	732	559	634	641	522	591
Yield	960	900	870	990	960	1119	1110	1110	1160	1431	1472	1319	1465	1574
Volume of production	646	594	607	689	709	786	747	623	849	800	934	846	765	896
Import	11	2	12	24	8	16	13	13	65	72	68	68	...	...
Domestic consumption	646	593	619	712	717	802	761	811	914	872	1002	914	...	...
Beans														
Area	88	78	81	101	85	151	177	179	113	91	158	133	110	95
Yield	650	650	650	650	650	430	370	370	370	770	690	560	672	838
Volume of production	57	51	53	66	56	65	65	66	42	70	109	74	73	79
Import	4	3	2	2	2	3	3	3	...	...	7	6	...	...
Domestic consumption	61	61	53	52	66	56	65	69	42	70	116	80	...	...
Wheat														
Area	27	31	36	30	29	33	31	34	28	44	39	37	47	...
Yield	990	950	870	1090	1100	1030	1210	1350	1660	1160	1170	1310	1200	...
Volume of production	27	30	32	33	33	36	38	46	46	50	45	48	56	...
Import	58	62	66	71	56	89	66	75	75	64	71	83	...	...
Domestic consumption	86	92	98	104	89	124	103	121	121	115	116	131	...	...

Table IV. Continued

Product	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
	(Area in thousand hectares, yield in kilograms per hectare, volume in thousand tons)													
Sorghum														
Area	49	51	44	47	48	40	50	53	60	35	38	45	35	43
Yield	900	700	700	900	1100	730	750	500	763	1207	1627	1000	1455	1481
Volume of production	44	34	32	42	54	30	38	27	45	42	62	50	52	64
Imports	...	...	3	1	3	4	4	5	5	...	...	...	...	...
Domestic consumption	43	32	35	42	57	34	42	32	50	42	62	50	...	...
Rice														
Area	8	8	12	14	14	11	20	24	31	15	19	19	11	12
Yield	1700	1750	2356	1749	1800	1500	2000	3000	2704	1466	2533	1271	2284	2258
Volume of production	13	15	21	25	27	23	59	24	53	21	46	24	25	29
Imports	---	---	2	2	1	5	2	2	2	7	6	6	...	...
Domestic consumption[d]	9	8	13	17	17	20	41	18	38	15	36	28	...	...
Potatoes														
Area	7	7	7	7	7	7	7	7	6	6	7	7	7	...
Yield	6000	6000	3900	5500	5500	4182	4246	4385	3994	4246	4061	4000	4500	...
Volume of production	39	39	27	37	38	28	29	29	24	24	26	26	29	...

[a]Adjusted for inventories.

[b]A conversion factor of 8.5 percent was used.

[c]In metric tons.

[d]Polished rice.

SOURCES: FAO, Production Yearbook; FAO Trade Yearbook; Banco de Guatemala.

Table V. Basic Grains Guaranteed Prices,[a] Purchases as Percent of Total Production, and Sales as Percent of Total Consumption by the National Agricultural Marketing Institute (INDECA) Of Guatemala, 1971-1978

Year	Maize			Beans			Rice			Sorghum		
	Gtd Price	Pur-chases	Sales	Gtd Price	Pur-chases	Sales	Gtd Price	Pur-chases[b]	Sales[c]	Gtd Price	Pur-chases	Sales
	(Guaranteed price in quetzales per ton)											
1971	61	1.1	0.2	174	0.6	0.6	87	5.3	7.6			
1972	56	0.2	0.8	174	1.4	0.2	87	13.5	1.2			
1973	76	0.1	4.5	196	0.6	2.3	104	0.4	6.5	61		
1974	138	1.6	6.9	315	9.8	8.5	149	0.1	6.0	126	1.7	
1975	152	1.4	5.7	413	1.5	17.5	168	6.4	14.6	109	0.1	1.2
1976	144	2.5	0.3	264	8.3	2.6	139	4.9	0.4	98	---	---
1977	125	1.5	...	294	---	...	159	---	...	113	---	...
1978	149	3.4	...	380	---	...	220	2.5	...	125	---	...

[a] Guaranteed prices refer to crop years and are averages of different regional guaranteed prices.

[b] Purchases of paddy rice.

[c] Sales of polished rice after 1973.

SOURCE: INDECA Balance Sheets.

Table VI. Variables Included in MAYA

1. PRODUCTION AND TRANSFORMATION BLOCK

Production Activities

Product	Units	Group 1	Group 2	Group 3
Maize	1000 ha	x	x	x
Late maize	"			x
Maize-sesame	"		x	
Maize-beans	"		x	
Beans	"	x		
Rice	"		x	x
Sorghum	"		x	x
Cassava	"		x	
Potatoes	"	x		
Wheat	"	x	x	
Bananas (domestic consumption)	"		x	x
Sugarcane	"			x
Coffee	"		x	x
Cotton	"			x
Bananas (export)	"			x
Lemon grass tea	"			x

