PB-225 518

POLICY MAKING FOR ECONOMIC DEVELOPMENT: A SYSTEM SIMULATION MODEL OF THE AGRICULTURAL ECONOMY OF SOUTHERN NIGERIA

Michael H. Abkin

Michigan State University

Prepared for:

Agency for International Development

February 1972

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

UNANNOUNCED (3)/aidh+110;12711,0001

PB-205 [illegible] 2) 2B, 5C

[illegible]13.50/[illegible]1.15
Michigan State Univ., East Lansing.
Dept. of Agricultural Economics.
6) Policy Making for Economic Development: A System Simulation Model of the Agricultural Economy of Northern Nigeria. (9) Staff rept.,
10) by Michael H. Abain. (11) Feb 72, (12) 330p
14) Staff paper ser-72-4
15) Contract AID/csd-1557, AID/csd-2975
16) Proj. AID-931-17-190-533
18) AID (19) NI-690.9669-A151
20) Agency for International Development.

Job/12/7/73/339072

DO NOT PUNCH

Added Entry

Release Date

A74-02

Check List for Fields

	DC	SA
1		
2		
4		
5		
6		
8		
9		
10		
11		
12		
14		
15		
16		
17		
18		
19		
21		
22		
23		
25		
27		
29		
30		
33		
34		
35		C

23) Descriptors

25) Identifiers

27) Abstract: See reverse ( ) Page (s) – LDC

29) Inventory

30) Annotated Title

33) Dist. Code

34) Serial

35) Code

FORM NTIS-59 (REV. 5-71)

U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE

DOCUMENT PROCESSING WORKSHEET

USCOMM-DC 41420-P71

BIBLIOGRAPHIC DATA SHEET	1. Report No. NI-63Ø.9669-A151	2.	PB 225 518/0 No.

4. Title and Subtitle

"POLICY MAKING FOR ECONOMIC DEVELOPMENT: A SYSTEM SIMULATION MODEL OF THE AGRICULTURAL ECONOMY OF SOUTHERN NIGERIA"

5. Report Date: Feb. 1972

6.

7. Author(s): Michael H. Abbiw

8. Performing Organization Rept. No.

9. Performing Organization Name and Address: Michigan State University, Dept. of Agric. Economics, East Lansing, Mich. 48823 ~~Michigan State~~

10. Project/Task/Work Unit No. 931-17-190-533

11. Contract/Grant No. AID/csd-1557 & 2975

12. Sponsoring Organization Name and Address
Department of State
Agency for International Development
Washington, D.C. 20523

13. Type of Report & Period Covered: Staff Report

14.

15. Supplementary Notes

16. Abstracts

The problems of planning for economic development in the new states of Africa and Asia as well as in the more established nations of Latin America arise from the interplay of political, social and economic subsystems. Chapter 1 briefly reviews these problems and discusses the "systems approach" to dealing with them, including a review of previous model-building efforts. The global model of the Nigerian agricultural economy with its regional and sectoral submodels, is then described briefly. Chapter 2 discusses how the southern agricultural submodel employs a lumped approximation to a distributed parameter process--specifically, the distribution of a population over time and over properties--to model the demography of perennial commodities, i.e., populations of trees. Part II describes the components of the southern model. Chapters 3 through 7 cover land allocation and modernization decisions, agricultural production, processing and marketing price generation policy entry points and the criteria and macro-budget accounting component. Part III looks at testing and validation procedures and results. Policy applications of the model, conclusions, and areas for further work are discussed in Part IV.

17. Key Words and Document Analysis

17b. Identifiers/Open-Ended Terms

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. COSATI Field/Group 338

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 330
	20. Security Class (This Page) UNCLASSIFIED	22. Price 15.50

Staff Paper Series 72-4

POLICY MAKING FOR ECONOMIC DEVELOPMENT: A SYSTEM SIMULATION MODEL OF THE AGRICULTURAL ECONOMY OF SOUTHERN NIGERIA

By: Michael H. Abkin

ia

To my parents,

who laid the foundation.

ACKNOWLEDGEMENTS

Breaking with tradition, my first acknowledgement is to my wife, Graciela. For her, the role of student's wife was compounded by the added duties of editorial consultant and typist for this thesis. It can be fairly said that this dissertation is as much hers as mine.

My work leading to this thesis was as part of a simulation team under contract to the United States Agency for International Development (contracts AID/csd1557 and AID/csd2975). Although I had major responsibility for the development of the southern model, and while I hold the responsibility for it--particularly its shortcomings--it could not have come about without the guidance, suggestions and advice of the whole team. In particular, I give special thanks to Professor Glenn Johnson for his overall guidance as administrator of the project, to Dr. Thomas Manetsch whose on-line direction of operations gave cohesiveness and motivation to the project team, and to Gloria Page, our computer programmer, for her efforts in trying to interpret what I wanted to do.

Finally, I thank my guidance committee for their acceptance of my program and for their patience in wading through this volume. I am particularly indebted to

Dr. Manetsch who, as my major advisor, gave me direction and inspired my interest in the socio-economic application of systems science as a career and as a vocation.

TABLE OF CONTENTS

	Page
LIST OF TABLES	viii
LIST OF FIGURES	ix
P A R T I - THE PROBLEM	1
Introduction	1
CHAPTER 1 - The Context: Development, System Simulation and Nigeria	3
Development and Planning	3
The Evolution of the Systems Simulation Approach to Economic Problems	5
The Nigeria Model	9
CHAPTER 2 - The Dynamic Demography of Perennials: A Model of a Distributed Parameter Process	21
General Population Balance Model	22
Lumped Approximations	24
Demography of Perennials	29
Summary	30
P A R T II - MODEL DESCRIPTION	31
Introduction and Summary	31
CHAPTER 3 - Land Allocation and Modernization Decisions--Annuals/Perennials (LAMDAP)	35
Ecological Zones	35
Land Uses	38
Perennials	38
Annuals	47
Other Land Uses	49
Alternatives	49
Economic Decisions	51
Profitabilities	51
Information Units	57
Availability of Land	59
Transition Responses	63
Noneconomic Responses	71
Summary	76
CHAPTER 4 - Agricultural Marketing, Production and Processing--Annuals/Perennials (AMPPAP)	77
Subsistence Level	77
Yields	82
Food Production	87

Page

Perennial Production 90
Marketing 91
Processing 93
Capacity 94
Modernization 96
Investment 98
Processing Outputs 99
Input Demands and Accounting 104
Summary 118

CHAPTER 5 - Price Generation (PG) 119
Export, Market and Processor Prices 119
Domestic Palm Oil Market 124
Producer Prices, Price Averages and Wage Rates 130
Summary 134

CHAPTER 6 - Policy Entries 135
Parameter Sensitivity and Policy Making 135
Policies 136
Production Campaigns 136
Marketing Boards 140
Taxes 141

CHAPTER 7 - Criteria and Macro-Budget Accounting (CRTMBA) 142
Performance Criteria 142
Budget Accounting 148
Summary 160

P A R T III - VALIDATION AND TESTING 161

Introduction 161

CHAPTER 8 - Data Usage and Model Tuning 163
Data 164
System Parameters 164
Technological Coefficients 170
Initial Conditions 174
Tuning 176
General Validation 180

CHAPTER 9 - Sensitivity Analysis: Results and General Applications 182
Applications 182
Model Development 182
Policy Making 184
Data Collection 187
Analysis of Results 188
Methodology 188
Production Coefficients 191
Land Allocation Coefficients 199
Price Parameters 206
Summary 211
Simulation Time Cycles 211

Page

P A R T IV - TOWARDS A SOLUTION 220

Introduction 220

CHAPTER 10 - Policy Formulation 221
Policy Experimentation 222
Run Definitions and Organization 223
Policies Related to the Cattle Industry 230
Northern Regional Policies 237
Southern Regional Policies 247
Policies Viewed on the National Level 258
Varying Production Campaign Budget Levels 272
Conclusions 277
Policy Sensitivity 279
Summary 286

CHAPTER 11 - Summary and Conclusions 287
Summary 287
Conclusions 291
Understanding the System 292
Policy Formulation 292
Research Activities 293
Improvements and Extensions of the Model 295
Improvements 296
Extensions 300
Implementation 307

BIBLIOGRAPHY 312

LIST OF TABLES

		Page
Table II.1.	Alternative land uses	50
Table II.2.	Production campaigns	139
Table III.1.	Profitability response parameters for traditional perennials (dimensionless)	166
Table III.2.	Profitability response parameters for annuals and bush	167
Table III.3.	Diffusion parameters	168
Table III.4.	Production parameters	169
Table III.5.	Perennial yields (lbs./acre-year)	171
Table III.6.	Input requirements for perennials	172
Table III.7.	Mean length of perennial production stages (years)	173
Table III.8.	Selected initial conditions (1953)	175
Table III.9.	Time series tracking	179
Table III.10.	Results of sensitivity tests of production coefficients of the southern model	195
Table III.11.	Results of sensitivity tests of land allocation coefficients of the southern model	202
Table III.12.	Results of sensitivity tests of price parameters of the southern model	209
Table III.13.	Results of sensitivity tests on time increments DT and DTX	214
Table IV.1.	Policy simulation runs	224
Table IV.2.	Results of policy sensitivity tests under three policy situations	281
Table IV.3.	Greatest deviations of three output variables from 29 parameter variations under three policy situations (percent of base values)	285

LIST OF FIGURES

		Page
Figure I.1	National model of interacting submodels	11
Figure I.2	Northern region ecological zones	12
Figure I.3	Southern region ecological zones	13
Figure I.4	Major sectors and interactions of the northern Nigerian agricultural model	16
Figure I.5	Major sectors and interactions of the southern Nigerian agricultural model	17
Figure I.6	Model of the nonagricultural economy and the national accounts	19
Figure I.7	A model of a generalized amphipod instar	26
Figure II.1	Building blocks of the southern model	32
Figure II.2	A Venn diagram of the ecological zones of southern Nigeria	36
Figure II.3	Perennial production cohorts	41
Figure II.4	The gamma distribution of maturation rates, R_m	41
Figure II.5	Land-use decision mechanism	52
Figure II.6	The profitability response function	63
Figure II.7	Abandonment response	70
Figure II.8	Land constraint	74
Figure II.9	Subsistence level determination	81
Figure II.10	Price generation component	120
Figure II.11	The palm oil market: three cases	129
Figure II.12	Modernization budget profile	138
Figure III.1	Approximate solutions of agricultural exports (AFORXS) and value added (ATVAS) for different simulation cycles	216

		Page
Figure III.2	Approximate solutions of per capita disposable income (PCDINA) and market price of food (PRFD) for different simulation cycles	217
Figure III.3	Simulation run times when varying one or both simulation cycles	218
Figure IV.1	Cattle population of males (PM) and females (PF), 1970-1995, with and without a fly eradication program	233
Figure IV.2	Cattle income from animal sales (YA) and milk (YM), 1970-1995, with and without a fly eradication program	234
Figure IV.3	Fly-free grazing land, 1970-1995, with and without a fly eradication program	235
Figure IV.4	Range condition index (the ratio of range land grass yields at a point in time to those yields at the initial time, 1970), 1970-1995, with and without a fly eradication program	236
Figure IV.5	Total value added in agriculture in the North, 1970-1995, under various policy conditions	241
Figure IV.6	Foreign exchange from northern agricultural exports (including imports of cotton and beef), 1970-1995, under various policy conditions	242
Figure IV.7	Total marketing board net revenues from northern commodities, 1970-1995, under various policy conditions	243
Figure IV.8	Disposable income per agricultural worker in the North, 1970-1995, under various policy conditions	244
Figure IV.9	Market price of food in the North, 1970-1995, under various policy conditions	245
Figure IV.10	Caloric consumption (of staples) per capita of the northern nonagricultural population, 1970-1995, under various policy conditions	246

		Page
Figure IV.11	Total value added in agriculture in the South, 1970-1995, under various policy conditions	251
Figure IV.12	Foreign exchange from southern agricultural exports, 1970-1995, under various policy conditions	252
Figure IV.13	Total marketing board net revenues from southern commodities, 1970-1995, under various policy conditions	253
Figure IV.14	Foreign exchange from palm oil exports, 1970-1995, under various policy conditions	254
Figure IV.15	Real disposable income per agricultural worker in the South, 1970-1995, under various policy conditions	255
Figure IV.16	Market price of food in the South, 1970-1995, under various policy conditions	256
Figure IV.17	Caloric consumption (of staples) per capita of the southern nonagricultural population, 1970-1995, under various policy conditions	257
Figure IV.18	Total value added in northern agriculture, 1970-1995, under various policy conditions	262
Figure IV.19	Total value added in southern agriculture, 1970-1995, under various policy conditions	263
Figure IV.20	Foreign exchange from northern agricultural exports (including imports of cotton and beef), 1970-1995, under various policy conditions	264
Figure IV.21	Foreign exchange from southern agricultural exports, 1970-1995, under various policy conditions	265
Figure IV.22	Total marketing board net revenues from northern and southern commodities, 1970-1995, under various policy conditions	266
Figure IV.23	Gross domestic product (assuming marketing board and export taxes are not put to productive use), 1970-1995, under various policy conditions	267

		Page
Figure IV.24	Total exports (agricultural and non-agricultural), 1970-1995, under various policy conditions	268
Figure IV.25	Total imports, 1970-1995, under various policy conditions	269
Figure IV.26	Market price of food in the North, 1970-1995, under various policy conditions	270
Figure IV.27	Caloric consumption (of staples) of the southern nonagricultural population, 1970-1995, under various policy conditions	271
Figure IV.28	Agricultural exports in the North (including beef and cotton imports) (EN) and South (ES), in 1995, under varying production campaign budgets	273
Figure IV.29	Total marketing board net revenues from northern and southern commodities in 1995 under varying production campaign budgets	274
Figure IV.30	Modern annuals cotton, groundnut and food land in 1995 under varying production campaign budgets	275
Figure IV.31	Modern perennials land in new planted cocoa (NC), replanted cocoa (RC), replanted palm where no other perennial competition (RP), replanted palm where rubber competition (RPR) and replanted rubber (RR) in 1995 under varying production campaign budgets	276
Figure IV.32	System simulation and the policy-making process	308

P A R T I

THE PROBLEM

Introduction

The problems of planning for economic development in the new states of Africa and Asia as well as in the more established nations of Latin America arise from the interplay of political, social and economic subsystems.

In this introductory part, Chapter 1 briefly reviews these problems and discusses the "systems approach" to dealing with them, including a review of previous model-building efforts. The global model of the Nigerian agricultural economy[1/], with its regional and sectoral submodels, is then described briefly. Chapter 2 discusses how the southern agricultural submodel, the subject of this dissertation, employs a lumped approximation to a distributed parameter process--specifically, the distribution of a population over time and over m properties--to model the demography of perennial commodities, i.e., populations of trees.

Part II describes in detail the components of the southern model. Chapters 3 through 7 cover respectively the

---

1/ The work was supported by the United States Agency for International Development, contracts AID/csd1557 and AID/csd2975.

land allocation and modernization decisions component, the agricultural production, processing and marketing component, the price generation component, policy entry points and the criteria and macro-budget accounting component.

Part III looks at testing and validation procedures and results. Chapter 8 discusses data needs and the process of tuning the model to track time series of recorded behavior. The results and implications of sensitivity tests on model parameters are presented in Chapter 9 along with an investigation of the sensitivity of the model's numerically generated solution to changes in the time increment used.

Policy applications of the model, conclusions and areas for further work are discussed in Part IV. Chapter 10 presents the results and analyses of runs experimenting with various agricultural development policy options. Experiments include an investigation of the sensitivity of policy results to changes in certain parameter values. Finally, Chapter 11 presents summary and conclusions and outlines areas for further work in refining, improving and extending the model; it concludes with a discussion of the form an implementation of the model might take.

CHAPTER 1

The Context:

Development, System Simulation and Nigeria

Development and Planning

Development planning is basically a political process. To be sure, the goals of development are generally socio-economic in nature; however, defining those goals and charting the paths to their attainment (i.e., planning) are necessarily political problems. That is, there are problems of reconciling conflicting interests and aspirations of various segments of the society and of evaluating the trade-offs among "goods" and "bads" as projected by psychological, sociological and economic analyses. Colm and Geiger define development planning as

> ... deliberate, rational, continuous efforts by governments to accelerate the process of development and to channel it into desired directions by means of the comprehensive and detailed choice of objectives and the determination and allocation of the resources necessary for their achievement. [6, p. 272]

But what is "development"? Or what is it to be "developed"? Chandrasekhar and Hultman point out that there is no universal acceptance of a definition or even of the criteria of development. They cite a number of definitions that have been offered. The common thread that seems to run

through them says something about relative levels of consumption and material well-being and the degree of application of science and technology to increase those levels [5, pp. viii-ix]. Colm and Geiger, in the passage quoted above, leave it to the domestic political process to choose the goals of development and to determine the means to reach them.

The definition of development planning quoted above implies, in those few words, a range of complex problems which have bedeviled planners. The basic problem, that which makes planning essential to the development process, is the allocation of scarce resources in an environment of complex interactions among physical, social, economic and political components. These interactions generate multiple and often conflicting development objectives. Examples might be employment, price stability, income, nutrition, balance of payments, education, etc. Planners and decision makers who are responsible for the allocation of scarce developmental resources need information on the many possible trade-offs among objectives under alternative policy conditions. That is, a display of the set of attainable output combinations is needed.

Another complication in development planning is due to imperfect knowledge about the present state and uncertainty as to the future consequences of policy options [48]. Data resources in most developing countries are notoriously lacking in both quantity and quality. Short- and long-run effects of alternative strategies are uncertain. In particular, the degree to which policies aimed at one set of economic phenomena

may have unintended side effects, "good" or "bad", on other aspects of the society is often even more in doubt than the direct consequences. In short, development planners are trying to design controls for a system which is complex and non-linear, is unobservable and may not even be controllable (in the control theory sense [49, pp. 75-85]).

The Evolution of the Systems Simulation Approach to Economic Problems

These difficulties imply the virtual nonexistence of analytical solutions. Researchers have thus turned to simulation as a possible means of generating numerical solutions and hence providing policy makers with information about the likely consequences of alternative resource allocations. Given specific assumptions about system structure (causal factors and relationships among them and values of system parameters) and exogenous variables, a simulation model generates time paths of relevant endogenous variables, including the vector of criterion variables needed by decision makers to evaluate alternative development strategies. A number of such strategies can thus be tested and their outcomes compared and evaluated. In addition, decision makers can creatively interact with a simulation model, using previous simulation results to assist in the design of new and improved strategies as well as to continuously validate and improve the model itself [20].

Early simulation modeling efforts began after World War II and expanded concomitantly with the development of

analog and digital computing machines and techniques. The excellent bibliography in [9] lists thousands of papers, books and monographs which have appeared since about 1950 reporting simulation models of behavioral and social aspects of human systems. A few examples of economic and, specifically, economic development models will set the scene for a brief introduction to the Nigeria simulation model in general and the southern regional submodel in particular.

While most early economic simulation model-building activity was concentrated on electronic analogs, Phillips constructed a mechanical model of production, consumption and price adjustment using colored water in a hydraulic system [42]. The accuracy of an electronic model was foregone for the illustrative advantages of a model whose dynamic behavior could be visually observed. Phillips also briefly describes other, more complicated macro-economic hydraulic models, some including components for government taxation and expenditures.

More typical of the early models is Smith and Erdly's electronic analog of a macro-economic system of investment, consumption and income generation [47]. Their model incorporates a time lag between investment and the delivery of capital goods. A perfect time delay is approximated by a cascaded series of three "time-constant delays", each with the same time constant. Smith and Erdly maintain that this approximation is actually closer to reality than a perfect delay since it generates a distribution of delay times about a mean; i.e., not all capital goods have the same production

lag. This delay model is analogous to the digital computer model of a third-order distributed lag described later in Chapters 2 and 3 (in connection with Equations 3.1) [16, 31, 33].

Smith and Erdly found that their linear model was unstable. They attributed this to information lost in the delay and to the positive feedback loop of income to consumption to income. They concluded that nonlinearities and other factors omitted from their model work to keep the real system within bounds.

Moving from models, such as the above, of single components of economic processes (e.g., investment and income generation, market price mechanisms, production decisions) to models of whole systems was a big step. Howard used the building-block approach in developing an analog computer simulation model of a colonial socio-economic system [23]. Two components were built and joined to simulate a three-class society--colonials, organized (urbanized) natives and primitives. The two components--national growth and national behavior--are very aggregative models of macro-economic growth and political behavior, the latter defined as the choice of the organized natives between the two political alternatives of status quo and change. Production and consumption functions are included as well as a limiting natural resource.

Researchers, however, concerned about the problems of economic development in the then fast-emerging, newly independent nations, were becoming frustrated with the limitations

of electronic analog computers. Disaggregated and complex analog simulation models necessary to address effectively real policy questions proved unwieldy, impractical and unfeasible [21]. Forrester's development [16] of the "industrial dynamics" approach provided the methodology and techniques (and even a programming language--DYNAMO [43]) needed to convert to the more versatile digital computer.

Holland did so with his generalized model of a developing economy [21] and went on, with the Simulmatics Corporation, to build policy-oriented models of the Venezuelan economy [22]. These were a series of increasingly disaggregated models to be used by policy makers in projecting consequences of policy options. The final one was generalized and quite disaggregated; it could simulate an economy (not necessarily Venezuela's) of up to 25 sectors.

Manetsch's model of the U.S. plywood industry [33] also follows the industrial dynamics approach to digital simulation. His model simulates the interactions of thousands of firms in the industry by aggregating them into seven relatively homogenous sectors: two producing sectors, three wholesaling sectors and two retailing sectors. As Smith and Erdly did in an electronic analog model, Manetsch uses a distributed delay process to aggregate the production lags of a large number of individual firms. A complex price mechanism is also included which incorporates a number of proportional and rate feedbacks from other system variables.

Drawing on the techniques and experiences of these and other modeling efforts, an agricultural simulation team was formed at Michigan State University to investigate the feasibility of applying the systems approach to real development-planning and policy-making situations. Taking advantage of the wealth of resources and expertise on Nigerian agricultural development available at MSU (primarily the work of the Consortium for the Study of Nigerian Rural Development, CSNRD [24]), the team developed a policy-oriented simulation model of the Nigerian agricultural economy [35]. The southern regional model of an agricultural economy typified by competition between perennial (tree) and annual crops for scarce productive resources--the subject of this dissertation--was part of that effort.

The Nigeria Model

The Nigeria simulation model is oriented specifically towards agricultural development because of the special role agriculture plays in the developing nations. Typically, agriculture accounts for 40-60% of national income and employs 50-80% of the labor force in these countries [25]. Johnston and Mellor cite a number of ways in which agriculture contributes to the development process. First, high population growth rates and positive income elasticities of demand mean agriculture is called upon to meet an increasing demand for food. Secondly, agricultural exports make important contributions to national income and foreign exchange earnings. Agriculture also provides, through rural-urban migration,

much of the nonagricultural labor force. Finally, agriculture can stimulate industrial growth by providing capital necessary for nonagricultural investment and by increasing agriculture's demand for consumer goods.

The simulation model of the Nigerian agricultural economy is composed of three major submodels: the northern regional agricultural submodel, the southern regional agricultural submodel and the nonagricultural/national accounts submodel. In addition, there are components which model the national food market and the population. Figure I.1 indicates the major interactions of these submodels as well as the principal inputs and outputs of the system.

Nigeria, with a population of over 55 million as of 1963 [12] and an area of over 356,000 square miles [13], is conceptually divided into two distinct regions: the North consisting of the six northern states of the federation (Figure I.2) and the South consisting of the six southern states (Figure I.3). The basis for this "political" definition rests on ecological, cultural and (thus) economic considerations.

Ecologically, the six southern states range from rain forest to intermediate savanna, while the North goes from savanna to near desert. In the South, annual crops typically compete with perennials (cocoa, rubber and oil palm) for scarce resources. The competition in the North is among annuals (primarily cotton, groundnuts[1/] and food). Cattle

---

1/ The British word for peanuts, groundnuts, will be used in this thesis as that is the word used in Nigeria.

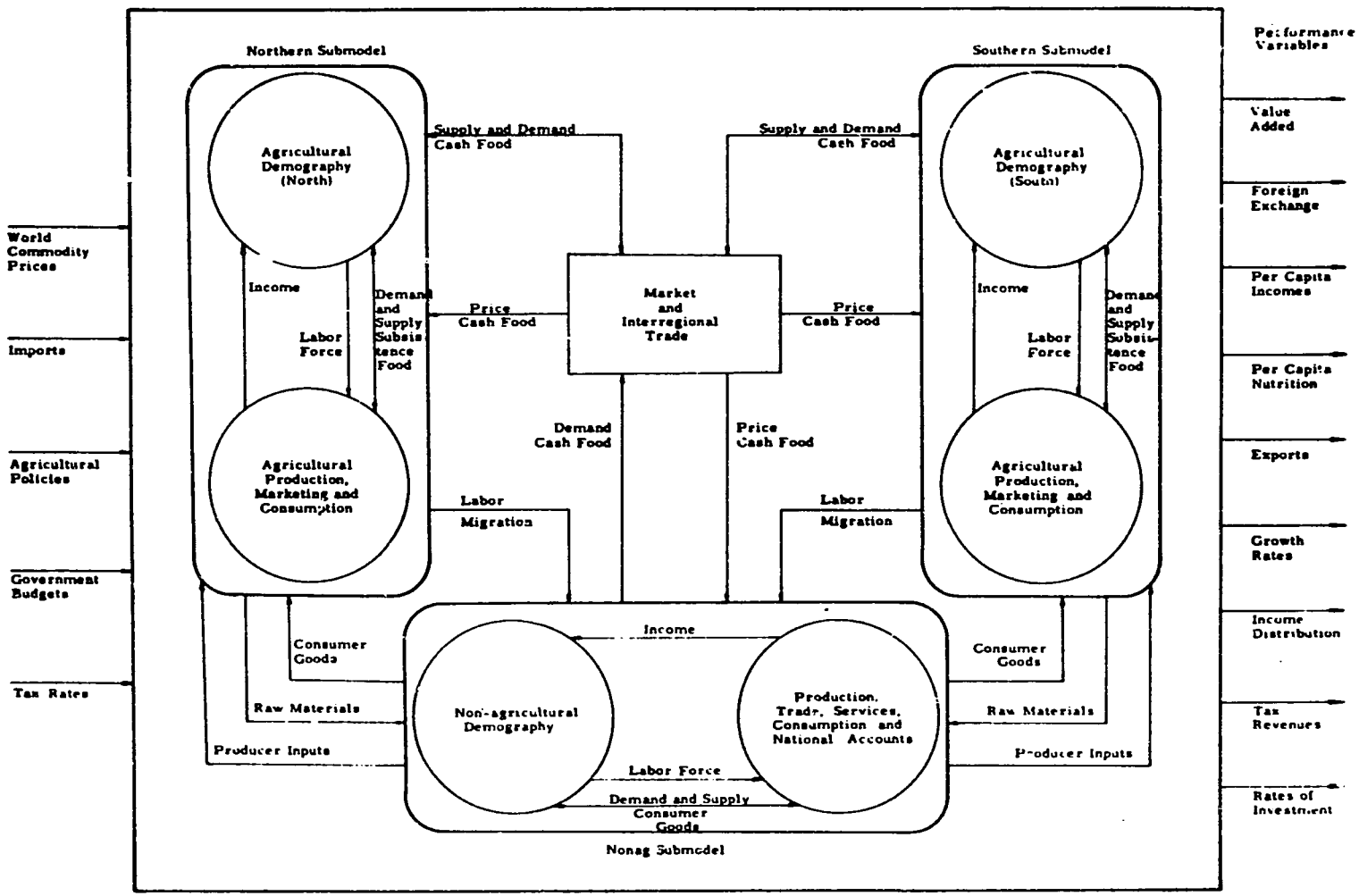


Figure I.1 National model of interacting submodels.

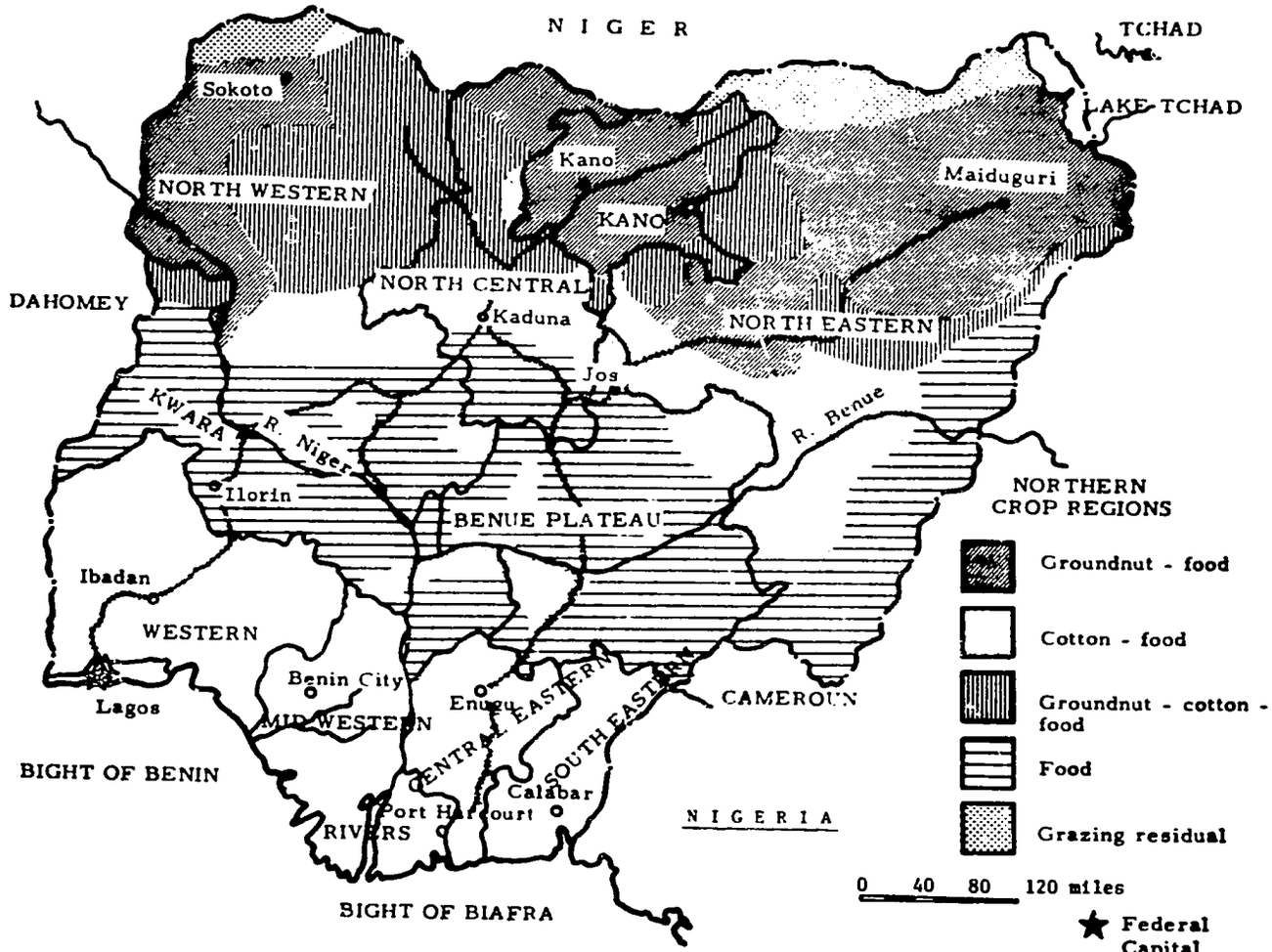


Figure I.2 Northern region ecological zones.

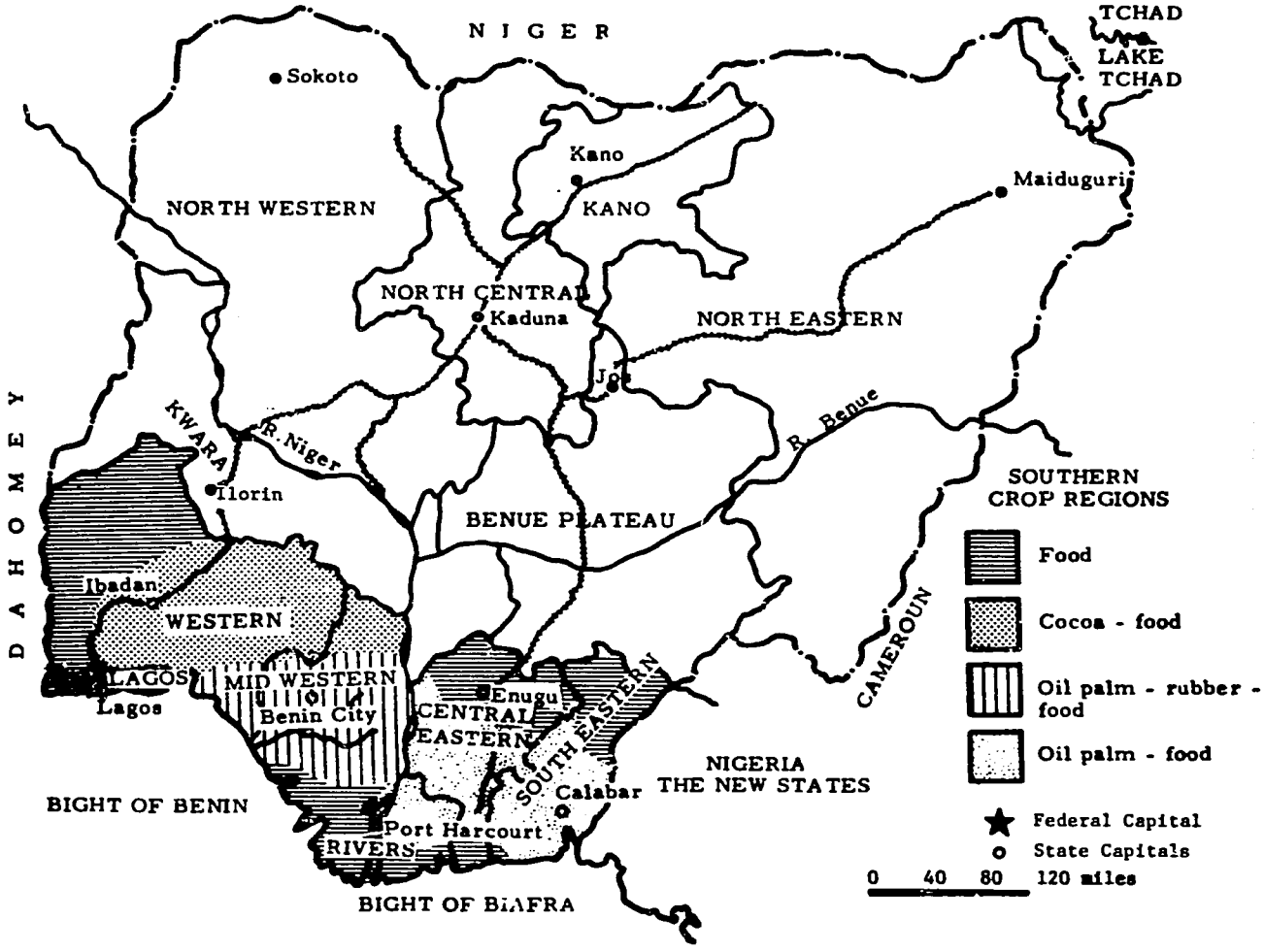


Figure I.3 Southern region ecological zones.

grazing is also an important activity in the North. In those areas of the South where perennials are not viable alternatives--particularly Oyo Division of the Western State and the northern divisions of the Southeastern State--annuals (food) may compete with other annuals (tobacco or cotton), as in the North, but the people of these areas are more economically and culturally tied to the South. Thus, the economic behavior of these people--which, as we shall see in Part II, is the foundation upon which the model is built--is probably more like that of the rest of the southern population than the people in the North.

