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J. DULOY

A PROGRAMMING MODEL OF THE AGRICULTURE SECTOR IN MEXICO

John H. Duloy and Roger D. Norton
Development Research Center
International Bank for Reconstruction and Development

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A PROGRAMMING MODEL OF THE AGRICULTURE SECTOR IN MEXICO 1/

John H. Duloy and Roger D. Norton

I. Introduction

The model for the agricultural sector in Mexico, CHAC 2/, was first envisioned in the framework of a multi-level planning study. Other parts of the study are addressed to economy-wide and energy sector policies; the role of CHAC is to formalize the main aspects of micro-level and sectoral decision-making in agriculture. The broad theme of the overall study is linkages between different levels of decision-making, but, as is usual in the case of large scale model building exercises 3/, there is more than one underlying purpose.

1/ This paper is a report on a large-scale, long-term research project being carried under the joint auspicies of the Mexican Government and the World Bank. A fuller version is forthcoming as several chapters in a North-Holland monograph on multi-level planning in Mexico. As in any large-scale undertaking, a number of individuals have been involved; a brief list of the major contributors includes Dr. Luciano Barraza of the Secretaría de Agricultura y Ganadería, Dr. Donald Winkelmann of the Ford Foundation in Mexico, Lic. Luz María Bassoco of the Secretaría de la Presidencia, Lic. Teresa Rendón of the Banco de Mexico, and Mr. Gary Kutcher of the World Bank. Lic. Leopoldo Solís of the Secretaría de la Presidencia has provided generous support and encouragement; Dr. Louis M. Goreux of the World Bank and Dr. Alan S. Manne of Stanford University conceived the idea of the agricultural study and have provided many helpful comments.

2/ One of CHAC's earlier manifestations was as a rain god of the Maya.

3/ CHAC alone has some 1500 equations and about 3000 activities.

Basically, the agricultural sector study has been oriented toward (a) the Mexican government's interest in analytic tools for planning sectoral policies, and (b) the World Bank's interest in the methodology of both project appraisal techniques and general policy planning models. As a tool for policy makers, CHAC is designed to be addressed to questions of pricing policies, for both inputs and outputs, trade policies, employment programs, and some categories of investment allocation. It is not particularly well suited for analyzing agricultural research and extension programs, crop insurance policies, or credit policies. It is structured so that it is a simple matter to change factor prices, including costs of labor, capital, water, and agricultural chemicals, and to fix product prices at alternative support price levels. The prices received by farmers and paid by consumers for tradeable commodities also may be adjusted readily to reflect tariff, taxation, and exchange rate policies.

Employment in agriculture is one of the major focuses of CHAC. The model is designed to yield the monthly employment patterns for farmers and hired labor, in twenty different geographical areas, and the interregional seasonal migration patterns which are associated with each set of policy assumptions. Accompanying parametric solutions are conducted to estimate the scope for labor-capital substitution (the first of these solutions are reported in section IV below). The model's structure makes it possible to divide labor absorption possibilities into three categories: those arising purely from the technology set, those arising from changes in the product mix, with consequent changes in relative product prices, and those arising from international trade.

The general project appraisal question to which CHAC is addressed is the effect of additional information on the project decision. In CHAC, the "projects" take the form of a package of investments in a particular locality. The question then arises as to how much information is required about the technology set of the particular locality, about the supply responses of other localities, about commodity demand functions, and about the appropriate shadow prices of sector-wide and economy-wide resources in order to make "acceptable" investment decisions. The model is designed to shed some light on these questions by embedding a set of investment choices for a particular submodel in a framework of narrower or wider information flows.

As a more general methodological study, the main interests are in the inclusion of price-responsive demand structures in linear programming, in different measures of factor substitution in the n product m factor case, in aggregation procedures, and in decomposition procedures for planning models.

II. Structure of the Model

i) Overview

CHAC is a sector-wide model in the sense that it describes total national supply and use - production and imports, domestic demand and exports - for the forty principal crops in Mexico 1/. It is a one-period model, so the timing of investment decisions cannot be studied, but investment choices are included in the model. On the demand side, consumer behavior is assumed to be price elastic, and commodity prices are endogenous to the model. On the production side it is decomposable into twenty submodels. Each submodel represents a geographical entity and each may be solved as an individual model, with appropriate assumptions on prices. In this manner, some of the differences between partial and general equilibrium approaches may be explored.

Separation of sources of supply and demand, for both products and factor inputs, is the basic rule under which the model is specified. For each crop, there are numerous alternative supplying activities, including imports and production under different techniques in different locations. There are corresponding activities for sales on the domestic and export markets. Effectively the model contains (multiple step) supply and demand functions for each crop, and these functions for different crops are interdependent.

1/ These forty crops represent about 95% of the value of crop production in Mexico.

Table 1. AREA AND VALUE OF PRODUCTION OF THE CROPS IN CHAC 1/

1966/1967

CROPS	Irrigated Area harvested (ha.)	Irrigated Value (000 pesos)	Non-irrigated Area harvested (ha.)	Non-irrigated Value (000 pesos)	Total Area harvested (ha.)	Total Value (000 pesos)	% of Total Value
Maíz	441,939	826,407	7,844,996	7,681,953	8,286,935	8,508,360	29.17
Algodón pluma	415,997	2,521,700	279,382	887,876	695,379	3,409,576	11.68
Caña de azucar	85,280	445,141	402,318	1,572,298	487,598	2,017,439	6.91
Frijol	45,569	109,628	2,194,453	1,704,005	2,240,022	1,813,633	6.21
Trigo	421.685	1,113,180	304,910	304,050	726,595	1,417,230	4.86
Café beneficiado	1,527	6,121	298,475	1,196,379	300,000	1,202,500	4.12
Sorgo en grano	268,037	487,479	307,823	414,040	575,860	901,519	3.09
Naranja	1,768	11,646	78,232	762,754	80,000	774,400	2.65
Alfalfa verde	24,784	151,465	83,347	602,982	108,131	754,477	2.59
Plátano	4,757	39,761	71,243	697,786	76,000	737,547	2.53
Jitomate	18,713	641,201	26,533		45,246	590,273	2.02
Arroz palay	58,482	211,843	94,160	206,916	152,642	418,759	1.44
Palma (copra)	16,789	66,362	64,461	328,888	81,250	395,250	1.35
Henequen	-	-	185,300	352,000	185,300	352,000	1.21
Ajonjolí	36,349	71,281	215,760	278,877	252,109	350,158	1.20
Cártamo	100,679	201,768	64,254	126,633	164,933	328,401	1.15
Fresa	3,371	45,412	5,454	282,849	8,825	328,261	1.14
Tabaco en rama	2,348	25,913	37,260	277,127	39,608	303,040	1.04
Sandia	3,272	20,669	30,228	258,637	33,500	279,306	0.96
Papa	3,428	33,550	30,854	228,382	34,282	261,932	0.80
Aguacate	601	4,240	9,549	225,353	10,150	229,593	0.79
Chile verde	5,975	57,337	36,527	150,417	42,502	207,754	0.71
Garbanzo	28,533	41,538	132,574	159,109	161,107	200,647	0.70
Mango	186	4,008	8,774	191,248	8,960	195,256	0.67
Vid	5,094	42,700	9,406	148,700	14,500	191,400	0.66
Cebada en grano	14,691	41,792	226,059	135,626	240,750	177,418	0.61
Pina	-	-	9,924	175,913	9,924	175,913	0.60
Chile seco	765	8,740	23,619	144,757	24,384	153,497	0.55
Alfalfa achicalada	31,989	137,819	-	-	31,989	137,819	0.47

Table 1 (continued)

CROPS	Irrigated		Non-irrigated		Total		
	Area harvested (ha.)	Value (000 pesos)	Area harvested (ha.)	Value (000 pesos)	Area harvested (ha.)	Value (000 pesos)	% of Total Value
Cacao en grano	417	692	69,583	136,508	70,000	137,200	0.47
Soya	42,601	122,771	11,642	12,635	54,243	135,346	0.46
Melón	7,167	68,689	8,567	65,272	15,734	133,961	0.46
Cacahuate	5,452	16,473	57,229	103,982	62,681	120,455	0.41
Camote	-	-	16,150	110,279	16,150	110,279	0.38
Cebolla	1,725	12,306	15,281	72,014	17,006	84,320	0.29
Papaya	301	5,669	2,949	51,379	3,250	57,048	0.20
Avena en grano	963	1,993	74,457	54,131	75,420	56,124	0.19
Haba	1,307	2,283	46,393	51,422	47,700	53,705	0.18
Ajo	602	5,430	5,231	30,305	5,833	35,735	0.12
Linaza	4,369	10,917	14,133	22,755	18,502	33,672	0.12

1/ Sources: Dirección General de Distritos de Riego, Secretaría de Recursos Hidráulicos, México; and Dirección General de Economia Agrícola, Secretaría de Agricultura y Ganadería, México.

The specification of alternative modes of supply is quite detailed, so that in most cases there are several dozen steps in the supply function. The demand formulation is flexible: it permits arbitrarily close linear approximation to a quadratic form, in the event of full information on the true demand functions, but it also may be based on very limited information on demand. Commodity balance equations require the clearing of markets, with simultaneous determination of equilibrium prices and quantities. Commodity prices are either completely endogenous (for non-traded goods) or endogenous between import and export prices. The assumed import and export prices may be varied in alternative solutions to reflect different world market conditions and tariff policies, and sets of prices may be fixed in order to investigate the effects of price support policies.

The incorporation of demand functions, instead of exogenous product prices, provides a more realistic description of aggregate market conditions faced by farmers, and it reduces the tendency of such programming models to seek solutions with extreme crop specialization. It also opens the door to investigation of alternative forms of market equilibrium. Under appropriate objective functions, the same model may simulate a sector which behaves either as a monopolistic supplier of products or as a collection of competitive producers. And by casting one of the two objective functions in the role of a constraint, it is possible to explore the trade-offs and complementarities between producers' and consumers' welfare 1/.