Transformation Activities

Primary Product	Units	Processed Product	Group 1	Group 2	Group 3
Raw cotton	1000 ha	Cotton fiber			x
		Cotton seed			x
		Cottonseed cake			x
		cottonseed oil			x
Sugarcane	"	Molasses		x	x
		Refined sugar		x	x
		Lump molasses		x	x
Coffee nuts	"	Ground coffee		x	x

Table VI. Continued

Transformation Activities (Continued)

Primary Product	Units	Processed Product	Group 1	Group 2	Group 3
Wheat	1000 ha	Wheat flour	x	x	
		Wheat bran	x	x	
Rice	"	Polished rice		x	x
		Rice bran		x	x

2. INPUT PURCHASES

Input Purchases (Groups 2 and 3)

Input	Units (thousands)
Resident labor (G3)	Man-days
Urban labor (G3)	"
Family labor (G2)	"
Migrant labor (G1), (G2), (G3)	"
Urban labor (G2)	"
Machinery	hours
Draft animals (G2)	"
Draft animals (G3)	"
Credit	Quetzales
Ammonium nitrate	tons
Ammonium sulphate	"
Urea	"
Diammonium phosphate	"
(20-20-0)	"
(12-24-12)	"
(15-15-15)	"
(16-20-0)	"
Soil insecticides	Quetzales
Foilage insecticides	"
Fungicides	"
Herbicides	"
Local seed	tons
Improved seed	"

Input Purchases (Group 1)

Input	Units (thousands)
Family labor	Man-days
Rural labor	"
Machinery	hours
Draft animals	days
Credit	Quetzales
Urea	tons
Other fertilizers	"
Soil insecticides	Quetzales
Other chemicals	"

Table VI. Continued

3. DEMAND

Product Demand Functions Estimated	Products Sold at Fixed Prices
Maize	Lump molasses
Rice	Molasses
Beans	Rice and wheat bran
Sorghum	Cottonseed cake
Cassava	Lemon grass tea
Potatoes	
Wheat flour	
Sugar	
Coffee	
Cotton fiber	
Cottonseed oil	
Bananas (domestic consumption)	

4. INTERNATIONAL TRADE

Imports from the ROW[a]	Exports to the ROW[a]	Imports from Central America
Maize	Coffee	Maize
Beans	Cotton	Sorghum
Wheat	Sugar	Beans
Rice	Bananas (export)	Rice

5. NATIONAL ACCOUNTS

Labor income (six groups of labor)
Income by group (three groups)
Foreign exchange
Tariffs and taxes to exports
Transformation differential
Total income

[a]Rest of the World.

Table VII. Transformation Coefficients and Transformation Differentials Used in MAYA

Product	Transformation Coefficients		Transformation Differentials		
	Raw Product	Transformed Product	Group 1	Group 2	Group 3
			(Quetzales per kilogram)		
Maize	0.930		0.019	0.030	0.022
Rice				0.104	0.104
polished rice		0.643			
bran		0.077			
Sorghum	0.950			0.017	0.016
Wheat			0.076	0.068	
wheat flour		0.718			
wheat bran		0.194			
Beans	0.980		0.077	0.077	
Cassava	0.870			0.068	
Potatoes	0.900		0.055		
Bananas (domestic consumption)	0.720			0.122	0.122
Bananas (export)	0.870				
Sugarcane[a]					
sugar		0.084			0.014
molasses		0.036			
lump molasses		0.074			0.012
Sesame				0.189	
vegetable oil		0.391			
Cotton					0.122
cotton fiber		0.329			
cottonseed cake		0.255			
cottonseed oil		0.074			
Coffee				0.815	0.800
ground coffee		0.323			
Lemon grass tea	0.930				

[a]Sugarcane can be processed to obtain refined sugar and either liquid molasses or lump molasses as byproducts.

Table VIII. Labor Restrictions in MAYA per Month, by Group

Month	Number of Man-days[a]		Group 1		Group 2		Group 3	
	G1	G2, G3	family	hired	family	hired	resident	temporal
			(Thousands of man-days)					
January	23	22	2762	1527	4468	4088	717	1316
February	21	20	2522	1394	4062	3453	652	1196
March	23	22	2762	1527	4468	3716	717	1315
April	18	17	2167	1195	3453	4088	554	1017
May	23	21	2762	1527	4265	3159	685	1256
June	23	21	2762	1527	4265	3902	685	1256
July	23	21	2762	1527	4265	3902	685	1256
August	23	21	2762	1527	4268	3902	685	1256
September	23	21	2762	1527	4265	3902	685	1256
October	23	21	2762	1527	4265	3902	685	1256
November	23	22	2762	1527	4468	4088	717	1316
December	18	17	2162	1195	3453	3159	554	1017

[a]The number of man-days is defined as the number of calendar days per month less holidays and weekends, as suggested by the Institute of Agricultural Science and Technology.