A major economic rationale for this particular regional delineation concerns the specific resources considered scarce in each region. The North is a land-rich, labor-poor economy. Land allocations in the northern submodel are thus based on economic returns to labor. In the South, however, land and capital appear to be the major constraints to the expansion or modernization of agricultural production, while labor, considering seasonal migration from the North, is not a limiting factor. Thus, land in the South is allocated to various enterprises according to the relative returns to land, and subject to the constraints of available capital.

As shown in Figures I.2 and I.3, the agricultural submodel of each region defines four ecological zones (or crop sectors) of competing cropping activities (plus an area in the North suitable for cattle grazing but not for crops). Land allocations, then, are determined in the submodels by

crop sector.

The basic component structures of the two agricultural submodels are quite similar, as is evident in Figures I.4 and I.5. The nature of perennial commodities, however--trees exhibiting demographic characteristics of gestation, growth, maturity and decline--considerably complicates the southern submodel, particularly in the land allocation and modernization component (Chapters 2 and 3).

Briefly, the agricultural submodels allocate land to the available commodities (indicated in Figures I.4 and I.5) based on profitabilities perceived by farmers and subject to input constraints. From the land allocations, and given commodity yields and other technological coefficients (e.g., factor input rates, marketing losses, etc.), the total production of each commodity is determined, and marketing and processing functions are accounted. Agricultural processing in the North is modeled with input-output ratios, while in the South, because of the significance of palm and rubber processing activities to the agricultural producers themselves, processing is modeled in considerably greater detail (Chapter 4). Finally, economic performance criteria are generated and the agricultural sector budgets are accounted.

Inputs to the agricultural submodels include policy specifications. These may involve stimulating the modernization of production, reducing or increasing marketing board surpluses (i.e., raising or lowering producer prices), and various forms of taxation. The simulation model will then

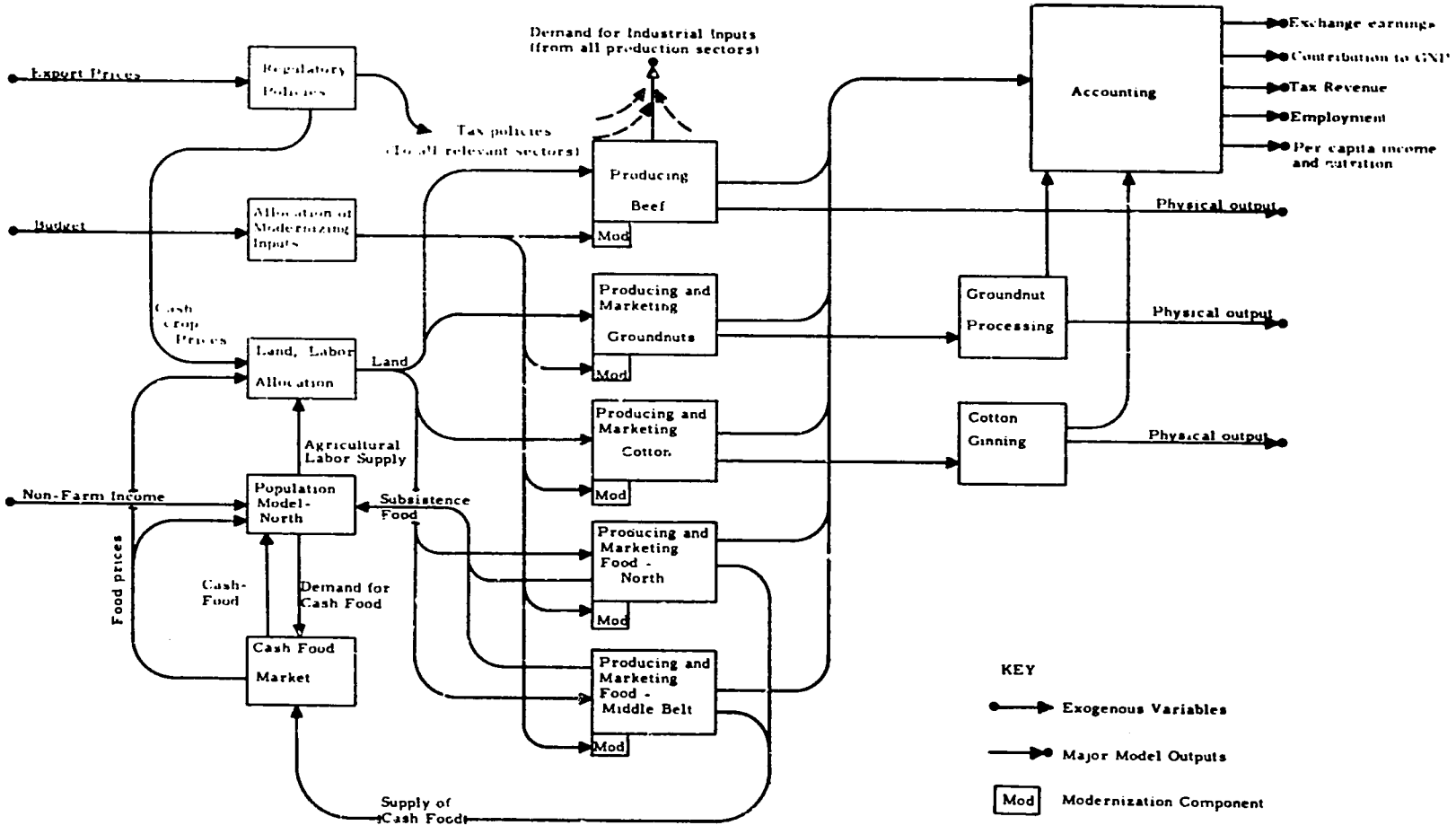


Figure I.4

Major sectors and interactions of the northern Nigerian agricultural model.

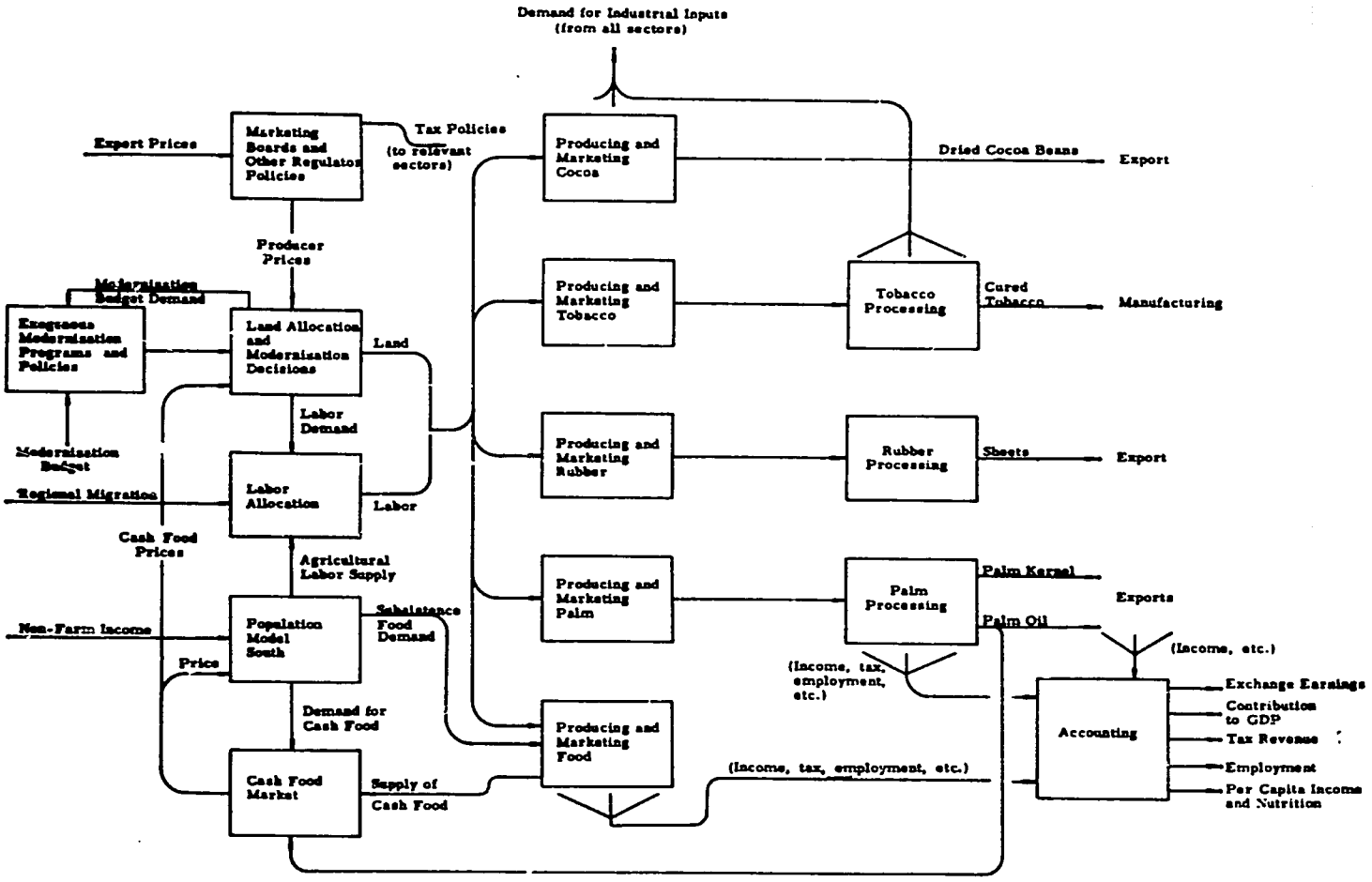


Figure I.5

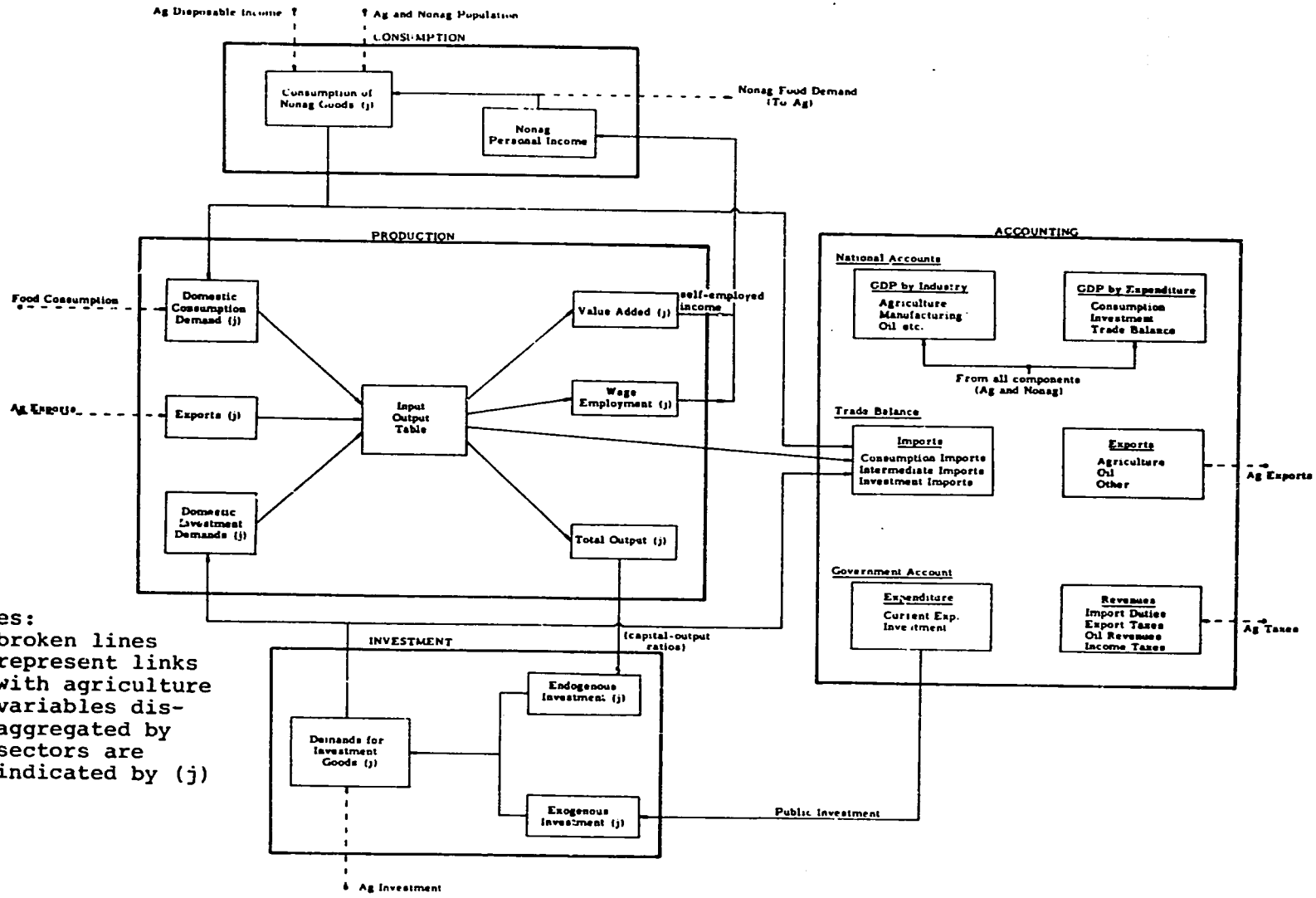
Major sectors and interactions of the southern Nigerian agricultural model.

make projections of the likely consequences of alternative policy options.

The nonagricultural submodel (Figure I.6) is an aggregated, ten-sector input-output model of the Nigerian economy. One of the ten sectors, the agricultural sector, is modeled in detail on the micro level by the agricultural submodels, while the nine nonagricultural sectors are aggregated on the macro level. Since the primary focus of the national model is on agriculture, the broad, aggregated nonagricultura submodel enables the key interactions between agriculture and nonagriculture--e.g., agriculture's demands for consumer good and capital inputs, nonagriculture's demands for raw material and food, rural-urban migration--to be investigated [4]. This submodel also constructs the national accounts.

The population component (Figure I.1) simulates the Nigerian demography. Births and deaths are computed for a population of 27 three-year age cohorts. In addition, the total labor force is determined and split between agricultural and nonagricultural occupations in each region and each ecological zone. Rural and urban food demands are computed as is rural-urban migration.

The market and interregional trade component (Figure I.1) models the national food market. It takes cash food supplies from the agricultural submodels and food demands from the population component, computes the price of transportation (based on investments in transport capacity) and interregional shipments of food, and thus determines the



Notes:
1. broken lines represent links with agriculture
2. variables disaggregated by sectors are indicated by (j)

Figure I.6 Model of the nonagricultural economy and the national accounts.

market price of food in both regions. In addition, the per capita consumption of food by the agricultural and nonagricultural populations in each region is calculated.

In summary, the national model is a very complex computer simulation model of the Nigerian agricultural economy. It is capable of investigating the consequences of various policy options, including interactions with the nonagricultural economy. The total model contains some 2,000 to 3,000 equations and requires about 60 to 70 seconds of central processor time on MSU's CDC 6500 computer for a run of 42 years of simulated time. The southern regional agricultural submodel to be discussed here incorporates behavioral characteristics peculiar to an agricultural economy exhibiting competition between perennial and annual commodities for scarce resources. Included, thus, is a model of the distributed parameter process of the demography of perennials, which is developed in the next chapter.

CHAPTER 2

The Dynamic Demography of Perennials: A Model of a Distributed Parameter Process

A perennial crop consists of a population of trees of various ages, i.e., trees planted at different times. Since certain characteristics of these trees depend on their age, e.g., yields and labor requirements, the age distribution of trees is very important in determining the output of the crop and thereby the foreign exchange, tax revenue, income and other benefits accruing to the public and private sectors. Thus, it is useful to model the tree crops along the lines of a demographic model. That is, the perennial population ages through time, with births (new plantings) and deaths generating a dynamic and crucial age distribution.

Equation 3.1 in Chapter 3 employs Euler's method to generate a numerical solution to the lumped approximation of a distributed parameter phenomenon--the growth of a population of trees. In this chapter, a general population balance model is presented, examples of lumped approximations are given, and the lumped approximation represented by Equation 3.1 is developed wherein distributed lags are incorporated to deterministically generate probability distributions which capture the effects of genetic and

environmental differences among individuals in the population.

General Population Balance Model[1/]

Population dynamics in general may be distributed in several dimensions in addition to time, depending on the needs and interests of the observer. Examples would be population distributions by spatial location, by age, by size, by productivity, by mass, by education, by income, by color (the visible spectrum of light), by emission of pollutants, etc.--in short, any property of individuals of the population which can be regarded as a continuum. This model can be applied to such disparate populations as people, cocoa trees, caterpillars (and butterflies), bacterial cells, cattle, shrimp, roses and even automobiles.

Let $\psi(t, \pi_1, \pi_2, \ldots, \pi_m)$ be the distribtuion (i,e., density) of individuals over time t[2/] and properties π_i, $i = 1, \ldots, m$. Thus, $\psi\Delta V$ is the number of individuals at time t in the m-dimensional region of volume V in the property space, where $V = \Delta\pi_1\Delta\pi_2\cdots\Delta\pi_m$; that is, the number of individuals with property values in the interval $(\Pi, \Pi+\Delta\Pi) = (\pi_1, \pi_1+\Delta\pi_1)X(\pi_2, \pi_2+\Delta\pi_2)X\cdots X(\pi_m, \pi_m+\Delta\pi_m)$.

The population balance requires that the rate of accumulation of individuals in an arbitrary, small volume V

1/ This section is drawn from the developments of [10, pp. 66-67] and [19,p. 38].

2/ The time dimension is shown apart from the others since it is virtually always of interest while the others are not, i.e., we might have m = 0.

of the property space be equal to the rate of net generation--i.e., births minus deaths--within V. Thus,

$$\frac{d}{dt}\int_V \psi dV = \int_V (B-D)\,dV \tag{2.1}$$

where

$B = B(t,\pi_1, \ldots, \pi_m)$ = births/(unit time-unit property change)

$D = D(t,\pi_1, \ldots, \pi_m)$ = deaths/(unit time-unit property change)

$dV = d\pi_1 d\pi_2 \cdots d\pi_m$

$\int_V = \int_{\pi_1}\int_{\pi_2}\cdots\int_{\pi_m}.$

Equation 2.1 can be written (assuming the necessary differentiability and continuity conditions [3, pp. 120-122]) as

$$\int_V \{\frac{\partial\psi}{\partial t} + \sum_{i=1}^{m} \frac{\partial}{\partial\pi_i}(v_i\psi) + D - B\}dV = 0 \tag{2.2}$$

where $v_i = d\pi_i/dt$, i.e., the rate of change of property i as an individual ages through time. Since V is arbitrary, we must have

$$\frac{\partial\psi}{\partial t} + \sum_{i=1}^{m} \frac{\partial}{\partial\pi_i}(v_i\psi) + D - B = 0. \tag{2.3}$$

Equation 2.3 is the general population balance equation.

The birth and death terms, B and D, will generally be derived from characteristics of the particular population. For instance, in [10, p. 38], microbial cell populations are discussed, where "births" and "deaths" consist of cell divisions and natural deaths. Also, Himmelblau and

and Bischoff [19, pp. 192-193] give an illustration of particle agglomeration where "births" and "deaths" occur as a result of particle collisions.

Lumped Approximations

In what follows, we assume $m = 1$, that is, only one property p is of interest. The lumping is completely generalizable to the cases $m > 1$.

Suppose [1/] p exists in an interval $p_m \leq p \leq p_M$, where p_m and p_M may be infinite. We can divide the population into n p-cohorts P_i, $i = 1, \ldots, n$, by defining correspondences

$$\begin{aligned} P_1 &\leftrightarrow p \varepsilon [p_0, p_1) \\ P_2 &\leftrightarrow p \varepsilon [p_1, p_2) \\ &\vdots \\ P_n &\leftrightarrow p \varepsilon [p_{n-1}, p_n] \end{aligned}$$

where $p_0 = p_m$ and $p_n = p_M$. The points $p_1, p_2, \ldots, p_{n-1}$ may be arbitrary but would probably be chosen in some way meaningful for the particular population. Then, defining

$$y_i(t) = \int_{p_{i-1}}^{p_i} \psi(t,p)\,dp \ , \ i = 1, \ldots, n, \tag{2.4}$$

where $y_i(t)$ = the number of individuals in cohort i, and integrating Equation 2.3 with respect to p, we have

$$\frac{dy_i(t)}{dt} = (v\psi)_{p_{i-1}} - (v\psi)_{p_i} + \int_{p_{i-1}}^{p_i} (B-D)\,dp \tag{2.5}$$

[1/] Generalized from [27, p. 7].

where $v = dp/dt$ and $(v\psi)_{p_i}$ is the rate at which individuals leave cohort P_i and enter cohort P_{i+1}, and where the integral term is the net generation per unit time of individuals in P_i.

Coulman, Reice and Tummala [7] developed a model for populations of amphipods. (The model is generalizable to other animals whose life spans can be lumped as below.) The property p is maturity m, which can be represented by proportion of life span lived. The total life span is divided into seven identifiable stages, called instars. Thus, $m_m = 0$, $m_M = 1$ and $n = 7$.

The basic model is composed of six equations (Figure I.7). The first is a difference equation[1/] representation of Equation 2.5.

$$Y_i(n+1) = Y_i(n) + S_{i-1}(n) - P_i(n) - M_i(n) \tag{2.6}$$

$$P_i(n) = p_i(n)Y_i(n) \tag{2.7}$$

$$M_i(n) = S_{i-1}[n-\eta_i(\tau)]\cdot\prod_{j=0}^{\eta_i(\tau)-1}[1-p_i(n-j)] \tag{2.8}$$

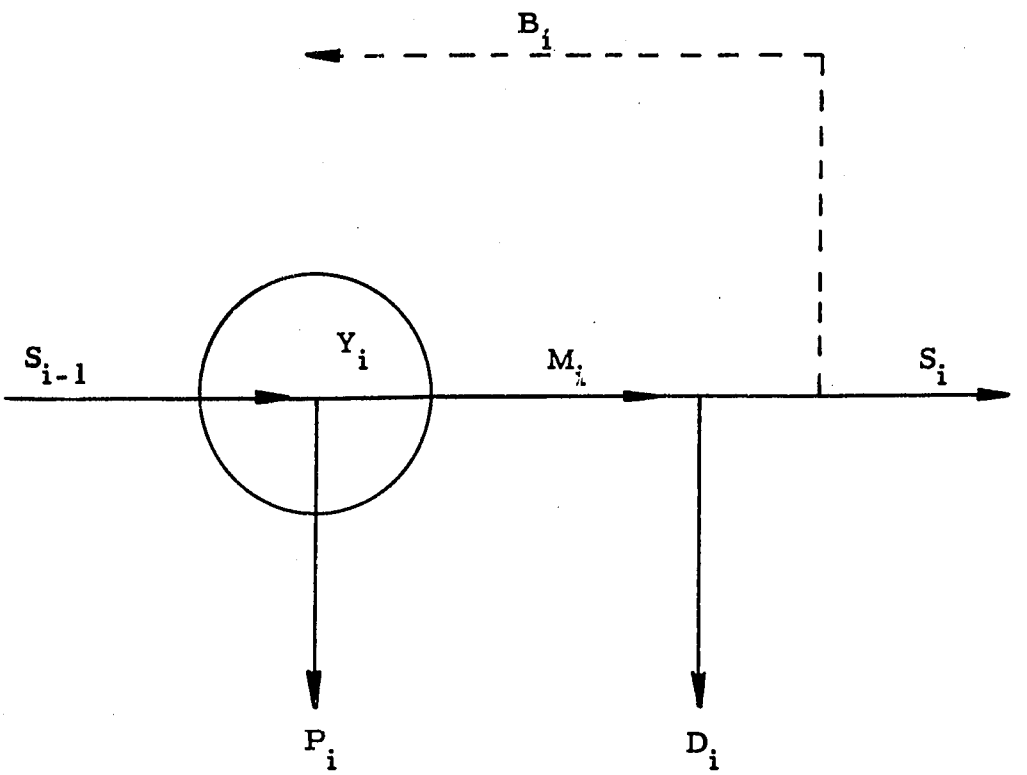
$$D_i(n) = d_i(n)M_i(n) \tag{2.9}$$

$$S_i(n) = M_i(n) - D_i(n) \tag{2.10}$$

$$B_i(n) = b_i(n)S_i(n) \tag{2.11}$$

1/ Kharkar [27, p.6] indicates that Equations 2.6 - 2.8 reduce to the differential equation

$$\frac{dY_i(t)}{dt} = -p_i(t)Y_i(t)+S_{i-1}(t)-\{1-\int_{t-\eta_i(\tau)}^{t} p_i(s)ds\}S_{i-1}(t-\eta_i(\tau)).$$



Y - population
B - birth
D - natural death
M - mature
P - predation
S - supply

Figure I.7 A model of a generalized amphipod instar.

where

Y	=	population
P	=	predation
M	=	maturation out
D	=	deaths
S	=	maturation in
B	=	births
$\eta(\tau)$	=	maturation time as a function of temperature τ
p, d, b	=	proportions
i	=	indexes the instars
n	=	indexes time (days).

Note (Figure I.7) that deaths occur after maturation, births occur after deaths and there are no births into an instar (i.e., $B = 0$ in Equation 2.5) unless $i = 1$. The number of individuals maturing from the ith instar at time n (Equation 2.8) is the number which entered the instar $\eta_i(\tau)$ days previously and which has survived predation.

In a simulation model of the cocoa industry of the Dominican Republic [36], Mathis considers populations of cocoa trees, where the property of interest is productivity. As in the model described above, the property is related to stages in the life span, so the distribution is lumped into 13 production cohorts[1/] of length d_i years, $i = 1, \ldots, 13$.

The demographic model used by Mathis may be written[1/]

1/ This is for traditional cocoa. Modern cocoa has 12 cohorts and is modeled similarly.

as three of the above equations. (No births or deaths are assumed.)

$$A_i(t+DT) = A_i(t) + M_{i-1}(t) - M_i(t) - R_i(t) \tag{2.12}$$

$$M_i(t) = A_i(t)/d_i \tag{2.13}$$

$$R_i(t) = \begin{cases} 0 & , i = 1, \ldots, 10 \\ P_i(t) & , i = 11, 12, 13 \end{cases} \tag{2.14}$$

where

A = population (acres of trees)

M = maturation

R = removal for replanting

P = removal policy

d = maturation time

i = indexes the cohorts

DT = time increment (years).

Note the assumption that the distribution within a cohort is uniform for all t; thus, if $d_i = 10$, for example, one-tenth of the individuals (acres) of cohort i pass to cohort i+1 each year (Equation 2.13). Removal of traditional cocoa is limited to the oldest three cohorts and is a matter of policy (constrained by available acres).

In the next section, we will look at the demographic model used in the southern regional agricultural submodel, where no assumption is made about the age distribution within a cohort and where the maturation lag (analogous to η_i of Equation 2.8) is a random variable.

Demography of Perennials

The most important property of perennials, particularly for a production model, is productivity. It is essential for determining the output of the crop and thereby the benefits accruing to the public and private sectors. Modeling the productivity dimension directly, however, is not feasible, for a given productivity value (yield) may characterize different segments of the population, i.e., young trees whose yields are rising and old ones whose yields are declining. In the notation of Equation 2.5, $v>0$ for part of ψ and $v<0$ for the rest of ψ. Thus, it is convenient to substitute, as Mathis does, the age dimension as a surrogate for productivity. The lumping can be done, however, in terms of production cohorts (or stages). In this manner, the demographic model of the tree crops contains the five production cohorts described in Chapter 3, Figure II.3.

The population balance model is virtually the same as Mathis' (Equation 2.12), where R_i in this case represents removal in order to transfer land to other commodities or for abandonment. The removal rate R_i is determined by the decision mechanism discussed in Chapter 3. The major departure from Equation 2.12 is in the determination of the maturation rate dM_i/dt. The model here is vaguely similar to that of Coulman, et al. (Equation 2.8), in that it incorporates a maturation lag. However, in the present model, the maturation lags are random variables which account for genetic and environmental differences among individuals in

the population.

Kharkar suggests (following Wangersky and Cunningham [52]) an exponential distribution for the maturation times [27, pp. 8-9]. Here we use the more general k^{th}-order gamma distribution (Figure II.4, Chapter 3). The effects of these probabilistic lag times can be simulated deterministically with k^{th}-order distributed delays, i.e., a series of k first-order (exponential) delays [31,32]. This is accomplished by Equation 3.1, where trees entering a production cohort are lagged DEL years <u>on the average</u> and where the output distribution looks like Figure II.4, depending on the value of k.

<u>Summary</u>

We have seen how Equation 3.1 in Chapter 3 uses Euler integration to generate numerical solutions to a lumped approximation (Equation 2.5) of the distributed parameter process (Equation 2.3) of population dynamics. In Part II, we shall see how this model serves as one component in the larger model of the agricultural economy of southern Nigeria, which in turn is a submodel of the Nigeria model outlined in Chapter 1.

P A R T II

MODEL DESCRIPTION

Introduction and Summary

The computer simulation model of the agricultural economy of southern Nigeria is composed of five basic components or building blocks (Figure II.1). The first, the land allocation and modernization decisions component (LAMDAP), allocates land among various commodities in each of four ecological zones of competing cropping activities. Land use decisions are based on perceived relative profitabilities and the availability of information, either from farmer to farmer in a diffusion process or from extension agents (or other communications media) as part of modernization promotion efforts. Expansion of total cultivated land may occur as a result of these economic decisions <u>and</u> as a consequence of a natural increase in the number of agricultural decision makers.

The second principal component of the southern model (AMPPAP) takes the allocation of land from LAMDAP and, given commodity prices and yields, computes agricultural production, processing and marketing for the five commodities considered--cocoa, oil palm, rubber, food and tobacco. The subsistence food production depends on the level of

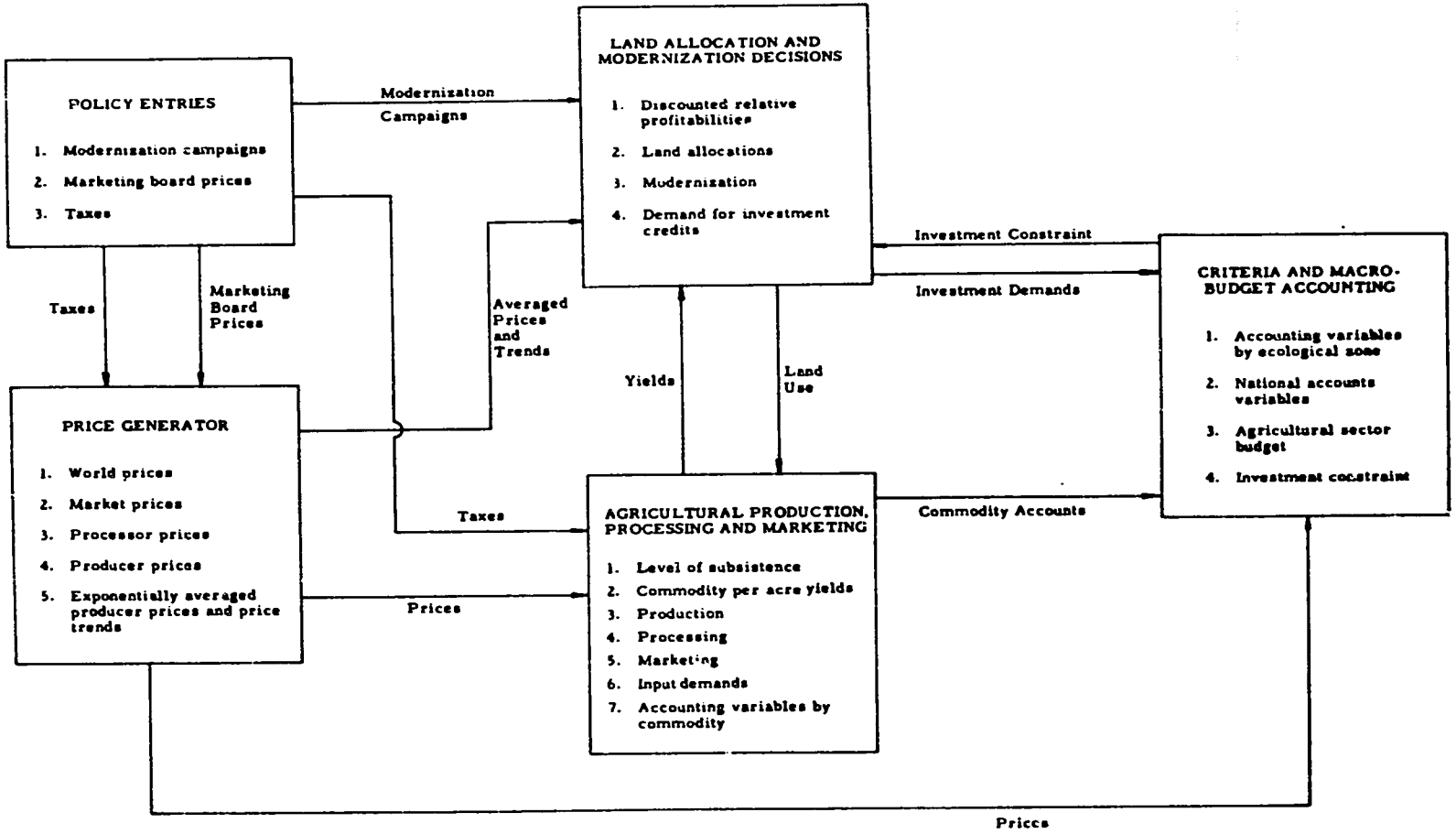


Figure II.1 Building blocks of the southern model.

agricultural subsistence, or, conversely, on the degree to which farmers depend on the market for their staple food needs. This subsistence level is computed endogenously for each ecological zone as a function of food market stability, the food price level, the level of agricultural sector food consumption and cash income from non-food commodities. The processing component determines the investment in processing capacity necessary to process the raw material inputs: palm fruit bunches are processed into palm oil and palm kernels, rubber latex is processed into sheets and raw tobacco is cured.