1/ These properties of the model are developed more fully in section II (v) below.

The cropping activities in the model also constitute factor demand activites. Factors are supplied by a separate set of factor supply activities, and there are balance equations which require equilibrium on the factor markets. The factor supply functions range from the perfectly elastic, for those inputs for which the agriculture sector is a price taker (e.g., chemicals, capital), to the perfectly inelastic (e.g., some categories of land). In the former category, factor prices are exogenous to the model, in the latter they are endogenous, and in intermediate cases they are endogenous within limits. Labor falls in the intermediate category. When factor prices are exogenous, the factor is regarded as a national resource, i.e., it has alternative uses in other sectors or in international trade. At the other extreme, factors in inelastic supply are purely sectoral resources which have no economic use outside the sector in the short-run; agricultural land and water are placed in this category.

Demands for land, labor, and water are generated monthly. All other inputs are treated on an annual basis, including services of farm machinery and draft animals. This is one of the instances of the model's being tailored to specifically Mexican conditions. Virtually all farm machinery (mainly tractors) is used in the irrigated areas of the central plateau and the arid northern zones, and due to the nearly uniform year-round climate in these areas, there is not a very pronounced degree of seasonality in aggregate demand for machinery services. Hence, to simplify an already complex model, the monthly specification has been dropped in this case.

Labor [1] is divided into three classes: farm owners plus their family labor, hired (landless) agricultural labor, and machinery operators. Local and interregional migration is permitted in the model for landless labor and for farmers on rainfed farms; associated with each solution there is a pattern of seasonal employment in each locality and a pattern of inter-regional seasonal migration. Machinery operators constitute less than five percent of the agricultural labor force, and they do not appear to be a binding resource in Mexican agriculture, so they are assumed to be supplied in fixed proportion to machinery services - with infinite elasticity of supply. The wage for machinery operators is higher than the wage for hired labor, and both types of wages vary among regions, in accordance with observed behavior.

In any particular month, farmers are assumed to be willing to work for an own wage, or reservation price, which is lower than the hired labor wage. Thus the basic steps on the labor supply function are the following: (1) using the labor of the farmer and his family, (2) hiring local landless labor, (3) hiring surplus landless labor from other regions, and (4) hiring landless labor away from lower-productivity employment in other regions. The model is structured in a form that permits ready adjustment of all wages, so that various experiments - such as measuring capital labor substitution - may be conducted.

1/ Labor in the model is discussed more fully in section II (iv) below.

ii) Spatial Disaggregation

On the product supply side, each of the twenty submodels represents either irrigated, rainfed, or tropical cultivation, and each covers a particular set of counties or districts, which are not necessarily contiguous. In the case of rainfed and tropical agriculture, the submodels are defined on the basis of annual rainfall and altitude, which determine climatic conditions. Cropping and investment activities are specified by submodel. The submodels are grouped into four geographical regions, and labor constraints are specified for each region, in order to capture the differential labor mobility and wage rates which exist in Mexico. The regions are as follows (see map):

(I) The Northwest - an arid region of large scale irrigation along a thousand-mile coastal strip between the Gulf of California and the Sierra Madre Occidental, plus Baja California. Agriculture is more extensively mechanized here than in any other region.

(II) The North - the rest of the northern part of the dountry; this region is also extremely arid and cultivatable only with irrigation except for the eastern portions near the Gulf of Mexico.

(III) The Central Plateau - an area of mixed rainfed and irrigated farms, concentrated along the course of the Lerma River; the farms are generally smaller than in the North and Northwest; twenty years ago this was the most productive region in Mexican agriculture, but it has been surpassed by the northern regions.

(IV) The South - tropical agriculture with very few systems of water control; due to the mountainous terrain, this region is the most remote from the major urban markets.

While there are landless agricultural laborers who live in each region, gaining a livelihood from part-time work on irrigated farms, the bulk of them reside in the Central Plateau region, where there is closer access to the major urban centers for part-time work and where small rainfed plots may be cultivated. The dominant direction of seasonal labor migration is between the Central Plateau and the North and Nortwest. There also is some movement from the South to the Central Plateau and the northern regions, but due to the distances involved this is more apt to be permanent rather than seasonal migration. To help limit the size of the model, seasonal and permanent migration activities have been specified only for the directions of significant net flow, i.e. (a) from Central Plateau to Northwest, (b) from Central Plateau to North, and (c) from South to Central Plateau. Observed wages for hired labor are lowest in the South and highest in the Northwest. This reflects, at least in part, the relative abundance of labor in the tropical areas and the Central Plateau: migration is a gradual process and disequilibria in regional labor markets often persist for decades.

The local constraints for each submodel - primarily the annual and monthly bounds on land, water, and farmers - form a block in the block-diagonal production tableau. Since the constraints in one block are independent of all other constraints, additional submodels may be added to the system, with appropriate modifications in the coverage of the existing submodels. In this way, the model may be focused on the detailed choices in one geographical area, while treating other areas in a more aggregate fashion.

Table 2 - Spatial Components of CHAC

Region	Location 1/	Farm Type 2/	Submodels Number	Submodels Name
Northwest	Río Yaqui	I	1	Rio Yaqui
	Culiacán Rio Humaya San Lorenzo	I	2	Culmaya
	Río Colorado	I	3	Rio Colorado
	Comisión del Fuerte	I	4	El Fuerte
	3/	I	5	Residual Northwes
North	4/	I	6	North Central
	5/	I	7	Northeast
Central Plateau 18/	6/	LR	8	El Bajio A 7/
	6/	SR	9	El Bajio B 7/
	Alto Río Lerma La Begoña	I	10	El Bajio Irrigated 7/
	Lands between 1500 and 200 meters of elevation with 600 to 800 mm. of annual rainfall 8/	R	11	Temporal A
	Lands of 1500 to 2000 meters elevation with more than 800 mm. of rainfall 9/	R	12	Temporal B
	Lands of 1000 to 2700 meters elevation with 400 to 600 mm. of rainfall 10/	R	13	Temporal C
	Lands of 2000 to 2700 meters elevation with 600 to 800 mm. of rainfall 11/	R	14	Temporal B
	Lands of 500 to 1500 meters elevation with 700 to 900 mm. of rainfall 12/	R	15	Temporal E
	13/	R	16	Central Irrigated
South 18/	Lands of 0 to 500 meters elevation with 900 to 1500 mm. of rainfall 14/	T	17	Tropical A
	Lands of 0 to 500 meters elevation with more than 1500 mm. of rainfall 15/	T	18	Tropical B
	Lands of 500 to 1500 meters elevation with more than 900 mm. of rainfall 16/	T	19	Tropical C
	17/	I	20	South Irrigated

Notes to table 2

1. For irrigation submodels, the location is defined in terms of the administrative irrigation districts of the Ministry of Water Resources (S.R.H). For rainfed and tropical areas, altitude and rainfall define the submodels, and each submodel's precise coverage is stated in terms of municipios (counties). Each municipio is assigned wholly to one submodel.

2. The farm types are as follows:
   I - irrigated
   LR - rainfed, large farms (ten has. or more)
   SR - rainfed, small farms (less than ten has.)
   R - rainfed
   T - tropical

   In many of the irrigation submodels there are additional distinctions among farms, based primarily on efficiency in water use.

3. The remaining S.R.H. districts in the states of Baja California, Sonora, and Sinaloa: Santo Domingo; Guasave; Mocorito; Colonías Yaquis; Costa de Hermosillo; Río Altar; Río Altar, Pitiquito y Caborca; Río Mayo; Guaymas.

4. The nine S.R.H. districts in the states of Chihuahua, Coahuila, and Durango (including Don Martín, which is in both Coahuila and Nuevo León).

5. The nine S.R.H. districts in the states of Nuevo León and Tamaulipas.

6. The rainfed portions of the 17 municipios in Guanjuato which are at least partly contained in the S.R.H. districts of Alto Río Lerma and La Begoña.

7. In order to evaluate a set of investment alternatives which includes transforming rainfed land into irrigated land, submodels 8, 9, and 10 are solved together, known collectively as "El Bajío".

8. Mostly the states of Puebla, Guanajuato, Hidalgo, and Querétaro.

9. Mostly the states of Jalisco, Michoacán and Morelos.

10. Mostly the states of the northern part of the Central Plateau plus those further north.

11. Mostly the state of México.

12. Mostly the states of Oaxaca, Guerrero, Nayarit and Véracruz.

13. The 73 irrigation districts in the states of Jalisco, Mexico, Michoacán, Morelos, Hidalgo, Aguascalientes, Puebla, Querétaro, Tlaxcala, and Zacatecas. Virtually all of these districts are quite small compared to those of the North and the Northwest.

14. Mostly the states of Chiapas, Guerrero, and Véracruz.

15. Mostly the states of Tabasco, Campeche, and Yucatán.

Notes to table 2, cont.

16. Mostly part of Puebla, Chiapas, and Véracruz.

17. The 31 irrigation districts in the tropical states of Véracruz, Chiapas, Campeche, Yucatan, Guerrero, Oaxaca, Colima, and Nayarit.

18. The coverage of the various rainfed and tropical submodels does not fall entirely in the Central Plateau and Tropical regions, respectively. However, the regional designations are good approximations, and the wages in rainfed and tropical areas are very similar in magnitude to those of the Central Plateau and South regions in general.

Demand functions are not specified for each submodel 1/, but rather nationally, except for a few food crops for which a separate South region market is introduced, due to the high cost of transportation between the tropics and other parts of Mexico. However, it is not assumed that each submodel can equally well supply the "national" market. Spatial price differential parameters are used which reflect the differential transport costs faced by each submodel area, based on the historical patterns of transportation. Thus the Northwest region farmers receive a lower farm-gate price for vegetables than the Central Plateau farmers do, for the latter are located closer to the major urban markets of Mexico City and Guadalajara. For export crops, proximity to major ports determines the spatial pattern of price differentials.