Table IX. Demand Functions in MAYA

Product	Demand Equation[a]
Maize	P = 895 - 1.385 Q
Beans	P = 2,764 - 30.110 Q
Rice	P = 1,996 - 92.356 Q
Sorghum	P = 628 - 9.477 Q
Wheat flour	P = 1,808 - 14.260 Q
Potatoes	P = 1,093 - 29.100 Q
Cassava	P = 1,683 - 214.713 Q
Bananas	P = 1,677 - 10.369 Q
Sugar	P = 1,173 - 5.604 Q
Cotton	P = 4,940 - 309.698 Q
Coffee	P = 14,521 - 531.325 Q
Vegetable oil	P = 3,244 - 86.325 Q

[a]Price is expressed in quetzales per ton, and quantity in thousand tons.

Table X. Average Prices Received by Farmers in Guatemala, by Group, 1966-1977

Product and Group	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
						(Quetzales per ton)						
Maize												
G1	79.0	98.0	95.0	85.0	99.0	84.0	77.0	122.0	143.0	161.0	136.0	167.0
G2	71.0	92.0	94.0	80.0	92.0	73.0	75.0	115.0	129.0	147.0	128.0	158.0
G3	72.0	94.0	95.0	84.0	95.0	82.0	80.0	121.0	135.0	155.0	132.0	165.0
Beans												
G1	208.0	213.0	226.0	220.0	257.0	218.0	220.0	260.0	290.0	347.0	326.0	448.0
G2	202.0	194.0	218.0	202.0	249.0	209.0	203.0	250.0	283.0	358.0	321.0	425.0
G3	203.0	211.0	238.0	222.0	275.0	228.0	228.0	271.0	311.0	361.0	338.0	447.0
Rice												
G1	166.0	144.0	181.0	142.0	157.0	124.0	152.0	142.0	181.0	265.0	232.0	266.0
G2	152.0	162.0	139.9	116.0	162.0	128.0	132.0	140.0	157.0	200.0	224.0	255.0
G3	138.0	141.0	141.0	111.0	114.0	121.0	132.0	142.0	177.0	197.0	217.0	244.0
Sorghum												
G1	60.0	69.0	87.0	63.0	78.0	71.0	72.0	94.0	130.0	136.0	109.0	132.0
G2	62.0	73.0	79.0	64.0	77.0	66.0	64.0	96.0	119.0	137.0	110.0	131.0
G3	78.0	68.0	72.0	64.0	76.0	66.0	60.0	99.0	112.0	129.0	93.0	118.0

Table X. Continued

Product and Group	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
						(Quetzales per ton)						
Wheat												
G1	122.0	120.0	121.0	117.0	126.0	122.0	124.0	129.0	184.0	246.0	252.0	246.0
G2	127.0	139.0	126.0	137.0	126.0	117.0	130.0	131.0	182.0	228.0	258.0	242.0
G3	140.0	157.0	139.0	132.0	163.0	131.0	137.0	158.0	185.0	235.0	259.0	220.0
Potatoes												
G1	89.0	106.0	95.0	96.0	112.0	100.0	108.0	127.0	157.0	170.0	146.0	164.0
G2	122.0	136.0	128.0	137.0	150.0	122.0	125.0	112.0	179.0	184.0	167.0	196.0
G3	129.0	141.0	131.0	153.0	150.0	163.0	119.0	147.0	182.0	215.0	176.0	223.0
Coffee												
G1	111.0	98.0	92.0	108.0	113.0	109.0	103.0	119.0	127.0	142.0	243.0	507.0
G2	100.0	96.0	97.0	123.0	99.0	106.0	106.0	135.0	151.0	142.0	251.0	452.0
G3	92.0	85.0	82.0	90.0	92.0	87.0	88.0	102.0	132.0	151.0	234.0	447.0
Bananas												
G1	16.0	16.0	16.0	16.0	22.0	21.0	18.0	22.0	23.0	21.0	24.0	25.0
G2	19.0	21.0	21.0	21.0	25.0	25.0	22.0	24.0	24.0	30.0	31.0	26.0
G3	17.0	18.0	18.0	20.0	21.0	26.0	22.0	26.0	30.0	31.0	33.0	30.0
Cotton--National Average	160.0	161.0	147.0	155.0	160.0	156.0	180.0	213.0	232.0	333.0	222.0	...
Sugarcane--National Average	7.0	6.0	6.0	6.0	7.0	7.0	7.0	7.0	7.0	18.0	12.0	8.0

SOURCES: DGE and Ministerio de Economia; Banco de Guatemala.

Table XI. Cropped Area Response to Different ϕ Values as Estimated with MAYA, by Group