A third unit of the model (PG) generates world, market, processor and producer prices. The domestic market prices of food and palm oil are determined endogenously as functions of excess domestic demand. Export commodity prices depend on export and marketing board tax policies and exogenous world prices. Producer prices are exponentially averaged; these averages are used for the projections made to determine profitabilities in component LAMDAP and as bases to which current prices are compared in AMPPAP to determine short run harvest supply responses.

The remaining two components are the primary entry and exit points of the system. As policy entry points, commodity production campaigns are specified and conducted, marketing board and export tax policies are set, and income taxes may be levied. Finally, in the criteria and macro-budget accounting component (CRTMBA), the agricultural sector

budget is balanced, performance variables are generated and agricultural sector accounts are computed for the nonagricultural/national accounts component of the total Nigeria model.

Each of these five building blocks of the southern agricultural submodel will be described in some detail in Chapters 3 through 7, respectively.

CHAPTER 3

Land Allocation and Modernization Decisions--Annuals/Perennials (LAMDAP)

Component LAMDAP of the simulation model allocates land to the production of the various commodities grown in each of the four ecological zones (or crop sectors) described below (Figure II.2): the Cocoa-Food Sector, the Palm-Food Sector, the Rubber-Palm-Food Sector and the Food-Cash Annual Sector. In making these allocations, LAMDAP simulates farmer's choices among the alternative uses for their land based on economic and cultural factors. Modernization of current land uses is an alternative as is transferring land into the production of alternative commodities.

Ecological Zones

Land use decisions in the South are based on the four ecological zones (or crop sectors) of competing cropping activities defined in the model. The sectors are determined roughly by climatic and soil conditions [15]. Figure II.2 is a Venn diagram of these zones. Sector 1 is the area where cocoa competes with food crops for land and capital. This sector covers all of the Western State (except Egbado, Oyo and Okitipupa Divisions) and Afenmai Division of the Midwest.

Although palm is a possible competitor to cocoa, the simplifying assumption is made that it is not really an economically viable alternative in this crop sector. In the major cocoa growing areas of the Western State, the profitability of cocoa relative to palm is such that cocoa production by far dominates palm production. Aside from the mere collection of wild palm fruits, farmers do not consider investment in the cultivation or modernization of palm a significant alternative. Thus, in Figure II.2, the Cocoa Sector circle does not overlap the Palm Sector circle. The wild palm harvested in the Cocoa Sector is included in the model as a product of the bush areas. The model can be revised if further evidence calls this assumption into serious question.

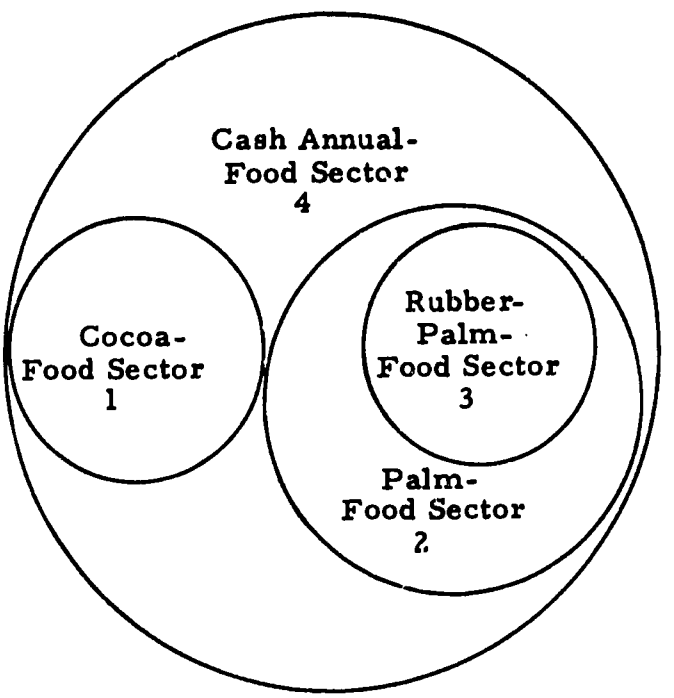


Figure II.2 A Venn diagram of the ecological zones of southern Nigeria.

In Sector 2, oil palm is the primary competitor with food for inputs. This includes all of the three Eastern states with the exception of the following divisions: Brass, Degema, Nsukka, Udi, Abakaliki, Ogoja, Obudu and Ikom. Okitipupa Division of the West and the Midwest State minus Afenmai and Western Ijaw Division comprise Sector 3, where oil palm, rubber and food all compete for resources. The remainder--including Lagos State, those parts of the West not in Sector 1, those parts of the East not in Sector 2, and Western Ijaw Division of the Midwest--comprises Sector 4, the areas where only annual crops can be economically farmed. In portions of this sector, cash annuals--e.g., cotton or tobacco--may compete with food.

These ecological zones are not entirely internally homogeneous. For example, not all the food land in the Cocoa Sector is suitable for cocoa, and vice versa. Thus, although the crop sectors are defined for ecologically competitive crops, compromises were made to delineate the ecological zones as contiguous areas (except the Food Sector). The primary reasons for this are twofold. First, any given farmer may hold some land suitable only for cocoa, some only for food and some where either is feasible. Since the infrastructure (roads, communication links, etc.) and the behavioral characteristics of farmers--e.g., risk aversion and confidence in government experts--which control the land use and modernization decisions are likely to be somewhat determined by contiguous areas of social contact, a case can be made for

compromising strictly "ecological" zones. Secondly, we will be interested in performing an agricultural sector budget accounting for each ecological zone. This budget includes not only agricultural income and investment but also consumption expenditures of the population. To the extent that consumption depends on common behavioral considerations, contiguous crop sectors again appear suitable.

Land Uses

In general, the land uses in the ecological zones include traditional and modern perennials, annuals, and bush. Specifically, Sector 1 has traditional and modern cocoa, food[1/], and bush, while Sector 2 has traditional and modern palm, food and bush. Sector 3, with two perennials competing, includes traditional and modern rubber, traditional and modern palm, food and bush. In Sector 4, the alternative to food and bush is tobacco, although the general mechanism could incorporate consideration of a cash annual other than tobacco, e.g., cotton or kenaf.

Perennials

Perennial commodities are modeled dynamically as populations distributed over time and productivity

---

1/ "Food" is defined as a weighted composite of the major staples produced and consumed in the South: yam, maize, cassava and cocoyam. The weights used are as follows: yam--.315; maize--.278; cassava--.310; and cocoyam--.097. These weights were derived from acres in production as reported in [14]. They are used with the four staples to determine the food yield, labor inputs, biological inputs, chemical inputs and the calorie yield of food.

(Chapter 2). The demographic model of the tree crops is divided into five production cohorts of varying lengths (Figure II.3). The respective cohort lengths reflect the five production stages of a perennial crop which the model identifies: a gestation stage, a stage of rising yields, a stage of maximum yields, a declining yield stage, and a stage of old trees where yields remain at some nominal level. The aging of trees through the first four cohorts is modeled by distributed lags (discussed below and Equation 3.1a). When trees finally enter the old age cohort, their aging rate is no longer modeled, and trees remain there indefinitely producing nominal yields to reflect their being phased out of production. The model may easily be modified to incorporate a death rate for trees in this last stage. However, rather than actual "death", this is more of an economic decision of the farmers to permanently abandon old trees (thus allowing eventual reversion to bush), i.e., an economic death rather than a physical death. Such abandonment is thus determined in the model as a land use decision in the same manner as are planting rates (births) and transitions out of the population to other commodities, modern or traditional.

The distributed lag model [31] allows us to simulate, in effect, a probability density [32] for the time it takes trees to mature from each production stage to the next, i.e., not all trees entering a particular production stage at the same time will leave it at the same time. For example,

suppose the stage of rising yields is a six-year cohort (as it is for traditional palm). Some trees entering this stage after gestation may actually mature to maximum yields in less than six years, while others may require considerably more time. On the average, however, traditional palm trees take about six years, once they begin to bear, to reach maximum yields.

A parameter k determines the shape of the probability density of maturation rates (Figure II.4). If $k = 1$, an exponential distribution is assumed, and, as $k \to \infty$, the distribution (a gamma distribution) approaches a normal distribution. The lag is called a kth-order delay, and it is equivalent to k first-order (exponential) delays in series, where the output of one stage is the input to the next. Whatever the value of k, the mean lag time for the cohort (the mean of the distribution) is given by the parameter DEL.

Each production cohort is modeled as third-order distributed lag. The value $k = 3$ is used in the model as a compromise between what might be a realistic distribution of maturation times (perhaps $k = 6$) and the desire to limit computer storage requirements. If experimental evidence suggests a larger value of k and if model tests indicate this is a sensitive parameter, the model may be modified accordingly. The aging rates and levels of the cohorts are updated each time period by Equations 3.1[1/], where transitions

[1/] FORDYN simulation uses the Euler method for numerical integration [31]. Equations appearing in this dissertation will be presented in this format.

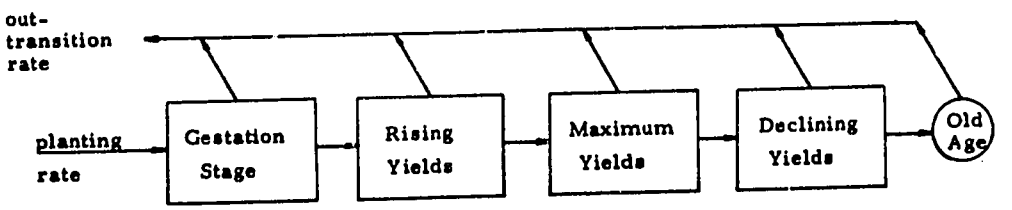


Figure II. 3 Perennial production cohorts.

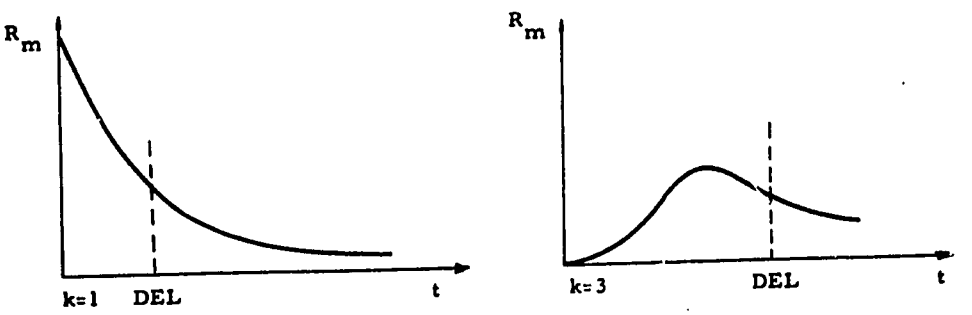


Figure II.4 The gamma distribution of maturation rates, R_m.

out of the population come from each of the intermediate rates proportionately.

$$COH_{ijn}(t) = COHDR_{ijn}(t-DT) + \frac{DT}{(DEL_{jn}/3)} * [COHDR_{(i-1)jn}(t-DT) - COHDR_{ijn}(t-DT)] \quad , i = 1, 2, 3 \qquad (3.1a)$$

$$COHDR_{ijn}(t) = COH_{ijn}(t) * \{1 - TREXIT_{jn}(t) * DT * 3 / [DEL_{jn} * \sum_{i=1}^{3} COH_{ijn}(t)]\} \qquad (3.1b)$$

$$TLPER_{jn}(t) = \frac{DEL_{jn}}{3} * \sum_{i=1}^{3} COHDR_{ijn}(t) \qquad (3.1c)$$

where:

$COHDR_i$ = the three intermediate rates (i = 1, 2, 3) of a third-order cohort delay after accounting for transitions out of the population--acres/year

DEL = the mean lag time of a production cohort--years

DT = the time period of a simulation cycle--years

TREXIT = the rate at which land leaves a cohort by transferring out of the population to other uses (determined endogenously by the decision component discussed below)--acres/year

TLPER = the amount of land in a cohort--acres

j = indexes the cohorts--j = 1, ..., 4

n = indexes the perennial population streams--n = 1, ..., 8.

When i = 1, $COHDR_{0jn}$ is the rate land enters the cohort. If j = 1, (the first cohort--gestation stage--of a perennial population stream), $COHDR_{01n}$ is the planting rate determined

by the land use decisions. Otherwise, $COHDR_{0jn}$ is the output rate of the previous cohort, where the output rate of cohort (j-1) is $COHDR_{3(j-1)n}$.

The level equation, Equation 3.1c, indeed gives the exact storage of the cohort delays for all t[1/]. We can see this by examining the differential equation describing the ith stage of the kth-order distributed delay process (i = 1, 2, 3, ..., k):

$$D_i \frac{dr_i(t)}{dt} = r_{i-1}(t) - r_i(t)$$

where:

$D_1 = D_2 = \ldots = D_k = DEL_{jn}/k$, and

$r_i(t) = COHDR_{ijn}(t)$ in Equation 3.1b.

Here, $r_i(t)$ is the total outflow from the delay stage and $r_{i-1}(t)$ the total inflow. Clearly, the right side is the rate of change of storage in the ith delay stage. Hence:

$$D_i \frac{dr_i(t)}{dt} = \frac{dQ_i(t)}{dt}$$

where:

Q_i = the storage in the ith stage.

On integrating we get:

$$Q_i(t) - Q_i(0) = D_i r_i(t) - D_i r_i(0).$$

It can be shown that $Q_i(0) = D_i r_i(0)$ and thus that:

1/ This representation and the following development of it were suggested by Dr. T. J. Manetsch.

$$Q_i(t) = D_i r_i(t)$$

for all t. The <u>total</u> storage, Q(t), in a k-stage delay process is, therefore:

$$Q(t) = \sum_{i=1}^{k} D_i r_i(t)$$

where:

$Q(t) = TLPER_{jn}(t)$ in Equation 3.1c.

<u>Modern vs. Traditional</u>. There are eight perennial population streams in the model: 1) traditional cocoa, 2) modern cocoa, 3) traditional palm (Palm Sector), 4) modern palm (Palm Sector), 5) traditional rubber, 6) modern rubber, 7) traditional palm (Rubber-Palm Sector), and 8) modern palm (Rubber-Palm Sector). All streams are modeled by Equations 3.1 as shown in Figure II.3, but the maturation lags of the production stages differ from one perennial population to another. Such biological differences (e.g., cohort lengths, yields) are the primary reason for modeling modern and traditional perennials separately. However, the differences between the modern and traditional population streams of a perennial commodity are not only biological--i.e., modern high-yielding and/or disease resistant hybrids versus traditional low-yielding, diseased varieties--but also cultural. The term "modern" also encompasses improved managerial practices such as spraying, weeding, fertilizing, spacing and pruning. Improved harvesting techniques, particularly rubber

tapping, are also subsumed under "modern".

Substreams. Each perennial population stream is further divided (Equation 3.2) into two subpopulations or substreams. In the case of the traditional perennials (i.e., traditional biological varieties), the two substreams--improved and traditional--are distinguished by the cultivation practices used, i.e., modern inputs and methods versus traditional. The modern cultivation practiced in the improved traditional substreams is the same as that practiced in the modern streams, but the latter include new higher-yielding, disease resistant hybrid varieties. The two substreams of the modern perennial population streams--replanted and newly planted--represent new varieties planted on former traditional perennial land and on former bush or food land (or, in the case of Sector 3, on land formerly in the traditional stream of the other perennial, i.e., rubber or palm), respectively.

The two substreams of each perennial population stream are treated as proportions. Specifically, the model keeps track of the proportion of land in the first substream via Equation 3.2.

$$PSPER_{jn}(t) = [RINR_{jn}(t)*DT*PSPER_{(j-1)n}(t-DT) + PSPER_{jn}(t-DT)* \{TLPER_{jn}(t-DT) - (ROUTR_{jn}(t) + TREXIT_{jn}(t)* PTOUT)*DT\} - TRMOD_{jn}(t)*DT]/TLPER_{jn}(t) \quad (3.2)$$

where:

PSPER = proportion of land which is in the first substream

RINR = the rate land enters the cohort--acres/year

ROUTR = the rate land leaves the cohort to the next older cohort--acres/year

TREXIT = the rate land leaves the cohort to alternative commodities--acres/year

PTOUT = a parameter determining how much of the land leaving a perennial stream comes from the first substream (PTOUT = 1 means proportionately from each substream)--dimensionless

TRMOD = the rate land moves from the first to the second substream within the same cohort (i.e., improvement of traditional perennials)--acres/year

j = indexes the cohorts--j = 1, ..., 5

n = indexes the perennial streams--n = 1, ..., 8.

For j = 1 (the first cohort), RINR is the planting rate and $PSPER_{0n}$ is the proportion planted into the first substream. Otherwise, RINR is the ROUTR of the previous cohort (equals $COHDR_{3(j-1)n}$ discussed in connection with Equations 3.1).

The primary reasons for defining two distinct substreams is that yields and input demands may differ between them. This is certainly the case for the traditional and improved substreams of the traditional perennials. Such differences between newly planted and replanted modern perennial commodities are less obvious, however, and a case could be made for simplifying the model by merging these two substreams. But there is a third, important advantage to be

gained by maintaining the distinction. Improvement, replanting and new planting are all modern alternatives that may be stimulated by overt, exogenous production campaign policies. As such, it is essential that the economic returns and costs of each of them separately be available in order to evaluate the alternative promotion policies. Thus, the model keeps track of replanted and newly planted modern perennials separately, as it does with traditional perennial varieties cultivated under improved and traditional methods.

Annuals

Food land (Equation 3.3) is land on which either subsistence or cash food is actually in production. There are also two subcategories (or "substreams", although there is no aging process as with the perennials) of food land: modern and traditional. The same rationale discussed above for the perennial substreams holds for the food substreams, the modernization of food production also being a potential production campaign policy.

Tobacco in Sector 4--or any other cash annual--is treated in the same manner as food, but there are no substreams. It is assumed there is no cash annual other than food traditional to the area. Therefore, any production of tobacco, cotton or whatever will have to have been exogenously promoted; thus we can assume it will be only modern.

Bush is all unused arable land, including land in fallow. Swamps, other wastelands, forest reserves and the

like--commonly called "bush" but not available for smallholder agricultural production--are not treated in the model.

Food land is computed by Equation 3.3. Cash annual (tobacco) land and bush land are computed by similar equations.

$$TLFD_k(t) = TLFD_k(t-DT) + [RINF_k(t-DT) - ROUTF_k(t-DT)]*DT \quad (3.3)$$

where:

TLFD = total food land--acres

RINF = rate land from other commodities is planted in food--acres/year

ROUTF = rate food land is transferred to the production of other commodities--acres/year

k = indexes the crop sectors--k = 1, ..., 4.

The proportion of food land in traditional production (the first substream) is determined by an equation similar to Equation 3.2.

Although, as mentioned earlier in the discussion of the ecological zones, the simplifying assumption is made that palm does not compete with cocoa in Sector 1, there is a significant level of wild palm production there. The model handles this by including wild palm in the Cocoa Sector as a proportion of the bush. It is further assumed that the wild palm is uniformly distributed therein, and any land leaving or entering the bush category does not change the proportion of bush that is wild palm. This treatment

applies only to the Cocoa Sector; wild palm in the Palm and Rubber-Palm Sectors--where it is the major or one of the major productive enterprises--is included in the traditional palm perennial population streams.

Other Land Uses

No further possible land uses are considered in the model. Alternative perennials (such as citrus, coffee and kola), non-staple foods (such as pineapple, banana, plantain, beans and green vegetables), and more than one cash annual alternative are ignored. Such simplifications--necessitated by our resource constraints (principally data and computer time and storage)--are justified by the relative economic insignificance, current and potential, of the omitted alternatives to the agricultural economy of southern Nigeria. Further research will be necessary to either confirm this judgment or to expand the model to treat the potential production of more commodities.

Alternatives

In principle, every current land use is a conceivable alternative to every other present use in the same ecological zone. In practice, however, certain behavioral assumptions can be made which will reduce the myriad alternatives to be considered and to simplify the model.

Table II.1 displays the present and alternative land uses currently considered in the model. The last column shows the minimum planning horizon relevant to each use

Present Use	Alternatives Omitted	Alternatives Considered	Planning Horizon
1. Traditional perennials	a. Food b. Traditional replanting *c. Traditional new planting of the other perennial	a. Improvement b. Modern replanting *c. Modern new planting of the other perennial d. Abandonment to bush	Remaining life to 30 years 30 years 30 years Remaining life to 30 years
2. Modern perennials	a. Food b. Traditional replanting c. Modern replanting *d. Traditional new planting of the other perennial *e. Modern new planting of the other perennial	a. Abandonment to bush	Remaining life to 30 years
**3. Cash annual (tobacco)	--	a. Food b. Abandonment to bush	1 year 1 year
4. Food	a. Traditional new planting of the 1st perennial *b. Traditional new planting of the 2nd perennial c. Abandonment to bush (other than fallow)	a. Modernization of food b. Modern new planting of the 1st perennial *c. Modern new planting of the 2nd perennial **d. Cash annual (tobacco)	1 year 30 years 30 years 1 year
5. Bush	--	a. Traditional new planting of the 1st perennial *b. Traditional new planting of the 2nd perennial c. Modern new planting of of the 1st perennial *d. Modern new planting of the 2nd perennial e. Food **f. Cash annual (tobacco)	30 years 30 years 30 years 30 years 1 year 1 year

Perennial alternatives do not apply to Sector 4.
* Alternatives with one asterisk (*) apply to Sector 3 only.
** Alternatives and present uses with two asterisks (**) apply to Sector 4 only.

Table II.1. Alternative land uses.

(discussed below). The second column in Table II.1 lists the conceivable alternatives that we have "assumed away". While some of these assumptions are quite reasonable (for example, it may be safe to assume that modern cocoa won't be cleared and replanted with traditional varieties; or that traditional cocoa won't be cleared and the land planted directly in food), others may bear closer scrutiny and may possibly have to be reconsidered, especially if they unrealistically constrain the land allocations.

Economic Decisions

Land use decisions depend on the relative profitability of each alternative, on modernization promotion efforts, on diffusion effects, on the availability of land and capital, and on the behavioral characteristics of the farmers making decisions. Figure II.5 indicates how these considerations, discussed in detail below, determine land use patterns

Profitabilities

Farmers' decisions among the alternative uses for their land are based upon their perceptions of the relative profitabilities (Equation 3.4) of the available alternatives.

$$PDR_{ij}(t) = \frac{DPVSUM_i(t) - DPVSUM_j(t)}{|DPVSUM_j(t)|} \quad , i = 1, \ldots, n_j \qquad (3.4)$$

where:

PDR = the relative profitability differential--dimensionless

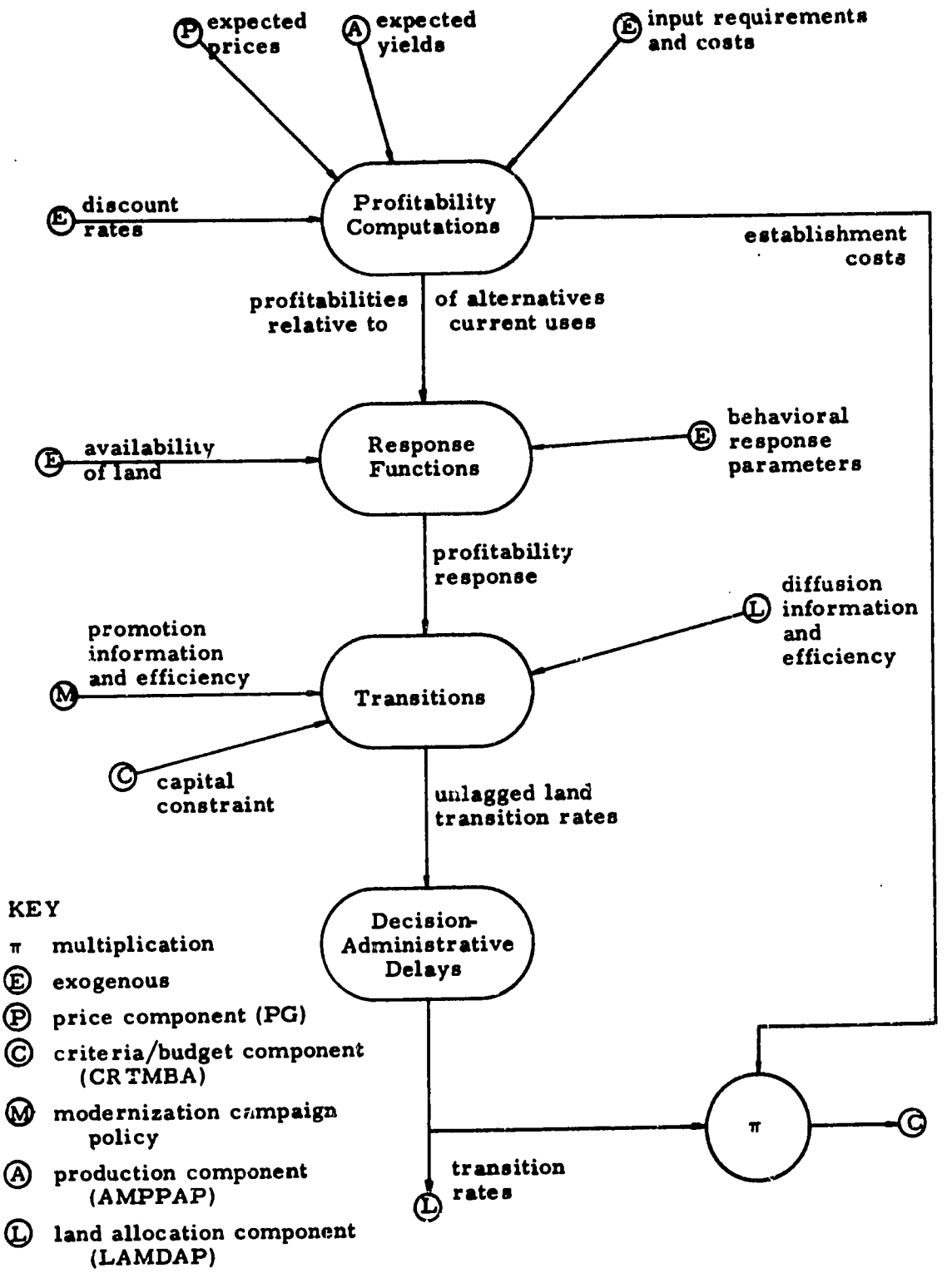


Figure II.5 Land-use decision mechanism.

DPVSUM = the discounted sum of returns over the planning horizon (see Equation 3.5)--£/acre[1/]

i = indexes the alternatives to a present use--$i = 1, \ldots, n_j$

n_j = the number of alternatives open to a present use (see Table II.1)

j = indexes the present uses of a crop sector.

Land use profitabilities are defined as the present value of the stream of net income which farmers expect to receive over some relevant planning horizon. (See the last column in Table II.1.) The model computes (Equation 3.5) the sum of the discounted present value of returns to a land use from the present up to the planning horizon. This discounted sum is the "profitability" of that land use.

$$DPVSUM(t) = \sum_{i=1}^{n} \frac{(TR_i(t) - TC_i(t))}{(1 + DR)^i} \qquad (3.5)$$

where:

DPVSUM = as defined above

n = the meaningful planning horizon (see Table II.1)--years

TR = total revenue (Equation 3.6a)--£/acre-year

TC = total cost (Equation 3.6b)--£/acre-year

DR = the relevant discount rate--proportion/year

1/ One Nigerian pound (£) equals US $2.80.

i = indexes the n years of the planning horizon--$i = 1, \ldots, n$.

In general, comparing the discounted present value of the total future returns accruing to an alternative (for instance, new planting of a modern perennial) with that of a present use (food) would be meaningless in view of the fact that each is based on a different planning horizon. In this case, the planning horizon for new planting is 30 years, while that of continuing with food production (an annual crop) is only one year (Table II.1). To avoid this difficulty, profitabilities are computed using the longest planning horizon of the alternatives being compared as common to all.

The discount rates used to compute the present value of future returns are behavioral parameters in the model. The discount rates for each alternative are different, the relative differences reflecting varying attitudes towards the adoption of the alternative land uses, particularly modern alternatives. The assumption is that the more risky and unfamiliar the alternative, the higher the discount rate. For example, discount rates for replanting are higher than for improvement of traditional perennials, while discount rates for planting annuals are lower than those for planting perennials. Continuing in the present use has the lowest discount rate.

Since we are concerned with farmer decision makers, the streams of future revenues and costs (Equations 3.6)

used in the profitability calculations should reflect the farmers' expectations. Thus, the producer prices used here are five-year exponential averages of recent prices. These price averages are projected into the future with trend factors (Equation 3.7) which are also exponential averages of recent producer price fluctuations. The form and computation of producer price averages and trends are discussed more fully later in the description of the price generating component of the southern model (Chapter 5). Similarly, the stream of yields farmers expect are the yields they currently experience rather than the potential production reported by experiment stations. Actual yields approach their potentials with time as farmers gain experience. This concept will be discussed more fully later in the AMPPAP component description (Chapter 4). Additions to expected revenues are any cash and/or price subsidies which may be offered as part of a modernization program.

The cost side includes--as technological coefficients--biological, chemical, labor, and capital (tools and equipment) input requirements over the planning period. Associated input prices are in the model as exogenous constants. The agricultural wage rate increases linearly with time (Equation 5.10a).

Total revenue and total cost are computed simply as:

$$TR_i(t) = PT_i(t)*Y_i(t) + FNCE_i(t) \qquad (3.6a)$$

$$TC_i(t) = PL(t)*XL_i*PLHIRE(t) + PBC*XBC_i + PXE_i + PXP_i(t) \quad (3.6b)$$

where:

PT	=	the expected producer price (Equation 3.7)--£/lb.
Y	=	the yield (Equation 4.4)--lbs./acre-year
FNCE	=	cash subsidy grant (policy--see Chapter 6)--£/acre-year
PL	=	agricultural wage rate (Equation 5.10a)--£/man-year
XL	=	labor input requirement--man-years/acre-year
PLHIRE	=	proportion of labor hired (Equation 4.29a)
PBC	=	the composite price for chemical and biological inputs (possibly subsidized)--£/lb.
XBC	=	the composite chemical and biological input requirement--lbs./acre-year
PXE	=	equipment costs (replacement investment = depreciation)--£/acre-year
PXP	=	processing costs when producers do their own processing (=PAGCST, Equation 4.32e)--£/acre-year
i	=	indexes the n years of the planning horizon--i = 1, ..., n.

Note the perhaps unrealistic assumption of zero opportunity cost for family and own labor. While Equations 3.6 thus probably underestimate costs, there is no basis to assume that farmers value family labor at the going wage rate or at any particular function of the wage rate. Costs would probably be overestimated if family labor were valued at the wage rate.

The producer price projected over the planning horizon has a trend factor applied to it at every fifth year of the profitability series.

$$PT_i(t) = PY(t)*(PYR(t))^{[i/5]} \qquad (3.7)$$

where:

PY = the five-year exponential average of recent producer prices (=PPAV of Equation 5.8a)--£/lb.

PYR = the trend factor--the averaged ratio of the current producer price to the previous time period's producer price (=PPAVR of Equation 5.8c)--dimensionless

[i/5] = the largest integer in the quotient in brackets.

Information Units

In estimating the profitability differentials of the various alternatives, the farm decision makers require certain informational inputs. These include information on future producer prices, expected yields, government or private subsidy and loan programs, and expected costs. The model provides this needed information through "information units".

We introduce the general concept of an information unit so that consideration can be given to various possible alternative means of disseminating information and promoting production campaigns. Of course, extension agents will be the main form of promotional information units. (In fact, diffusion and promotion information are both modeled in

units of extension agent equivalents.) But, in addition, radio broadcasts, film showings, and newspaper coverage can be used by both government and private agencies. At present, the use of newspapers and other printed matter may not always be the most effective medium; however, as literacy rates increase in the population, this means of communication may become more important in Nigeria and other developing countries.

While promotional information units (extension agent equivalents) are endogenously generated as a policy (Chapter 6), the model also computes (Equation 3.8) diffusion information units to represent the demonstration effect of farmers learning from one another about alternative land uses. The demonstration effect of an alternative to a present land use depends on the amount of land in each use: if there is no land in either, no diffusion information units are generated, while the diffusion rate is greatest when there is as much land in the alternative use as in the present use. Thus, the rate at which diffusion information units are generated reflects the s-shaped curve of diffusion theory [45].

$$DINF_{ij}(t) = \frac{TLAVD_{ij}(t)*TLALT_i(t)*CIUD_{ij}}{TLAVD_{ij}(t) + TLALT_i(t)} \qquad (3.8)$$

where:

DINF = diffusion information units--units (extension agent equivalents)

TLAVD = land in a present use suitable for an alternative by diffusion (Equation 3.9e)--acres

TLALT = land in the alternative use--acres

CIUD = a coefficient reflecting the information effect of demonstration land units--units/acre

i = indexes the alternatives

j = indexes the present uses.

Availability of Land

Several factors contribute to determining the proportion of land in a present use which would be suitable for a particular alternative use, i.e., land available for a particular decision. The major factor derives from the imperfect homogeneity of the crop sectors (discussed earlier). The consequences of this are that in considering the alternatives to a present land use (Table II.1), not all the land in the present use will necessarily be available for transition to a given alternative (Equations 3.9d and 3.9e). Let's consider the Cocoa-Food Sector as an example. Not all food land is suitable for cocoa, nor is all traditional cocoa land even suitable for replanting. Soil and rainfall conditions in certain traditional Amelonado cocoa areas, for instance, may not be good for modern Upper Amazon cocoa.

Another factor, a policy one, may dictate that the proportion of land available for a particular alternative use will be different for land transferring as a result of promotion campaigns than from diffusion effects. Modernization program policies could be rather restrictive as to soil conditions, local road conditions, farmer experience, etc., in allowing farmers to enter the program, whereas such

limitations won't exist for the diffusion effect.

Finally, there is a special restriction on how much bush land can be put to other uses. This restriction stems from the fact that "bush", as defined in the model, includes fallow land, both short-cycle and long-cycle. An amount of bush land (Equation 3.9a)--representing short-cycle fallow which farmers expressly reserve to maintain subsistence food production yields in future years--is considered not available for other uses (Equation 3.9b).

$$FALNEC(t) = SUBFDL(t)*[FFT*PSFD(t) + FFM*(1 - PSFD(t))] \tag{3.9a}$$

$$TLPT_b(t) = \max\{[(TLP_b(t) - FALNEC(t)) - DADLV_b(t)], 0.)\} \tag{3.9b}$$

$$TLPT_j(t) = TLP_j(t) - DADLV_j(t),\ j \neq b \tag{3.9c}$$

$$TLAVP_{ij}(t) = TLPT_j(t)*CLAVR_{ij}(t) \tag{3.9d}$$

$$TLAVD_{ij}(t) = TLPT_j(t)*CLAVRD_{ij}(t) \tag{3.9e}$$

where:

TLPT = total land in a present use available for transition decisions--acres

TLP = total land in a present use (e.g., Equations 3.1c and 3.3)--acres

DADLV = land in the decision and administrative delay (see discussion below, preceding Equation 3.13)--acres

TLAVP = land in a present use available for a particular alternative by promotion--acres

TLAVD = as defined in Equation 3.8

CLAVR = proportion of land in a present use available for a particular alternative by promotion (see Equations 3.10)

CLAVRD = proportion of land in a present use available for a particular alternative by diffusion (see Equations 3.10)

FALNEC = fallow land necessary to maintain subsistence food yields--acres

SUBFDL = subsistence food land (Equation 4.7)--acres

FFT(FFM) = proportion of traditional (modern) subsistence food land which must be cycled into fallow to maintain yields

PSFD = proportion of food land that is traditional (Equation 3.2)

i = indexes the alternatives

j = indexes the present uses (j = b = bush).