In the case of the South, the submodels there may sell maize, for example, against a downward sloping local demand schedule and, by incurring a fixed transportation charge per ton, offer any additional maize on the national market. Similarly, the Central Plateau has the option of selling part of its output on the South's market, provided it incurs the transportation differential 2/.

1/ For two reasons: there is insufficient information on the spatial distribution of demand, and the introduction of local demand activities would make the model much larger.

2/ Local markets can be introduced for areas other than the South, but as a first approximation they have been omitted.

iii) The Production Technology Set

CHAC contains approximately 2500 cropping activities to describe alternative techniques for producing the forty crops. Each cropping activity defines a yield and fixed proportions of the following current inputs: land (monthly), water (monthly, annual), labor (monthly), machinery services, draft animals, chemicals, purchased seeds, and short-term institutional credit. Relations between inputs and outputs are taken to be those which are observed (and projected) in each locale, and not necessarily the biological or profit-maximizing optima. In principle, possibilities for movement toward more nearly optimal input mixes could be represented with activities for extension services, but existing data do not provide a basis for doing so.

The ratio of each input to output varies over the submodels for every crop . Some localities have shorter growing seasons than others, so the number of months of land differs; fertilization practices vary, especially between irrigated and non-irrigated areas; and for irrigation the amount of gross water release required at the dam depends on the length and condition of the canals, and this too varies from area to area. In addition to these variations across submodels, there are systematic variations within many of the submodels in the input-output ratios, particularly in the amounts of water, machinery services, and labor per unit of output 1/.

1/ Variations in water-output ratios occur within five of the ten irrigation submodels, and the machinery and labor requirements per unit of output vary within all twenty submodels.

For some of the irrigation submodels, the land is grouped into four classes, based on efficiency of gross water use 1/. Observed average yields differ over these land classes. Given approximately standard practices within a submodel area with respect to fertilization, seed and credit use, the amounts of these inputs per unit of output also differ over land classes.

For all of the submodels, alternative degrees of mechanization have been specified for attaining the same yields. Three degrees of mechanization have been specified in CHAC: totally non-mechanized (all power operations done with draft animals), partially mechanized, and fully mechanized (no draft animal use). Obviously there can be many degrees of partial mechanization, but in actuality the choices are discrete and few, e.g., the plowing is done with either mules or tractors but not with both. To avoid overstating farmers' short-run flexibility with respect to technique, one-degree changes of technique are permitted but not two-degree changes. If the farmers in the area covered by one submodel use totally non-mechanized techniques, that submodel contains non-mechanized and partially mechanized techniques only. Similarly, it is assumed that fully mechanized farms may revert to partial mechanization but not to non-mechanization, under significant relative price changes.

1/ Which in turn is due to terrain conditions, distance from the water source, and state of repair of the canals. The land classes are designated by the Secretaría de Recursos Hidraulicos.

The major advantage of mechanization, vs. use of draft animals, lies in land savings. A crop can be harvested, and the ground prepared for a new crop, significantly faster with tractors than with draft animals 1/. In some cases, this time saving makes the difference of being able to plant a second crop during the year. This saving is shown in the model by requiring fewer months of land with the more mechanized techniques, e.g., the first month of land is represented by a coefficient of 0.3 instead of 1.0 (one hectare for ten days instead of thirty days).

Differential land (and labor) requirements also constitute the distinction between two forms of the crop in the case of alfalfa: the crop may be sold green, at a lower price per ton, or left on the land longer and sold dry, at a higher price. In the case of barley, the farmer also faces a choice - of harvesting the entire plant and selling it as forage, or of using substantially less labor and harvesting only the grain. As in the case of alfalfa, there is a separate demand function for both types, 2/ so prices move in the model in response to these production choices. For grain barley, there is an additional component on the demand side, the demand for malt grain. There is a minor amount of post-harvest on-farm processing for the grain which is destined for malt, but this is ignored as an approximation, so there are two markets specified for grain barley: malt and non-malt.

1/ One might think that the same savings could be achieved by simply using more mule teams, but, as anyone who has worked with mules knows, there are limits to the number which one farmer can supervise.

2/ This is an over-simplified account. In fact, the two forms of alfalfa are contained in the same product group. See Section II (v) for a definition of this concept.

For cotton also CHAC contains two markets, but this arises from the joint-product nature of the cotton crop. Separate demand functions are specified for both cotton fibre and cotton seeds, and in the case of seeds, the price depends partly on the volume of production of other oilseeds. Hence in the model, the profitability of growing cotton depends on (a) the demand schedule for cotton fibre, (b) the demand schedule for oilseeds, (c) the production surface for competing oilseed crops, and (d) the production surface for cotton.

iv) Factor Supply Activities

Three classes of factors may be distinguished in CHAC: those supplied at the level of each submodel, those supplied at the regional level, and those supplied at the sector-wide level. At the submodel level are supplied land, water, and the labor of farmers plus their families. Agricultural land is not priced, for, as explained, it has no opportunity cost in the short-run, but the dual solution of CHAC yields the value of rents which accrue to the land. Similarly, endowments of water are not priced but the cost of tapping the water supply and providing it to farms is charged against the objective function. However, there is a price charged for the labor of farmers and their families; farmers may be fixed on the land in the short-run but their presence is due to a longer-run decision which is based in part on recognition of their opportunity cost. If it were assumed that farmers were willing to work for zero wages, cropping activities would enter the optimal basis which would not enter under more realistic assumptions, and hence all of the supply functions in the model would be biased toward overestimation of the supply offered at a given set of product prices. Also, unless extensive fiscal redistributional schemes are to be considered, policy oriented models must, if they are to provide solutions amenable to implementation, be based on wage assumptions not very different from actual wages.

Factors supplied at the regional level include hired labor and chemical inputs. There are some interregional price variations for delivered agricultural chemicals which follow from the transportation costs inherent in the spatial pattern of their production and use. Sector-wide factor supply activities in CHAC include those for credit, seeds, draft animals, and machinery services. A sector-wide water pricing activity has been included in order to perform policy experiments regarding the effects of systematic sector-wide variations in water charges.

Most of the factor supply activities are straightforward; a step function could have been included to represent the supply of agricultural chemicals, but it was felt that supply conditions in Mexico do not warrant it. The labor activities and constraints constitute the most complex part of the factor supply set. One of the major purposes of the agricultural sector study is to measure the impact on employment patterns of various policies, and the labor components of CHAC have been designed accordingly. Some of the elements of the labor structure have been mentioned: monthly labor demands are generated within each submodel and these demands are met either with local labor or through interregional migration. Regional wage differentials are incorporated, and provision is made for a reservation price for farmers' own labor which is different than the wage for landless, or day, labor.

The number of farmers is fixed for each district, and the number of landless laborers is given for the sector as a whole; ie, rural-urban migration is exogenous. While farmers do migrate to cities, the number of farms in Mexico does not change very rapidly over time, so in the short-run the assumption that the number of farmers in each locality is given appears tenable. Farmers in non-irrigated areas in Mexico often work seasonally on irrigated farms, so this kind of labor transfer is allowed in the model, with the exception that people leaving tropical areas are assumed to move permanently rather than temporarily, since the distances are so great. The reverse flow, of farmers with irrigated land working on non-irrigated farms, virtually never occurs in Mexico, so it is not an option in the model. Labor duration contraints are imposed to insure that, on a sector-wide basis, the laborers in the peak period are not employed for only one or two months; laborers in these circumstances almost certainly would have moved to urban areas. If, in early solutions, sector labor is exhausted in at least the peak period, an activity for urban-rural migration, at a higher wage, will be added.

The landless labor force is divided into four regional pools in the model, and if one region employs all the members of its pool in a particular month, it may draw redundant laborers from another region.

The regional wage differentials are incorporated in the model by multiplicative factors, so that the proportional differences remain constant when experiments are conducted with different base wage rates. The wages for day labor tentatively are based on the official minimum salaries. Regional averages have been calculated from the minimum salary regulations. These averages are, in 1968 pesos/day, 19.5, 20.5, 24.0, and 26.0 for the South, Central Plateau, North, and Northwest regions, respectively. In terms of the model structure, 19.5 is the "base wage" 1/. It is generally agreed that these "minimum salaries" are in fact maximum salaries. Hence alternative solutions will be conducted with a base wage of 15 pesos 2/ (regional wages of 15 to 20 pesos, maintaining the proportionate regional differences).