Farm Group and Product	Actual	Risk Levels			
		0-0-0	1.5-.75-.25	2-1.25-.75	2.5-1.75-1.25
		(Thousand hectares)			
Group 1					
maize	92.0	125.7	118.2	77.3	76.3
beans	2.0	---	---	---	---
maize-beans	31.0	53.0	53.2	58.4	58.3
potatoes	38.0	39.5	40.8	40.8	40.8
Group 2					
maize	208.0	237.1	240.0	249.1	251.3
beans	39.0	97.1	94.3	84.7	81.2
maize-beans	29.5	27.5	24.5	17.8	16.4
maize-sorghum	18.0	---	---	---	---
maize-sesame	9.0	22.7	22.4	20.1	19.3
sorghum	7.3	---	---	---	---
rice	9.0	11.8	12.2	12.2	12.2
wheat	5.0	---	---	---	---
cassava	1.0	0.8	0.8	0.8	0.8
bananas	26.9	---	---	---	---
coffee	131.0	120.0	120.0	120.0	120.0
Group 3					
maize	88.2	81.9	82.7	85.0	87.1
rice	4.2	---	---	---	---
sorghum	4.5	20.2	19.1	18.5	16.3
bananas (domestic consumption)	21.2	20.8	20.8	20.8	20.8
bananas (export)	5.5	5.5	5.5	5.5	5.5
cotton	102.0	96.7	97.0	99.0	99.6
coffee	117.4	95.0	95.0	95.0	95.0
sugarcane	65.0	66.4	66.4	62.7	62.1
lemon grass tea	4.4	---	---	---	---

Table XII. Production Response to Different ϕ Values as Estimated with MAYA, by Group

Farm Group and Product	Actual	Risk Levels			
		0-0-0	1.5-.75-.25	2-1.25-.75	2.5-1.75-1.25
		(Thousand tons)			
Group 1					
maize	159.0	227.8	217.9	168.6	167.0
beans	16.0	20.8	20.9	23.0	22.9
wheat	50.1	55.2	56.6	56.6	56.6
potatoes	62.5	65.8	64.7	64.7	63.5
Group 2					
maize	471.0	501.9	500.1	496.4	493.0
beans	45.0	82.2	78.9	69.1	65.9
sorghum	49.0	---	---	---	---
rice	15.0	26.6	27.4	27.4	27.4
sesame		11.8	11.6	10.4	10.0
wheat	6.0	---	---	---	---
cassava	9.7	8.3	8.3	8.3	8.3
bananas	27.0	---	---	---	---
coffee	166.0	163.7	163.7	163.7	163.7
Group 3					
maize	220.0	175.4	178.2	185.6	192.5
rice	7.6	---	---	---	---
sorghum	5.0	58.5	55.3	53.7	47.3
bananas (domestic consumption)	180.0	194.4	194.4	194.4	194.4
bananas (export)	336.0	347.6	347.6	347.6	347.6
cotton	318.0	308.9	309.7	316.1	318.2
coffee	295.0	267.6	267.6	267.6	267.6
sugarcane	5910.0	6041.7	6041.7	5705.2	5651.0
lemon grass tea	0.2	---	---	---	---

Table XIII. Area and Technology Response to Different Maize Prices as Estimated with MAYA, by Group

Product and (Technology)	Price per Ton (quetzales)						
	109.0	124.0	142.5	159.3	165.0	180.0	209.0
	(Thousand hectares)						
Group 1							
Single-crop maize	40.7	57.3	78.3	77.3	92.2	125.0	126.1
(A1)	40.7	57.3	78.3	77.3	92.2	125.0	119.0
(A4)							1.5
(D2)							5.6
Maize-beans (A1)	39.2	49.8	56.1	58.4	57.0	52.4	52.6
Wheat	40.7	42.7	43.6	40.9	40.8	40.8	39.6
(A3)	6.0	18.2	4.1	1.2	1.2	1.2	
(B3)	13.9						
(B4)		3.7	18.7	18.9	18.8	18.8	18.8
(C2)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
(C3)	9.5	9.5	9.5	9.5	9.5	9.5	9.5
(D3)	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Other	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Group 2							
Single-crop maize	199.5	221.7	246.6	249.0	265.5	261.3	252.3
(B3)	91.8	121.8	148.5	153.9	173.3	170.2	168.6
(C2)	107.7	99.9	98.1	95.1	92.2	91.1	83.7
Associated maize	75.0	65.2	40.3	37.9	21.5	25.6	30.6
Maize-beans (A1)	56.2	45.3	19.4	17.8	0.6	4.7	4.3
Maize-sesame (A1)	18.8	19.9	20.9	20.1	20.9	20.9	26.3
Beans (A1)	70.2	70.9	82.8	84.7	95.7	95.8	95.9
Rice (C1)	12.2	12.2	12.2	12.2	12.2	12.2	12.2
Sorghum (D3)							4.1
Other	121.0	121.0	121.0	121.0	121.0	121.0	121.0
Group 3							
Single-crop maize	75.0	81.2	82.6	85.0	87.4	88.2	97.6
(C1)	75.0	75.0	75.0	75.0	75.0	75.0	75.0
(D1)		6.2	7.6	10.0	12.4	13.2	22.6
Sorghum (D3)	19.1	19.1	18.5	18.5	16.9	16.3	11.5
Cotton (D3)	100.0	99.1	98.2	98.9	98.2	98.2	93.7
Other export crops	187.1	187.1	187.1	184.0	184.0	183.7	183.7

Table XIV. Yields, Input Use, and Risk per Hectare for Selected Activities in MAYA, by Group