Perennial and food land uses have a further restriction--a behavioral one--affecting the proportion of land available for alternative uses. (Bush proportions are constant.) For food land, the assumption is made that only cash food land will be considered for possible transition to other uses (Equation 3.10a). In the case of perennials, it is assumed that land in some stages of production will not be transferred to other uses (Equation 3.10b). For example, farmers won't remove traditional cocoa trees in the stage of maximum yields. Obviously, such behavior should not be assumed but rather be a result of economic decisions. However, simulating this decision for each cohort of each perennial population stream would vastly complicate and enlarge the model. Therefore, the decisions are modeled for each perennial stream in its entirety, and land leaves each cohort in

the same proportion as that cohort's proportion of the total population of those production stages which are available for transition. Again, modernization program constraints may indicate certain cohorts to be available by promotion, while behavioral characteristics of the farmers will decide the diffusion responses.

Equations 3.10 compute the availability proportions for promotion. Those for diffusion (CLAVRD) are the same, with "P" prefixes and suffixes replaced with "D".

$$CLAVR_{if}(t) = CLAVF_i * [1 - SUBFDL(t)/TLFD(t)] \tag{3.10a}$$

$$CLAVR_{ij}(t) = CLAVT_{ij} * \frac{\sum_{k=1}^{5} TLPER_{kj}(t) * PCTR_{kj}}{\sum_{k=1}^{5} TLPER_{kj}(t)} \tag{3.10b}$$

where:

TLPER = defined in Equation 3.1

TLFD = defined in Equation 3.3

CLAVT, CLAVF
= proportion of traditional perennial and food land available for promotion, respectively, due to soil, climatic, etc. conditions

PCTR = parameters indicating perennial cohorts available for transition to alternative uses by promotion (= 0 or 1)

i = indexes the alternative uses

f = indexes the food present use

j = indexes the traditional perennial present uses--j = 1, ..., 4

k = indexes the perennial cohorts .

Transition Responses

Changes in land use patterns reflect a farmer's responses to the perceived profitabilities of the cropping alternatives available to him. The assumption is made that the most profitable alternative is likely to be the first choice of most of the decision makers, and so on, in order of decreasing profitability.

The profitability response function (Equation 3.11)[1/] determines how many acres of land an information unit (either extension agent promotion or demonstration effect) can "convert" per year from one use to another. This calculation depends on the profitability of the alternative, the efficiency of the information unit (discussed below), the land available for transition and the behavioral characteristics of the farm decision makers (see Figure II.6).

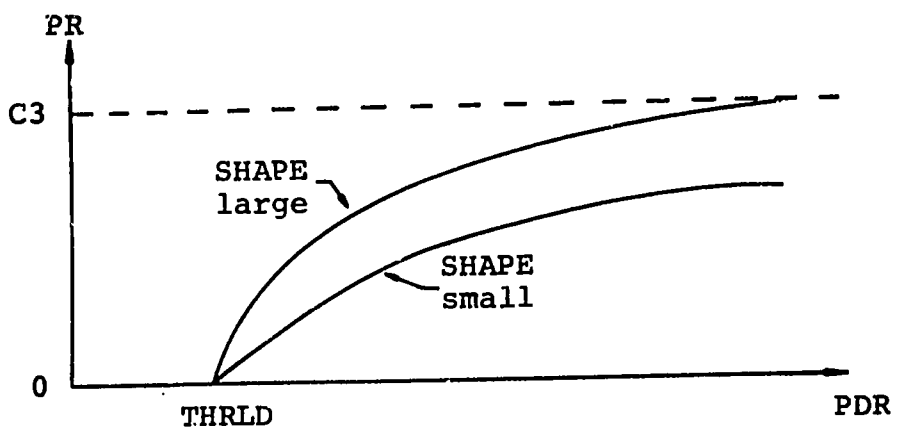


Figure II.6 The profitability response function.

[1/] Equations 3.11 - 3.13 compute the response to exogenous promotion. Similar equations handle the diffusion response.

$$PR_{ij}(t) = \max\{C3_{ij}*(1 - \exp[-SHAPE_{ij}*(PDR_{ij}(t) - THRLD_{ij})]), 0.\} \quad (3.11)$$

where:

PR = the profitability response to promotion efforts--proportion

C3 = the maximum proportion attainable (Equation 3.12)

exp = the exponential function

max = takes the maximum of the term within the braces

SHAPE = the rate of promotion response with respect to profitability--dimensionless

THRLD = the promotion response threshold--dimensionless

PDR = the relative profitability differential (Equation 3.4)--dimensionless

i = indexes the alternatives

j = indexes the present uses.

The efficiency of an extension agent (the same holds for a demonstration unit) is the maximum number of acres he is able to convert in a year as the profitability of the alternative grows. Figure II.6 shows that the response function, Equation 3.11, actually computes the proportion of that efficiency (profitability response) which can be attained for a given profitability. The maximum proportion is, of course, 1.0; however, if there is a land constraint relative to the number of information units and their efficiency, the maximum attainable will be something less than the potential efficiency (Equation 3.12).

$$C3_{ij} = \min\left[\frac{TLAVP_{ij}(t)}{EINF_{ij}(t)*CEFF*DT}, 1.\right] \qquad (3.12)$$

where:

TLAVP = as defined in Equation 3.9d

EINF = promotion (extension agents) information units (policy--see Chapter 6)--units

CEFF = potential efficiency of promotion--acres/information unit-year

i = indexes the alternatives

j = indexes the present uses.

The threshold and response rate parameters shown in Figure II.6 reflect the farmers' attitudes and behavioral characteristics which affect the rate of their response to the relative profitabilities of the various alternatives facing them. The factors represented by both of these parameters include, for instance, the degree to which the trees are fixed assets, risk aversion, the amount of inconvenience the farmers may see in an alternative use (including the extent and quality of roads and the transport system), farmers' attitudes towards government programs and promises in general, and the land tenure system. The threshold parameter of an alternative marks the point (relative profitability of the alternative to a current use) below which there will be no transition to that alternative. Since farmers will have different attitudes towards extension agents (or other promotional efforts) than they will towards one another, the values of

these parameters may be different for promotion responses than for diffusion responses.

The transition rates (Equation 3.13) are constrained by available capital and lagged to account for decision-making delays and (in the case of externally promoted alternatives) delays involved in program administration and distribution of necessary inputs and subsidies. Land currently stored in these delays (i.e., already allocated) is assumed unavailable for further allocation (see Equation 3.9c above). The capital available in an ecological zone for investment in alternatives includes capital generated endogenously as income (after allowing for consumption) and potential credit, which in turn depends on the capitalized value of cultivated land. The availability of capital and credit will be discussed more fully later in the discussion of the Criteria and Macro-Budget Accounting component (Chapter 7). Any capital constraint in a crop sector is applied uniformly to all alternative land uses in that sector.

$$TRLDP_{ij}(t) = CEFF*EINF_{ij}(t)*PR_{ij}(t)*CNSIN(t) \qquad (3.13)$$

where:

TRLDP = unlagged promoted land transition rate--acres/year

PR = as defined in Equation 3.11

CNSIN = investment constraint (capital availability--Equation 7.12b)--proportion

i = indexes the alternatives

j = indexes the present uses.

The demand for capital--which is compared (component CRTMBA, Chapter 7) with available resources to determine if capital is a constraint--is merely the sum of the establishment costs (Equation 3.14a) incurred by the decisions to move land to alternative productive uses. The establishment cost of an alternative is defined as the net cost which would be incurred in the first year of the establishment of an alternative on a particular piece of land (Equation 3.14c). This cost will include items such as tools, biological and chemical materials and hired labor necessary for land-clearing and planting. This definition of establishment cost is used--rather than total net costs over the planning period until positive net revenues occur or, alternatively, until production begins--so the capital required in the year the transition is made can be used to compare with what is available that same year. Since this is the major cost which would need to be met with either credit or the currently available cash flow, it would be the primary financial constraint to production enterprise changes. Costs incurred over the remainder of what might otherwise be called the establishment period are included as operating expenses computed in component AMPPAP.

$$ECAPRT(t) = \sum_j \sum_i CSHR_{ij}(t) * (DTRLP_{ij}(t) + DTRLD_{ij}(t)) \qquad (3.14a)$$

$$CSHR_{ij}(t) = \max(ESTAB_{ij}(t), 0) \tag{3.14b}$$

$$ESTAB_{ij}(t) = [TR_{1ij}(t) - TC_{1ij}(t)]/(1 + DR_{ij}) \tag{3.14c}$$

where:

ECAPRT = total capital required for land use transitions in a crop sector--£/year

CSHR = capital required for alternatives--£/acre-year

DTRLP, DTRLD = lagged values of TRLDP and TRLDD (see Equation 3.12), respectively--acres/year

ESTAB = establishment cost--£/acre-year

TR_1, TC_1 = the values of TR and TC (Equations 3.5 and 3.6) in the first year of the planning horizon--£/acre-year

DR = discount rate

i = indexes the alternatives

j = indexes the present uses.

In addition to capital resources, demands for modern inputs generated by farmer responses to the modernization programs are computed (Equations 3.15). These include biological inputs, such as new hybrid seedlings and other planting materials, and chemicals, such as fertilizers and sprays.

$$ECAPMP_m(t) = \sum_j \sum_i CSHR_{ij}(t) * DTRLP_{ij}(t) \tag{3.15a}$$

$$EBIOMP_m(t) = \sum_j \sum_i EBT_{ij} * DTRLP_{ij}(t) \tag{3.15b}$$

$$ECHEMP_m(t) = \sum_j \sum_i ECHT_{ij} * DTRLP_{ij}(t) \qquad (3.15c)$$

where:

ECAPMP = capital demands--£/year

EBIOMP = modern biological input demands--units/year

ECHEMP = chemical input demands--lbs./year

EBT = biological input requirements for establishment--units/acre

ECHT = chemical input requirements for establishment--lbs./acre

m = indexes the modernization programs--m = 1, ..., 5

i = indexes the modern alternatives relevant to program m

j = indexes the present uses relevant to program m.

A final economic decision to be made is whether some perennial land is to be abandoned <u>indefinitely</u> (as opposed to a short term "abandonment" discussed in the next chapter as a supply price response), thus reverting to bush. Such an abandonment decision would be made if <u>both</u> the current returns (PRFT in Equation 4.28m) are negative <u>and</u> the long-run profitability (DPVSUM in Equation 3.5, above) is below some threshold value. Figure II.7 shows how the model (Equation 3.16) handles this decision. Thus, even if current returns are negative, no abandonment will occur unless the long-term profitability also drops below some threshold value (which may be

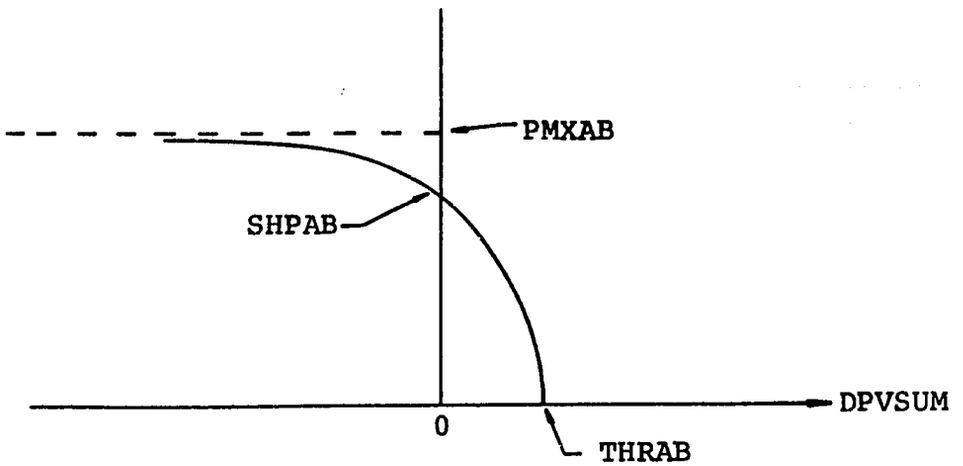


Figure II.7 Abandonment response.

positive, negative, or zero, depending on behavioral characteristics of farmers particular to a given perennial commodity and possibly depending on potential income which might be derived from nonagricultural occupations), in which case, abandonment will occur at an increasing rate, up to a maximum, as the profitability continues to fall.

$$ABANR_j(t) = TLPT_j(t)*\max\{PMXAB_j*(1 - \exp[-SHPAB_j*(THRAB_j - DPVSUM_j(t))], 0.\} \quad (3.16)$$

where:

ABANR = abandonment rate--acres/year

TLPT = defined in Equation 3.9c

DPVSUM = defined in Equation 3.5

PMXAB = maximum proportion that will be abandoned--proportion/year

SHPAB = a parameter regulating the abandonment rate--dimensionless

THRAB = abandonment threshold--£/acre

j = indexes the present uses.

Noneconomic Responses

In addition to the economic land use decisions described so far, the number of acres cultivated will increase as the number of decision makers increases with the population. The economic decisions discussed above represent the activities of established farmer decision makers, i.e., whether to increase or decrease the amount of land cultivated or whether and how to shift land currently in production to alternative uses. Those young men coming of age and starting new farms of their own, on the other hand, won't make that economic decision (as long as there is at least a positive profitability--Equations 3.19). Constrained by the available bush land (Equations 3.20), new land comes into production (Equation 3.17a) at a rate proportional (Equation 3.18) to the rate of increase in the number of decision makers (Equation 3.17c). If there is an economic or land constraint, then those new farmers not acquiring land of their own will wait until conditions are more favorable, adding to the pressure of new decision makers for land (Equation 3.21). This "pressure" would be a significant factor to consider if rural-urban migration is to be determined endogenously in the model.

Equations 3.17 to 3.21 are given for the first perennial commodity of a crop sector. Similar equations

compute this response for the second perennial in the Rubber-Palm Sector, for tobacco in Sector 4 and for food.

$$RLTPP_k(t) = A1P_k(t)*[RAGDMX_k(t) + RPSP_k*RAGDSP_k(t)]$$
$$*EIPA_k(t)*BAPXF_k(t) \quad (3.17a)$$

$$RAGDMX_k(t) = \max[RAGDMA_k(t), 0.] \quad (3.17b)$$

$$RAGDMA_k(t) = RAGDMA_k(t-DT) + \frac{DT}{PEXDEL}*[RAGDCM_2(t-DT)$$
$$*DLABOR_{k12} - RAGDMA_k(t-DT)] \quad (3.17c)$$

where:

RLTPP = rate land transfers to the first perennial of a crop sector due to agricultural population growth--acres/year

A1P = average landholding of the first perennial (Equation 3.18)--acres/decision maker

RAGDMX = the positive rate of change of agricultural decision makers--decision makers/year

RAGDMA = the lagged rate of change of agricultural decision makers in a crop sector--decision makers/year

$RAGDCM_2$ = unlagged rate of change of agricultural decision makers in the South (from the population component)--decision makers/year

RAGDSP = population "pressure" for land (i.e., those constrained out by economic conditions and the availability of land (Equation 3.21)--decision makers

RPSP = the rate constrained new decision makers acquire land as the constraints are eased (a model parameter)--proportion/year

EIPA = lagged economic constraint coefficient for the first perennial of a crop sector, $0 \leq EIPA \leq 1$ (Equation 3.19b)--dimensionless

BAPXF = bush land availability constraint coefficient, $0 < BAPXF \leq 1$ (Equation 3.20b) --dimensionless

$DLABOR_{k12}$ = proportion of southern agricultural labor in each crop sector (a parameter of the population component)

PEXDEL = the smoothing lag for the population growth effect on land use--years

k = indexes the perennial crop sectors--k = 1, 2, 3.

Note that this process is constrained so that a decline in the number of agricultural decision makers will not cause a decline in the number of acres cultivated.

Equation 3.18 computes the average landholdings in the first perennial, A1P.

$$A1P_k(t) = \frac{TLT_k(t) + TLM_k(t)}{AGDCM_{k2}(t)} \tag{3.18}$$

where:

TLT, TLM = total acres in the first perennial of a crop sector, traditional and modern, respectively--acres

$AGDCM_{k2}$ = agricultural decision makers in the South in each crop sector (from the population component)--decision makers

k = indexes the perennial crop sectors--k = 1, 2, 3.

The economic constraint coefficient (EIPA) computed in Equations 3.19 requires the profitability of the first perennial to be at least the threshold value for full

response (EIPA = 1) and at least zero for any response.

$$EIP_k(t) = \max[\min(\frac{PDR_{pb}(t)}{THRLD_{pb}}, 1), 0.] \quad (3.19a)$$

$$EIPA_k(t) = EIPA_k(t-DT) + \frac{DT}{PEXDEL}*(EIP_k(t-DT) - EIPA_k(t-DT)) \quad (3.19b)$$

where:

EIP	=	unsmoothed economic constraint coefficient --dimensionless
PDR	=	the relative profitability differential (Equation 3.4)--dimensionless
THRLD	=	the profitability response threshold
p	=	indicates perennial alternatives
b	=	indicates the bush present use
k	=	indexes the perennial crop sectors-- k = 1, 2, 3.

The bush land availability constraint coefficient goes to zero as non-fallow bush land decreases with time (Figure II.8). The constraint is relative to time zero; therefore, BAPXF = 1 initially.

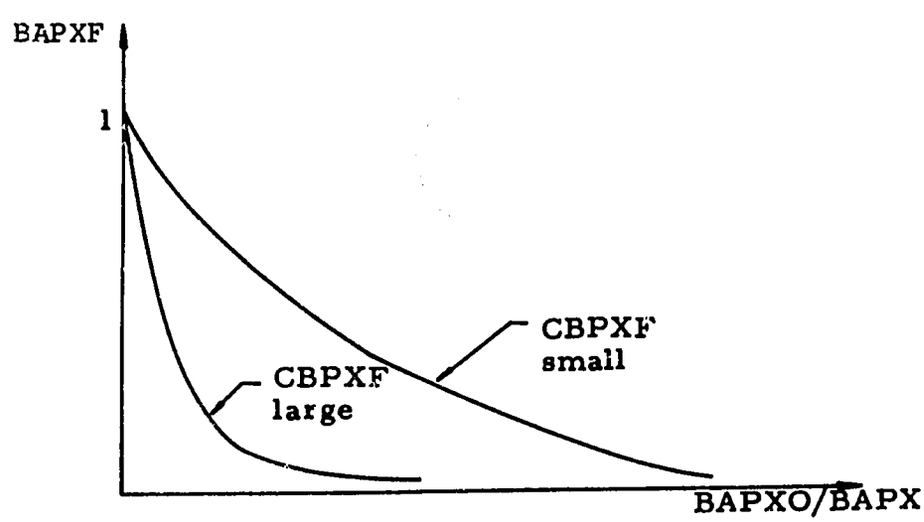


Figure II.8 Land constraint.

$$BAPX_k(t) = TLBF_k(t) - TRTOB_k(t)*DT \tag{3.20a}$$

$$BAPXF_k(t) = \exp[-CBPXF*(\frac{BAPXO_k}{BAPX_k(t)} - 1)] \tag{3.20b}$$

where:

BAPXF = bush land availability constraint factor--dimensionless

exp = exponential function

CBPXF = a parameter

BAPX = bush land available--acres

BAPXO = initial value of BAPX (at t = 0)

TLBF = non-fallow bush land (= $TLPT_b$ of Equation 3.9b)--acres

TRTOB = total rate land transfers out of bush to all alternatives as a result of economic decisions--acres/year

k = indexes the crop sectors--k = 1, ..., 4.

The population "pressure" for land due to economic and land constraints is computed by Equation 3.21.

$$RAGDSP_k(t+DT) = (1 - RPSP_k*EIPA_k(t)*BAPXF_k(t))*RAGDSP_k(t) + (1 - EIPA_k(t)*BAPXF_k(t))*RAGDMX_k(t)*DT \tag{3.21}$$

where:

RAGDSP = as defined in Equation 3.17a

EIPA = as defined in Equation 3.19b

RAGDMX = as defined in Equation 3.17b

RPSP = as defined in Equation 3.17a

k = indexes the perennial crop sectors--k = 1, 2, 3.

Summary

Component LAMDAP simulates the demography of perennial commodities (cocoa, palm and rubber) and allocates land to alternative productive activities among perennials and annuals. Included in these alternatives are the modernization options promoted exogenously and diffused within the agricultural sector. These land use decisions are based on the discounted profitabilities of alternatives relative to current uses. The discounting depends on farmers' expectations regarding prices and yields, while the decision responses are determined by such behavioral characteristics as risk aversion and confidence in outside information sources. An essentially noneconomic expansion of cultivated land also takes place as the number of farm decision makers increases.

CHAPTER 4

Agricultural Marketing, Production and Processing--Annuals/Perennials (AMPPAP)

Component AMPPAP generates the production, processing, and marketing activities of the six agricultural commodities (cocoa, palm oil, palm kernels, rubber, food, and tobacco), determines the food subsistence level of the population in each ecological zone (crop sector) and the yields of the various commodities.

Subsistence Level

Of the staple food produced in each crop sector, one portion is consumed directly by the agricultural population of that sector while the rest goes through the cash food market. The portion retained for subsistence consumption is determined by the total demand for calories by the agricultural population and the proportion of that demand met by food consumed directly from the farm. The remainder of the total food demand is purchased in the cash food market. The assumption is that the subsistence level proportion is not necessarily one (total subsistence) but may be less depending on conditions in the food market and the cash income generated from the cash crops. Since the cash crops and (thus) the degree of dependence on the

cash economy differ across the crop sectors, the subsistence level is sector-specific.

Farmers will change their desired subsistence level depending on the degree of stability[1/] in the cash food market, on the food price level and on the income from cash (primarily export) crops. Instability in the food market will tend to increase a farmer's reliance on his own efforts for his food needs, i.e., the subsistence level will go up. This effect on the subsistence level is generated by the magnitudes of the relative food price changes (up or down) summed for the three preceding years (Equations 4.1). This assumes farmers have a three-year memory regarding the effect of market food prices on market stability. While the impact of Equations 4.1 loses much of its force and meaning because the model does not simulate seasonal price fluctuations, it does capture general trends. In any case, the concept of food market stability is a meaningful and useful one.

$$FPRA(i) = \left(\frac{PRFD_2(i) - PRFD_2(i-DT)}{PRFD_2(i-DT)}\right)^2 \quad , i = t-3, t-3+DT, \ldots, t \tag{4.1a}$$

$$FPSF(t) = \sum_{i=t-3}^{t} FPRA(i) \tag{4.1b}$$

where:

FPRA(i) = the square of the relative change of the food price in the South at time i--dimensionless

$PRFD_2$ = market price of food in the South (=$PPRCM_5$ of Equation 5.2b)--£/lb.

1/ "Stability" in the food market means, here, that food prices are constant.

FPSF = the food price stability factor--dimensionless

i = indexes three years of time periods incremented by DT.

Squaring the relative price change has the effect of including price decreases as well as price increases as a factor of instability in the market. It also gives relatively more weight to large deviations than to small ones.

Perfect stability in the food market, however, is not enough to lower the subsistence level. The second factor determining changes in the level of subsistence is represented as the ratio of the value, at market prices, of the food consumed by the agricultural population to the net revenue from cash crops (other than cash food). This formulation (Equations 4.2) incorporates as a factor the foo price level in addition to the price changes of Equations 4.1. However, the price level must also be related to the cash revenue farmers have available to purchase food in the market and to how much food would have to be purchased to meet the demand for calories. Decreases, for example, in the food expenditure/cash revenue ratio--due to falling food prices, rising producer prices for cash crops or falling costs in cash crop production--will tend to decrease the subsistence level, i.e., increase producer reliance on the food market for their caloric needs. Equations 4.3 combine these two factors--food market stability and the food expenditure/cash revenue ratio--to

determine the subsistence level in each crop sector (Figure II.9).

$$EXPFD_k(t) = \left(\frac{DEMRS_k(t)}{CALY*PYCNS}\right)*PRFD_2(t) \qquad (4.2a)$$

$$FXCR_k(t) = EXPFD_k(t)/CSHRN_k(t) \qquad (4.2b)$$

$$FXCRA_k(t) = FXCRA_k(t-DT) + \left(\frac{DT}{FXDEL}\right)*[FXCR_k(t-DT) - FXCRA_k(t-DT)] \qquad (4.2c)$$

where:

CSHRN = total net cash revenue to the agricultural sector in an ecological zone from non-food crops (= REVCN of Equation 4.28j aggregated by crop sector)-- £/year

EXPFD = value of food consumed by the agricultural sector in an ecological zone-- £/year

DEMRS = the caloric requirements of the agricultural sector in an ecological zone (from the population component)--Calories/year

CALY = the caloric content of food--Calories/lb.

PYCNS = the proportion of food which is actually consumed (after spoilage and waste)

FXCR = the food expenditure cash revenue ratio-- dimensionless

FXCRA = the lagged food expenditure cash revenue ratio of an ecological zone

FXDEL = the length of the smoothing lag-- years

k = indexes the perennial crop sectors-- k = 1, 2, 3[1/].

$$SLRSP_k(t) = SLSHP_k*FPSF(t)^{EFPSF} \qquad (4.3a)$$

1/ The agricultural population in the annuals sector (Sector 4) is assumed to maintain total subsistence. This assumption can be relaxed if desired.

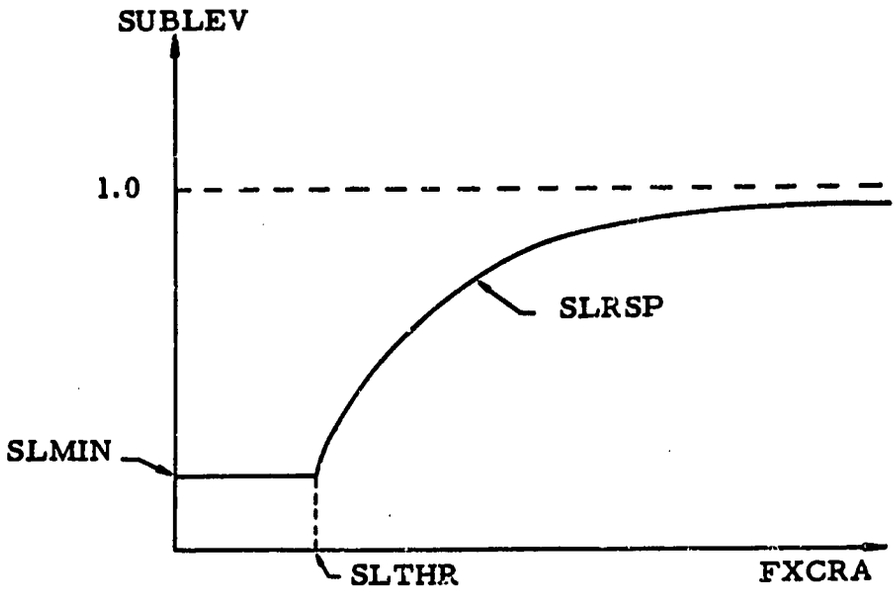


Figure II.9 Subsistence level determination.

$$SUBLEV_k(t) = \max\{[(1 - SLMIN_k)*\exp(-SLRSP_k(t-DT)*(FXCRA_k(t-DT) - SLTHR_k))], SLMIN_k\} \quad (4.3b)$$

where:

EFPSF = a parameter which controls the effect of the food price stability factor on the subsistence level response rate

SLRSP = subsistence level response rate adjusted by market instability

SLSHP = subsistence level response rate in a perfectly stable food market

SLMIN = the minimum level of subsistence farmers will maintain--proportion of food demand

SLTHR = the value of FXCRA which is the subsistence level response threshold

SUBLEV = the subsistence level: the proportion of the food requirements of the agricultural population of an ecological zone which is not obtained from the market economy

k = indexes the perennial crop sectors--
k = 1, 2, 3.

Yields

There are three determinants of commodity yields. First, provision is made in the model for yields to increase spontaneously (i.e., independently of outside influences) as farmers gain production experience. We might call this a learning curve yield response. Secondly, the yields of the substreams[1/] are combined, weighted by the amount of land in each substream, to obtain an average yield for each cohort[1/] (in the case of perennials) of each stream. Finally, commodity yields are adjusted to account for a short run harvest supply response to the current producer prices. Each of these factors will now be discussed in more detail.

Learning curves for the perennial and food yields serve two functions in the model. Since we are interested in keeping the definitions of "modernization" and "modernizing programs" as rigid as possible in order to evaluate these programs, the learning curve allows us to simulate past behavior which included spontaneous adoption, to a limited degree, of certain modern methods and inputs. For simulation runs including modernization programs, the learning curve also allows us to simulate behavior whereby farmers, in adopting modern methods and inputs, do not immediately achieve the maximum potential yield of the crop. Initially, modern land

---

1/ These terms are defined above in the discussion of the land allocation and modernization component, Chapter 3.

will not be yielding its potential, but this yield will increase over time towards that potential as farmers gain experience with the new methods and materials. Since this learning behavior represents a diffusion phenomenon (i.e., farmers learning from one another), the learning curve effect (modeled by Equation 4.4) won't take place unless a minimum number of acres in a particular use has been surpassed.

Equation 4.4 gives the learning curve increase for, as an example, the first substreams of the perennial population streams. Similar equations simulate the learning curves for yields of the second perennial substreams, $YPER2_{ij}$, and for yields of the first and second substreams of food, YF1 and YF2.

$$YPER1_{ij}(t) = YPER1_{ij}(t-DT) + (DT/YMDEL1)*(YPER1M_{ij} - YPER1_{ij}(t-DT)) \qquad (4.4)$$

where:

YPER1 = the yield of the <u>first</u> substream of perennials--lbs./acre-year

YPER1M = the maximum potential yield of perennials in the <u>first</u> substream--lbs./acre-year

YMDEL1 = a lag regulating the rate at which the current yield approaches the potential yield--years

i = indexes the yielding cohorts--i = 1, ..., 6

j = indexes the perennial streams--j = 1, ..., 8.

After the learning curve adjustment, the yield of each crop is averaged across land use substreams, i.e., traditional and modern food, newly planted and replanted modern perennials, and traditional and improved traditional perennials[1/]. In calculating this average (Equation 4.5), the yield of each substream is weighted by the proportion of the crop land in that substream. Again, similar equations apply to the food yields, YFA and YFAP.

$$YPERA_{ij}(t) = PSPER_{ij}(t)*YPER1_{ij}(t) + [1 - PSPER_{ij}(t)]* YPER2_{ij}(t) \qquad (4.5)$$

where:

YPERA = the perennial yields averaged across the substreams--lbs./acre-year

PSPER = the proportion of land in a perennial stream which is in the first substream (Equation 3.2)

i = indexes the yielding cohorts--i = 1, ..., 6

j = indexes the perennial streams-- j = 1, ..., 8.

The proportion of the total capacity (acreage) of a commodity actually harvested is a function of that proportion under "normal" producer price conditions (a behavioral parameter) and the ratio of the current price to the normal price. The normal price is taken to be an exponential average of past producer prices. The model (Equation 4.6a)

1/ These terms are defined above in the discussion of the land allocation and modernization component, Chapter 3.

incorporates behavioral parameters which can generate negatively sloped, positively sloped, or perfectly inelastic supply curves.

Finally, while the harvest response is a short-term response, the input response is medium-term. In perennial crop production, farmers may put forth less harvest effort (as we have seen above) in response to unfavorable prices. However, they may also cut back on some cultivational practices, particularly in the case of modern production. The practices which may be affected include weeding, spraying, fertilizer application, and similar modern techniques. The cut-back, albeit temporary, in the application of these practices will result in reduced yields later--one to three years, say. This deferred yield effect is a factor contributing to the determination of the yield actually attained (Equation 4.6b) in any given year. Perennial yields are shown in Equations 4.6; food yields adjusted for a supply response, YFAP, are similarly computed.

$$YPER_{ij}(t) = YPERA_{ij}(t) * PPLHV_j * \left(\frac{PPPC_k(t)}{PPAVH_k(t)}\right)^{SUPRSP_k} * (SRIA_k(t))^{ESRIA_j} \tag{4.6a}$$

$$SRI_k(t) = \min\left(\left(\frac{PPPC_k(t)}{PPAVH_k(t)}\right)^{SUPRSI}, 1.\right) \tag{4.6b}$$

where:

YPER = the yield of perennials adjusted for a price response--lbs./acre-year

PPPC = the current agricultural producer-processor price (Equation 5.9)-- £/lb.

PPAVH = a ten-year exponential average of recent agricultural producer-processor prices (Equation 5.8b)-- £/lb.

SUPRSP = perennial supply response elasticity

PPLHV = the proportion of perennial land harvested

SRIA = the lagged input application response (computed as a first-order lag)--dimensionless

ESRIA = exponent regulating the effect of the input response on yields

SRI = the unlagged input application response

SUPRSI = input response elasticity

i = indexes the yielding cohorts--i = 1, ..., 6

j = indexes the perennial streams--j = 1, ..., 8

k = indexes the perennial commodities--k = 1, 2, 3.

Notice how the price response works. If the current agricultural producer-processor price, PPPC (Equation 5.9), is greater than exponentially averaged recent prices, for example, the supply response exponent, SUPRSP, will work as follows: if it is zero, the supply is perfectly inelastic; if SUPRSP is positive, an upward sloping supply curve is assumed; if SUPRSP is negative, a negatively sloped supply curve is assumed. The supply response is based on a ten-year moving average of recent prices so that farmers respond to deviations from what might be called a normal price level, where farmers have a ten-year memory of what is "normal".

Food Production

In computing food production, AMPPAP first calculates (Equation 4.7a) the food land necessary to meet the subsistence demand of the agricultural population. A constraint is placed on the total food land in production so that it at least covers what is necessary to produce subsistence food (Equation 4.7b). Any remaining food land goes for cash food production (Equation 4.7c).

$$SUBFDL_k(t) = SUBFDL_k(t-DT) + (DT/SDEL)*\left(\frac{DEMRS_k(t)*SUBLEV_k(t)}{CALY*YFA_k(t)*PYCNS} - SUBFDL_k(t-DT)\right) \quad (4.7a)$$

$$TLFD_k(t) = \max(TLFDU_k(t),\ SUBFDL_k(t)) \quad (4.7b)$$

$$CSHFDL_k(t) = TLFD_k(t) - SUBFDL_k(t) \quad (4.7c)$$

where:

SUBFDL = subsistence food land--acres

DEMRS = demand for Calories from the agricultural sector of the population (population component)--Calories/year

SUBLEV = the subsistence level, i.e., the proportion of DEMRS that farmers produce themselves (Equation 4.3b)

CALY = the Calorie content of food--Calories/lb.