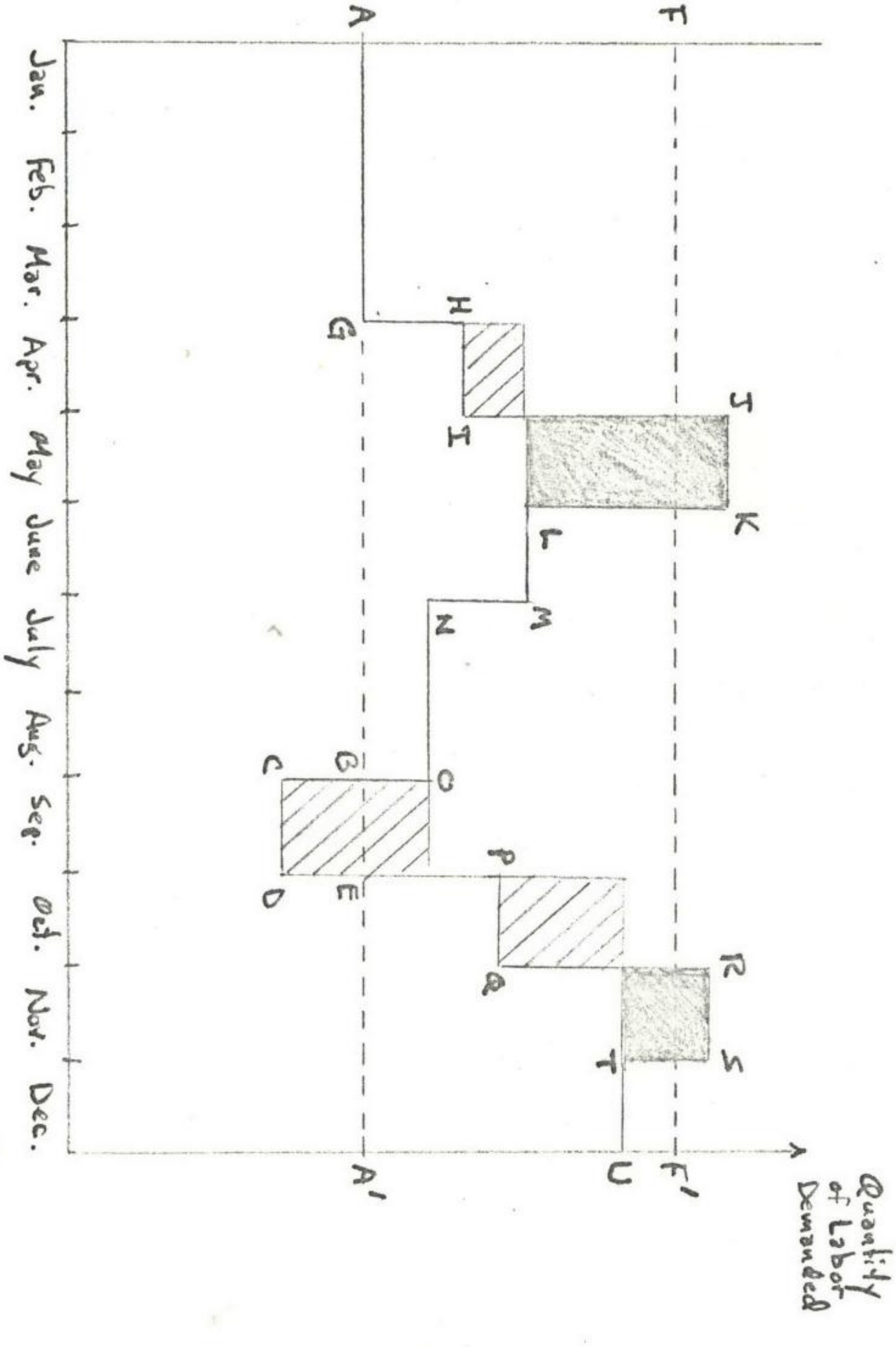
The model is structured so that any ratio of the farmers' own-wage to the day labor wage may be employed, but in the initial solutions it is assumed that the ratio is 40%. This ratio gives an own-wage for farmers ranging from about eight to ten pesos per day. Ten pesos/day is equivalent to 2640 pesos/year at full employment, 3/ 4/ but recall that the farmers' actual returns are much higher in many months.

1/ A wage of 19.5 pesos/day is equivalent to 5148 pesos/year at full employment.
2/ A wage of 15 pesos/day is equivalent to 3960 pesos/year at full employment.
3/ All types of labor are regarded as available for working 264 days/year, or 22 days/month. All months are uniformly defined to have 30.4 days. This approach avoids the necessity of using a multiplicity of conversion factors because calendar months have different numbers of days and the monthly pattern of holidays is not smooth.
4/ The exchange rate is 12.5 pesos to the dollar.

In irrigation submodels which do not have a large variety of basic farm types, the model is designed so that farmers are "supplied" on the basis of quarterly contracts, rather than monthly or annual contracts. This treatment in effect allows for the incomplete mobility of farm labor within districts which is observed. If both farm and day labor were supplied monthly, the lower reservation price would imply that day labor is hired only in the months when farmers are fully employed. In actuality, some farmers in a district may hire day labor in months when other farmers are idle. Hence use of monthly contracts in the model overstates labor mobility within the district. The quarterly contract device makes it optimal to hire day labor in months when farmers are less than fully employed. For example, with a day labor wage of 20 pesos and a farmer reservation price of 8 pesos, one-month peaks in labor demand will be met with hired labor but two-month peaks will be met with farmers on quarterly contracts.

Thus CHAC effectively incorporates both supply and demand functions for labor and it determines equilibrium levels of employment and of the average (farmer + non-farmer) wage, by month and by district. The quantity of labor demanded is in part a function of the labor supply functions. However, if, for the sake of illustration, it is assumed for the moment that the monthly labor demands are given in a district, the role of the quarterly contract assumption can be seen readily. Figure 1 illustrates the impact of the quarterly contract assumption on labor hire pattern, given that the farmer reservation price is less than half but more than one-third the

Figure 1. Alternative Labor Hire Patterns



day labor wage. A hypothetical seasonal pattern of labor demand is drawn (the line AGHIJKLMNOCDPQRSTU). Under the quarterly contract, the number of days of labor hired is equivalent to the shaded areas, and the cross-hatched areas show the number of "farmer-days" for which the model is charged when farmers are in fact idle. If monthly farmer contracts were assumed, the amount of labor hired would be the area contained under the demand curve but above the line FF', which measures the district's endowment of farmers. If annual contracts were assumed, the labor hire would be all the area under the demand curve and above line AA'; in this case, the amount of idle farmer days for which the model is charged is the area BCDE.

Obviously the amount of labor hired in the model depends directly on four variables: (a) the base wage, (b) the productivity of labor and other factors in the various cropping activities, (c) the ratio of the day labor wage to the farmer reservation price, and (d) the length of the farmer contract. The latter two variables are subject to various assumptions, but they are interrelated. Whatever set of assumptions is adopted, it should be designed to tend to offset the implicit assumption of complete farmer mobility within a district. Ultimately, the choice of assumption sets is a matter of calibrating the model so that it yields labor hire figures which approximately correspond to those observed.

Unfortunately, there exist only informal estimates of actual patterns of labor hire. However, the following figures from two solutions of a single submodel (Río Colorado) illustrate the impact of alternative assumptions on the ratio of the reservation price to the wage rate.

1.	Solution	1	2
2.	Wage ratio 1/	.615	.231
3.	Total employment 2/	1448	1484
4.	Farmer employment 3/	1280	1331
5.	(4)/(3)	.884	.897
6.	Stock of farmers 3/	1604	1604
7.	(4)/(6)	.798	.830
8.	Non-farmer man-years 4/	6.4	5.8

Apart from the demands for labor generated in the district-level cropping activities, the labor rows and columns can be considered as a separate submatrix of the sector model. Although a detailed discussion of all components of CHAC is beyond the scope of this paper, the labor submatrix ids discussed at some length to provide an illustration of how one component of CHAC is structured. The accompanying schematic tableau displays the elements of the labor submatrix.

1/ Ratio of farmer reservation price to the wage for day labor.
2/ In 10,000 man-days; including machinery operators (only about 4% of the total).
3/ In 10,000 mand-days.
4/ Non-farmer employment, in thousand man-years at full employment per man.

Figure 2

AGRICULTURAL SECTOR LABOR MATRIX

Row \ Column	SALS	SAL1	SAL2	SAL3	SAL4	RES1	RES2	RES3	RES4	LMAN	LMANt	dDLt (I)	dDLt (II)	dDLt (IIIi)	dDLt (IIId)	dDLt (IVi)	dDLt (IVt)	dFLq (I)	dFLq (II)	dFLq (IIIi)	(IIId) dFLt	(IVi) dFLq	(IVt) dFLt	Cropping Activities (I)	Cropping Activities (II)	Cropping Activities (IIIi)	Cropping Activities (IIId)	Cropping Activities (IVi)	Cropping Activities (IVt)	MDL31t	MDL32t	MDL43A	MA33t	MA44A	RHS
SØB	-W																													ε···ε	ε···ε	12ε	δ···δ	12δ	(Max)
SIN1	-W																													ε···ε	ε···ε	12ε	δ···δ	12δ	≥ Y_1
SIN2	-W					a_1	a_2	a_3	a_4																					ε···ε	ε···ε	12ε	δ···δ	12δ	≥ Y_2
SIN3																																			≥ Y_3
SSAL	–	w_1	w_2	w_3	w_4																														= 0
S1SAL		–				+k						+···+																							≤ 0
S2SAL			–				+k						+···+																						≤ 0
S3SAL				–				+k						+···+	+···+																				≤ 0
S4SAL					–				+k							+···+	+···+																		≤ 0
S1RES						–												3···3																	= 0
S2RES							–												3···3																= 0
S3RES								–												3···3	+···+														= 0
S4RES									–													3···3	+···+												= 0
SMAN										-12	+···+																								= 0
SMANt											-2.2···-2.2	+···+	+···+	+···+	+···+	+···+	+···+	‡···‡	‡···‡	‡···‡	+···+	‡···‡	+···+												= 0
S1MANt												+···+																		–···–					≤ L_1
S2MANt													+···+																		–···–				≤ L_2
S3MANt														+···+	+···+															+···+	+···+	–⋮–	–···–		≤ L_3
S4MANt																+···+	+···+															+⋮+		–⋮–	≤ L_4
S3MIGt																														+···+	+···+	–⋮–	–···–		≤ M_{3t}
S3MIG																														+···+	+···+	-12	–···–		≤ M_3
S4MIG																																+12		+12	≤ M_4
I) dMØNCt												–···–						≡···≡						+⋮+											≤ 0
II) dMØNCt													–···–						≡···≡						+⋮+										≤ 0
IIIi) dMØNCt														–···–						≡···≡						+⋮+									≤ 0
IIId) dMØNCt															–···–						–···–						+⋮+								≤ 0
IVi) dMØNCt																–···–						≡···≡						+⋮+							≤ 0
IVt) dMØNCt																	–···–						–···–						+⋮+						≤ 0
I) dAGRIq																		+···+																	≤ A_d
II) dAGRIq																			+···+																≤ A_d
IIIi) dAGRIq																				+···+															≤ A_d
IIId) dAGRIt																					+···+												+···+		≤ A_d
IVi) dAGRIq																						+···+													≤ A_d
IVt) dAGRIt																							+···+											+⋮+	≤ A_d
IIId) dMIGRA																																	+···+		≤ MA_3
[illegible]) dMIGRA																																		+12	≤ MA_4

$a_i = kw_iW$

The rows and columns are as follows: 1/

Row Symbol 2/	Purpose
SOB	Objective function
SIN1-SIN3	Measures of sectoral income
SSAL	Sectoral wage accounting equations
SrSAL	Regional wage accounting equations
SrRES	Reservation price accounting equations
SMAN	Total annual labor accounting equations
SMANt	Total monthly labor accounting equations
SrMANt	Regional monthly constraints on day labor
S3MIGt	Monthly constraints on migration of day labor out of region 3 (Central Plateau)
SrMIG	Annual constraints on migration of day labor out of South and Center regions (r = 3,4)
dMONCt	Submodel labor balances
dAGRIq	Quarterly submodel constraints on the supply of farm labor, for irrigation districts only
dAGRIt	Monthly submodel constraints on the supply of farm labor, for non-irrigation submodels
dMIGRA	Annual constraints on migration of farmers, non-irrigation submodels in regions 3 and 4 only.