Product and (Technology)	Yield Maize (kg)	Yield Other (kg)	Labor (man-days)	Draft Animals (hours)	Machinery (hours)	Fertilizers and Chemicals (Q)	Seeds (Q)	Risk[a] (Q)
Group 1								
Maize								
(A1)	1349		110.6					317.7
(A4)	2513		82.8			83.8	15.1	590.0
(D2)	2576		83.9		6.0	56.8		604.1
Maize-beans								
(A1)	1100	393	70.8	---		---	---	575.2
Group 2								
Maize								
(B3)	1300		39.2	---		7.0		275.9
(C2)	3200		48.4	8.0	4.0	51.8	13.7	549.3
Maize-beans								
(A1)	1300	429	130.5			9.7		627.6
Maize-sesame								
(A1)	1286	520	98.0			7.0	1.1	320.0
Beans (A1)		725	104.4			28.3		648.8
Group 3								
Maize								
(C1)	2040		27.3	3.2	7.0	2.0	7.6	435.4
(D1)	3250		28.0	---	13.3	32.2	13.7	693.4

[a] Risk is defined as the sum of absolute deviations of total returns per hectare from the fitted regression over a 10-year period.

APPENDIX B
EQUATIONS OF THE MODEL

Equations of the Model

MAYA contains 325 structural equations. Except for a few strictly accounting equations, they are set out fully in algebraic form in this appendix.

Capital letters represent variables and right-hand values, and Greek letters and lower case letters indicate parameters. A description of each term is also given for some equation sets, and the number of equations within each set is given on the right-hand side.

All of the equations are written in inequality form. Obviously, many of them will be binding in any solution, and hence, those equations could have been written as strict equalities. However, writing them as inequalities reduces the computer time associated with each solution, for it eliminates the need to pass through phase I of the simplex algorithm; and by appropriate use of the signs for equations with zero right-hand side elements, one can be sure that restrictions will be binding when exact equalities are desired (Cappi et al., 1978).

The initial step in preparing the model's computer version was to design a nomenclature for columns and rows, assigning certain fields to group indices, others to product and input indices, and so forth. This convention is not readily apparent in the equation names given below because empty fields are ignored. Special symbols were also used to designate restrictions (R) and balances (B). Product and input symbols (two characters) and all other abbreviations were dedicced upon at the outset. The equations were then developed in sets, beginning with group specific equations, and then moving to national balances and restrictions. A description of the notation used follows in Table XV.

MAYA Equations

1. Objective Function (FOB)

$$\sum_{j,g} \omega_{j,g} D_{j,g} + \sum_j p^e_j XR_j - \sum_j p^m_j MR_j - \sum_{t,\bar{\ell}} w_{\bar{\ell},h=1,2} SMF_{t,\bar{\ell},h=1,2}$$

$$- \sum_{t,\ell,h} w_{\ell,h} \overset{1/}{SMH}_{t,\ell,h} - \sum_{\bar{f}} c_{\bar{f}} SF_{\bar{f},h=1} - \sum_f c_f SF^*_f - \sum_q SQ_{q,h=1}$$

$$- \sum_q SQ^*_q - \sum_{\bar{s}} c_{\bar{s},h=1} S_{\bar{s},h=1} - \sum_s c^*_s S^*_s - c'_{h=1} SMQ_{h=1} - c'^* SMQ^*_q$$

$$- TCR_{h=1} - TCR^* - TR - TA \longrightarrow \max \qquad (1)$$

[area under the domestic demand function for final products] + [gross revenue from sale of exports] - [c,i,f value of imports] - [reservation wages of family labor G1, G2] - [market wage costs of hiring labor] - [total cost of fertilizers G1] - [total cost of fertilizers of both G2 and G3] - [total cost of chemicals G1] - [total cost of chemicals of both G2 and G3] - [total cost of seeds G1] - [total cost of seeds of both G2 and G3] - [total cost of machinery use G1] - [total cost of machinery use of both G2 and G3] - [total cost of credit, G1] - [total cost of credit, G2 and G3] - [total processing cost differential] - [total trade taxes] $\longrightarrow$ max

---

[1]Detailed in equations 11-14.

Table XV. Symbols Used to Define Variables in MAYA

Symbol	Description	Superscripts and Subscripts
Variables		
FOB	Objective function in millions of quetzales	
$D_{j,g}$	Demand curve interpolation weight variable (segment choice variable)	j = final (processed) product[a] g = demand curve segment
XR_j	Total export in thousand tons	
MR_j	Total imports in thousand tons	
$SMF_{t,\bar{\ell},h}$	Input of family labor in thousand man-days	t = time period in months (= 1, ..., 12) $\bar{\ell}$ = reservation wage (= 1, 2) h = farm group (= 1, 2, 3)
$SMH_{t,\ell,h}$	Sum of incomes of different types of labor in millions of quetzales	ℓ = market wage (= 1, ..., 6)
$SMR_{t,\ell,h}$	Hired labor in G1 and G2, residents in G3,[b] in thousand man-days	
$SMG_{t,\ell,h}$	Migrant labor from G1 and G2 in thousand man-days	
$SMU_{t,\ell,h}$	Urban temporary labor in G3 in thousand man-days	