YFA = the food yield averaged between modern and traditional (Equation 4.5)--lbs./acre-year

PYCNS = the consumable proportion of food produced, after accounting for loss and spoilage

TLFD = total food land--acres

TLFDU = unconstrained food land (= TLFD of Equation 3.3)--acres

CSHFDL = cash food land--acres

SDEL = the subsistence food land smoothing lag--years

k = indexes the crop sectors--k = 1, ..., 4.

Notice that Equation 4.7a calculates the subsistence food land requirement and at the same time smoothes changes in that requirement by lagging it a period SDEL.

The output of food, then, is a function of food yields, food land and food intercropped with perennials in the gestation stage of production. The amounts of food produced for consumption by the agricultural and nonagricultural populations are also computed for use in the national accounts component of the total Nigeria model.

$$PDCNCF_k(t) = YFAP_k(t)*\left(CSHFDL_k(t) + \sum_{j=1}^{8} YDMIX*\frac{TLPER_{1j}(t)}{3}\right) \quad (4.8a)$$

$$PDCNSF_k(t) = SUBFDL_k(t)*YFA_k(t) \quad (4.8b)$$

$$TFPAG(t) = \sum_{k=1}^{4} PDCNSF_k(t) + [\sum_{k=1}^{4} PDCNCF_k(t) - DEMBIO_4(t)]* \frac{(TDCFS(t) - DEMCFS(t))}{TDCFS(t)} \quad (4.8c)$$

$$TFPNAG(t) = [\sum_{k=1}^{4} PDCNCF_k(t) - DEMBIO_4(t)]*\frac{DEMCFS(t)}{TDCFS(t)} \quad (4.8d)$$

where:

$TLPER_{1j}$ = total perennial land in cohort 1 of stream j (Equation 3.1c)--acres

PDCNCF = the production of cash food--lbs./year

CSHFDL = cash food land (Equation 4.7c)--acres

YFAP = the averaged and price-response-adjusted food yield (Equations 4.5 and 4.6)--lbs./acre-year

YDMIX = a factor adjusting food yield for food intercropped on land in the first cohort (gestation) of the perennial streams--dimensionless

PDCNSF = production of subsistence food--lbs./year

SUBFDL = subsistence food land (Equation 4.7a)--acres

YFA = averaged food yields (not price adjusted--Equation 4.5)--lbs./acre-year

TFPAG = total food produced for agricultural consumption--lbs./year

TFPNAG = total food produced for nonagricultural consumption--lbs./year

$DEMBIO_4$ = demand for food biological materials for replanting the following year (Equation 4.26f)--lbs./year

DEMCFS = demand for cash food Calories from the nonagricultural population (population component)--Calories/year

TDCFS = total demand (agricultural and nonagricultural) for cash food Calories--Calories/year

k = indexes the crop sectors--k = 1, ..., 4.

There are two basic assumptions to be noted in these equations. First, it is assumed that food will be intercropped on land in the first third of the perennial gestation period[1/] and that this food will be cash food. Secondly, Equation 4.8b assumes that subsistence food production does not respond

---

1/ Strictly speaking, Equation 4.8a uses one-third of the land in the gestation stage as an approximation to the amount of land in the first third of the gestation period.

to changes in price (except through the subsistence level adjustment in Equations 4.1 - 4.3).

Perennial Production

The production of each perennial population stream--traditional cocoa, modern cocoa; traditional palm and modern palm in the Palm Sector; traditional rubber, modern rubber, and traditional palm and modern palm in the Rubber-Palm Sector--is computed (Equation 4.9a) as the sum of the output (yield times acres) of each producing cohort of that stream. As discussed in Chapter 3, wild palm in the Cocoa Sector is considered a product of bush land (Equation 4.9b). The outputs of streams of like commodities (e.g., traditional and modern cocoa) are then added to get production by commodity, i.e., cocoa, palm and rubber (OPT_i, i = 1, 2, 3).

$$PDCNP_j(t) = \sum_{i=3}^{8} TLPER_{ij}(t) * YPER_{k_i j}(t) \tag{4.9a}$$

$$PDCNWP(t) = PBWP * TLBSH_1(t) * YBWP * \left(\frac{PPPC_2(t)}{PPAVH_2(t)}\right)^{SUPRSB} * PBLHV \tag{4.9b}$$

where:

PDCNP = the production of perennials--lbs./year

TLPER = land in perennials, by cohort (Equation 3.1c)--acres

YPER = yield of perennials, by cohort (Equation 4.6a)--lbs./acre-year

PDCNWP = wild palm output from Cocoa Sector bush land--lbs./year

PBWP = the proportion of Cocoa Sector bush land in wild palm production

$TLBSH_1$ = total bush land in the Cocoa Sector (Equation 3.3)--acres

YBWP = the wild palm yield of bush land--lbs./acre-year

$PPPC_2$ = the current agricultural producer-processor price of oil palm products (Equation 5.9)--£/lb.

$PPAVH_2$ = the exponentially weighted average of recent palm prices (Equation 5.8b)--£/lb.

SUPRSB = a parameter determining the price responsiveness of wild palm products (elasticity)

PBLHV = proportion of wild palm normally harvested

k = indexes the producing cohorts--i = 3, ..., 8 corresponds to k = 1, ..., 6

i = indexes the cohorts--i = 3, 4, 5 corresponds to the second cohort; i = 6, 7, 8 corresponds to the third through fifth cohorts (see below)

j = indexes the perennial streams--j = 1, ..., 8.

The second cohort (rising yields) is divided in three parts to more accurately compute production outputs during this period of rapidly increasing yields.

Marketing

Accounting equations model the marketing and processing of the agricultural output. The marketing of each commodity is represented by proportions of marketable output (Equations 4.11) going to processing, domestic consumption, or export. The model currently assumes these proportions to be fixed parameters which characterize the place of each commodity in the domestic economy, i.e., how much of it is processed domestically (before consumption or export), how

much is consumed domestically, and how much is exported. The marketable output is the portion of the total production of a commodity (Equation 4.10b) which is neither consumed on the farm nor lost (due to spoilage or waste) between field and market.

$$OUTSUB_i(t) = SUBP_i(t)*OPT_i(t) \tag{4.10a}$$

$$OUTMKT_i(t) = PLOSS_i*[OPT_i(t) - OUTSUB_i(t)] \tag{4.10b}$$

$$SUBP_4(t) = \{\sum_{k=1}^{4} PDCNSF_k(t) + DEMBIO_4(t)\}/OPT_4(t) \tag{4.10c}$$

where:

OUTSUB = the portion of output consumed on the farm --lbs./year

SUBP = the proportion of total output that is consumed on the farm

OPT = the total output of a commodity--lbs./year

OUTMKT = the marketable output of a commodity--lbs./year

PLOSS = the proportion of a crop not lost between field and market

$DEMBIO_4$ = demand for food biological materials for planting the following year (Equation 4.26f)--lbs./year

i = indexes the commodities--i = 1, ..., 5.

The only commodity which may be consumed directly on the farm is, by assumption, food. None of the export crops are so consumed. Palm oil <u>is</u> consumed domestically, but only after processing.

The marketable output of each commodity is directed to consumption, processing or export, and the supply of cash

food calories is computed to be used in determining the food prices in the North and South and the interregional trade in food, the major link between the regional submodels.

$$OMCNS_i(t) = POMC_i*OUTMKT_i(t) \quad (4.11a)$$

$$OMPRC_i(t) = POMP_i*OUTMKT_i(t) \quad (4.11b)$$

$$OMXPT_i(t) = POMX_i*OUTMKT_i(t) \quad (4.11c)$$

$$SUPCFS(t) = CALY*OMCNS_4(t)*PYCNS \quad (4.11d)$$

where:

OMCNS = marketed output consumed directly--lbs./year

POMC = proportion of marketed output that is consumed

OMPRC = marketed output processed--lbs./year

POMP = proportion of marketed output that is processed before consumption or export

OMXPT = marketed output exported directly--lbs./year

POMX = proportion of marketed output that is exported

SUPCFS = supply of cash food in the South--Calories/year

CALY, PYCNS = defined in Equation 4.7a

i = indexes the commodities--i = 1, ..., 5.

Processing

Of the commodities produced in southern Nigeria, palm fruit, rubber latex, and raw tobacco are processed (in the

model) into palm oil, palm kernels, rubber sheets, and cured tobacco. The production of cocoa and food is assumed to include any processing performed on those commodities, e.g., the drying of the cocoa beans or the making of gari from cassava.

Capacity

The capacity of the processing industry for each commodity (i.e., the physical limit on the amount that can be processed at a given time) is a function (Equation 4.12b) of the raw material input. The assumption is made that the nature of agricultural processing methods is such that there is enough flexibility for total capacity to exceed raw material input even when that input may be rising. Total capacity will decrease if excess capacity, exponentially averaged over the last few years (Equation 4.13), exceeds some critical value (say sixty percent). Rather than overt dismantling or disinvestment, replacement investment ceases until a desired (lower) level of capacity is attained (Equations 4.14). Thus, <u>if</u> excess capacity does not exceed its critical value, Equations 4.12 hold.

$$C_i(t) = PCT_i*PRT_i(t-DT) + PCM_i*PRM_i(t-DT) \qquad (4.12a)$$

$$PCAP_i(t) = \max[C_i(t)*PRMS_i(t),\ PCAP_i(t-DT)] \qquad (4.12b)$$

where:

C = a proportion greater than 1

PCT = a proportion greater than 1 for traditional processing

PCM = a proportion greater than 1 for modern processing

PRT = proportion of total processing capacity that is traditional

PRM = proportion of total processing capacity that is modern

PCAP = total processing capacity--lbs.(of input)/year

PRMS = smoothed raw material input (a first-order lag on OMPRC of Equation 4.11b)--lbs./year

i = indexes the commodities processed--i = 1, 2, 3.

Thus, increasing production will see increasing processing capacity to handle it. Decreasing production will only lower capacity, however, <u>if</u> excess capacity, exponentially averaged, exceeds some critical value.

$$XESCAP_i(t) = PCAP_i(t) - RM_i(t) \tag{4.13a}$$

$$PXSCA_i(t) = PXSCA_i(t-DT) + \frac{DT}{DELXS}[XESCAP_i(t-DT) - PXSCA_i(t-DT)] \tag{4.13b}$$

where:

XESCAP = excess capacity--lbs./year

RM = unsmoothed raw material input (=OMPRC of Equation 4.11b)--lbs./year

PXSCA = exponentially averaged excess capacity--lbs./year

DELXS = the averaging lag time--years

i = indexes the commodities processed--i = 1, 2, 3.

If excess capacity exceeds a critical proportion of total capacity, capacity is reduced by stopping replacement investment.

$$DCAP_i(t) = C_i(t)*PRMS_i(t) \tag{4.14a}$$

$$PCAP_i(t) = \max(\{PCAP_i(t-DT) - [PRT_i(t-DT)*PDT_i*\left(\frac{PREPIT_i(t)}{PKCRT_i}\right) + PRM_i(t-DT)*PDM_i*\left(\frac{PREPIM_i(t)}{PKCRM_i}\right)]*DT\},\ DCAP_i(t)) \tag{4.14b}$$

$$CAPMD_i(t) = PRM_i(t-DT)*PDM_i*\left(\frac{PREPIM_i(t)}{PKCRM_i}\right)*DT \tag{4.14c}$$

where:

DCAP = desired capacity--lbs./year

PREPIT = replacement investment in traditional capacity (Equation 4.18a)--£/year

PREPIM = replacement investment in modern capacity--£/year

PKCRT = capital-capacity ratio (traditional)--£-years/lb.

PKCRM = capital-capacity ratio (modern)--£-years/lb.

CAPMD = decrease in modern capacity--lbs./year

PDT, PDM = parameters (which may be given values of 0, 1 or reciprocals of PRT and PRM, respectively) controlling the contributions to the decrease in total capacity from traditional and modern processing--dimensionless

i = indexes the commodities processed--i = 1, 2, 3.

Modernization

While the model focuses principally on policies related to agricultural production, there may be significant benefits to be gained by the agricultural sector (primarily since agricultural producers essentially do their own processing, either as individuals or in cooperatives)

by increasing processing efficiency and/or improving the quality of processed commodities. Modern processing capacity can be generated (Equation 4.15) by exogenous (policy) modernization investment.

$$PCAPM_i(t) = \min[\{PCAPM_i(t-DT) + DT*\left(\frac{PINVMX_i(t)}{PKCRM_i}\right) - CAPMD_i(t)\},$$

$$PPCAPX_i*PCAP_i(t)] \qquad (4.15)$$

where:

PCAPM = modern processing capacity--lbs./year

PINVMX = exogenous net investment in modern capacity (a policy)--£/year

PPCAPX = desired modern proportion of capacity (a policy)

i = indexes the commodities processed--i = 1, 2, 3.

Once a desired level (proportion) of modern capacity (also a policy) has been attained, the exogenous investment ceases, and any further investment subsequently required to maintain that proportion, as total capacity changes over time, is endogenous to the agricultural sector (Equations 4.18). Modern capacity is thereafter maintained at a constant proportion of total capacity.

$$PCAPM_i(t) = PPCAPX_i*PCAP_i(t). \qquad (4.16)$$

This model of investment in modern agricultural processing is admittedly rudimentary and even unrealistic. The investment should be endogenous (possibly with exogenous credit made available) and based on profitability considerations.

This could be done if eventually deemed necessary for valid applications of the model; however, given both the model's concentration on agricultural production and the computer constraints imposed on the current (total Nigeria) model, the present processing investment mechanism appears sufficient.

In any case, once modern capacity has been determined, the remainder of total capacity will be provided by traditional facilities:

$$PCAPT_i(t) = PCAP_i(t) - PCAPM_i(t) \qquad (4.17)$$

where:

PCAPT = traditional processing capacity--lbs./year.

Investment

Replacement investment in traditional and modern agricultural processing is assumed to equal depreciation of the capital stock (Equation 4.18a), while net investment is the investment required to change capacity. Capital stock is defined as the time integral of net investment. Investment in traditional processing is computed endogenously in the model (Equation 4.18b) as the replacement and net investment which must take place to generate the traditional capacity. Modern investment (PINVM) is similarly determined once the exogenous policy investment ceases. Since the investment computed in Equation 4.18b is intended to be endogenous (agricultural sector) investment, PINVM consists only of replacement investment as long as any

exogenous net investment is being made (PINVMX >0). Equations 4.18 show the computation of traditional investment and capital stock. The modern equations are exactly analogous, with the "T" suffixes replaced by "M".

$$PREPIT_i(t) = PDRT_i * PCAPIT_i(t-DT) \tag{4.18a}$$

$$PINVT_i(t) = PREPIT_i(t) + \frac{1}{DT} * (PCAPT_i(t) - PCAPT_i(t-DT)) * PKCRT_i \tag{4.18b}$$

$$PCAPIT_i(t) = \max\{[PCAPIT_i(t-DT) + DT*(PINVT_i(t) - PREPIT_i(t)], 0.\} \tag{4.18c}$$

where:

PREPIT = replacement investment in traditional capacity--£/year

PDRT = depreciation rate for traditional processing facilities--proportion/year

PCAPIT = capital invested (stock) in traditional processing--£

PINVT = gross investment in traditional processing--£/year

PKCRT = capital-capacity ratio (traditional)--£-years/lb.

PCAPT = traditional processing capacity (Equation 4.17)--lbs./year

i = indexes the commodities processed--i = 1, 2, 3.

Processing Outputs

The amount of raw material input processed is constrained by capacity and processing losses and waste.

$$RMA_i(t) = \min(RM_i(t), PCAP_i(t)) \quad (4.19a)$$

$$NRMA_i(t) = PCL_i(t)*RMA_i(t) \quad (4.19b)$$

where:

RMA = constrained raw material input--lbs./year

NRMA = input processed (not wasted or lost)--lbs./year

PCL = proportion not lost or wasted (Equation 4.21a).

One or two outputs may then be derived from an input, depending on the particular commodity. For example, palm fruit is processed into palm oil and kernels, while rubber latex becomes only sheets.

$$POUT1_i(t) = NRMA_i(t)*PROP1_i(t) \quad (4.20a)$$

$$POUT2_i(t) = NRMA_i(t)*PROP2_i(t) \quad (4.20b)$$

where:

POUT1 = the first processed output--lbs./year

PROP1 = the proportion of input going to the first output (Equation 4.21b)

POUT2 = the second processed output--lbs./year

PROP2 = the proportion of input going to the second output (Equation 4.21c).

The loss and input/output proportions are weighted between traditional and modern capacities.

$$PCL_i(t) = PCLM_i*PRM_i(t) + PCLT_i*PRT_i(t) \quad (4.21a)$$

$$PROP1_i(t) = PROP1M_i*PRM_i(t) + PROP1T_i*PRT_i(t) \quad (4.21b)$$

$$PROP2_i(t) = PROP2M_i*PRM_i(t) + PROP2T_i*PRT_i(t) \quad (4.21c)$$

where:

PCLM, PCLT
= proportions of input weight not lost in modern and traditional processing, respectively

PROP1M, PROP1T
= proportions of input going to the first output in modern and traditional processing, respectively

PROP2M, PROP2T
= proportions of input going to the second output in modern and traditional processing, respectively

PRM, PRT
= proportions of total capacity that are modern and traditional, respectively.

Domestic consumption and export of processed outputs are computed by Equations 4.22.

$$OPXPT_j(t) = POPX_j(t)*\begin{cases} POUT1_i(t) & , j\neq 2 \\ POUT2_1(t) & , j=2 \end{cases} \quad (4.22a)$$

$$OPCNS_j(t) = POPC_j(t)*\begin{cases} POUT1_i(t) & , j\neq 2 \\ POUT2_1(t) & , j=2 \end{cases} \quad (4.22b)$$

where:

OPXPT = processed output exported--lbs./year

POPX = proportion of processed output that is exported

OPCNS = processed output consumed domestically--lbs./year

POPC = proportion of processed output that is consumed domestically

i = indexes the raw material input commodities (palm fruit bunches, rubber latex, tobacco) --i = 1, 2, 3

j = indexes the processed output commodities (palm oil, palm kernels, rubber sheets, cured tobacco)--j = 1, 2, 3, 4.

In the case of palm oil, these proportions (POPX and POPC) are determined endogenously. Fixed proportions are assumed for rubber and tobacco. In addition, if the domestic market price of palm oil equals the import price plus the import tax, then palm oil will be imported[1/].

$$DEMPO(t) = \left\{ \sum_{m=1}^{2} POCNS_m * (TPOPAG_m(t) + TPOPNA_m(t)) \right\} * \left(\frac{DMPPO(t)}{PPOMI} \right)^{EDPO} \tag{4.23a}$$

$$POPC_1(t) = \min\left(\frac{DEMPO(t)}{SUPPO(t)}, 1 \right) \tag{4.23b}$$

$$POPX_1(t) = 1. - POPC_1(t) \tag{4.23c}$$

$$POIMP(t) = \begin{cases} \max[(DEMPO(t) - SUPPO(t)), 0.] & \text{if } DMPPO(t) = WPIPO(t) * (1 + TXIMPO) \\ 0 & \text{, otherwise} \end{cases} \tag{4.23d}$$

where:

POCNS = per capita consumption of palm oil--lbs./person-year

TPOPAG, TPOPNA = total agricultural and nonagricultural population, respectively (from the population component)--persons

---

1/ See Chapter 5 for a detailed discussion of the palm oil market model.

DEMPO = the domestic demand for palm oil--lbs./year

SUPPO = the total supply of palm oil (=$POUT1_1$ of Equation 4.20a)--lbs./year

DMPPO = domestic market price of palm oil (Equations 5.4)--£/lb.

PPOMI = initial market price of palm oil--£/lb.

EDPO = elasticity of demand for palm oil--dimensionless

POIMP = palm oil imports--lbs./year

WPIPO = palm oil import price (Equation 5.4b)--£/lb.

TXIMPO = palm oil import tax--proportion of price

m = indexes the regions (North and South)--m = 1, 2.

The model deals only with smallholder production. Therefore, it is necessary to include a mechanism to generate the output of rubber and palm plantations and estates. Thus, an exogenous growth of the output of rubber estates (Equations 4.24) is modeled. Oil palm production is similarly augmented by an oil palm estates factor (OPESF).

$$RUBESF(t) = RUBESF(t-DT) + \frac{DT}{15}*[.5 - RUBESF(t-DT)] \qquad (4.24a)$$

$$XPT_4(t) = OPXPT_3(t)*[1 + RUBESF(t)] \qquad (4.24b)$$

where:

RUBESF = rubber estates factor--dimensionless

XPT_4 = rubber exports--lbs./year.

Note the assumption that the contribution of estates increases gradually to one-third of total exports.

Input Demands and Accounting

Finally, component AMPPAP computes the input demands and performs the macroeconomic commodity accounting for agricultural production, processing and marketing. Production input demands are calculated by Equations 4.25 and 4.26. First, demands for labor by commodity and by crop sector are generated. Equation 4.25a is for the perennials produced in the Rubber-Palm Sector; the other perennial sectors are analogous. Labor is assumed not to be a constraint; any shortage will be made up by seasonal migration from the North[1/].

$$DEMLSP_{3i}(t) = \sum_{j=j_i}^{J_i+1} \left\{ \left(\sum_{n=1}^{5} [PLA1_{jn} * PSPER_{jn}(t) + PLA2_{jn} * (1 - PSPER_{jn}(t))] * TLPER_{jn}(t) \right) + PDCNP_j(t) * \left(PLY_j + \frac{PAGEMP_i(t)}{OPT_i(t)} \right) \right\} \quad , i = 2, 3 \qquad (4.25a)$$

$$DEMLSP_{k4}(t) = [FDLAB1 * PSFD_k(t) + FDLAB2 * (1 - PSFD_k(t))] * TLFD_k(t) + FDLABY * [PDCNSF_k(t) + PDCNCF_k(t)] \qquad (4.25b)$$

$$DEMLS_k(t) = \sum_{i=1}^{5} DEMLSP_{ki}(t) \qquad (4.25c)$$

$$DEMLP_i(t) = \sum_{k=1}^{4} DEMLSP_{ki}(t) \qquad (4.25d)$$

1/ The current situation in Nigeria, and indeed in many developing countries, may dictate the eventual inclusion of a labor constraint in the model. This will be discussed in Chapter 11.

$$TLABD(t) = \sum_{k=1}^{4} \sum_{i=1}^{5} DEMLSP_{ki}(t) \qquad (4.25e)$$

where:

DEMLSP = demand for labor by sector and commodity--man-years/year

j_i = indexes the traditional perennial stream corresponding to commodity i in Sector 3 (i=2=palm corresponds to j_i = 7; i=3= rubber corresponds to j_i = 5)

PLA1, PLA2
= labor input requirements in each cohort of the first and second perennial substreams, respectively--man-year/acre-year

PSPER = proportion of land in the first substream of a perennial population stream, by cohort (Equation 3.2)

TLPER = land in each cohort of a perennial population stream (Equation 3.1c)--acres

PLY = labor required for perennial harvesting--man-years/lb.

PAGEMP = agricultural employment in processing (Equation 4.32f)--man-years/year

PDCNP = output of a perennial stream (Equation 4.9a)--lbs./year

OPT = total output of a commodity--lbs./year

FDLAB1, FDLAB2
= labor input requirements for traditional and modern food, respectively--man-years/acre-year

FDLABY = labor required for harvesting food--man-years/lb.

PSFD = proportion of food land which is traditional (Equation 3.2)

TLFD = total food land (Equation 3.3)--acres

PDCNSF, PDCNCF
= production of subsistence and cash food, respectively (Equations 4.8)--lbs./year

DEMLS = labor demand by crop sector--man-years/year

DEMLP = labor demand by commodity--man-years/year

TLABD = total agricultural labor demanded in the South--man-years/year

i = indexes the commodities--i = 1, ..., 5

k = indexes the crop sectors--k = 1, ..., 4

j = indexes the perennial streams--j = 1, ..., 8

n = indexes the perennial cohorts--n = 1, ..., 5.

Chemical, capital and biological inputs are computed by Equations 4.26. The equations are given for cocoa and food (i = 1, 4); inputs for the other perennials are treated similarly.

$$DEMCH_1(t) = \sum_{j=1}^{2} \sum_{n=1}^{5} [PCA1_{jn}*PSPER_{jn}(t) + PCA2_{jn}* (1 - PSPER_{jn}(t))]*TLPER_{jn}(t) \quad (4.26a)$$

$$DEMCH_4(t) = \sum_{k=1}^{4} [FDCH1*PSFD_k(t) + FDCH2*(1 - PSFD_k(t))]* TLFD_k(t) \quad (4.26b)$$

$$CAPDEP_1(t) = \sum_{j=1}^{2} EQPER_j*\left(\sum_{n=1}^{5} TLPER_{jn}(t)\right) \quad (4.26c)$$

$$CAPDEP_4(t) = \sum_{k=1}^{4} [EQFT*PSFD_k(t) + EQFM*(1 - PSFD_k(t))]* TLFD_k(t) \quad (4.26d)$$

$$DEMBIO_1(t) = EBIOT_1*RINPT1_1(t) + EBIOM_1*RINPM1_1(t) \quad (4.26e)$$

$$DEMBIO_4(t) = FDBIO* \sum_{k=1}^{4} [TLFD_k(t) + (RINF_k(t) - ROUTF_k(t))*DT] \quad (4.26f)$$

where:

DEMCH = the demand for chemicals to produce a commodity--lbs./year

PCA1, PCA2
= the per acre chemical requirement of the first and second perennial substreams, respectively--lbs./acre-year

FDCH1, FDCH2
= the per acre chemical requirement of traditional and modern food, respectively--lbs./acre-year

CAPDEP = capital invested (depreciation = equipment replacement) in a commodity--£/year

EQPER, EQFT, EQFM
= equipment (capital) costs for perennial and traditional and modern food production, respectively--£/acre-year

DEMBIO = the demand for biological inputs--units (seedlings or lbs.)/year

EBIOT, EBIOM, FDBIO
= biological input rate for traditional and modern perennials and food, respectively--units/acre-year

RINPT1, RINPM1
= planting rate of traditional and modern perennials, respectively (output of the decision mechanism, component LAMDAP, Chapter 3)--acres/year

RINF, ROUTF
= rate land enters and leaves food production, respectively (output of the decision mechanism)--acres/year

k = indexes the crop sectors--k = 1, ..., 4.

Processing capital is calculated in Equations 4.18 above. Chemicals and labor for processing and labor for marketing are computed in Equations 4.27. No marketing labor is assumed necessary for the portion of production output which is wasted or lost in processing.

$$EMPPM_k(t) = RMA_k(t)*PRM_k(t)*PLIRM_k \quad (4.27a)$$

$$EMPPT_k(t) = RMA_k(t)*PRT_k(t)*PLIRT_k \quad (4.27b)$$

$$VALCHP_k(t) = PCHT_k*OPCT_k(t) + PCHM_k*OPCM_k(t) \quad (4.27c)$$

$$PWLOSS_i(t) = [1 - POMP_i*(1 - PCL_i(t))]*\min\left(\frac{PCAP_k(t)}{OMPRC_i(t)}, 1\right) \quad (4.27d)$$

$$DEMLM_i(t) = OLABM_i(t)*OUTMKT_i(t)*PWLOSS_i(t) \quad (4.27e)$$

where:

EMPPM, EMPPT
= modern and traditional processing labor, respectively--man-years/year

PLIRM, PLIRT
= labor input requirements for modern and traditional processing, respectively--man-years/lb.

VALCHP = the value of chemical inputs to processing --£/year

PCHT, PCHM
= proportions of traditional and modern processing operating costs, respectively, that are chemical inputs

OPCT, OPCM
= traditional and modern processing operating costs, respectively (Equation 4.31e)--£/year

PWLOSS = processing weight loss factor--dimensionless

DEMLM = demand for labor in the marketing sector--man-years/year

OLABM = the labor required to market a pound of produce--man-years/lb.

OMPRC = marketable output processed (Equation 4.11b) --lbs./year

OUTMKT = marketed production output (Equation 4.10b) --lbs./year

PCAP = processing capacity (Equations 4.12b or 4.14b)--lbs./year

POMP = defined in Equation 4.11b

PCL = defined in Equation 4.19b

k = indexes commodities processed (k = 1, 2, 3 corresponds to i = 2, 3, 5)

i = indexes commodities produced--i = 1, ..., 5.

The accounting and criteria variables for agricultural production and marketing are computed in Equations 4.28 for each commodity. The capitalized value equation (Equation 4.28q) is given for food; the values of the other commodities are similarly computed.

$$WAG_i(t) = PL(t)*DEMLP_i(t)*PLHP_i(t) \tag{4.28a}$$

$$WMKT_i(t) = PLM(t)*DEMLM_i(t) \tag{4.28b}$$

$$COSTML_i(t) = OLABM_i*\frac{PLM(t)}{PPRCM_i(t)} \tag{4.28c}$$

$$CCBEI_i(t) = PCI_i*DEMCH_i(t) + PBI_i*DEMBIO_i(t) + CAPDEP_i(t) \tag{4.28d}$$

$$REVSUB_i(t) = PPRC_i(t)*OUTSUB_i(t) \tag{4.28e}$$

$$REVCSH_i(t) = PPRC_i(t)*OUTMKT_i(t)*\left(\frac{PSOLD_i(t)}{PLOSS_i}\right) \tag{4.28f}$$

$$VALADP_i(t) = PPRC_i(t)*OPT_i(t) - [CCBEI_i(t) - CAPDEP_i(t)] \tag{4.28g}$$

$$VALADM_i(t) = PPRCM_i(t)*OUTMKT_i(t)*PSOLD_i(t)*PWLOSS_i(t) - REVCSH_i(t)*(1 - POMP_i) - PINC_i(t) \tag{4.28h}$$

$$REVCN_i(t) = REVCSH_i(t) - CCBEI_i(t) - WAG_i(t) + PAGREV_i(t) \quad (4.28j)$$

$$TAXMS(t) = \max[TAXMR_i*(PPRCM_i(t)*OUTMKT_i(t)*PSOLD_i(t)* PWLOSS_i(t) - WMKT_i(t)), 0.] \quad (4.28k)$$

$$TAXPS_i(t) = \max[TAXPR_i*(REVCN_i(t) - PAGREV_i(t)), 0.] \quad (4.28\ell)$$

$$PRFT_i(t) = PPRC_i(t)*OPT_i(t) - CCBEI_i(t) - TAXPS_i(t) - WAG_i(t) + PAGREV_i(t) - PTAX_i(t) \quad (4.28m)$$

$$PRFTM_i(t) = PPRCM_i(t)*OUTMKT_i(t)*PSOLD_i(t)*PWLOSS_i(t) - WMKT_i(t) - TAXMS_i(t) - REVCSH_i(t)* (1 - POMP_i) - PINC_i(t) \quad (4.28n)$$

$$PRFTLB_i(t) = [PRFT_i(t) + WAG_i(t)]/DEMLP_i(t) \quad (4.28o)$$

$$PRFTLD_i(t) = PRFT_i(t)/TLD_i(t) \quad (4.28p)$$

$$CAPVAL_4(t) = \frac{1}{RI}*\max[(PRFT_4(t) + TAXPS_4(t) + PTAX_4(t)), 0.] \quad (4.28q)$$

where:

WAG	= cash wages paid--£/year
PL	= wage rate in the agricultural sector (Equation 5.10a)--£/man-year
PLHP	= proportion of labor which is hired (Equation 4.29b)
WMKT	= wages paid in the marketing sector--£/year
PLM	= wage rate in the marketing sector (Equation 5.10b)--£/man-year

COSTML = marketing labor costs (to be used in the price generating component, Equation 5.5b) --proportion of market price

PPRCM = market price (Equations 5.2)--£/lb.

CCBEI = cost of chemical, capital and biological inputs--£/year

PCI = the price of chemical inputs--£/lb.

PBI = the price of biological inputs--£/unit (seedling or lb.)

REVSUB = revenue in kind--£/year

PPRC = producer price (Equation 5.7)--£/lb.

PSOLD = proportion of output sold (Equation 4.30)

PLOSS = proportion of output not lost between field and market

PWLOSS = proportion of output not lost in processing (Equation 4.27b)

REVCSH = cash revenue--£/year

VALADP = value added in the production sector--£/year

VALADM = value added in the marketing sector--£/year

REVCN = net cash revenue--£/year

PAGREV = processing revenue to the agricultural sector (Equation 4.32d)--£/year

TAXPS = tax revenue from the production sector--£/year

TAXPR = tax rate in the production sector

TAXMS = tax revenue from the marketing sector--£/year

TAXMR = tax rate in the marketing sector

PTAX = tax revenue from processing (Equation 4.32a) --£/year

PRFT = profit in the production sector--£/year

PRFTM = profit in the marketing sector--£/year

POMP = defined in Equation 4.11b

PINC = gross income to agricultural processing (Equation 4.31a)--£/year

PRFTLB = returns to labor--£/man-year

PRFTLD = returns to land--£/acre-year

CAPVAL = capitalized value of commodity land--£

RI = interest rate--proportion/year

i = indexes the commodities--i = 1, ...,5.

A note is in order here about two factors affecting wages paid and cash revenues in Equations 4.28a and 4.28f--the proportion of labor which is hired (PLHP) and the proportion of marketed output which is sold (PSOLD). First, the proportion of agricultural labor hired for the production of each commodity reflects two concepts (Equation 4.29b). One is the extent to which non-family (hired) labor is employed to maintain and harvest a commodity. This will differ from commodity to commodity depending on the farmers' attitudes towards each--attitudes such as trust in non-family workers with a given commodity and the social desirability of a particular type of work (e.g., rubber tapping). Assuming that labor is not a constraint, as this model does, any positive excess demand for agricultural labor is met by labor from outside the region, i.e., seasonal migration from the North. Such hired labor is arbitrarily assigned to each commodity in proportion to the commodity's total labor usage.

Secondly, the quantity of output sold on the market depends on the ratio of demand to supply. If there is excess

demand, everything is sold. For the major cash crops--cocoa, palm, rubber and tobacco--demand is assumed to equal supply. That is, Nigeria can sell all it wants on the export market, and the Nigerian Tobacco Company buys all the tobacco produced. It is only for food, the demand for which is endogenously generated in the population component of the total model, that supply may exceed demand and vice versa (Equation 4.30).