1/ The labor duration constraints are omitted from this version of the tableau.

2/ The letter r (= 1, ..., 4) is the regional index; t (= 1, ..., 12) is the monthly index; q (= 1, ..., 4) is the quarterly index; and d (takes on alphabetic values) is the submodels index.

Column Symbol	Purpose
SAIS	Sectoral wage charging activity
SAIr	Activities for charging regional wage differentials
LMAN	Sector annual employment counter (man-years at full employment equivalent)
LMANt	Sector monthly employment counter
dDLt	Monthly day labor supply activities in each submodel
dFLq, dFLt	Farm labor supply activities by submodel, quarterly in irrigation submodels, monthly otherwise.
MDLrr't	Migration activities for day labor from region r to region r' by months (rr' = 31, 32, 43).
MA33t	Migration activities in region 3 for farmers to the pool of day laborers.
MA44A	Migration activities for region 4 farmers on annual basis.

The remainder of this section constitutes a "guided tour" of the tableau, to clarify its driving mechanisms 1/. The monthly demand for labor is generated by cropping activities in the submodels. This demand is registered in the submodel-level labor balance equations (dMONCt). To meet the demand are a set of activities supplying labor, a set of activities charging the objective function for labor use, and a set allowing migration of labor. Labor can be supplied by local farmers, or by drawing upon the regional pool of

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1/ In the tableau, a "+" signifies + 1, and a "-" signifies - 1.

landless laborers. In the r^{th} region, the cost to the model of a unit of farmer labor working on his own farm is kw_rW, where W is the base wage rate, w_r is the proportional regional wage differential, and k is the ratio of the farmer reservation price to the wage. For non-irrigated farms, on which the incidence of labor demands is markedly seasonal, there are monthly constraints on the number of farmers (dAGRIt), and for irrigated submodels, quarterly constraints (dAGRIq), following the quarterly contract approach discussed above.

Day labor is supplied to the submodels by a set of activities (dDLt) on a monthly contract, at a wage rate per unit of w_rW drawing upon four regional pools of day laborers, defined by the set of monthly constraints (SrMANt). The sizes of the regional pools are given by the magnitudes L_i on the right-hand side of the regional labor balances. The regional pools may be augmented through use of the migration activities. There is a seasonal movement of labor, following the seasonal demands associated with the cropping cycle. The model distinguishes between migration of day labor and of farmers. Migration flows of day labor on a monthly basis are allowed from region 3 (Central) to regions 1 (NW) and 2 (North) and on an annual basis from region 4 (South) to 3. Migration from, e.g., 3 to 1, increases the pool of day laborers in 1, reduces it correspondingly in 3, and is constrained both by a monthly and an annual limit (rows S3MIGt and S3MIG).

If labor is fully employed in one region in a given month and there is unemployment in another region in that month, labor will move between the regions to seek employment. If labor is fully employed in both regions in that month, it still will move from one region to another if its productivity differential in the two regions exceeds the wage differential. The numbers ϵ and δ in the migration activities are accounting devices; they are negative numbers arbitrarily small in magnitude, and $/\epsilon/ < /\delta/$. They insure that, if there is surplus labor in both regions, there will be no interregional migration, and also that landless labor will migrate out of a region before farmers do. Except for the regional wage differentials, which partly reflect interregional transport costs, there is no explicit cost of migration in the model.

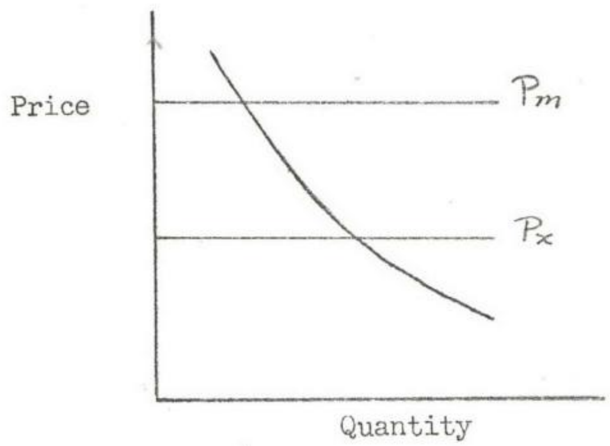
As noted earlier, day labor in the model may migrate from the Center to either of the northern regions, or from the South to the Center. Given the present labor surplus in the Center, the latter movement will occur only if seasonal migration northward is sufficiently strong to exhaust the Center's pool in a least one month. In that case, movement from the South to the Center would, by releasing constraints S3MIGt and S3MIG, permit more movement out of the Center northward, and hence allow a double migratory movement (at a cost of 2ϵ).

Farmers on non-irrigated farms may offer themselves as day labor in their own region or they may join the seasonal migration to other regions. Activity MA33t permits farmers in region 3 (Center) to join the day labor pool on a monthly basis, reflecting the existence of irrigation districts nearby offering seasonal employment. Activity MA44A does the same for farmers on tropical farms in the South but on the basis of an annual commitment, reflecting the lack of local employment opportunities and the distances involved in travelling to other regions. The presence of δ as a cost in the objective function in these activities insures that all landless labor will be utilized before farmers are drawn from non-irrigated farms.

v) The Structure of Demand

The major departure in CHAC from the conventional structure of sector planning models is in the formulation of demand. In most sector planning models the problem addressed is either that of minimizing the costs of producing a fixed bundle of output or of maximizing value added at exogenous product prices. In CHAC, product prices are endogenous. For a particular product, the demand function is illustrated in Figure 3.

Figure 3



In the diagram, P_m and P_x refer to import and export prices respectively. The difference between these reflects the difference between effective import and export prices, and it may be large for some bulky agricultural products. Export and import prices are treated as fixed and exogenous, although this assumption can readily be relaxed. Also, for convenience of exposition, all demand functions are assumed to be linear. This assumption also can be relaxed.

The purpose of this treatment of demand is threefold. Firstly, it allows a model solution to correspond to a market equilibrium. The effects of various policies, e.g. subsidizing or taxing product prices or varying the exchange rate, etc., can then be investigated. Secondly, it allows the model greater flexibility. For instance, substitution between capital and labor, corresponding to different ratios of the wage rate to the rate of interest, can occur not only directly through the technology set or through changes in the commodity mix of output, but also through substitution in demand due to changing relative prices of outputs which are more or less labor or capital intensive. Thirdly, it enables a more realistic appraisal of the benefits (and particularly of their distribution as between producers and consumers) accruing from an increase in agricultural output. In the not-unlikely situation of agricultural production for the domestic market at prices between those at import and at export, and where domestic demand is price inelastic, then the financial return to producers as a whole from an increase in output is negative. For consumers, the benefits are positive.

Two forms of market equilibrium are distinguished. The first, the competitive case, involves producers acting as price takers and equating marginal costs to the prices of products. In the second, the monopolist case, the sector maximizes its net income by equating marginal costs to the marginal revenues of products. For agriculture, the equilibrium prices and quantities of the competitive case correspond more closely to reality than do the solutions of the monopolistic case, although the demand structures for both cases are incorporated in CHAC.

For simplicity of exposition, it is first assumed that no external trade occurs. Import-export opportunities are introduced later. The set of domestic demand functions is written , assuming linearity, as

$$p = a + Bq \quad \ldots\ldots\ldots\ldots (1)$$

where p is a J x 1 vector of prices

a is a J x 1 vector of constants

B is a J x J matrix of demand coefficients

q is a J x 1 vector of quantities

Defining c as a J x 1 vector of exogenously-determined marginal costs[1/],

the objective function for the competitive case becomes

$$Z = q' \left[a + \tfrac{1}{2}Bq - c\right] \quad \ldots\ldots\ldots (2)$$

which yields the equilibrium condition that

$$p = c \quad \ldots\ldots\ldots (3)$$

The objective function, Z, can be decomposed into components which correspond to consumer surplus and producer surplus:

$$CS = \tfrac{1}{2} q' \left[a - p\right] = -\tfrac{1}{2} q'Bq \quad \ldots\ldots\ldots (4)$$

$$PS = q' \left[p - c\right] = q' \left[a + Bq - c\right] \quad \ldots\ldots (5)$$

1/ As is evident from previous sections of this paper, the supply functions of the model are in fact more complex than is implied by this simplified exposition.

The appropriate objective function for the monopolist case is

$$Y = q'\left[a + Bq - c\right] \quad \ldots\ldots\ldots (6)$$

which yields the equilibrium conditions that

$$a + 2\,Bq = c \quad \ldots\ldots\ldots\ldots (7)$$

where the left-hand term is a vector of marginal revenues.