Table XV. Continued

Symbol	Description	Superscripts and Subscripts
$SF_{\bar{f},h}$	Input of fertilizers in G1 in thousand tons	$\bar{f}$ = fertilizers I (= 1, 2)
SF^*_f	Input of fertilizers in G2 and G3 in thousand tons	* = indicates Gs and G3 f = fertilizers II (= 1, ..., 8)
$SQ_{q,h}$	Input cost of chemicals in G1 in millions of quetzales	q = type of chemical (= 1, ..., 4)
SQ^*_q	Input cost of chemicals in G2 and G3 in millions of quetzales	
$S_{\bar{s},h}$	Input of seeds in G1 in thousand tons	$\bar{s}$ = type I seeds (= 1, 2, 3)
S^*_s	Input of seeds in G2 and G3 in thousand tons	s = type II seeds (= 1, ..., 8)
SMQ_h	Input of machinery in G1 in thousand hours	
SMQ^*	Input of machinery in G2 and G3 in thousand hours	
TCR_h	Total cost of credit in G1 in millions of quetzales	
TCR^*	Total cost of credit in G2 and G3 in millions of quetzales	
TR	Total cost of processing products in millions of quetzales	

Table XV. Continued

Symbol	Description	Superscripts and Subscripts
TA	Total trade taxes in millions of quetzales	
$Q_{i,h}$	Quantity of crop in thousand tons	i = crop
D_j	Sales activity for fixed-price products in thousand tons	
$RMF_{t,h}$	Total monthly family labor available in G1 and G2 in thousand man-days	
$RMR_{t,h}$	Total monthly hired labor available in thousand man-days	
$RMU_{t,h}$	Total monthly temporal urbal labor available in G3 in thousand man-days	
$CIN_{\ell,h}$	Total income in millions of quetzales	
$P_{i,h}$	Area planted with crop i in thousand hectares	
$RTI_{t,h}$	Total land used per month in thousand hectares	
$RBU_{t,h}$	Total monthly hours of draft animals available in thousands	
$RMQ_{t,h}$	Total monthly tractor hours available in G1 in thousands	
RMQ^*_t	Total monthly tractor hours available in G2 and G3 in thousands	

Table XV. Continued

Symbol	Description	Superscripts and Subscripts
SCR_h	Total credit used by G1 farmers in millions of quetzales	
CRS	Total short term credit used by G2 and G3 in millions of quetzales	
CRM	Total medium term credit used by G2 and G3 in millions of quetzales	
CRL	Total long term credit used by G2 and G3 in millions of quetzales	
$z_{\bar{t},h}$	Total yearly income deviations from the mean in thousand quetzales	$\bar{t}$ = time period in years (= 1, ..., 10)
$\hat{s}_h$	Population income deviation estimates in millions of quetzales	
Parameters		
$\omega_{j,g}$	Areas under the domestic demand function in millions of quetzales	j = final product g = demand curve segment
p_j^e	Price of exports in thousand quetzales per ton	e = exports
p_j^m	Price of imports in thousand quetzales per ton	m = imports
$w_{\bar{\ell},h}$	Reservation wage in thousand quetzales per day	$\bar{\ell}$ = reservation wage (= 1, 2)

Table XV. Continued

Symbol	Description	Superscripts and Subscripts
$w_{\ell,h}$	Market wage in thousand quetzales per day	ℓ = market wage (= 1, ..., 6
$c_{\bar{f}}$	Unit cost of fertilizers in G1 in thousand quetzales	$\bar{f}$ = fertilizers I (= 1, 2)
c_f	Unit cost of fertilizers in G2 and G3 in thousand quetzales per ton	f = fertilizers II (= 1, ..., 8)
$c_{\bar{s},h}$	Unit cost of seeds in G1 in thousand quetzales per ton	$\bar{s}$ = type I seeds (= 1, 2, 3)
c_s^*	Unit cost of seeds in G2 and G3 in thousand quetzales per ton	s = type II seeds (= 1, ..., 8)
c'_h	Unit cost of machinery use in G1 in thousand quetzales per hour	
c'^*	Unit cost of machinery use in G2 and G3 in thousand quetzales per hour	
c_i	Unit of transformation differential in thousand quetzales per ton	i = crop
a_j^m	Import tax rate in thousand quetzales per ton	
a_j^e	Export tax rate in thousand quetzales per ton	
μ_i^j	Unit output of final good j from the processing of crop i, dimensionless	

Table XV. Continued

Symbol	Description	Superscripts and Subscripts
$\theta_{j,g}$	Quantity of product j sold at segment g of the demand curve in thousand tons	
$y_{i,h}$	Yield per hectare in kilograms	
$P_{i,h}$	Farm-gate price in thousand quetzales per ton	
$\lambda_{i,t,h}$	Labor requirements in days per month per hectare	
$\phi^{\bar{r}}_{i,h}$	Fertilizer requirements in G1 in kilograms per hectare	$\bar{r}$ = fertilizers used by G1 (= 1, 2)
$\phi^{r}_{i,h}$	Nutrient requirements in G2 and G3 in kilograms per hectare	r = nutrient type (= 1, 2, 3)
k^{r}_{f}	Percent of nutrient r needed per tone of fertilizer f in kilograms per hectare	f = fertilizers used by G2 and G3 (= 1, 2, ..., 8)
$\kappa_{i,q}$	Cost of chemical q in quetzales per hectare	q = type of chemical (= 1, ..., 4)
$\tau_{i,t,h}$	Machinery requirements per month per hectare in tractor hours	t = time in months (= 1, ..., 12)
$\alpha_{i,t,h}$	Draft animals requirements per month per hectare in hours	