The proportions of labor hired by commodity and by crop sector are, then, functions of non-family indigenous labor and seasonal migration.

$$PLHIRE_k(t) = \max\left(\frac{DEMLS_k(t) - LABAS_k(t)}{DEMLS_k(t)}, 0.\right) + \sum_{i=1}^{5} PNFL_i * \frac{DEMLSP_{ki}(t)}{DEMLS_k(t)} \tag{4.29a}$$

$$PLHP_i(t) = PNFL_i + \sum_{k=1}^{4} \max\left(\frac{DEMLS_k(t) - LABAS_k(t)}{DEMLS_k(t)}, 0.\right) * \frac{DEMLSP_{ki}(t)}{DEMLP_i(t)} \tag{4.29b}$$

$$RSMIGL(t) = \max\{[TLABD(t) - \sum_{k=1}^{5} LABAS_k(t)], 0.\} \tag{4.29c}$$

where:

DEMLS = defined in Equation 4.25c

DEMLSP = defined in Equation 4.25a

DEMLP = defined in Equation 4.25d

TLABD = defined in Equation 4.25e

LABAS = labor supply (from the population component) --man-years/year

PNFL = proportion of a commodity's labor requirements hired from the indigenous (to a crop sector) population--a model parameter

PLHIRE = proportion of labor hired (including migration into the crop sector), by crop sector

PLHP = proportion of labor hired (including migration), by commodity

RSMIGL = seasonal labor migration into the South--man-years/year

i = indexes the commodities--i = 1, ..., 5

k = indexes the crop sectors--k = 1, ..., 4.

The proportion of food output sold is the demand-supply ratio constrained so as not to exceed one. The proportion of the other commodities sold is assumed fixed and equal to one.

$$PSOLD_4(t) = \min\left(\frac{TDCFS(t)}{SUPCFS(t)}, 1.\right) \tag{4.30}$$

where:

TDCFS = total demand for cash food (agricultural and nonagricultural)--Calories/year

SUPCFS = supply of cash food (Equation 4.11d)--Calories/year.

Accounting equations similar to Equations 4.28 are computed for the traditional processing of each agricultural commodity. Similar equations are executed for modern processing, where the suffixes "T" are replaced by "M".

$$PINC_i(t) = POUT1_i(t)*PPRCP1_i(t) + POUT2_i(t)*PPRCP2_i(t) \tag{4.31a}$$

$$INCT_i(t) = PRT_i(t)*PINC_i(t) \quad (4.31b)$$

$$WAGEST_i(t) = EMPPT_i(t)*PWRT_i*PPNFLT_i \quad (4.31c)$$

$$VOIT_i(t) = RMA_i(t)*PRT_i(t)*PPRC_i(t) \quad (4.31d)$$

$$OPCT_i(t) = RMA_i(t)*PRT_i(t)*POCUT_i \quad (4.31e)$$

$$GROSPT_i(t) = INCT_i(t) - OPCT_i(t) - PREPIT_i(t) - WAGEST_i(t) - VOIT_i(t) \quad (4.31f)$$

$$TAXT_i(t) = GROSPT_i(t)*TRPT_i + INCT_i(t)*TRIT_i \quad (4.31g)$$

$$VALADT_i(t) = INCT_i(t) - OPCT_i(t) - VOIT_i(t) \quad (4.31h)$$

where:

PINC = gross processing income--£/year

PPRCP1, PPRCP2
= processor price of the first and second processed outputs, respectively, of a commodity (correspond to PPRCP of Equation 5.3)--£/lb.

POUT1, POUT2
= the first and second processed outputs, respectively, of a commodity (Equations 4.20)--lbs./year

INCT = income to traditional processing--£/year

PRT = the proportion of total processing capacity that is traditional

WAGEST = cash wages paid in traditional processing --£/year

EMPPT = labor demand for traditional processing (Equation 4.27b)--man-years/year

PPNFLT = proportion of non-family (hired) labor used in traditional processing--a model parameter

PWRT = wage rate in traditional processing--£/man-year

VOIT = cost of raw material inputs--£/year

RMA = actual raw material input (Equation 4.19a) --lbs./year

PPRC = producer price (Equation 5.7)--£/lb.

OPCT = operating cost of traditional processing--£/year

POCUT = operating cost rate--£/lb.

GROSPT = gross profit in traditional processing--£/year

PREPIT = replacement investment in traditional processing (Equation 4.18a)--£/year

TAXT = taxes paid from traditional processing--£/year

TRPT, TRIT = profits and income tax rates, respectively, for traditional processing

VALADT = value added in traditional processing--£/year

i = indexes the commodities processed-- i = 1, 2, 3.

Finally, totals are made across traditional and modern processing and returns to the agricultural production sector are computed (Equation 4.32d). Most of the agricultural processing in Nigeria is performed by the producers themselves, either as individuals or in cooperative ventures. Therefore, the portion of processing revenues returning to the agricultural sector (PAGREV) is computed so it can be included as agricultural income available for investment in production, for consumption or for taxation (Equations 4.28j, 4.28ℓ, 4.28m). Also, the processing costs per unit of input (PAGCST)

is computed for the agricultural producers' contribution to processing. This figure is used on the cost side of the land use profitability equation (= PXP of Equation 3.6b). Similarly, agricultural labor employed in processing activities (PAGEMP) is calculated in Equation 4.32f and added to labor used in production (Equation 4.25a).

$$PTAX_i(t) = TAXT_i(t) + TAXM_i(t) \tag{4.32a}$$

$$PVALAD_i(t) = VALADT_i(t) + VALADM_i(t) \tag{4.32b}$$

$$PRFTP_i(t) = GROSPT_i(t) + GROSPM_i(t) - PTAX_i(t) \tag{4.32c}$$

$$PAGREV_i(t) = GROSPT_i(t)*PAGT_i + GROSPM_i(t)*PAGM_i \tag{4.32d}$$

$$PAGCST_i(t) = [(OPCM_i(t) + PREPIM_i(t) + EMPPM_i(t)*WRM_i)* PAGM_i + (OPCT_i(t) + PREPIT_i(t) + EMPPT_i(t)* WRT_i)*PAGT_i]/RM_i(t) \tag{4.32e}$$

$$PAGEMP_i(t) = EMPPM_i(t)*PAGM_i + EMPPT_i(t)*PAGT_i \tag{4.32f}$$

where:

PTAX = total taxes paid from agricultural processing--£/year

PVALAD = total value added in agricultural processing--£/year

PRFTP = profits from agricultural processing--£/year

PAGREV = returns to the agricultural sector from agricultural processing--£/year

PAGT, PAGM = proportion of traditional and modern

processing, respectively, performed by the agricultural sector--a model parameter

PAGCST = processing cost rate incurred by agricultural producers--£/lb.

PAGEMP = agricultural employment in processing--man-years/year

i = indexes the commodities processed--i = 1, 2, 3.

Summary

In summary, AMPPAP simulates the production, processing and marketing of agricultural commodities for southern Nigeria. In doing so, it determines commodity yields and the agricultural population's subsistence level. In addition, AMPPAP generates input demands and macroeconomic performance criteria for use by other components of the southern model and the national model.

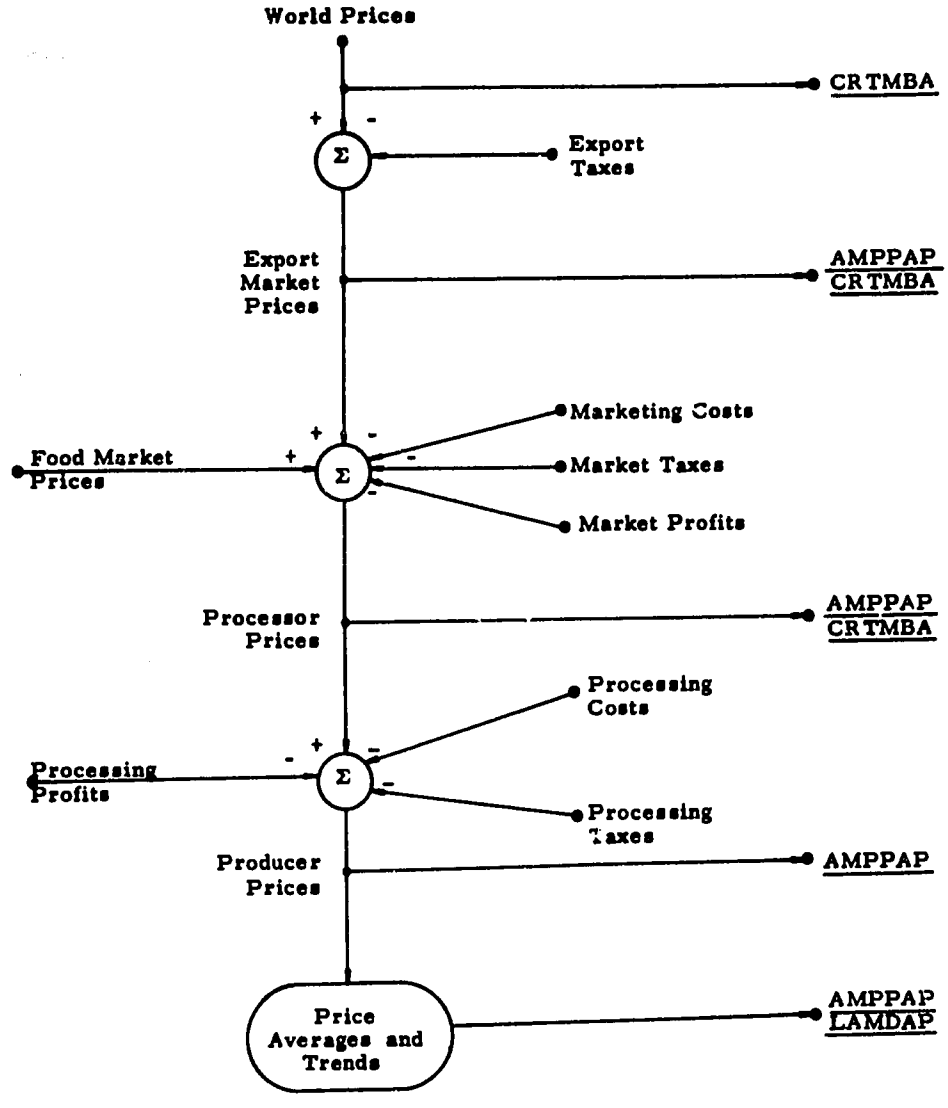
CHAPTER 5

Price Generation (PG)

Component PG services the rest of the southern model by generating world prices for the export commodities and market, processor and producer prices of all six commodities considered--cocoa, oil palm products (oil and kernels), rubber, food, and tobacco. The domestic palm oil market is also modeled by PG. In addition, five- and ten-year exponential averages of the producer prices and price trends are computed for use by component LAMDAP in the profitability calculations for the land allocation decisions and by component AMPPAP in the determination of the price response of yields.

Export, Market and Processor Prices

Figure II.10 indicates schematically how prices are generated. It is assumed participants further down in the producer-to-consumer chain are price takers in general. Thus, costs (including taxes) are passed on down the line. At the top, world prices for the export commodities are exogenously generated by Equation 5.1.



Key to components using the various prices:
AMPPAP - Agricultural marketing, production and processing--annuals/perennials
CRTMBA - Criteria and macro-budget accounting
LAMDAP - Land allocation and modernization decisions--annuals/perennials

Figure II.10 Price generation component.

$$WP_i(t) = \begin{cases} VALWP_{1i} + \frac{t}{13}*(VALWP_{13i} - VALWP_{1i}) & , 0<t\leq 13 \\ VALWP_{13i} + \frac{t-13}{4}*(WP1970_i - VALWP_{13i}) & , 13<t\leq 17 \\ WP1970_i*(1 + WPR_i*(t-17)) & , t>17 \end{cases} \quad (5.1)$$

where:

WP = world (FOB) price--£/lb.

$VALWP_{ki}$ = recorded world price of commodity i at time k, k = 1953, 1954, ..., 1965

WP1970 = recorded world price in 1970

WPR = rate of change of world price after 1970 --proportion/year

t = simulated time (t = 0 is 1953)--years

i = indexes the export commodities (cocoa, palm oil, palm kernels, rubber)--i = 1, ..., 4.

Equations 5.2 compute the prices received by the marketing boards (or other export marketers in the case of rubber) for export commodities and by the domestic marketers of food. The domestic price of palm oil is discussed below (Equations 5.4). The tobacco price to the Nigerian Tobacco Company is an exogenous constant.

$$PPRCM_i(t) = WP_i(t)*(1 - EXTAX_i) \quad , i = 1, ..., 4 \quad (5.2a)$$

$$PPRCM_5(t) = PPRCM_5(t-DT) + DT*CF1*PPRCM_5(t-DT)* \frac{[TDCFS(t-DT) - SUPCFS(t-DT) - SFNS(t-DT)]}{TDCFS(t-DT)} \quad (5.2b)$$

$$PPRCM_6(t) = PMCA \quad (5.2c)$$

where:

PPRCM = market price--£/lb.

EXTAX = export tax--proportion of world price

PMCA = constant cash annual (tobacco) market price--£/lb.

TDCFS = total demand for cash food in the South from the agricultural and nonagricultural populations--Calories/year

SUPCFS = supply of cash food in the South (Equation 4.11d)--Calories/year

SFNS = shipments of food, North to South (from the market component, linking the northern and southern submodels)--Calories/year

CF1 = parameter regulating the food price response to excess demand (see the discussion below)--proportion/year

i = indexes the commodities marketed--i = 1, ..., 6.

Equation 5.2b, which generates the market price of food as a function of excess demand, is derived directly from the definition of the demand price elasticity ε:

$$\varepsilon = \frac{\Delta q/q}{\Delta p/p}$$

where $\Delta q = q_t - q_{t-DT}$ and $\Delta p = p_t - p_{t-DT}$ and the ratios are taken relative to the initial price and quantity, p_{t-DT} and q_{t-DT}. Thus,

$$\Delta p = p_t - p_{t-DT} = \frac{1}{\varepsilon}(q_t - q_{t-DT})\frac{p_{t-DT}}{q_{t-DT}}$$

and

$$p_t = p_{t-DT} + \frac{1}{\varepsilon}p_{t-DT}\,\frac{q_t - q_{t-DT}}{q_{t-DT}}\,.$$

Equation 5.2b assumes that the <u>target</u> change in quantity,

Δq, will be the excess demand in the previous period and that the equilibrium price will not necessarily be reached in one period, i.e., if $DT*CF1 < 1/\varepsilon$. The domestic palm oil price mechanism (Equation 5.6a) is similarly derived.

The next price computed (Equation 5.3) is the price to the processor for those commodities whose processing is explicitly modeled[1/], namely, palm oil, palm kernels, rubber and tobacco. For cocoa and food, the prices computed here will be the producer prices, PPRC. These prices are the market prices less marketing costs, taxes and profit surplus. For the commodities marketed through marketing boards, the profit surplus represents the marketing board tax policy. In the case of palm oil, this price may be modified somewhat by Equations 5.5 if there is positive excess domestic demand.

$$PPRCP_i(t) = PPRCM_i(t)*(1 - SRPMB_i - COSTM_i - COSTML_i(t) - TAXMR_i)*PLOSS_i \qquad (5.3)$$

where:

PPRCP = processor price--£/lb.

SRPMB = marketing board (or other marketer) profits --proportion of market price

COSTM = marketing costs--proportion of market price

COSTML = marketing labor costs (Equation 4.28c)--proportion of market price

TAXMR = marketing tax rate--proportion of market price

1/ See the description of component AMPPAP, Chapter 4.

PLOSS = marketing loss factor--proportion

i = indexes the commodities marketed--i = 1, ..., 6.

Domestic Palm Oil Market

The domestic consumption of palm oil competes considerably with exports. Indeed, as the domestic demand grows with the population and unless current production trends are reversed by programs to modernize oil palm production, by 1980 Nigeria may have ceased to export palm oil and may even have become an importer. Thus, the determination of the market and processor prices of palm oil is considerably more complicated than Equations 5.2 and 5.3. The palm oil supply-demand-price relationships are discussed below in connection with Figure II.11.

The market price of palm oil computed in Equation 5.2a, $PPRCM_2$, is the price received by the export marketer, the palm oil marketing board. The domestic market price (Equations 5.4) depends on the processor price set by the marketing board, on the domestic excess demand and on the import price of palm oil.

$$DMPPO(t) = \min\{WPIPO(t)*(1 + TXIMPO), \max[DMPPOU(t), DMPPOL(t)]\} \quad (5.4a)$$

where:

$$WPIPO(t) = WP_2(t) + WPOTC \quad (5.4b)$$

$$DMPPOU(t) = PPRCP_2(t)/[(1 - SRPMB_5 - COSTM_5 - COSTML_5(t) - TAXMR_2)*PLOSS_2] \quad (5.4c)$$

$$DMPPOL(t) = DMPPOL(t-DT) + \frac{DT}{POMDEL}*[DMPPOU(t-DT) - DMPPOL(t-DT)] \quad (5.4d)$$

and where:

DMPPO = actual domestic market price of palm oil --£/lb.

WPIPO = import price of palm oil--£/lb.

TXIMPO = import tax--proportion of price

DMPPOU = unlagged domestic market price of palm oil --£/lb.

DMPPOL = lagged domestic market price of palm oil --£/lb.

WP_2 = export (FOB) price of palm oil (Equation 5.1)--£/lb.

WPOTC = palm oil world transport cost--£/lb.

$PPRCP_2$ = processor price of palm oil (Equation 5.5a) --£/lb.

$SRPMB_5$, $COSTM_5$, $COSTML_5$, $TAXMR_2$, $PLOSS_2$ = defined in Equation 5.3 (5 = food; 2 = palm oil)

POMDEL = exponential lag time--years.

Several points are to be noted in Equations 5.4. First, it is assumed that the domestic marketing costs and profit margin for palm oil are the same as for food. This is not unreasonable since palm oil and food pass through much the same market system. Secondly, the import (CIF) price of palm oil is the FOB price plus the cost of transport

to Nigeria. The domestic market price is bounded above by the import price and below by the processor price (Equations 5.5) plus marketing margins. If the processor price is falling, the domestic market price will lag behind it, creating extra profits for the marketers. However, if the processor price is rising, the market price will be constrained to cover costs and a minimum profit margin.

As long as there is negative excess domestic demand for palm oil (i.e., there are exports), the processor price paid by both export and domestic marketers will be as set by the marketing board in Equation 5.3. If domestic demand exceeds supply, however, a lagged price rise will occur (Equations 5.6) until the market price equals the import price (Equation 5.4b), at which time the processor price will be set by the domestic marketers. This behavior is modeled by Equations 5.5.

$$PPRCP_2(t) = \begin{cases} P_d(t) & \text{if } POIMP(t-DT)>0 \\ DPPO(t) & \text{if } POIMP(t-DT)=0 \text{ and } DEMPO(t-DT)\geq SUPPO(t-DT) \\ P_x(t) & \text{if } DEMPO(t-DT)<SUPPO(t-DT) \end{cases} \quad (5.5a)$$

where:

$$P_d(t) = DMPPO(t)*(1 - SRPMB_5 - COSTM_5 - COSTML_5(t) - TAXMR_2)*PLOSS_2 \quad (5.5b)$$

and where:

$PPRCP_2$ = palm oil processor price--£/lb.

P_d = processor price set by domestic marketers --£/lb.

P_x = processor price set by the marketing board (Equation 5.3)--£/lb.

DPPO = lagged processor price when there is excess demand (Equations 5.6)--£/lb.

POIMP = palm oil imports (Equation 4.23d)--lbs./year

DEMPO = domestic demand for palm oil (Equation 4.23a)--lbs./year

SUPPO = supply of palm oil (Equation 4.20a)--lbs./year.

If there is positive excess domestic demand for palm oil and the market price hasn't yet reached the import price (i.e., there are no imports to supplement the domestic supply), the processor price is determined by the amount of excess demand.

$$DPPOU(t) = \begin{cases} DPPOU(t-DT) + DT*CPPO*DPPOU(t-DT)* \dfrac{DEMPO(t-DT) - SUPPO(t-DT)}{DEMPO(t-DT)} \\ \qquad \text{if } DEMPO \geq SUPPO \text{ and } POIMP=0 \\ PPRCP_2(t) \quad , \text{ otherwise} \end{cases} \tag{5.6a}$$

$$DPPO(t) = DPPO(t-DT) + \frac{DT}{PPODEL}*[DPPOU(t-DT) - DPPO(t-DT)] \tag{5.6b}$$

where:

CPPO = a parameter regulating the price response to excess demand--proportion/year

PPODEL = a smoothing lag--years.

Figure II.11 shows how the palm oil market operates in the simulation model. It is assumed Nigeria's demand for or supply of palm oil is sufficiently small to have negligible effect on world prices. Thus, Nigeria can export all she wants at the FOB price corresponding to p_x in the figure. (The price axis is of the processor price of Equation 5.5[1/].) Similarly, Nigeria can import as much as she wants at the CIF price corresponding to the processor price p_i. These situations are reflected in the import supply (S_i) and export demand (D_x) curves of Figure II.11.

Three cases are depicted in the figure. Current trends suggest these cases are in chronological order. Each case is relative to its contemporary world prices (the S_i and D_x curves), so these prices need not necessarily be the same in all three cases, although they appear so in the figure. Also, the domestic demand and supply curves pictured assume the ceteris paribus conditions, i.e., that tastes and technologies do not change. (Interactions with the markets of domestic substitutes for palm oil, particularly groundnut oil, are not modeled.)

1/ There is some debate as to which variable, quantity or price, should be placed on the vertical axis, i.e., which is the dependent variable. Actually, in the cases depicted in Figure II.11, it depends. In Cases 1 and 3, price determines the quantities demanded and supplied, while in Case 2, demand and supply jointly determine the equilibrium price.

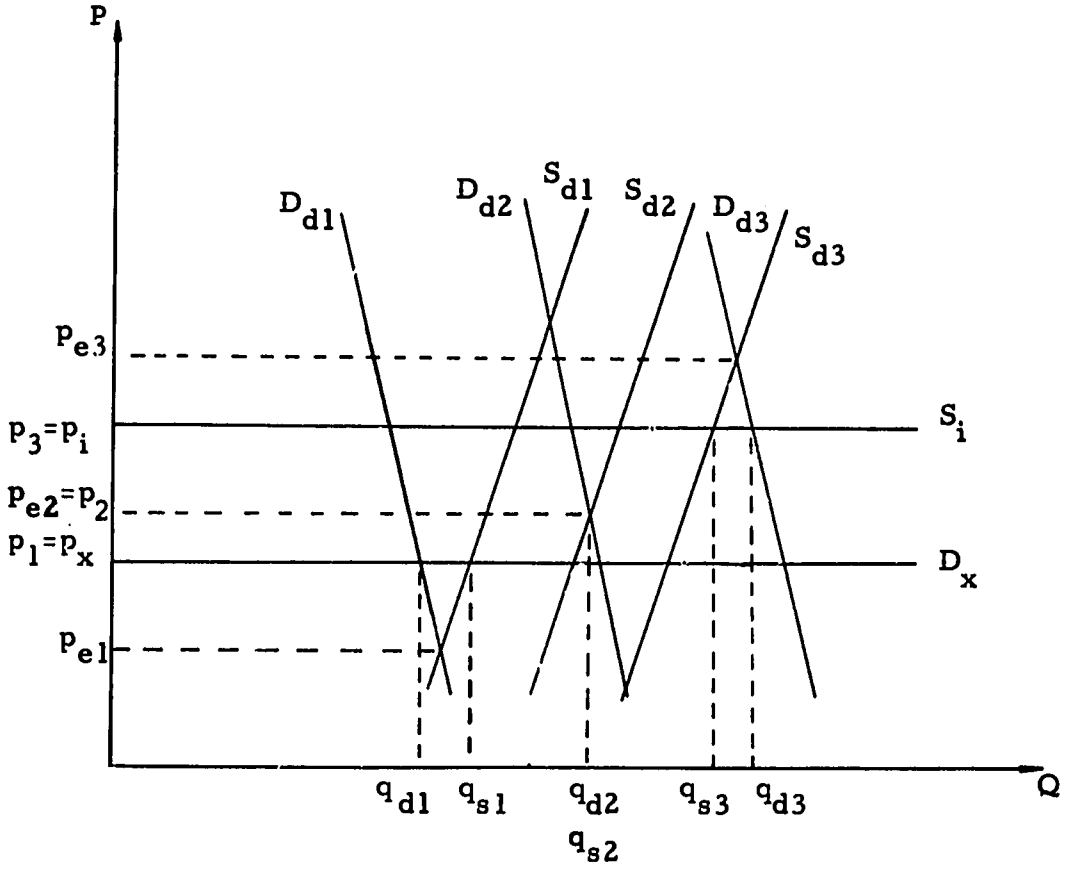


Figure II. 11 The palm oil market: three cases.

Case 1 is represented by domestic demand and supply curves D_{d1} and S_{d1}, respectively. In this case, the processor price p_1, as determined by the marketing board, is above the domestic market-clearing price p_{e1}, and the resulting excess supply $(q_{s1}-q_{d1})$ is exported.

Domestic demand grows (with the population) at a faster rate than supply due to the traditional nature of production and the increasing scarcity of land. Thus, by the time of Case 2, D_{d2} and S_{d2}, the equilibrium price p_{e2} is the actual price p_2 (Equations 5.6) and is above the marketing board price based on export demand. Hence, q_3 clears the domestic market and there are no exports of palm oil.

Finally, Case 3, D_{d3} and S_{d3}, represents the situation where domestic demand has continued to outstrip the supply, and the equilibrium price p_{e3} has risen above the processor price p_3 based on the import price. The lower import price obtains (Equation 5.4a), and the resulting excess demand $(q_{d3}-q_{s3})$ is met by imports[1/].

Producer Prices, Price Averages and Wage Rates

Next, producer prices are computed in Equation 5.7. Since two palm commodities are processed outputs of one raw material input (palm fruit bunches), the processor prices for kernels and oil are averaged to determine the producer

---

1/ Imports and exports of palm oil are computed in component AMPPAP, Equations 4.23.

prices. The variable $PPRCPP_2$, then, is this weighted average. The others, $PPRCPP_i$, i = 1, 3, 4, 5, are simply equal to the corresponding $PPRCP_j$, j = 1, 4, 5, 6. For those commodities not processed (cocoa and food), the producer price will equal the processor price.

$$PPRC_i(t) = PPRCPP_i(t)*(1 - TAXPPR_i - COSTP_i(t) - PSRP_i(t))* PCL_i(t) \quad (5.7)$$

where:

PPRC = producer price--£/lb. produced

PPRCPP = processor price (weighted between processed outputs)--£/lb. processed

TAXPPR = processing tax rate--proportion of price

COSTP = processing costs (computed from the processing costs determined in Equations 4.31)--proportion of price

PSRP = processing profit margin (weighted between traditional and modern processing margins) --proportion of price

PCL = processing loss factor (Equation 4.21a)--lbs. processed/lb. produced

i = indexes the commodities produced--i = 1, ..., 5.

Exponential price and price trend averages are computed in Equations 5.8 for use in determining land allocation decisions (Equation 3.7) and harvest price responses (Equations 4.6).

$$PPAV_i(t) = PPAV_i(t-DT) + \frac{DT}{PRCDEL}*[PPPC_i(t-DT) - PPAV_i(t-DT)] \quad (5.8a)$$

$$PPAVH_i(t) = PPAVH_i(t-DT) + \frac{DT}{PRCDLH} * [PPPC_i(t-DT) - PPAVH_i(t-DT)] \tag{5.8b}$$

$$PPAVR_i(t) = PPAVR_i(t-DT) + \frac{DT}{PRCDEL} * \left(\frac{PPPC_i(t-DT)}{PPPC_i(t-2DT)} - PPAVR_i(t-DT) \right) \tag{5.8c}$$

where:

PPAV = exponential average of agricultural producer-processor prices, used in LAMDAP --£/lb.

PPAVH = exponential average of producer-processor prices, used in AMPPAP--£/lb.

PPPC = agricultural producer-processor prices (see Equation 5.9)--£/lb.

PPAVR = producer-processor price trends--dimensionless

PRCDEL = averaging lag--years

PRCDLH = averaging lag--years

i = indexes the commodities produced--i = 1, ..., 5.

Since much, if not all, of the processing of agricultural commodities is performed by the agricultural sector itself, the prices used to determine profitabilities for land allocation decisions and harvest price responses are weighted averages of producer prices and processor prices.

$$PPPC_i(t) = PPRC_i(t) + PAG_i(t) * [PPRCPP_i(t) * PCL_i(t) - PPRC_i(t)] \tag{5.9}$$

where:

PPPC = producer-processor price--£/lb.

PPRC = producer price (Equation 5.7)--£/lb.

PPRCPP = processor price--£/lb.

PCL = processing loss coefficient (Equation 4.21a)

PAG = proportion of agricultural processing done by the agricultural sector itself, weighted between PAGT and PAGM (defined in Equations 4.32d - 4.32f)

i = indexes the commodities produced--i = 1, ..., 5.

Finally, PG assumes an exogenous growth rate for agricultural production and marketing wage rates (Equations 5.10). In the case of labor for agricultural production, the wage rate includes payments in kind, e.g., food and lodging. The growth is to reflect the effects of urbanization and industrialization and increasing degrees of consumerism--the former competes for labor and the latter may contribute to inflation. These effects should be endogenous in the model, as should the rural-urban migration rate, since they are of considerable importance in planning for agricultural development. However, the lack of any generally accepted theory in this area precludes incorporation into the model at this time (see discussion in Chapter 11).

$$PL(t) = PL(t-DT) + DT*PLR \qquad (5.10a)$$

$$PLM(t) = PLM(t-DT) + DT*PLMR \qquad (5.10b)$$

where:

PL = agricultural production wage rate--£/man-year

PLM = agricultural marketing wage rate--£/man-year

PLR = rate of growth of PL--£/man-year-year

PLMR = rate of growth of PLM--£/man-year-year.

Summary

The world, market, processor and producer prices and the price averages generated by component PG are used by other components of the southern model to determine the allocation of land, the production of the various commodities and the resulting incomes, taxes, and other accounting criteria. In addition, the palm oil market modeled in PG determines the domestic prices and the quantities of palm oil exported and consumed domestically.

CHAPTER 6

Policy Entries

Since this is a policy-oriented model, there are a number of places in which the policy maker can enter the simulated system to perform experiments. Two primary modes of investigation may be employed. One involves changing system parameters and technological coefficients to see the effect on the model's performance, i.e., sensitivity tests. This is an indirect method since such parameter changes would be made to reflect the intended consequences of some policy or program. The other mode of investigation is direct policy experimentation, wherein policies and programs are specified explicitly and the consequences are simulated as a result of the system structure of the model. Simulation runs testing parameter sensitivity and conducting direct policy experiments with the southern model are discussed in Chapters 9 and 10.

Parameter Sensitivity and Policy Making

Briefly, two purposes may be served by changing the values of system parameters and/or technological coefficients. First, the policy maker may feel the values of some of these parameters are not realistic, or he may be unsure as to what they should be. By entering alternative likely values, he

will be able to compare what effect different parameter values have on the simulated behavior of the system. If system behavior is insensitive to changes in some parameter, the policy maker need not concern himself further with that parameter. On the other hand, a parameter which does significantly affect system performance would play a role in future policy planning decisions. Secondly, it would be possible to evaluate likely consequences of investments in alternative areas of research--e.g., the development of high-yielding hybrid varieties, or research into the use of chemical sprays and fertilizers--by making corresponding changes in the relevant technological coefficients in the model, i.e., per acre yields, labor input requirements, or other input requirements and costs.

Policies

Three basic policy classes are structured in the simulation model. Others could be added, but the three included were seen to be the most relevant for Nigerian policy makers at the time the model was defined. Policies may be set and experimented within any one or combination of the following areas: production campaigns, marketing board pricing policies and tax policies.

Production Campaigns

Production campaigns make up the first class of policies which may be investigated. Promotion efforts aimed at modernizing agricultural production can generate

substantial returns to both the public and private sectors. Such modernization may entail the introduction of higher-yielding biological varieties and/or the encouragement of improved cultural practices such as weeding, spacing, time of planting and the application of fertilizers and insecticides. The increase in output can then result in higher incomes for the farmers and increased tax revenues and foreign exchange earnings for the public sector. The nonagricultural sector can also experience growth as a result of increased demands from the agricultural sector.

A modernization executive routine [34] is used to allocate a modernization budget among up to five production campaigns. This budget is used to generate the promotional information units (particularly extension agents) discussed earlier in the description of component LAMDAP, Equations 3.12 and 3.13. Cash and price subsidies (Equations 3.6), technical assistance to farmers entering the campaigns and campaign overhead expenses are also paid out of the modernization budget. The maximum yearly size (RMAX) and time span (T0, T1, T2, TF) of this budget may be specified by the experimenter, and the model generates the time profile shown in Figure II.12[1/].

Table II.2 lists the seventeen possible production campaigns; any five may be considered in the southern model

---

1/ For a detailed description of the modernization executive routine, see [34].

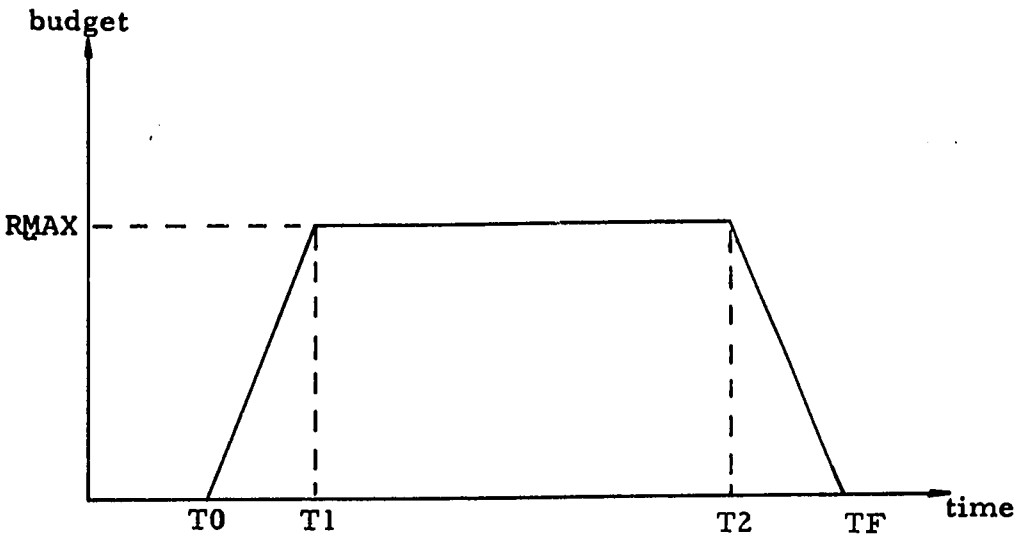


Figure II.12 Modernization budget profile.

at a time. The table also defines what is implied in the three classes of campaigns--improvement, replanting, and new planting.

Associated with these production campaigns is the policy determination of the eligibility requirements placed on farmers and land entering the modernization program. In the case of farmers, these requirements might include a particular level of experience and/or financial resources, while land could be constrained by soil conditions and contiguity requirements. These policy considerations are roughly aggregated in the model by the concept of land availability discussed above in component LAMDAP (Equations 3.9 and 3.10).