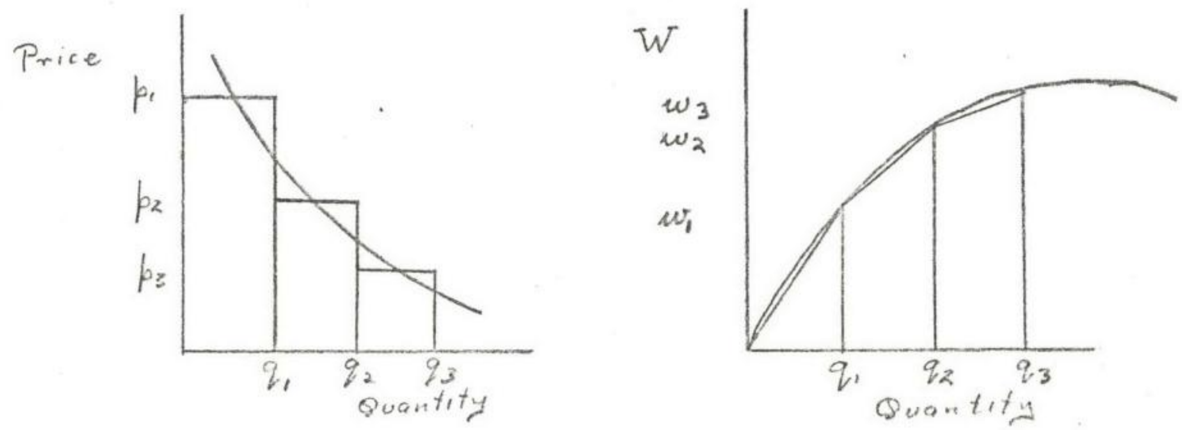
In both cases, the maximand involves a quadratic form in q. Either case could, in principle, be handled by quadratic programming. Problems arise in practice because non-linear programming models rapidly approach the bounds of computer technology as the models become large. For this reason, approximation procedures were sought in order to take advantage of the computational efficiencies of linear programming. Two such procedures have been developed: the first for the case where estimates of the coefficients of B are available, and the second where less information is to be had on the structure of demand interrelationships.

In this exposition, it is assumed, as in the case in CHAC, that costs are accounted for in factor-supply activities, so that the demand activities account only for the areas under the demand function (in the competitive case) or the area under the marginal revenue function (in the monopolist case). For one product, in the competitive case, this area is

$$W = q'\left[a + \tfrac{1}{2}\,Bq\right]$$

which is the function sketched in Figure 4 together with the corresponding demand function, assuming only three segments in the approximation.

Figure 4



The linear programming tableau corresponding to the segmented approximation of the function W for one product is the following:

	Cropping Activities			Selling Activities			RHS
ØBJ	$-c_1$	$-c_2$	$-c_3$	w_1	w_2	$w_3 \ldots\ldots w_n$	(MAX)
Commodity Balance	y_1	y_2	y_3	$-q_1$	$-q_2$	$-q_3 \ldots\ldots -q_n$	$\geqslant 0$
Demand Constraint				1	1	1……1	$\geqslant 1$

where the c_i are costs associated with crop-producing activities

the y_i are yields of the product

the w_i are values of W corresponding to q_i and

the q_i are the total quantities sold at the limit of each segment of the function W.

The main point to be noted in this formulation is that the demand function (or the area function W) can be approximated as closely as is necessary for the problem, with no additional rows being required in the model. This approach is readily extended to two or more products, with one commodity balance per product and one convex combination constraint for the entire set of selling activities. For instance, with the first commodity being segmented into two parts only, q_{11} and q_{12}, and the second into three parts q_{21}, q_{22}, q_{23}, the approximation is presented in the tableau below:

	Cropping Activities				Selling Activities						RHS
	Crop 1		Crop 2								
ØBJ	$-c_{11}$	$-c_{12}$	$-c_{21}$	$-c_{22}$	w_{11}	w_{12}	w_{13}	w_{21}	w_{22}	w_{23}	(MAX)
Commodity Balance 1	y_{11}	y_{12}			$-q_{11}$	$-q_{11}$	$-q_{11}$	$-q_{12}$	$-q_{12}$	$-q_{12}$	≥ 0
Balance 2			y_{21}	y_{22}	$-q_{21}$	$-q_{22}$	$-q_{23}$	$-q_{21}$	$-q_{22}$	$-q_{23}$	≥ 0
Demand Constraint					1	1	1	1	1	1	≤ 1

where the c_{ij} are costs for the i^{th} crop in the j^{th} activity producing that crop
the y_{ij} are yields of the i^{th} crop in the j^{th} activity producing that crop
the q_{ij} define the commodity bundles of the two products and
the w_{ij} are the values of W corresponding to the i^{th} level of the first commodity and the j^{th} level of the second.

Alternatively, the monopolist case can be formulated merely by replacing the w_{ij} in the objective function above by computing corresponding r_{ij}, values of the total revenue function R, where

$$R = q' \left[a + Bq \right] .$$

Of course, an income or profit equation or constraint could be incorporated in a model with the competitive objective function to serve as either a counter of, or a constraint on, producers' incomes.

In the treatment above, it was assumed that the elements of B were known or could be estimated. Frequently, this information is not available. For CHAC, the available information consisted of crude estimates of own-price elasticities for a number of individual commodities and of commodity groups. The approximation procedure developed for this situation of limited information has the following properties 1/:

i) Because of the lack of information on the off-diagonal elements of B, the system does not reflect a continuous range of price interdependence amongst commodities. Instead, it distinguishes between commodities with prices determined independently of other commodity prices 2/ and those with fixed relative prices. The latter constitute a number of demand groups. For example, the various vegetable oils constitute one such demand group, in which the relative prices of soybean oil, peanut oil, sunflower oil, etc. are held constant. Again on the demand side, the price for each commodity group is determined independently of the prices of other commodity groups or of individual commodities.

1/ Proofs of these properties are not presented here. They are available upon request from the authors, together with an algebraic statement of the linear programming tableau.

2/ This, of course, applies to the demand structure only. There is interdependence in product prices amongst all commodities arising from the interdependence of marginal costs on the supply side.

ii) For any commodity group, both the consumers' surplus and producers' gross revenue are independent of the commodity mix in that group. Within a group, the marginal rate of substitution between any two products is constant and equal to the inverse of the ratio of their prices. Again, within a group, the derivative of the demand function with respect to the production of a particular product in the group, holding constant the production of all other products in the group, is equal to the price of that product.

iii) The system is structured such that substitution amongst products within a group is constrained within pre-assigned bounds on the commodity mix.

iv) The system preserves the desirable property of the linearization of a quadratic form presented above, that the area function, W, can be approximated to any desired degree of accuracy by adding activities without adding additional rows.

v) The revenue function is similarly linearized, so that the demand activities have coefficients in rows defining producers' profits and incomes. These rows can be used as alternative objective functions, implying monopolist behavior of the sector, or used as constraints upon the social welfare maximization encompassed by the competitive equilibrium objective function. Similarly, this last can be included as a constraint upon monopoly behavior.

vi) Export selling activities are included as additional demand activities for individual products, and import activities are added as alternatives to domestic producing activities 1/. These last will never enter the basis under the monopolist objective function unless the model also includes a social welfare constraint.

1/ Such activities, of course, can also be included in the "full information" demand structure.

vi) Time and Investment Choices

CHAC is a static model. Its size virtually prohibits consideration of simultaneous multi-period solutions, but it can be solved in sequential multi-period form, with appropriate inter-period linkage equations. The work to date has been devoted entirely to the static version, since many policy and planning choices can be explored on that basis. The methodological and empirical problems of just the static version already have provided a good many man-years of employment for model builders.

The model is based on data for 1968, and solutions are conducted for 1971 and 1974, the former to test the model and the latter for actual policy results. The three-year period between the present and the solution date allows sufficient time for implementation of investment programs formulated with the assistance of CHAC. The absorptive capacity limitations which constrain the amount of investment in any one locality in any one year cannot be identified easily, so it was decided to solve for the final year of a single three-year period.

Resource endowments are projected from 1968 to the solution year, and the demand functions are located by projection of national income growth rates and application of income elasticities of demand for agricultural products.

Most of the investment choices in CHAC are of the short-gestation lag variety, such as well digging, canal lining, and land levelling, which take less than a year. For these, the investment is assumed to take place instantaneously and the resulting benefits also are assumed to commence immediately. In the model, one year's (annualized) costs and benefits are entered in the objective function and income constraints. Annualized investment costs are defined to be one year's linearized depreciation (= amortization) and one year's interest charges against the full capital cost. Current operating costs of a project like a well are charged through current use activities. In the case of the three types of investment mentioned, the "output" of the investment activity is an additional unit of irrigated land, an additional unit of net water availability, or an additional unit of higher-yield irrigated land.

Investment choices of longer gestation lag are also represented through annualized costs and benefits, with a discount factor applied to the delayed benefit stream. While this treatment does violence to some aspects of project analysis, it permits the assessment of all major forms of investment in a locality for purposes of measuring the marginal efficiency of capital curve discussed in section IV (ii) below.

vii) Data Sources

It is axiomatic that existing data are never as adequate as analysts or administrators would like. Nonetheless, administrators must make decisions continuously, and in the absence of better information they are forced to rely on existing data. Mexico is relatively well endowed with micro-level data series for agriculture, and CHAC is based on this micro-level information; thus CHAC is only an analytic structure for assessing the same information which is currently used for decisions. It is hoped that, by carefully drawing some of the implications of existing data, the need for improvements in data collection procedures will become more apparent to policy makers 1/.

On the production side, the basic information sources are, for irrigated areas, the cost of production tabulations published annually, by crop and by district, by the Secretaría de Recursos Hidráulicos (S.R.H). For non-irrigated areas, information from the Aseguradora Nacional de Agricultura y Ganadería and the Secretaría de Agricultura y Ganadería (S.A.G.) was utilized, plus extensive field studies in the northern, central and southern parts of the country by Lic. Luz María Bassoco. Her studies also formed the basis for the specification of alternative degrees of mechanization in both irrigated and non-irrigated areas.