Table XV. Continued

Symbol	Description	Superscripts and Subscripts
Σ_i	Seeds requirements in kilograms per hectare	
$\bar{y}_{i,\bar{t},h}$	Coefficient of income deviations from the mean in year $\bar{t}$ in quetzales per hectare	$\bar{t}$ = time period in years

[a] Some final products do not require processing.

[b] G1, G2, and G3 refer to farmer groups 1, 2, and 3.

2. Processing costs accounting row (RTRRI)

$$- TR + \sum_{i,h} c_i Q_{i,h} \leq 0 \qquad (1)$$

$- [$total processing cost differential$] + \sum_{i,h} [$unit costs times quantity processed of raw product i$] \leq 0$

3. Trade taxes accounting row (RTARI)

$$- TA + \sum_j a^m_j MR_j + \sum_j a^e_j XR_j \leq 0 \qquad (1)$$

$- [$total trade taxes$] + \sum_j [$import tax rate times quantity imported$] + \sum_j [$export tax rate time quantity exported$] \leq 0$

4. Consumer level commodity balances for endogenous price products (BjBP)

$$- \sum_h \mu^j_i Q_{i,h} + \sum_g \theta_{j,g} D_{j,g} - MR_j + XR_j \leq 0 \qquad (12)$$

$- \sum_h [$net output of final good j from the processing of farm-gate product i$] + \sum_g [$quantity of final product j demanded$] - [$total imports of product j$] + [$total exports of product j$] \leq 0$

5. Consumer level commodity balances for fixed price products (BiBP)

$$- \sum_h \mu^j_i Q_{i,h} + D_j - MR_j + XR_j \leq 0 \qquad (5)$$

6. Convex combination constraints on the interpolation weight variables for the demand function (RjRC)

$$\sum_g D_{j,g} \leq 1.0 \qquad (12)$$

7. Family-labor constraints for Groups 1 and 2 (hRMF)

$$SMF_{t,h} + SMG_{t,h} \leq RMF_{t,h} \qquad h = 1, 2 \qquad (24)$$

[Supply of family labor in month t] + [Supply of migratory labor in month t] $\leq$ [Total availability of family labor]

8. Hired-labor constraints (hRMR)

$$SMR_{t,h} \leq RMR_{t,h} \qquad (36)$$

9. Regional temporal labor constraints of Group 3 (RMU)

$$SMU_{t,h} \leq RMU_{t,h} \qquad (12)$$

10. Hired-labor income balances (lBINBI)

$$\sum_t w_{\ell,h}\, SMR_{t,\ell,h} - CIN_{\ell,h} \leq 0 \qquad \ell = h = 1, 2 \qquad (2)$$

$\sum_t$ [wage coefficient times total number of man-days of hired labor] - [total income earned by hired labor] $\leq$ 0

11. Migratory-labor income balances (lBINBI)

$$\sum_t w_{\ell,h}\, SMG_{t,\ell,h} - CIN_{\ell,h} \leq 0 \qquad \begin{matrix} h = 1 \\ \ell = 3 \end{matrix} \text{ and } \begin{matrix} h = 2 \\ \ell = 4 \end{matrix} \qquad (2)$$

$\sum_t$ [wage coefficient times total number of man-days of migratory labor] - [total income earned by migratory labor] $\leq$ 0

12. Resident-labor income balance (lBINBI)

$$\sum_t w_\ell \, SMR_{t,\ell,h} - CIN_{\ell,h} \leq 0 \qquad \ell = 5 \text{ and } h = 3 \qquad (1)$$

$\sum_t$ [wage coefficient times total number of man-days of resident labor] - [total income earned by resident labor] $\leq$ 0

13. Temporal-labor income balance (lBINBI)

$$\sum_t w_\ell \, SMU_{t,\ell,h} - CIN_{\ell,h} \leq 0 \qquad \ell = 6 \text{ and } h = 3 \qquad (1)$$

$\sum_t$ [wage coefficient times total number of regional-urban labor man-days] - [total income earned by regional-urban labor] $\leq$ 0

14. Producer level product balances (hBiBP)

$$- y_{i,h} \, P_{i,h} + 1000 \, Q_{i,h} \leq 0 \qquad (27)$$

[yield per hectare times total number of hectares planted with crop i] + [scale factor times total number of tons produced] $\leq$ 0

15. Producer income balances (hBINBI)

$$\sum_i P_{i,h} \, Q_{i,h} - INC_h \leq 0 \qquad (3)$$

$\sum_i$ [farm gate price of product i times quantity produced] - [total income of producers] $\leq$ 0