A policy related to production campaigns would be the modernization of rubber and palm processing. Currently, the model takes modern palm processing to be the use of

Table II.2. Production campaigns.

Campaigns

1. Cocoa improvement
2. Cocoa replanting
3. Palm improvement (Palm Sector)
4. Palm replanting (Palm Sector)
5. Rubber improvement
6. Rubber replanting
7. Palm new planting from rubber
8. Palm improvement (Rubber-Palm Sector)
9. Palm replanting (Rubber-Palm Sector)
10. Rubber new planting from palm
11. Cocoa new planting from bush/food
12. Palm new planting from bush/food (Palm Sector)
13. Rubber new planting from bush/food
14. Palm new planting from bush/food (Rubber-Palm Sector)
15. Food modernization (perennials sectors)
16. Food modernization (annuals sector)
17. Tobacco new planting from bush/food (annuals sector)

Definitions

1. Improvement of perennials: the application of modern inputs (e.g., fertilizers, sprays) and improved methods of managerial control (e.g., weeding, spacing, tapping) to traditional biological varieties.

2. Replanting of perennials: replacing traditional varieties with modern hybrids (e.g., higher-yielding, disease resistant) and applying modern inputs and cultivational practices.

3. New planting of perennials: planting modern hybrid perennials on bush or food land (or replacing another perennial commodity) and applying improved methods.

4. Modernization of food: introducing improved varieties and/or methods into staple food crop production.

5. New planting of tobacco: introducing tobacco (or some other cash annual), presumably under modern production.

Stork hydraulic presses and modern rubber processing to be centralized crumb rubber factories. As indicated in Chapter 4 (Equations 4.15 and 4.16), the modernization of processing facilities takes place regardless of its profitability. All that is required is an exogenous rate of investment which can be set as a policy. Problems of this model formulation are discussed in Chapter 11.

Marketing Boards

The second major policy area which can be investigated with the model is the area of marketing board pricing policies. Most export commodities in Nigeria are handled through so-called "commodity marketing boards" (rubber is the major exception) which buy from the farmers at one price, perform marketing and other services, and sell in world commodity markets at a higher price. Marketing boards have the power to set producer prices as a matter of policy, whereby the boards may generate surpluses for themselves or run at a loss. Surpluses may be used for price stabilization purposes or to finance development or other projects. These producer prices can have significant impacts on producer incentives and hence commodity outputs. With simulation runs incorporating different levels of marketing board surpluses for each commodity, questions can be answered regarding the likely consequences these policies will have on production levels, foreign exchange earnings, agricultural income, and other relevant economic performance criteria.

Taxes

Finally, the model allows experimentation with several kinds of taxing policies. Specifically, income taxes can be set on agricultural producers, processors and marketers, respectively, and profit taxes can be levied on agricultural processors. In addition to these, the effects of different levels of export taxes on the various agricultural export commodities can be investigated.

CHAPTER 7

Criteria and Macro-Budget Accounting (CRTMBA)

The major exit points of the southern model are located in component CRTMBA. These include economic and accounting criteria and the agricultural sector budget.

Performance Criteria

Equations 7.1 through 7.5 compute the performance variables of the southern model. These include: (1) value added, foreign exchange and government revenues; (2) other variables needed for the national accounts/nonagricultural sector model [35, Chapter 7]; and (3) capital and modern input demands.

Equations 7.1 compute total value added from agricultural production, marketing and processing.

$$TVAP_2(t) = \sum_{i=1}^{5} VALADP_i(t) \tag{7.1a}$$

$$TVAM_2(t) = \sum_{i=1}^{5} VALADM_i(t) \tag{7.1b}$$

$$TVAPP(t) = \sum_{j=1}^{3} PVALAD_j(t) \tag{7.1c}$$

$$TVAS(t) = TVAP_2(t) + TVAM_2(t) + TVAPP(t) \tag{7.1d}$$

$$ATVAS(t) = ATVAS(t-DT) + DT*TVAS(t) \tag{7.1e}$$

where:

$TVAP_2$ = total value added in agricultural production in the South (subscript 1 indexes northern outputs)--£/year

$TVAM_2$ = total value added in agricultural marketing in the South--£/year

TVAPP = total value added in agricultural processing in the South--£/year

VALADP, VALADM, PVALAD
= value added by commodity in agricultural production, marketing and processing, respectively (Equations 4.28g, 4.28h and 4.32b)--£/year

TVAS = total value added in agriculture in the South--£/year

ATVAS = accumulated value added--£

DT = simulation time increment--years

i = indexes the commodities produced (cocoa, palm, rubber, food, tobacco)

j = indexes the commodities processed (palm, rubber, tobacco).

The value of agricultural exports at FOB and processor prices are computed by Equations 7.2.

$$VALEXP_2(t) = \sum_{i=1}^{4} WP_i(t)*XPT_i(t) - WPIPO(t)*POIMP(t) \quad (7.2a)$$

$$VALXPP_2(t) = \sum_{i=1}^{4} PPRCP_i(t)*XPT_i(t)/PLOSS_i \quad (7.2b)$$

$$AFORXS(t) = AFORXS(t-DT) + DT*VALEXP_2(t) \quad (7.2c)$$

where:

$VALEXP_2$ = the value, at FOB prices, of agricultural exports in the South--£/year

$VALXPP_2$ = the value, at processor prices, of agricultural exports in the South--£/year

WP = world (FOB) price (Equation 5.1)--£/lb.

WPIPO = import price of palm oil (Equation 5.4b) --£/lb.

PPRCP = processor price (Equation 5.3)--£/lb.

XPT = quantity exported (from component AMPPAP) --lbs./year

POIMP = palm oil imports (Equation 4.23d)--lbs./ year

PLOSS = marketing loss factor--proportion

AFORXS = accumulated foreign exchange from agricultural exports in the South--£

i = indexes the export commodities (cocoa, palm oil, palm kernels, rubber).

Government revenues, Equations 7.3, include tax revenues and marketing board surpluses.

$$TAXAG_2(t) = \sum_{i=1}^{5} [TAXPS_i(t) + TAXMS_i(t) + PTAX_i(t)] \qquad (7.3a)$$

$$TTAXGS(t) = TAXAG_2(t) + \sum_{j=1}^{4} WP_j(t)*EXTAX_j*XPT_j(t)$$

$$+ WPIPO(t)*TXIMPO*POIMP(t) \qquad (7.3b)$$

$$REVMBS_k(t) = XPT_k(t)*\left(PPRCM_k(t)*(1. - COSTM_k - COSTML_k(t)) - \frac{PPRCP_k(t)}{PLOSS_k}\right) \qquad (7.3c)$$

$$TMBREV_2(t) = \sum_{k=1}^{3} REVMBS_k(t) \qquad (7.3d)$$

$$TMOVHD_2(t) = \sum_{k=1}^{3} XPT_k(t)*PPRCM_k(t)*COSTM_k \qquad (7.3e)$$

$$ATTXGS(t) = ATTXGS(t-DT) + DT*TTAXGS(t) \quad (7.3f)$$

$$ATRMBS(t) = ATRMBS(t-DT) + DT*TMBREV_2(t) \quad (7.3g)$$

where:

$TAXAG_2$ = southern agricultural sector tax revenues --£/year

TAXPS, TAXMS, PTAX = producer, market and processor tax revenues, respectively, by commodity (Equations 4.28h, 4.28ℓ and 4.32a)--£/year

EXTAX = export tax rate

TXIMPO = palm oil import tax rate

TTAXGS = total southern agricultural sector tax revenues--£/year

ATTXGS = accumulated tax revenues--£

REVMBS = marketing board revenues in the South, by commodity--£/year

PPRCM = market price (Equation 5.2a)--£/lb.

COSTM = marketing overhead factor--proportion of market price

COSTML = marketing wages paid (Equation 4.28c)--proportion of market price

PPRCP = processor price (Equation 5.3)--£/lb.

PLOSS = proportion marketed after losses

$TMBREV_2$ = total marketing board revenues in the South --£/year

$TMOVHD_2$ = total marketing board overhead expenses--£/year

ATRMBS = accumulated marketing board revenues--£

i = indexes the commodities produced

j = indexes the commodities exported

k = indexes the commodities handled by marketing boards (cocoa, palm oil, palm kernels).

Equations 7.4 compute other variables needed for the national accounts/nonagricultural sector model.

$$TAXEXP(t) = TTAXGS(t) - TAXAG_2(t) \tag{7.4a}$$

$$VALCP_2(t) = \sum_{i=1}^{5} DEMCH_i(t)*PCI_i \tag{7.4b}$$

$$VALCPP(t) = \sum_{j=1}^{3} VALCHP_j(t) \tag{7.4c}$$

$$CAPDPP(t) = \sum_{j=1}^{3} [PINVT_j(t) + PINVM_j(t)] \tag{7.4d}$$

$$CAPDP_2(t) = \sum_{i=1}^{5} CAPDEP_i(t) \tag{7.4e}$$

where:

TAXEXP = agricultural export tax revenues--£/year

$VALCP_2$ = value of agricultural production chemical input demands in the South--£/year

DEMCH = quantity demand for chemicals, by commodity (Equations 4.26a and 4.26b)--lbs./year

PCI = price of chemical inputs--£/lb.

VALCPP = value of agricultural processing chemical input demands--£/year

VALCHP = value of agricultural processing chemical input demands, by commodity (Equation 4.27c)--£/year

CAPDPP = processing capital investment demands--£/year

PINVT, PINVM = investment in traditional and modern processing, respectively, by commodity (Equation 4.18b)--£/year

$CAPDP_2$ = total investment in agricultural capital equipment in the South--£/year

CAPDEP = agricultural replacement investment in equipment, by commodity (Equations 4.26c and 4.26d)--£/year

i = indexes the commodities produced

j = indexes the commodities processed.

Finally, Equations 7.5 compute input demand totals generated by modernization campaigns and the demand for agricultural net investment.

$$TCHEMP(t) = \sum_{m=1}^{5} ECHEMP_m(t) \tag{7.5a}$$

$$TCAPMP(t) = \sum_{m=1}^{5} ECAPMP_m(t) \tag{7.5b}$$

$$TCAPRT(t) = \sum_{k=1}^{4} ECAPRT_k(t) \tag{7.5c}$$

where:

TCHEMP = total demand for chemicals from modernization promotion efforts--lbs./year

TCAPMP = total demand for net investment from modernization promotion efforts--£/year

TCAPRT = total agricultural demand for net investment--£/year

ECHEMP = chemical demands, by production campaign (Equation 3.15c)--lbs./year

ECAPMP = net investment demands, by production campaign (Equation 3.15a)--£/year

ECAPRT = net investment demands, by crop sector (Equation 3.14a)--£/year

m = indexes the modernization programs

k = indexes the crop sectors.

Budget Accounting

In order to determine agricultural consumption and investment, component CRTMBA computes disposable income in the agricultural sector. This includes disposable income from production and from the processing performed by the agricultural sector. The macro-budget accounting is performed for each ecological zone (or crop sector) since investment and consumption decisions depend on the alternative income-generating activities facing the farmers. Therefore, the production and processing revenues and expenditures computed by commodity in component AMPPAP are here distributed by crop sector. Revenues include the gross cash income derived from the sale of commodity outputs, disposable income to the agricultural sector from agricultural processing (discussed below, Equations 7.13) and credit payments from outside the agricultural sector. Expenditures are the costs of chemical, biological and capital equipment inputs and income tax payments, as well as cash food purchases and debt service and interest payments.

The apportionment is done (Equations 7.6) by assigning to each crop sector the revenues and expenditures of each commodity in proportion to that sector's contribution to the total output of the commodity. This distribution scheme, while not ideal, is not too far off the mark since commodity revenues and expenditures are directly proportional to output and since the constants of proportionality (commodity and input prices) are assumed to be uniform throughout the South.

Output, in turn, is directly proportional to land, which is distributed by commodity in each ecological zone. However, the proportionality constants in the latter case, namely yields, may differ from crop sector to crop sector. For example, if a modernization campaign in palm production has been going on in the Palm Sector (Sector 2), palm yields there will be higher than palm yields in the Rubber-Palm Sector (Sector 3). Only the equations for the Rubber-Palm Sector are given here as an example; the others are quite analogous.

$$PSC_{32}(t) = \frac{(PDCNP_7(t) + PDCNP_8(t))}{OPT_2(t)} \tag{7.6a}$$

$$PSC_{31}(t) = \frac{PDCNCF_3(t)}{\sum_{k=1}^{4} PDCNCF_k(t)} \tag{7.6b}$$

$$AGINC_3(t) = REVCSH_3(t) + REVCSH_2(t)*PSC_{32}(t) + REVCSH_4(t)* PSC_{31}(t) + CRDT_3(t-DT) + CAPDIA_2(t) + CAPDIA_1(t)* PSC_{32}(t) \tag{7.6c}$$

$$SCCBEI_3(t) = CCBEI_3(t) + CCBEI_2(t)*PSC_{32}(t) + CCBEI_4(t)* PSC_{31}(t) \tag{7.6d}$$

$$STAX_3(t) = TAXPS_3(t) + TAXPS_2(t)*PSC_{32}(t) + TAXPS_4(t)* PSC_{31}(t) \tag{7.6e}$$

$$SCV_3(t) = CAPVAL_3(t) + CAPVAL_2(t)*PSC_{32}(t) + CAPVAL_4(t)*PSC_{31}(t) \quad (7.6f)$$

where:

PSC_{32} = proportion of palm fruit produced in Sector 3 (Rubber-Palm Sector)

PSC_{31} = proportion of cash food produced in Sector 3

$PDCNP_7$, $PDCNP_8$
= output of the traditional and modern palm perennial population streams, respectively, in Sector 3 (Equation 4.9a)--lbs./year

$PDCNCF_3$ = output of cash food in Sector 3 (Equation 4.8a)--lbs./year

OPT_2 = total production of palm in the South--lbs./year

$AGINC_3$ = gross agricultural income in Sector 3--£/year

$REVCSH_3$, $REVCSH_2$, $REVCSH_4$
= gross income from agricultural production of rubber, palm and food, respectively (Equation 4.28f)--£/year

$CAPDIA_2$, $CAPDIA_1$
= agricultural disposable income derived from agricultural processing of rubber and palm products, respectively (Equation 7.13e)--£/year

$CRDT_3$ = credits granted to the agricultural sector in the Rubber-Palm zone (Equation 7.11b) --£/year

$SCCBEI_3$ = cost of chemical, modern biological and capital equipment inputs to agricultural production in Sector 3--£/year

$CCBEI_3$, $CCBEI_2$, $CCBEI_4$
= cost of chemical, modern biological and capital inputs to rubber, palm and food production, respectively (Equation 4.28d) --£/year

$STAX_3$ = producer income tax revenues in Sector 3--£/year

$TAXPS_3$, $TAXPS_2$, $TAXPS_4$
= producer income taxes from the production of rubber, palm and food, respectively (Equation 4.28ℓ)--£/year

SCV_3 = capitalized asset value of cultivated land in Sector 3--£

$CAPVAL_3$, $CAPVAL_2$, $CAPVAL_4$
= capitalized asset value of rubber, palm and food land, respectively (Equation 4.28q) --£

k = indexes the crop sectors--k = 1, .., 4.

A portion of the agricultural sector's consumption expenditures (Equation 7.7b) is fed back to the agricultural sector itself and, hence, is treated (Equation 7.7a) as additional agricultural income. These internal consumption expenditures are for cottage industries and other economic activities of the agricultural population apart from the production and processing of agricultural commodities.

$$TAGINC_k(t) = \frac{AGINC_k(t)}{(1 - CMUL_{k2})} \tag{7.7a}$$

$$SINAC_k(t) = CMUL_{k2} * TAGINC_k(t) \tag{7.7b}$$

where:

TAGINC = total agricultural income--£/year

$CMUL_2$ = proportion of income consumed within the agricultural sector in the South

SINAC = consumption within the agricultural sector --£/year

k = indexes the crop sectors--k = 1, ..., 4.

The outstanding agricultural sector debt is the time integral (Equation 7.8c) of credit payments to the sector less the debt service. The assumption is made that a fixed proportion of the debt is repaid each year. This may be treated as government (or other lending agency) policy or simply a behavioral characteristic. It is further assumed that interest is not allowed to accumulate. Rather, interest charged against the outstanding debt is paid each year.

$$SDS_k(t) = \max[(SDSR_k * SDBT_k(t-DT)), 0.] \tag{7.8a}$$

$$SINT_k(t) = RI * SDBT_k(t-DT) \tag{7.8b}$$

$$SDBT_k(t) = SDBT_k(t-DT) + DT*[CRDT_k(t) - SDS_k(t)] \tag{7.8c}$$

where:

SDS = debt service paid--£/year

SDSR = repayment rate--proportion of debt repaid/year

SDBT = agricultural sector debt--£

CRDT = agricultural sector credits (Equation 7.11b) --£/year

SINT = interest payments--£/year

RI = interest rate on agricultural production loans--proportion of debt/year

k = indexes the crop sectors--k = 1, ..., 4.

Disposable income in the agricultural sector (Equations 7.9) is the gross income minus the cost of non-farm inputs (chemicals, equipment, modern biologicals), taxes, the

debt service, interest payments, internal consumption expenditures, and cash food expenditures. The last item assumes farmers will first feed themselves and their families before disposing of their income in other ways. Wages paid are not deducted since they remain within the agricultural sector as part of disposable income for consumption or investment. Disposable income is constrained to be at least enough to cover a subsistence level of non-food consumption. Any shortage of actual income below this minimum consumption level is assumed to be made up by credits (Equation 7.11b) and is added to the debt.

$$SAGDIU_k(t) = TAGINC_k(t) - SDS_k(t) - SINT_k(t) - SCCBEI_k(t) - STAX_k(t) - SINAC_k(t) - DEMRS_k(t)* (1 - SUBLEV_k(t))*PRFD_2(t)/(CALY*PYCNS) \quad (7.9a)$$

$$CNSMIN_k(t) = TPOPAG_2(t)*DLABOR_{k12}*PCCNS_k \quad (7.9b)$$

$$SAGDI_k(t) = \max[SAGDIU_k(t), CNSMIN_k(t)] \quad (7.9c)$$

where:

SAGDIU = unconstrained disposable income--£/year

CNSMIN = subsistence non-food consumption--£/year

$TPOPAG_2$ = agricultural sector population (from the population component)--people

$DLABOR_{12}$ = proportion of southern labor force in each crop sector

PCCNS = per capita subsistence non-food consumption--£/person-year

SAGDI = constrained disposable income--£/year

DEMRS = southern agricultural sector demand for Calories (from the population component) --Calories/year

SUBLEV = agricultural subsistence level (Equation 4.3b)--proportion

CALY = Calorie content of food--Calories/lb.

$PRFD_2$ = market price of food in the South (= $PPRCM_5$ in Equation 5.2b)--£/lb.

PYCNS = proportion of marketed food that is consumed

k = indexes the crop sectors--k = 1, ..., 4.

Consumption is determined (Equations 7.10) by the average propensity to consume, while the income available for investment is the disposable income minus consumption. If the demand for investment generated by the land allocation decisions (i.e., net investment; replacement investment--equipment costs--are treated as operating costs) is less than the available investment capital, the excess capital is added to consumption. If the demand for investment exceeds the available supply, a demand for credit from outside the agricultural sector is generated (Equations 7.11). This demand for credit is constrained by the availability of credit, which is a straight proportion of the equity value of cultivated land. Equity value is defined as the capitalized value of the land minus the outstanding debt.

$$SAGDII_k(t) = (1 - APC)*SAGDI_k(t) \qquad (7.10a)$$

$$SAGDIC_k(t) = APC*SAGDI_k(t) + \max[0., -(ECAPRT_k(t) - SAGDII_k(t))] \quad (7.10b)$$

$$TAGDIP_2(t) = \sum_{k=1}^{4} SAGDIC_k(t) \quad (7.10c)$$

where:

SAGDII = agricultural income available for investment--£/year

SAGDIC = agricultural income available for consumption--£/year

APC = agricultural average propensity to consume --proportion of income

ECAPRT = agricultural demand for net investment (Equation 3.14a)--£/year

$TAGDIP_2$ = total agricultural consumption in the South--£/year

k = indexes the crop sectors--k = 1, ..., 4.

$$CRDTAV_k(t) = \max[0, PEQCR*(SCV_k(t) - SDBT_k(t-DT))] \quad (7.11a)$$

$$CRDT_k(t) = \min\{CRDTAV_k(t), \max[(ECAPRT_k(t) - SAGDII_k(t)), 0.] + \max[(CNSMIN_k(t) - SAGDIU_k(t)), 0.]\} \quad (7.11b)$$

$$TDCTS(t) = \sum_{k=1}^{4} CRDT_k(t) \quad (7.11c)$$

where:

CRDTAV = credit available--£/year

PEQCR = proportion of equity which can be used as a credit base

CRDT = agricultural sector credits--£/year

TDCTS = total demand for credit in the South--£/year

SAGDIU = agricultural disposable income (Equation 7.9a)--£/year

CNSMIN = subsistence non-food consumption (Equation 7.9b)--£/year

k = indexes the crop sectors--k = 1, ..., 4.

If the investment capital available from agricultural disposable income and the credit available from sources outside the agricultural sector together do not meet the demand for investment (ECAPRT), a constraint is placed on the land allocation decisions (as discussed earlier in component LAMDAP, Equation 3.13). The constraint is the ratio (Equation 7.12a) of the available investment capital to the investment demand if this ratio is less than unity[1/]. The ratio is applied directly to the land transition response (Equation 3.13). The constraint mechanism is purposely simple; however, if further evidence should indicate that this formulation does not sufficiently represent the actual capital constraint faced by the farm decision makers and its (the constraint's) consequences for agricultural investment patterns, the mechanism could be developed further. Indeed, it may be that this phenomenon cannot be fully incorporated into the model until

---

1/ The constraint is exponentially averaged over the period of a decision cycle. The decision mechanism described in Chapter 3 operates on a longer cycle than the rest of the model, i.e., DTX > DT. This is necessary to keep the computer running time of the model within reason and is justified since prices, yields and, hence, relative profitabilities don't change rapidly. Model sensitivity to DT and DTX is discussed in Chapter 9.

the whole question of the distribution of income in the agricultural sector is modeled into the land allocation decisions and production responses. (See the discussion in Chapter 11.)

$$CNSINU_k(t+DT) = \min\left(\frac{CRDTAV_k(t) + SAGDII_k(t)}{ECAPRT_k(t)}, 1.\right) \qquad (7.12a)$$

$$CNSIN_k(t+DT) = CNSIN_k(t) + \frac{DT}{DTX}*[CNSINU_k(t) - CNSIN_k(t)] \qquad (7.12b)$$

where:

CNSINU = consumption constraint on agricultural investment--dimensionless

CNSIN = averaged constraint--dimensionless

DTX = the decision cycle--years

k = indexes the crop sectors--k = 1, ..., 4.

The disposable income generated by agricultural processing, part of which is included with agricultural income, is computed (Equations 7.13) in a manner similar to the agricultural disposable income discussed above. The processing debt service, interest payments, operating costs, taxes and investments are subtracted from gross income to generate disposable income for consumption. It is assumed that a proportion of the processing investment (discussed in component AMPPAP, Chapter 4) is financed by credits granted from outside the agricultural processing sector. These credits make up the processing debt. The portion of disposable income from processing which is added to agricultural income (Equation 7.6c) is proportional to the amount of processing done by agricultural producers.

$$PCDS_i(t) = \max[PCDSR_i*PCDBT_i(t-DT),\ 0.] \tag{7.13a}$$

$$PCINT_i(t) = PRI*PCDBT_i(t-DT) \tag{7.13b}$$

$$PCDBT_i(t) = PCDBT_i(t-DT) + DT*[PICT_i*PINVT_i(t) + PICM_i*PINVM_i(t) - PCDS_i(t)] \tag{7.13c}$$

$$CAPDI_i(t) = PINC_i(t) - PTAX_i(t) - (1 - PICT_i)*PINVT_i(t) - (1 - PICM_i)*PINVM_i(t) - PCDS_i(t) - PCINT_i(t) - OPCT_i(t) - OPCM_i(t) \tag{7.13d}$$

$$CAPDIA_i(t) = PAG_i(t)*CAPDI_i(t) \tag{7.13e}$$

$$CAPDIN_i(t) = (1 - PAG_i(t))*CAPDI_i(t) \tag{7.13f}$$

where:

PCDS = the debt service for the agricultural processing sector--£/year

PCDSR = repayment rate for agricultural processing loans--proportion of debt repaid/year

PCINT = interest payments--£/year

PRI = interest rate on agricultural processing loans--proportion/year

PCDBT = agricultural processing debt--£

PICT, PICM = proportion of traditional and modern processing investment, respectively, financed by credits from outside the processing sector

PINVT, PINVM
= traditional and modern investment in agricultural processing, respectively (Equation 4.18b)--£/year

CAPDI = disposable income from agricultural processing--£/year

PINC = gross income to agricultural processing (Equation 4.31a)--£/year

PTAX = processing taxes (Equation 4.32a)--£/year

OPCT, OPCM
= traditional and modern processing operating costs, respectively (Equation 4.31e)--£/year

PAG = proportion of agricultural processing done by the agricultural producers themselves

CAPDIA = disposable income from agricultural processing going to the agricultural sector accounts--£/year

CAPDIN = disposable income from agricultural processing going to the nonagricultural sector accounts--£/year

i = indexes the commodities processed--i = 1, 2, 3.

Finally, disposable income in the marketing sector (Equation 7.14) is marketing profits plus wages paid in the marketing sector plus the marketing board overhead. The last item assumes that overhead goes primarily for the salaries of marketing board personnel.

$$TAGDIM_2(t) = TMOVHD_2(t) + \sum_{i=1}^{5} (PRFTM_i(t) + WMKT_i(t)) \quad (7.14)$$

where:

$TAGDIM_2$ = disposable income in the agricultural marketing sector in the South--£/year

$TMOVHD_2$ = southern marketing board overhead costs (Equation 7.3e)--£/year

PRFTM = marketing profits (Equation 4.28n)--£/year

WMKT = wages paid in the marketing sector (Equation 4.28b)--£/year

i = indexes the commodities marketed--i = 1, ..., 5.

Summary

Component CRTMBA, then, computes performance criteria both as exit points of the southern model and to be fed back to the national accounts/nonagricultural sector model. It also determines agricultural consumption and investment by balancing the agricultural sector budget.

P A R T III

VALIDATION AND TESTING

Introduction

For a decision maker to base policy decisions on the experimental results of a model--any model, verbal or mathematical, paper and pencil or computer--he must have some degree of confidence in the validity of that model, i.e., how well it simulates the relevant behavior of the real system or phenomenon it is supposed to represent. There are primarily three ways in which the model under discussion may be validated.

The first is by a sort of knowledgeable intuition. During the building of the model, much reliance for both data and structural and causal relationships was placed on people with a great deal of experience in Nigeria and other developing countries. In addition, secondary sources were used. The experiences of the Consortium for the Study of Nigerian Rural Development proved invaluable as a background and basis for the simulation work. By studying the simulated behavior of the model, these same people and others like them may, through their expertise, have an intuitive feel for how well the model represents the real economy. This would be an on-going process, continuing even once the model has been implemented and is in routine use.

More concretely, behavior predicted by the model under various policy conditions can be compared with what actually occurs as real time passes under the same conditions. Alternatively, the model can be compared with historical data from the real world which has not been used in the model-building process. Once the model has been implemented, it would be tuned and updated as an on-going process by making such comparisons.

A common criticism leveled at the validity and usefulness of the system simulation approach in the economic development context concerns the vast data needs of the model where the available data are notoriously unreliable or even non-existant. Chapters 8 and 9 briefly discuss the model's data requirements and problems and examine a couple of approaches to dealing with some of those problems; namely, tuning the model to track recorded time series and analyzing the model's sensitivity to variations in parameter values.

CHAPTER 8

Data Usage and Model Tuning

Socio-economic research often runs into data problems even in the so-called developed countries. Needed data may not exist. Techniques for directly gathering data of a particular kind may be unknown, forcing the researcher to indirectly infer necessary data from other sources. The reliability of existing data may be suspect because of questionable sampling procedures. In the less developed countries, these and other problems are often compounded by poor or erratic communications and data processing facilities, a shortage of well-trained data collecting manpower, an even greater shortage of funds (government or private) to support and maintain data collecting and processing activities, and, frequently, a distrust on the part of respondents of outsiders (i.e., interviewers) in general and of government in particular.

Nevertheless, researchers, planners and policy makers cannot wait for perfectly reliable data (which may never come, anyway) to recommend, plan and make decisions on policies and programs for development. Techniques must be found and used not only to improve the quality of data but also to make best use of the data available at the time.

The system simulation approach used in the Nigeria

model offers three ways of at least meeting, if not solving, the data problem. Sensitivity tests (discussed in the next two chapters) can demonstrate the implications of parameter variability both for the validity of the model and for policy formulation. They can also indicate the directions data collecting efforts could most profitably take. Secondly, given coarse probability distributions for a set of key parameters, running the model in a Monte Carlo mode can directly generate output statistics reflecting data uncertainties [35, Chapter 4]. Finally, the model may be tuned to track a number of reliable recorded time series by adjusting uncertain parameter values. This procedure will be discussed later in this chapter.

Data

Data for the southern annuals/perennials model fall into three broad categories: system parameters, technological coefficients, and initial conditions. The data requirements of each category number in the hundreds, and each class of data has its own particular needs and sources. In this section, we will briefly discuss the three categories and their data sources.

System Parameters[1/]

System parameters are primarily parameters reflecting the behavioral characteristics of the system being modeled.

1/ See Tables III.1-III.4 for tabulated values of selected system parameters used in the southern model.

Thus, in a sense, they, along with the structural equations, actually define the system. A few examples of the many system parameters of the southern model are:

1. the land use profitability response parameters (THRLD, SHAPE in Equation 3.11);

2. the profitability discount rates (DR in Equation 3.5);

3. the many delays and averaging and smoothing lags of the model (e.g., PEXDEL in Equation 3.17c, SDEL in Equation 4.7a and PRCDEL in Equations 5.8);

4. the subsistence level parameters (SLMIN, SLTHR, EFPSF in Equations 4.3);

5. the short-term supply response elasticities (SUPRSP in Equation 4.6a);

6. the marketing distribution parameters (POMC, POMP, POMX in Equations 4.11);

7. the average propensity to consume (APC in Equations 7.10).

Little data exist on most of the behavioral system parameters. The kinds of field research which would be necessary to estimate many of them have never been conducted. Values used in the early stages of building and testing the model were educated and intuitive guesstimates. The education and intuition were acquired from various secondary sources (e.g., [14, 17, 24, 28, 30, 41, 44]) and from such primary sources as interviews with Nigerian officials and farmers and a number of man-years of personal experience in Nigeria and other developing countries. Let's look at the land use transition response thresholds for traditional perennial land as an illustration (THRT in Table III.1). The values shown (.1, .3 and .5) mean that the alternatives of improvement, replanting and new planting a different perennial (Table II.2)

Table III.1. Profitability response parameters for traditional perennials (dimensionless).

Variables (Eqn. No.) (definition)	Present Uses	Alternative Uses		
		improvement	replanting	new planting other perennial
THRT (3.11) (response threshold)	Cocoa	.1	.3	--
	Palm (Palm Sector)	.1	.3	--
	Rubber	.1	.3	.5
	Palm (Rubber Sector)	.1	.3	.5
SHPT (3.11) (governs response rate)	Cocoa	1.1	1.	--
	Palm (Palm Sector)	1.1	1.	--
	Rubber	1.1	1.	.9
	Palm (Rubber Sector)	1.1	1.	.9
DRT (3.5) (discount rate)	.03	.04	.06	.07

Source: Initial guesstimates and model tuning.

Table III.2. Profitability response parameters for annuals and bush.

Present Uses	Variables (Eqn. No.)[a]	Alternative Uses			
		Traditional	Modern perennials	Food	Tobacco
Bush	DRB (3.5)	.06	.07	.05	.05
	SHPB (3.11)	.6	.3	.01	1.
	THRB (3.11)	.3	.5	.2	.2
		Modern food	Modern perennials	Tobacco	
Food	DRF (3.5)	.04	.07	.05	
	SHPF (3.11)	1.1	.8	1.	
	THRF (3.11)	.2	.4	.2	
		Food			
Tobacco	DRCAF (3.5)	.04			
	SHPCA (3.11)	1.			
	THRCA (3.11)	.2			

[a] Variables are defined by prefixes:
DR_ = discount rates
SHP_ = governs response rates
THR_ = response thresholds

Source: Initial guesstimates and model tuning.

Table III.3. Diffusion parameters.

Present Uses	Variables (Eqn. No.)	Alternative Uses				
		Crop Sector[a]	Traditional perennial	Modern perennial	Food	Tobacco
Bush	CIUDB (3.8)	1	.001	.002	.0005	--
		2	.001	.002	.0005	--
		3	.002/.001	.002/.002	.0005	--
		4	--	--	.001	.001
		Crop Sector	Modern food	Modern perennial	Tobacco	
Food	CIUDF (3.8)	1	.001	.01	--	
		2	.001	.01	--	
		3	.001	.01/.01	--	
		4	.001	--	.01	
		Present Use	Improvement	Replanting	Other modern perennial	
Traditional Perennials	CIUDT (3.8)	Cocoa	.10	.005	--	
		Palm (Sector 2)	.05	.003	--	
		Rubber	.05	.01	.002	
		Palm (Sector 3)	.05	.003	.001	
		Crop Sector	Food			
Tobacco	CIUDC (3.8)	4	.001			

[a] Crop Sectors: 1 = Cocoa-Food Sector; 2 = Palm-Food Sector; 3 = Rubber-Palm-Food Sector; 4 = Food-Cash Annual Sector

Source: Initial guesstimates and model tuning.

Table III.4. Production parameters.

Variable (Eqn. No.) (definition)	Commodity				
	Cocoa	Palm	Rubber	Food	Tobacco
PLOSS (4.10b) (marketing loss factor)	.9	.95	.95	.9	.8
POMC (4.11a) (proportion consumed)	0.	0.	0.	1.	0.
POMP (4.11b) (proportion processed)	0.	1.	1.	0.	1.
POMX (4.11c) (proportion exported)	1.	0.	0.	0.	0.
SUPRSP (SUPRSF) (4.6a) (perennials (food) harvest supply elasticity)	.05	.2	.4	1.2	0.
PROP1T (4.21b) (proportion of raw material processed as the first processed output)	--	.60	1.	--	1.
PNFL (4.29) (proportion of non-family labor used in production)	.2	.2	.2	.1	.05
PPNFLT (4.31c) (proportion of non-family labor used in traditional processing)	--	.2	.25	--	.5

Sources: [15] and initial guesstimates and model tuning.

must be at least 10%, 30% and 50% more profitable, respectively, than the traditional perennial crop currently on that land before farmers will transfer the land to the alternative use. The relative values hypothesize different farmer attitudes (e.g., risk aversion; see the discussion of component LAMDAP in Chapter 3) towards the three alternatives.