1/ Such a feedback has already occurred in the case of the water input requirements and availability by locality. Initial linear programming solutions showed inconsistencies, and so the Secretaría de Recursos Hidráulicos carefully revised its estimates.

Resource endowments by locality were estimated from census and S.R.H. information by staff members of the Banco de Mexico and the Secretaría de la Presidencia. Investment cost information, which probably is the most reliable data in the models due to the use of relatively standard techniques for small scale investment projects, was drawn from field studies of Sra. Bassoco, Dr. Donald Winkelmann, and Lic. Rafael Pedrero of the Banco de Mexico. Trade data come from standard trade statistics.

Prices are taken from time series of S.R.H. and S.A.G. Demand elasticities were crudely estimated on the basis of meagre econometric studies for Mexico and similar studies for other countries. Given the importance of price support policies in agriculture, this is one area where CHAC may demonstrate the value of better information.

III. Multi-Level Aspects

CHAC is part of a study which is concerned with multi-level planning and with information flows between different levels of decision-making. Three major levels are distinguished: the individual district (submodel), the agricultural sector, and the national economy.

i) District-Sector Linkages

As stated in the Introduction, a major objective in the construction of CHAC was to address the question of how much information is required at the district level concerning the agricultural sector as a whole to make "acceptable" district-level investment decisions. This question is of particular relevance to the World Bank, which is primarily a lender on projects, which in agriculture frequently take the form of a set of investments to be undertaken within a geographical area. The El Bajío model 1/, being the most detailed district model in CHAC, is used as the project area model.

El Bajío can be solved in isolation from the rest of CHAC, assuming product prices to be exogenous, and assuming that seasonal labor hire is unrestricted. Solutions were obtained for different definitions of the investment choice set and different quantities of capital. This procedure simulates the appraisal of investment projects utilizing only district-level sources of information.

1/ Sub-models 8, 9, 10

However, it is to be expected that a major determinant of the profitability of investment in El Bajío is the investment program in other submodel districts, which compete for the same domestic markets, and also compete for such sector-wide resources as labor. These outside-district effects can be captured by solving El Bajío as part of CHAC for the same sets of investment choices in El Bajío as in its solutions in isolation, but varying the investment program for the other parts of the sector.

The information flow is not just one way from sector to district. Information is required by sector-level policy makers concerning technology sets and resource endowments at the district levels. This type of information is needed, for instance, in determining the level and allocation of public investment funds. CHAC is a convenient means of organizing such information.

ii) Sector-National Economy

In solutions of CHAC the prices of nation-wide resources, such as labor, capital and foreign exchange are exogenous, as is the rate of growth of income per caput. Values of these are obtained from solutions of DINAMICO, a multi-sector dynamic macro model of Mexico constructed by A.S. Manne. However, the information flow is not one way: parametric solutions of CHAC can yield improved estimates of the agriculture technology vectors in DINAMICO. Because agriculture bulks large in the Mexican economy, these new vectors can be expected to lead to changes in the solutions of DINAMICO, and changes in the relevant shadow prices and the growth rate of income. It is the present intention to run several iterations of this "informal decomposition" procedure.

iii) Decomposition

CHAC itself, being block-diagonal in the submodels, can be decomposed into its components and solved by a number of decomposition algorithms. In particular, a variant of the Dantzig-Wolfe algorithm has been developed in which the extremal problem is defined to include the full set of demand rows and activities and of rows and activities associated with factor supply. Preliminary experiments with a simplified structure suggest that very much more rapid convergence can be expected with this modified algorithm than with Dantzig-Wolfe.

IV. Some Preliminary Results

At the date of writing, most of the component submodels of CHAC have been solved, although not yet the complete system. Two series of experiments have been conducted on the El Bajío model 1/ to investigate capital-labor substitution, and to evaluate the marginal efficiency of capital function. The main purpose of these particular experiments was to make methodological explorations using a relatively small model before embarking on studies utilizing the full model system in CHAC. The actual numerical results are therefore not interesting per se, and particularly so as the El Bajío model is still being modified in some respects. For this reason, numerical results are not presented.

i) Capital-Labor Substitution

A major purpose of the CHAC model system is to evaluate the labor-absorbing or labor-releasing characteristics of Mexican agriculture and the set of policy instruments available to influence the level of employment in agriculture. Labor absorption varies with changes in the scale of output and with changes in relative factor proportions. The set of experiments described below was directed to the latter. The sources of substitution can be classified into those defined by the technology set, those arising from the output mix under constant output prices (i.e. with a system of price controls, or through trade where the trade share is small) and those arising also from substitution in demand.

1/ Submodels 8, 9, 10.

Measures of substitution (e.g. the marginal rate of substitution, MRS, along a capital-labor ray, or the Hicksian elasticity of substitution) are unambiguously defined in the textbook case of one output and two inputs. The models in CHAC, however, distinguish many different products and include as primary factors of production many factors, such as fertilizer, which are primary inputs for the agricultural sector but which are intermediate inputs in an economy-wide context. For defining substitutability along an isoquant, the problem is one of defining output constancy and constancy of these other primary factors. The initial experiments were run with the El Bajio model only, so that consideration of substitution in demand or through trade was precluded. For these experiments, seven definitions corresponding to seven sets of constraints on output and on other factors were enumerated.

To define these, let S_k be the MRS between capital and labor at some fixed capital-labor ratio; let q_i be the quantity produced of the i^{th} crop and $\bar{p}_i$ its constant price, with $Q = \sum_i \bar{p}_i q_i$ being the gross value of production; and let f_j be the quantity used of the j^{th} other factor of production purchased from outside the district at constant price $\bar{p}_j$; with $F = \sum_j \bar{p}_j f_j$ being the total expenditure on these factors. Throughout, a bar over a symbol indicates that the corresponding quantity is held constant for the experiments. Seven definitions of S_k are set out in the table below. In S_1 through S_3, the output mix as well as the total gross value of output is held constant, whereas only the total gross value of output is held constant in S_4 through S_6, allowing changes in the output mix. In S_1 and S_4, the expenditure on each of the other factors of production is held constant while in S_2 and S_5 only the total expenditure on other factors is a constant, the mix being unconstrained. In S_3 and S_6 the expenditure on all other factors is to be minimized. In S_7 only one constraint is imposed: constancy of value added 1/.

Table 3 Assumption Sets for the Capital-Labor Substitution Experiments

S_k	Output Constraints	Other Factor Constraints
S_1	$\bar{p}_i q_i$ all i	$\bar{p}_j f_j$ all j
S_2	"	$\bar{F} = \sum_j \bar{p}_j f_j$
S_3	"	minimize F
S_4	$\bar{Q} = \sum_i \bar{p}_i q_i$	$\bar{p}_j f_j$ all j
S_5	"	$\bar{F} = \sum_j \bar{p}_j f_j$
S_6	"	minimize F
S_7	$\bar{W} = Q - F$	$\bar{W} = Q - F$

1/ Value added in this sense is defined as the gross value of output net of expenditures on purchases "other inputs"; that is, payments to labor capital, including the farmers' rents which accrue to the fixed factors of land and water.

For each definition S_k, an "isoquant" is traced out by successive solutions of the linear programming model under varying capital-labor price ratios, where the "quant" held constant is defined by the constraint set for S_k shown in the table. The objective function in each of these experiments is net farmers' profits, over and above their own wages, evaluated at exogenous prices 1/.

Complementarity between other factors and labor or capital is the basic reason why seven alternative definitions of S_k are set out; otherwise there would be only two definitions, covering fixed and variable output mix. Were the arguments of the production function independent of each other, substitutability between capital and labor would be properly measured by holding other inputs, as well as output, constant. However, there do exist complementarities between the two primary factors and these other factors, e.g., between labor and fertilizer and between capital and tractor operating expenses. Given the complementarity, holding other factors constant leads to an understatement of the degree of subsitution between capital and labor.

1/ It is convenient to express the linear program in each case as minimization of total wages and payments to capital (and, in the case of S_3 and S_6, expenditures on other factors), subject to the constraints set out in table

Hence the following orderings should be expected in substitutability as measured by the different S_k:

$$S_3 \geqslant S_2 \geqslant S_1$$

$$S_6 \geqslant S_5 \geqslant S_4$$

$$S_7 \geqslant S_5 .$$

$$S_4 \geqslant S_1$$

$$S_5 \geqslant S_2$$

$$S_6 \geqslant S_3$$

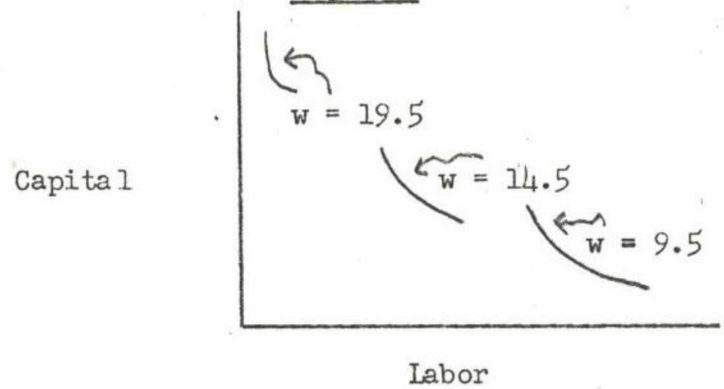
Prior to the experiments, a base solution was obtained to produce values for all the variables entering the constraint sets; these therefore are values corresponding to a feasible solution 1/. For the constraint set corresponding to each S_k, the interest rates actually used are 12, 16, 20, and 24 percent, and the wage rates are taken as 19.5, 14.5, and 9.5 pesos per day. These values give twelve solutions corresponding to points on an isoquant as defined above.

So far, results have been obtained on S_3, S_6 and S_7. These results are preliminary in the sense that the model is still undergoing some modification. However, some conclusions from these results are worth noting.