16. Land constraints (hRTI)

$$\sum_i P_{i,t,h} \leq RTI_{t,h} \qquad (36)$$

$\sum_i$ [total number of hectares planted with product i]

$\leq$ [total area planted]

17. Labor input balances for Groups 1 and 2 (BMh)

$$\sum_i \lambda_{i,t,h} P_{i,t,h} - SMF_{t,h} - SMR_{t,h} \leq 0 \quad h = 1, 2 \qquad (24)$$

$\sum_i$ [labor requirements per hectare times total number of hectares planted] - [supply of family labor] - [supply of hired labor] $\leq$ 0

18. Labor input balances for Group 3 (BMh)

$$\sum_i \lambda_{i,t,h} P_{i,h} - SMR_{t,h} - SMU_{t,h} - SMG_{t,h} \leq 0 \quad h = 3 \qquad (12)$$

$\sum_i$ [labor requirements per hectare times total number of hectares planted] - [supply of resident labor] - [supply of urban labor] - [supply of migratory labor from Groups 1 and 2] $\leq$ 0

19. Fertilizer balances for Group 1 (hBF)

$$\sum_i \phi^{\bar{r}}_{i,h} P_{i,h} - SF_{\bar{f},h} \leq 0 \quad h = 1 \qquad (2)$$

20. Fertilizer balances for Groups 2 and 3 (hBF)

$$\sum_{i,h} \phi^r_{i,h} P_{i,h} - \sum_f k^r_f SF^*_f \leq 0 \qquad h = 2, 3 \qquad (3)$$

21. Chemicals balances for Group 1 (hBQq)

$$\sum_i \kappa_{i,q} P_{i,h} - SQ_{q,h} \leq 0 \qquad h = 1 \qquad (4)$$

22. Chemical balances for Groups 2 and 3 (hRQq)

$$\sum_{i,h} \kappa_{i,q} P_{i,h} - SQ^*_q \leq 0 \qquad h = 2, 3 \qquad (4)$$

23. Machinery use restrictions (hRMQ) for Group 1

$$\sum_i \tau_{i,t,h} P_{i,t,h} \leq SMQ_{t,h} \qquad h = 1 \qquad (11)$$

24. Machinery use restrictions for Groups 2 and 3 (hRMQ)

$$\sum_{i,h} \tau_{i,t,h} P_{i,t,h} \leq RMQ^*_t \qquad h = 2, 3 \qquad (8)$$

25. Draft animals restrictions (hRBU)

$$\sum_i \alpha_{i,t,h} P_{i,h} \leq RBU_{t,h} \qquad (17)$$

26. Seeds balances for Group 1 (hBiS2)

$$\sum_i \sigma_i P_{i,h} - S_{\bar{s},h} \leq 0 \qquad h = 1 \qquad (3)$$

27. Seeds balances for Groups 2 and 3 (BiS2*)

$$\sum_{i,h} \sigma_i \, P_{i,h} - S_s^* \leq 0 \qquad h = 2, 3 \qquad (8)$$

28. Credit balance for Group 1 (hBCR)

$$\sum_f c_f \, SF_{f,h} + \sum_{q,h} SQ_{q,h} + \sum_s c_s \, S_{s,h} + c'_h \, SMQ_h$$

$$- SCR_h \leq 0 \qquad h = 1 \qquad (1)$$

29. Credit balance for Groups 2 and 3 (BCR*)

$$\sum_{f,h} c_f \, SF_{f,h} + \sum_{q,h} SQ_{q,h} + \sum_{s,h} c_s \, S_{s,h} + c'^* \, SMQ^*$$

$$- (CRS + CRM + CRL) \leq 0 \qquad h = 2, 3 \qquad (1)$$

30. Risk balance rows (hRRI)

a. Revenue balances

$$\sum_i \bar{y}_{i,\bar{t},h} \, P_{i,h} - z_{\bar{t},h} \geq 0 \qquad (30)$$

$\sum_i$ [coefficient of income deviations from the mean times area planted with product i] - [total of income deviations in period t] $\geq$ 0

b. Total sum of negative deviations

$$\sum_{\bar{t}} 2 \, z_{\bar{t},h} - 7569 \, \hat{s} = 0 \qquad (3)$$

$\sum_{\bar{t}}$ [constant times total of income deviations over $\bar{t}$] - [constant times the population income deviation estimator] = 0

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BIOGRAPHICAL SKETCH

Hilda Yumiseva was born in Quito, Ecuador, on June 13, 1948. She completed high school in 1967 and obtained her B.A. degree in economics in 1970. During 1971-1972 she did the course work for the master's degree at the University of the Americas in Puebla, Mexico. In 1973 she obtained an OAS scholarship and enrolled in the Ph.D. program at the University of Florida. She completed her course work in 1976 and has since worked at the World Bank and the Secretariat of Central American Economic Integration in Guatemala City. Upon the completion of her doctorate she plans to continue working in Washington, D.C.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Max R. Langham, Chairman
Professor of Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Chris O. Andrew, Co-chairman
Professor of Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

W. W. McPherson

W. W. McPherson
Graduate Research Professor of Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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December, 1981

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