1/ The values of the constraints used in the experiments were, in fact, only 95 percent of the values obtained from the base solution. This was done to eliminate the chance of an infeasible problem due to round-off errors.

Both S_3 and S_6 yield "iso-quants" of a form illustrated in Figure 5. That is,

Figure 5



the sets of results for the same range of interest rates but for different wage rates fall on different curves. For both again, there is very little charge in the level of employment with the cost of capital doubling from 12 to 24 percent at the high wage rate, 19.5 pesos per day, but more flexibility in the amount of labor used as a function of the cost of capital when the wage rate is low. Secondly, there are substantially greater changes in capital-labor ratios in S_6 than in S_3. That is, in spite of the wide range of choice in the technology set in the model 1/, a large component of the flexibility of factor use lies in variation of the output mix. Thirdly, the results for S_7 all lie on the same curve, the shape of which is graphed

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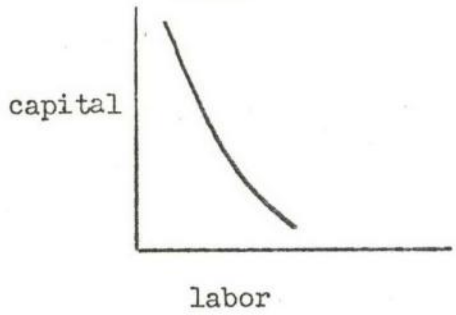
1/ El Bajío contains 584 cropping activities for 14 crops, plus a number of investment activities.

in Figure 6 . The measure S_7 has therefore a certain aesthetic appeal.

Figure 6



While these results are sketchy and tentative, it is interesting to extrapolate some of the implications which would follow if they were confirmed in later experiments. The lack of substitutability in S_3, especially at higher wage rates, and the differences between S_6 and S_3 suggest that variations in the output mix will be important if agriculture is to absorb significant quantitites of labor. Either changes in the aggregate consumption mix, with corresponding changes in relative prices of commodities,or changes in the trade mix, would be required. Typically agricultural planning is based on long-term projections of domestic demands for each commodity, assuming fixed relative prices. Also most governments are hesitant to consider radical changes in the pattern of importation and domestic production for foods. Both of these practices may have to be revised if the employment absorption potential of agriculture is to be realized.

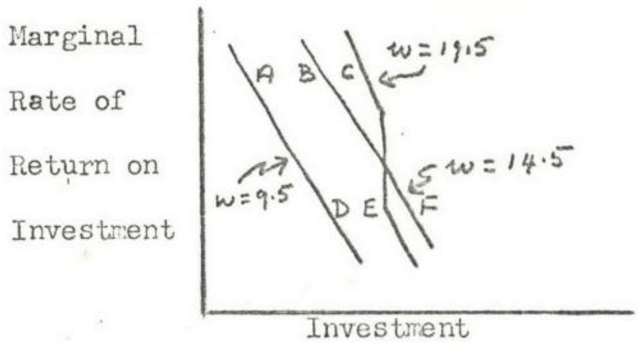
ii) The Marginal Efficiency of Capital

The relationship between the quantity of capital employed in the model and its marginal value product can be studied in two ways. The first is to constrain the availability of capital to the model and to vary the constraint, measuring the marginal product of capital by its shadow price. The second is to use primal solutions only, by including a capital-supply activity in the model with the interest rate varying over the experiments. Both approaches are computational devices only, and both involve unacceptable behavioral assumptions 1/. In the experiments conducted on the El Bajio model, the second was chosen, for the reason that it was easier to define ex ante a meaningful range of rates of interest than a meaningful range of quantities of capital. The interest rates and wage rates used in the experiments were 12, 16, 20 and 24 percent and 9.5, 14.5 and 19.5 pesos per day, with the objective function being farmers' profits.

The results obtained are illustrated in Figure 7 , with, of course,

Figure 7

Marginal Efficiency of Capital in an Agricultural Project District



1/ In the first case, the supply of capital is assumed to be infinitely inelastic beyond the constraint, and in the second, it is assumed to be available in infinitely elastic supply at a given rate of interest separate curves for each value of the wage rate. For each wage rate, the rate of return on investment monotonically decreases with the volume of investment. The position of the curves depends on two effects: the output effect and the substitution effect. At high marginal rates of return on investment, the substitution effects dominate; for a given return to investment, increases in the wage rate result in greater use of capital and less employment (movements from points A to B to C). However, at lower rates of return but high wages, the negative effect upon output of wage increases dominates the substitution effect, so that less capital is used as wages increase (movement from F to E). This kind of reversal is caused by an asymmetric production surface, a schematic version of which is projected on to capital-labor space in Figure 8, where the vertical components of the segments M and N correspond to lines DE and EF in Figure 7. Segments M and N constitute the locus of tangencies to isoquants Q_1, Q_2 and Q_3 as the price line is rotated.

Further experiments are planned to investigate the impact on the marginal efficiency of capital schedule of alternative assumptions on demand and on supply response in other areas.

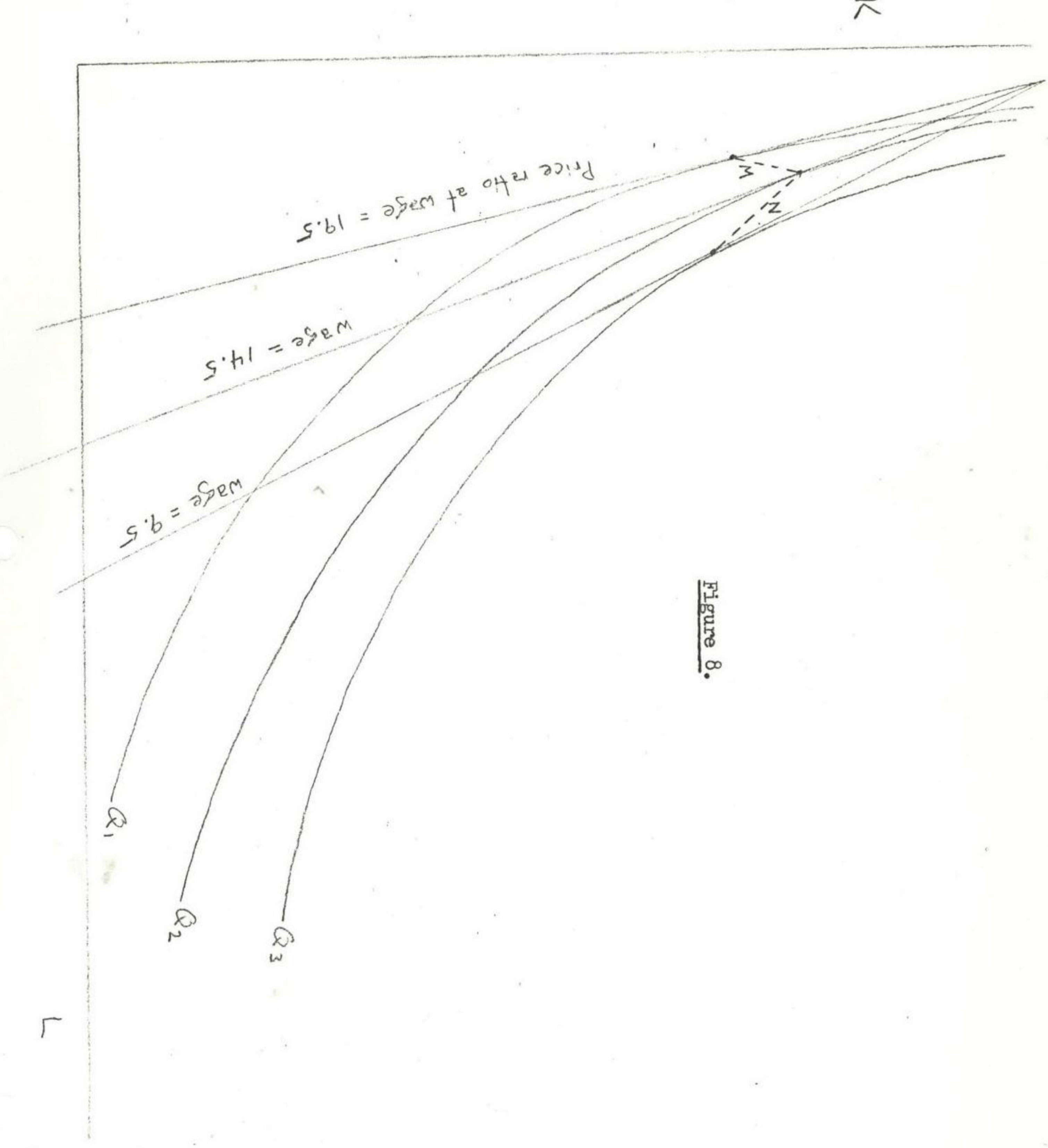


Figure 8.

V. Concluding Remarks

Obviously the sector study of agriculture has been a fairly major undertaking, involving coordination of different agencies and the input of about seven man-years of economists' time. Computing and data processing expenses have not reached their peak, but probably they will sum to several tens of thousands of dollars. The extent of the undertaking is one reason why emphasis is being placed on methodological lessons, including aggregation possibilities, so that future studies can benefit from this experience. From the World Bank's viewpoint, this study will not have been very useful if the final recommendation is to build equally large models of agriculture for all other developing countries!

Since the study progressed in an exploratory, ad hoc manner, retrospect provides a couple of useful rules of thumb about such undertakings. It is clear that large-scale models have significantly increased utility if they are designed to be easily expandable and compressable to serve different purposes, as the submodels in CHAC can be rearranged, aggregated, or expanded. By the same token, the computational and interpretive tasks are simplified if the individual components can be solved, de-bugged, and modified one by one before the entire structure is put to the test. In the course of testing each component, sensitivity analyses can be run to assist in answering some micro-level policy questions.

Schematic Map of Regions and Submodels in CHAC