Parameters such as this one play an important role in the validation of the model in spite of the uncertainty as to their "actual" values. Some of them provide a number of degrees of freedom with which to tune the model to track historical time series and to adjust the model's behavior to conform, where appropriate, with the expectations of economic and social theory and of the intuitions and knowledge of people with experience in Nigeria. Others, as shown by sensitivity tests, are not crucial to the model's performance, i.e., changing the values of these parameters has little effect.

Technological Coefficients[1/]

Technological coefficients are perhaps the easiest to come by. Our principal sources for values of these parameters were several publications [16, 42, 17, 41, 54], Nigerian agricultural seminar reports [37, 38, 39, 40] and project proposals of Nigerian federal and state ministries [55, 56]. The existence of data for these parameters does not mean there is either perfect confidence or general agreement on them. Further

---

1/ See Tables III.5-III.7 for tabulated values of selected technological coefficients used in the southern model.

Table III.5. Perennial yields (lbs./acre-year).

Variable (Eqn. No.)	Perennial Stream (substream)	Production Cohort					
		Rising Yields			Maximum Yields	Declining Yields	Old Age
		1	2	3			
YPER1 (4.4)	1. traditional cocoa (trad.)	100	250	300	350	250	100
	2. mod. cocoa (replanted)	300	550	750	850	750	650
	3. trad. palm (Palm Sector) (trad.)	1000	2300	3600	4500	2300	1900
	4. mod. palm (Palm Sector) (replanted)	1500	3400	5500	6700	3400	2900
	5. trad. rubber (trad.)	100	250	350	400	350	350
	6. mod. rubber (replanted)	450	700	900	1000	950	900
	7. trad. palm (Rubber Sec.) (trad.)	1000	2300	3600	4500	2300	1900
	8. mod. palm (Rubber Sec.)	1500	3400	5500	6700	3400	2900
YPER2 (4.4)	1. trad. cocoa (improved)	150	350	450	510	350	175
	2. mod. cocoa (new planted)	350	600	850	950	850	750
	3. trad. palm (Palm Sector) (improved)	1250	2800	4500	5600	2800	2400
	4. mod. palm (Palm Sector) (new planted)	1500	3400	5500	6700	3400	2900
	5. trad. rubber (improved)	200	350	450	500	450	450
	6. mod. rubber (new planted)	450	700	900	1000	950	900
	7. trad. palm (Rubber Sec.) (improved)	1250	2800	4500	5600	2800	2400
	8. mod. palm (Rubber Sec.) (new planted)	1500	3400	5500	6700	3400	2900

Sources: A composite of data from [15, 55, 56, 42, 37, 38, 39, 40], some of it adjusted by model tuning.

Table III.6. Input requirements for perennials.

Variable (Eqn. No.) (Units)	Perennial Stream[a]	Production Cohorts				
		Gestation	Rising Yields	Maximum Yields	Declining Yields	Old Age
PLA1[b] (4.25a) (man-days/ acre-year)	1	25	10	12	12	6
	2	80	33	40	40	42
	3	8	6	4	4	2
	4	40	12	10	10	12
	5	12	8	6	6	4
	6	30	16	12	12	14
	7	8	6	4	4	2
	8	40	12	10	10	12
PLA2[b] (4.25a) (man-days/ acre-year)	1	40	20	18	18	20
	2	60	33	42	42	44
	3	20	10	8	8	10
	4	40	12	10	10	12
	5	20	12	8	8	10
	6	30	16	12	12	14
	7	20	10	8	8	10
	8	40	12	10	10	12
PCA1[c] (4.26a) (lbs./acre-year)	1	0	0	0	0	0
	2	165	10.4	16.3	16.3	16.3
	3	0	0	0	0	0
	4	140	132	132	132	132
	5	0	0	0	0	0
	6	190	190	190	190	190
	7	0	0	0	0	0
	8	140	132	132	132	132
PCA2[c] (4.26a) (lbs./acre-year)	1	.0730	10.4	16.3	16.3	16.3
	2	.0730	210	296	296	296
	3	0	0	0	0	0
	4	140	132	132	132	132
	5	0	0	0	0	0
	6	217	0	0	0	0
	7	0	0	0	0	0
	8	140	132	132	132	132
PLY[d] (4.25a)	Commodity	Value				
	Cocoa	.0117 man-days/lb.				
	Palm	.0015 man-days/lb.				
	Rubber	.0275 man-days/lb.				

a/ Definitions of the perennial population streams are given in Table III.5 above.
b/ Does not include harvesting labor.
c/ Composite of recommended sprays, fertilizers, etc.
d/ Harvesting labor only.

Sources: A composite of data from [15, 54, 55, 56, 37, 38, 39, 40], some of it adjusted by model tuning.

Table III.7. Mean length of perennial production stages (years).

Variable (Eqn. No.)	Perennial Stream[a/]	Production Cohorts[a/]				
		1	2	3	4	5[b/]
DEL (3.1)	1	6	7	14	13	--
	2	3	7	20	10	--
	3	6	6	20	8	--
	4	3	5	20	12	--
	5	8	4	25	3	--
	6	6	6	20	8	--
	7	6	6	20	8	--
	8	3	5	20	12	--

a/ See Tables III.5 and III.6 for definitions of the perennial population streams and the production cohorts.
b/ Trees remain in the old age stage indefinitely--see the description of component LAMDAP, Chapter 3.

Sources: [15, 55, 56].

research and field work will be necessary to increase the level of confidence in the values given many of the technological coefficients.

Some examples of technological coefficients used in the southern model are:

1. commodity yields (YPER1, YPER2, YF1, and YF2 in Equation 4.4);
2. labor input rates (PLA1, PLA2, PLY, FDLAB1, FDLAB2, and FDLABY in Equations 4.25);
3. chemical input rates (PCA1, PCA2, FDCH1, and FDCH2 in Equations 4.26);
4. input prices (PCI, PL, PLM, and PBI in Equations 4.28);
5. processing capital/capacity ratios (PKCRT, PKCRM in Equations 4.14, 4.15 and 4.18);
6. mean times spent in the perennial production stages (DEL in Equation 3.1a).

Almost all of the technological coefficients remain constant throughout a simulation run. A notable exception is commodity yields. Learning curves and supply responses for yields are discussed in detail above in component AMPPAP, Equations 4.4-4.6.

Initial Conditions[1/]

Initial conditions (1953) of variables whose values change during the course of a run must be reset at the start of each run. Some of these include:

1. land usage (TLPER in Equation 3.1c and TLBSH in Equation 3.3);

1/ See Table III.8 for tabulated values of selected initial conditions used in the southern model

Table III.8. Selected initial conditions (1953).

Variable (Eqn. No.) (definition)	Perennial Stream[a/]	Production Cohorts[a/] 1	2	3	4	5	Total
TLPER (3.1c) (perennial land) (thousand acres)	1	125	175	425	250	150	1125
	2	0	0	0	0	0	0
	3	280	280	1120	280	840	2800
	4	0	0	0	0	0	0
	5	115	60	170	25	10	380
	6	0	0	0	0	0	0
	7	90	90	360	90	270	900
	8	0	0	0	0	0	0
	Crop Sector[a/]:	1	2	3	4		
TLBSH (3.3) (bush land) (thousand acres)		5300	2000	2000	5000		
SUBLEV (4.3b) (subsistence level) (proportion)		.8	.9	.9	1.[b/]		

a/ Definitions of perennial population streams, production cohorts and crop sectors are in Tables III.3, III.5 and III.6.

b/ Sector 4 is assumed to always have total subsistence.

Sources: [15, 50] and initial guesstimates and model tuning.

2. perennial substream proportions (PSPER in Equation 3.2);
3. commodity prices and price averages (component PG, Chapter 5);
4. traditional and modern processing proportions (PRT and PRM in Equations 4.12-4.21);
5. subsistence levels (SUBLEV in Equation 4.3b).

A few of these variables present no data problems. For instance, assuming all agricultural processing at time zero (1953) is traditional, we have PRT = 1 and PRM = 0. Others, particularly initial land usages, are more elusive. Initial acreages were estimated from FAO and ministry figures and land surveys [15, 50]. The model is quite sensitive to the initial land usages, as we shall discuss later (Chapter 9), so more complete and accurate land surveys would be a profitable venture from the point of view of increasing this model's accuracy (if that were desired).

In concluding this section, it must be stressed that the model can be useful to the policy maker in spite of imprecise parameter estimates. Runs can be made in a Monte Carlo mode where parameter values are drawn from a probability distribution; a range of statistics for each performance criterion can then be generated, which may be more realistic than a "precise" point prediction. More importantly, however, predicting the <u>relative</u> consequences of alternative policy options are usually of more decision-making value than accurate predictions of absolute output levels.

Tuning

Before the model is ready to be implemented it must be "tuned" to track one or more time series of past behavior. The tuning may require adjusting the values of certain system parameters, the addition of new mechanisms, or the modification of structural relationships. In attempting to track a particular time series, dozens of parameters may be likely candidates for adjustment. It takes an understanding of the real system and a deep familiarity with the simulation model to focus on the one or two parameters which would be meaningful to adjust, or to know where a structural relation must be added to the model to make its behavior conform more closely to experienced behavior.

Four time series (1953-1965) were used to initially tune the southern model: exports of cocoa, palm oil and rubber and food prices. The measure of goodness-of-fit used (one of many possible [8]) is:

$$TSS = \sum_{i=1}^{4} SS_i$$

where:

$$SS_i = \sum_{j=1}^{13} \left(\frac{Y_{ij} - \hat{Y}_{ij}}{\bar{Y}_i}\right)^2 \quad , i = 1, 2, 3, 4$$

$$\bar{Y}_i = \frac{1}{13}\sum_{j=1}^{13} Y_{ij} \quad , i = 1, 2, 3, 4$$

and where:

SS_i = the sum of squared normalized deviations for series i

TSS = the total sum of squared deviations

Y_{ij} = the real data value at year j of series i

$\hat{Y}_{ij}$ = the simulated data value at year j of series i

$\bar{Y}_i$ = the mean of the real series i.

The squared deviations are normalized so the four sums have equal weight when added together. The closer to zero, the better the fit. If the model generated nothing but zeros (i.e., $\hat{Y}_{ij} = 0$ for all i and j), we would have:

$$SS_i = 13 + \frac{12S_i^2}{\bar{Y}_i^2} \quad , i = 1, 2, 3, 4$$

where:

S_i^2 = the sample variance of series i.

Thus, TSS would be somewhat greater than 52.

During the 13 years of time series tracking, the model uses the actual FOB prices received by Nigeria and producer prices set by the marketing boards in those years (1953-1965). These values are used in place of values computed in Equations 5.1 and 5.3.

Table III.9 displays the four time series resulting after the initial coarse tuning. Data values generating this fit were used in the policy runs discussed in Chapter 10.

Adjustments made in the tuning process included data values and structural relationships. For example, the model was not simulating the rapid increase in either cocoa or rubber exports. In the case of cocoa, it was necessary to incorporate the diffusion of improved practices (defined in

Table III.9. Time series tracking.

YEAR	COCOA EXPORTS (thous. lbs./yr.)		PALM OIL EXPORTS (thous. lbs./yr.)		RUBBER EXPORTS (thous. lbs./yr.)		FOOD PRICE (£/lb.)	
	DATA	SIMULATED	DATA	SIMULATED	DATA	SIMULATED	DATA	SIMULATED
1953	234,463.	249,399.	451,013.	430,580.	47,622.0	57,217.3	.0100000	.0100570
1954	220,355.	258,666.	467,000.	399,597.	46,816.0	61,232.8	.0108300	.0100753
1955	198,045.	267,738.	408,000.	370,527.	68,051.0	74,560.9	.0120800	.0100857
1956	262,378.	275,423.	414,926.	342,659.	85,454.0	78,923.7	.0141700	.0100660
1957	303,072.	290,547.	372,288.	341,530.	89,582.0	87,304.2	.0120800	.0101449
1958	196,331.	309,771.	381,938.	344,892.	92,301.0	96,390.0	.00917000	.0102748
1959	319,872.	333,073.	366,670.	324,788.	119,558.	110,198.	.0104200	.0108076
1960	352,074.	355,417.	410,726.	319,494.	128,193.	123,737.	.0125000	.0108254
1961	411,964.	370,297.	368,686.	313,286.	123,574.	120,777.	.0133300	.0108882
1962	436,020.	392,714.	265,816.	262,274.	133,580.	127,519.	.0137500	.0110317
1963	392,000.	413,624.	282,240.	253,238.	141,[illegible]31.	135,752.	.0108300	.0112229
1964	441,280.	434,161.	300,160.	253,072.	161,435.	139,043.	.0112500	.0114399
1965	571,200.	439,963.	336,000.	239,682.	152,038.	146,242.	.0137500	.0116414
SS	.370560		.285964		.0985511		.336367	

TSS = 1.09144

Table II.2), a process which actually did take place in the 1950's and 1960's in Nigeria. This was accomplished in the model by setting, as an initial condition, 5% of the traditional cocoa in the improved substream ($PSPER_{1k}(0) = .95$ for all k, in Equation 3.2) and adjusting the diffusion parameter (CIUD in Equation 3.8 and $CIUDT_{11}$ in Table III.3) so that by the end of the tracking period (1965), about 95% of the traditional cocoa in the model was being managed under improved practices. Similarly, simulated smallholder rubber production was not generating the exports actually experienced FAO estimates of acreages and outputs of rubber estates [15] indicated that this would make up most of the discrepancy. Thus, the rubber estates factor discussed earlier (Equations 4.24) was added to the model. Further agreement with actual rubber exports was obtained by increasing the initial (1953) estimated rubber acreage ($TLPER_{5k}(0)$ for all cohorts k) from a total of 350,000 acres to 380,000 acres.

General Validation

Tuning the model to track four time series is not nearly enough. The southern model, merged with the other major components of the total Nigeria model, was further refined in a process of intuitive, theoretical, and empirical consistency analyses. Indeed, this process is continuing. Some aspects of simulated behavior considered are:

1. the national accounts have to balance;
2. the agricultural and nonagricultural per capita consumption of food have to be in the "right" neighborhood according to intuitive judgments and empirical evidence about nutritional levels in the Nigerian population;

3. the market price of food has to be in a "reasonable" range, neither too large nor too small, and growing at a "reasonable" rate;

4. GDP and value-added growth rates in the agricultural and nonagricultural sectors have to approximate expectations based on economic theory and empirical and simulated conditions in Nigeria;

5. land use decisions have to respond "properly" to changing profitabilities of alternatives.

This process of general validation is very judgmental and often intuitive in nature. In spite of this--or even because of it--the process must be an on-going part of the model's application if the model is to remain both useful and credible.

CHAPTER 9

Sensitivity Analysis:
Results and General Applications

Sensitivity tests identify those parameters to which the model is most sensitive. That is, such tests can compare the relative response of the model to changes in the values of different parameters. Such information is useful not only for model tuning and validation but also for policy making and as a guide to data collection priorities. A brief discussion of these applications follows, and then an analysis is presented of the results of a series of sensitivity runs of the southern model.

Applications

Model Development

Sensitivity tests play an essential role in model building and validation[1/]. For one thing, they identify those parameters which can most effectively be used in tuning the model to track recorded behavior of the economy

---

1/ Actually, these two processes--model building and validation--are intimately linked. The validation procedure may (most likely will) point up weaknesses in the model and suggest areas that need further development. The model-building activity then addresses these problems, preparing the model for another round of validation, and so forth.

(discussed in Chapter 8). The diffusion response parameters (Table III.3) are prime examples of this, as we shall see below (Table III.11). In addition to time series tracking, sensitive parameters such as these may be adjusted, as part of the validation process, to bring the model's behavior in line with the expectations of accepted theory and knowledgeable intuition. For example, the supply elasticity of food (SUPRSF in Table III.10) was adjusted--within a range acceptable to that same theory and intuition--to "validate" the demand-supply behavior--i.e., consumption levels and price levels--of the food market.

An analysis of sensitivity test results may also be used in validation to check the logic and internal consistency of the model. Troublespots can be located in the course of tracing through the model to find explanations for simulated behavior exhibited as a result of a change in the value of some parameter[1/]. For example, initial tests on an early version of the southern model indicated an extreme sensitivity of the model to variations in oil palm production coefficients. The model was (realistically) projecting the future disappearance of Nigerian palm oil exports as domestic demand increased with the population and eventually surpassed production. The price mechanism then translated an increasing excess demand into higher and higher prices. It was a serious shortcoming of the model

---

1/ It is this process which is most exemplified by the detailed analyses presented later in this chapter.

that there were no factors limiting the price rise. Further development of the palm oil market mechanism in the model placed bounds on the palm oil price by giving domestic demand a non-zero elasticity (Equation 4.23a), by modeling a domestic palm oil market (Equations 5.4-5.6) and by allowing the importation of palm oil (Equation 4.23d) once the domestic price has reached the import price, thus placing an upper bound on the former.

Another illustration of the use of sensitivity test results as a check on internal consistency is described in [35, Chapter 8]. Briefly, a not unreasonable change (upward) in the parameter controlling the rural-urban migration rate caused the model to blow up. It was then discovered that the consequently larger nonagricultural population was demanding and consuming food in excess of the nonagricultural income available to pay for it. An income constraint was duly added to the model.

Policy Making

The model has the built-in capability of directly and explicitly evaluating three policy areas--commodity production campaigns, marketing board pricing and various taxing policies. These are discussed in Chapter 6 and demonstrated in Chapter 10. Sensitivity tests can supplement these features in two ways.

First, a policy or program goal may be assumed to have been achieved and the model thus run to examine the

consequences. For example, rather than running a production campaign to modernize food production and simulating the promotion and diffusion of the requisite technologies with the attendant consequences, it might be assumed from the outset that average food yields have attained a higher value. The model would then be run with this higher value to see the likely effects on income, exports, food consumption, etc.

Other examples might include investigations into the consequences of:

1) population control policies by appropriately modifying birth and death rates in the population component;

2) modernizing the processing of agricultural commodities (e.g., rubber and oil palm) by making the necessary changes in relevant processing coefficients;

3) policies to stimulate regional specialization in agriculture (i.e., the South concentrating on perennial export crops and relying on the North for food) by appropriately lowering southern subsistence levels, thus increasing reliance on the food market; and

4) increasing the availability of credit[1/] to agricultural entrepreneurs.

Sensitivity analyses may be used not only to experiment with pre-specified policy options as discussed above but

---

1/ This would be a potential experiment. However, it would not be feasible with the present model, for currently, the model inadequately reflects the very real capital constraint faced by Nigerian farmers desiring to invest in expanded capacity or new technologies.

also to help pinpoint and design new and potentially effective alternatives. A knowledge of the relative sensitivity of relevant parameters and coefficients will indicate the most promising areas for policy attention, that is, those areas which would be the most responsive at the least cost. For example, a quick look at Tables III.10 and III.12 below will show that for a policy to increase exports, efforts to decrease spoilage and waste in marketing (Runs 9-12) may prove more fruitful than attempts to decrease marketing costs (e.g., labor and transportation) (Runs 50-54).

To the extent that sensitivity tests are conducted to reflect the degree of confidence in the values given key parameters in the model, such tests can be valuable in the design of policies in the face of uncertainty. It is important to develop policies whose simulated consequences are relatively insensitive to parameter variation. It would be disastrous to allocate scarce resources to the implementation of a policy which, due to the uncertainty of model parameters, produced effects vastly different from, and perhaps even negative to, those intended. Thus, sensitivity tests can identify policies which are relatively stable for some appropriate range of parameter values.

An important and essential extension of sensitivity testing procedures for the design of stable policies is the Monte Carlo analyses mentioned in Chapter 8. Rather than deterministically testing one parameter at a time,

probability distributions for a number of key parameters may be specified to reflect a range of likely values, and a large number of simulation runs may be made, each drawing samples from all the specified distributions. The statistics generated for the output criteria can then be used to evaluate the relative sensitivity of a policy to variations not in one parameter (nor even many parameters one at a time) but in a number of parameters simultaneously. Relatively small variances for the output criteria would indicate a stable policy[1/].

The words "relative" and "relatively" have been used extensively here to emphasize the importance of evaluating and comparing a number of policy alternatives rather than one in isolation. Indeed, the term "sensitivity" is meaningless in an absolute sense. It must refer to comparisons of policies or to comparisons of the results of varying a series of parameter values (as in Tables III.10-III.12).

Data Collection

Finally, sensitivity tests can identify the most profitable uses of data collection resources. For example, the model is relatively sensitive to the diffusion response parameters (Table III.11), while variations in the harvest

---

1/ Chapter 11 discusses some problems which raise questions as to the feasibility of using Monte Carlo techniques in this framework.

elasticities for perennial crops have negligible effect (Table III.10). From the point of view of the model's data needs, expenditures to estimate the latter would be virtually wasted. It would be worthwhile, on the other hand, to devote resources to sharpening estimations of the former.

Again it must be stressed that running the model in the Monte Carlo mode could greatly reduce the urgency of acquiring improved data.

Analysis of Results

Methodology

The series of 69 sensitivity runs conducted with the southern submodel may be grouped into four sets. The first three investigate the effects of varying selected production coefficients, land allocation coefficients and price parameters, respectively. The fourth set of runs examines the sensitivity of the numerical solution of the model to changes in the time period increments used in the simulation.

Each run simulates the agricultural economy of southern Nigeria over a 32-year period, 1953-1985. These test runs were conducted with the southern submodel alone, that is, without the rest of the Nigeria model. Thus, the results presented below and in Tables III.10-III.12 may differ somewhat from those which would be obtained in the presence of: 1) links with northern agriculture through the food market and 2) interactions with the nonagricultural economy. For example, with the North supplementing the

southern food supply, food prices in the South would be generally lower (by about 25% for the base run) than was the case here. Furthermore, the presence of interregional trade would probably make the market price of food less sensitive to parameter variations than is indicated by these runs.

A strict test of parameter sensitivity would require all parameters to be varied in the same way, e.g., plus 20%. The results could then be compared on the basis of a given deviation. This procedure would contribute nothing, however, either to understanding the nature of or coping with the uncertainty arising from varying degrees of confidence in parameter values. In statistical terms, is it meaningful to compare the relative consequences of 20% variations in each of two parameters, one of which has a standard deviation perhaps 1/10 to 1/5 of that 20% and the other of which has a standard deviation 10 to 20 times 20%?

The general rule followed, therefore, in defining the sensitivity runs described here, was to vary each parameter by an amount which I felt covered most of its uncertainty distribution,say two standard deviations. It must be cautioned, however, that the term "two standard deviations" may convey a degree of precision which did not exist. Lacking informed judgments or other estimates of relevant distributions, the variations used were extreme guesstimates on my part. They do reflect, however, the relative lengths

of subjective confidence intervals. Where possible, similar parameters were varied similar amounts. For example, the perennial yields were each increased 20% (Table III.10) and the diffusion parameters were each increased 400%, i.e., to five times the base value (Table III.11).

The output criteria tabulated in Tables III.10-III.12 include agricultural exports (AFORXS), value added (ATVAS) and net revenues (ATRCN) accumulated over the simulation run, and marketing board net revenues (ATRMBS), also accumulated over the 32-year simulation. In addition, effects of parameter variations are shown for agricultural per capita disposable income (PCDINA), nonagricultural per capita food consumption (PCFNAG) and the market price of food (PRFD). A final criteria displayed is the aggregate measure of goodness-of-fit, TSS, defined and discussed in Chapter 8[1/].

A final comment must be made preliminary to the analyses which follow immediately. The reader may find the level of detail in that discussion somewhat tedious. (Indeed, not all that might be said will be said, for some effort is made to limit the discussion to the major explanations of the more appreciable output deviations.) However, the comments and explanations presented are quite illustrative of

---

1/ As a reminder: the closer TSS is to zero, the better the fit, i.e., the better the time series tracking.

how sensitivity analyses may be used not only for model validation but also to add to one's understanding of the real system being simulated. I found it so in my own case.

Production Coefficients

Twenty-seven production coefficients were tested: the yields of four perennials; food yields in each of the four crop sectors; marketing losses for each of the four commodities (a cash annual--tobacco--was not assumed for these runs); processing losses for palm and rubber; the proportions of acres harvested under normal conditions for four perennials and wild palm in the Cocoa Sector; short-term supply (harvest) elasticities for three perennials, wild palm in the Cocoa Sector and food; the caloric content of food; and the per capita consumption of palm oil in the North and South. Parameter deviations and results are shown in Table III.10.

One observation that can be made concerning all 61 runs presented in Tables III.10-III.12 is that the effects of parameter changes on nonagricultural food consumption and the market price of food are consistently (with one exception) in opposite directions and roughly proportional. That is, the change in food consumption is generally 30 to 40 percent of the change in market price and of opposite sign. This is due to the fact that the former is a function of the latter in the population component of the model. Food consumption is also a function of nonagricultural

income, but this is determined exogenously in the absence of links between the agricultural and nonagricultural sectors, as discussed above. If these interactions were present, we wouldn't expect the consistency of the relative responses of food consumption and price to be maintained. For example, in Run 12, the increase in agricultural income would lead to increases in nonagricultural income (due to multiplier effects discussed in Chapter 1), and thus the 2.67 percent decrease in food consumption would be considerably lessened and perhaps even reversed, showing, in the latter case, an increase in both food price and consumption.

Another consistent result of these sensitivity runs is the nil response of marketing board net revenues to changes in parameters concerning rubber production, e.g., Runs 3, 11, 14, 17 and 22. This is because rubber marketing is not handled by a marketing board.

The tests increasing perennial yields 20 percent[1/] (Runs 1-4) show effects on AFORXS, ATVAS, ATRCN and ATRMBS in the same direction (i.e., increases) except for cocoa yields. Increasing traditional cocoa yields depresses these output variables. It was discussed in Chapter 8 that the model simulates a diffusion of improved practices in traditional cocoa production in order to reflect what actually

---

1/ YPER1M(i), in Table III.10, is a proportion of the yields of all the producing cohorts of perennial stream i.

took place in the late 1950's and early 1960's. Increasing traditional cocoa yields in Run 1 decreased the relative profitability differential of improved over traditional cocoa production. This slowed up the diffusion of improved cultural practices and, so, resulted in less output as reflected in the decrease in the criteria variables.

Palm yields (Runs 2 and 4) appear to be substantially more sensitive than the other perennial yields. In fact, most of the parameters related to oil palm production are relatively quite sensitive (Runs 13, 16, 18, 19, 21, 26, and 27). This sensitivity is due to the competition between the domestic and export palm oil markets. While the extreme sensitivity reported earlier in this chapter has been corrected, the present level of sensitivity of palm parameters is not unreasonable.

A final comment that can be made about palm yield sensitivity is that although the time series tracking fit may be improved by better than 20 percent (Run 4), there is currently no empirical evidence to support an assumption that palm yields are higher in the Rubber-Palm Sector than in the Palm Sector. There may be grounds, on the other hand, for assuming a lower per capita palm oil demand in the North in order to attain a better fit (Run 27). There is still some uncertainty in Nigeria, however, as to what could accurately be assumed to be the domestic palm oil demand in either region [39].

While palm parameters appear to be the most sensitive of the perennial production coefficients, the rubber parameters are almost invariably the least sensitive (Runs 3, 11, 14, and 17). Only the short-run supply elasticity (Run 22) shows mixed results. The lack of a rubber marketing board, as already discussed, explains the nil effect on ATRMBS. An additional explanation is the relatively smaller part rubber plays in overall southern cash crop production. For example, rubber exports in the base run at the end of the 32-year simulation period account for less than 14% of total agricultural exports, while cocoa accounts for about 68%.

The production coefficients for food are most sensitive, naturally, for the food market price and nonagricultural consumption, PRFD and PCFNAG (Runs 5-8, 12, 24, and 25). Value added, ATVAS, is also somewhat affected, due primarily to food making up about 75% of value added. Varying food yields causes the sharpest output deviations in the Cocoa and Food Sectors (Runs 5 and 8) because these crop sectors have most of the food land in the South.

It is potentially significant that the Calorie content of food (Run 25) is rather sensitive. This may have important implications for Nigerian policy makers should the food composite used for southern production in the model--defined as a weighted average of yam, cocoayam, maize and cassava--shift in reality to higher proportions of

Table III.10. Results of sensitivity tests of production coefficients of the southern model.

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a]							
						AFORXS	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
1	YPER.M(1)	Proportion of traditional cocoa yields	+20.0	1.2	1.0	-1.08	-.156	-1.76	-2.04	.260	-.149	.483	32.5
2	YPER1M(3)	Proportion of traditional palm yields (Palm Sector)	+20.0	1.2	1.0	8.39	1.80	3.16	9.68	.714	0.	0.	27.1
3	YPER1M(5)	Proportion of traditional rubber yields	+20.0	1.2	1.0	2.36	.391	1.19	0.	.909	.0187	-.0403	28.5
4	YPER1M(7)	Proportion of traditional palm yields (Rubber Sector)	+20.0	1.2	1.0	3.00	.626	1.07	3.45	-.390	0.	0.	-21.6
5	YF1(1)	Yield of traditional food in Cocoa Sector (lbs./acre-yr.)	+14.5	7500.	6550.	.101	-1.72	.811	.126	-2.34	1.64	-4.95	1.55
6	YF1(2)	Yield of traditional food in Palm Sector (lbs./acre-yr.)	+14.5	7500.	6550.	.135	-1.09	1.39	.151	-1.69	1.10	-3.34	.343
7	YF1(3)	Yield of traditional food in Rubber Sector (lbs./acre-yr.)	+14.5	7500.	6550.	.0675	-.224	.521	.0252	-.260	.168	-.523	.343
8	YF1(4)	Yield of traditional food in Food Sector (lbs./acre-yr.)	+14.5	7500.	6550.	.0338	-2.03	.145	0.	-2.92	2.11	-6.16	1.63

Table III.10. (cont'd.)

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a]							
						AFORXS	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
9	PLOSS(1)	Marketing loss coefficient for cocoa	-11.1	.8	.9	-6.68	-1.33	-3.15	-15.7	-1.17	-.112	.362	16.6
10	PLOSS(2)	Marketing loss coefficient for palm products	-15.8	.8	.95	-9.96	-.157	-.666	-16.1	-.974	.765	-2.41	321.
11	PLOSS(3)	Marketing loss coefficient for rubber	-5.27	.9	.95	-.708	0.	-.232	0.	-.390	0.	0.	7.81
12	PLOSS(4)	Marketing loss coefficient for food	-11.1	.8	.9	0.	-1.95	4.02	0.	4.28	-2.67	8.93	2.83
13	PCLT(1)	Processing loss coefficient for palm products	-14.3	.15	.175	-8.17	-4.30	-4.34	-8.47	-1.49	2.67	-8.13	277.
14	PCLT(2)	Processing loss coefficient for rubber	-5.00	.95	1.0	-.573	-.0785	-.348	0.	-.195	0.	0.	7.29
15	PPLHV(1)	Proportion of traditional cocoa acres harvested	-5.00	.95	1.0	-2.63	-.547	-1.30	-3.15	-.584	0.	.0403	2.14
16	PPLHV(3)	Proportion of traditional palm acres harvested (Palm Sector)	-14.3	.6	.7	-9.34	-1.33	-1.36	-9.40	2.53	-.243	.523	354.
17	PPLHV(5)	Proportion of traditional rubber acres harvested	-16.7	.5	.6	-1.96	-.313	-.984	0.	-.714	0.	0.	46.6

Table III.10. (cont'd.)

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a]							
						AFORXS	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
18	PPLHV(7)	Proportion of traditional palm acres harvested (Rubber Sector)	-14.3	.6	.7	-3.41	-.626	-.811	-3.88	2.14	-.0330	0.	69.3
19	PBLHV	Proportion of wild palm acres harvested (Cocoa Sector)	-20.0	.4	.5	-1.25	-2.50	-1.36	-1.33	-2.66	2.02	-6.12	23.2
20	SUPRSP(1)	Harvest elasticity for cocoa	-80.0	.01	.05	.169	0.	.116	.151	0.	.0330	0.	-3.09
21	SUPRSP(2)	Harvest elasticity for palm	+100.	.4	.2	-.777	-.157	-.405	-.882	.0065	0.	0.	48.8
22	SUPRSP(3)	Harvest elasticity for rubber	+100.	.8	.4	-.810	-.0785	-.260	0.	-.260	0.	0.	2.83
23	SUPRSB	Harvest elasticity for wild palm (Cocoa Sector)	+25.0	1.0	.8	-.101	0.	-.0579	-.101	0.	0.	0.	4.21
24	SUPRSF	Harvest elasticity for food	+25.0	1.5	1.2	.0338	-3.75	-1.65	0.	-5.65	4.13	-11.6	1.37
25	CALY	Calorie content of food (Cals./lb.)	-9.31	750.	827.	-.236	9.55	6.28	-.302	9.94	-1.89	6.08	-.945
26	POCNSS	Palm oil consumption in the South (lbs./person-yr.)	+25.0	30.	24.	-5.57	1.10	3.30	-4.87	6.76	-.261	.564	251.
27	POCNSN	Palm oil consumption in the North (lbs./person-yr.)	-50.0	2.	4.	3.48	0.	-.116	4.08	-1.62	0.	0.	-21.0

Table III.10 (cont'd.)

a/ Values are at the end of a 32-year simulation run (1985).
Variables are:
AFORXS = time integral of agricultural exports
ATVAS = time integral of agricultural value added
ATRCN = time integral of agricultural net cash revenues
ATRMBS = time integral of marketing board net revenues
PCDINA = agricultural per capita disposable income
PCFNAG = nonagricultural per capita food consumption
PRFD = market price of food
TSS = measure of goodness-of-fit of time series tracking.

high caloric grains (such as maize or rice) or of higher caloric roots and tubers (i.e., to less yam and more cassava). This would also have implications for further model development activities (discussed in Chapter 11) since the current model makes no provisions for a dynamic shift in the food composite and, hence, parameters such as the food yields, the caloric content of food and the labor and other input requirements for production.

Land Allocation Coefficients

Runs 28-49 test the sensitivity of a number of land allocation coefficients and initial conditions. Included in these 22 runs are the initial (1953) acreages in four perennial streams and in bush for each crop sector, diffusion response parameters of bush for traditional perennial and food alternatives, profitability response parameters of bush, and proportions of bush land available for particular alternatives. The results are tabulated in Table III.11.

It is perhaps conspicuous that all the coefficients tested are for land currently in bush faced with productive alternatives of traditional perennials and food. No parameters pertaining to decisions among alternatives to perennial or food present uses (e.g., CIUDT, CIUDF, THRT, THRF, etc. in Tables III.1-III.3, Chapter 8) are tested. This is because the alternatives to traditional perennials and to food all involve some sort of modernization--replanting

perennials, for example (Table II.1, Chapter 3)--requiring the model to execute a series of production campaigns in order to test the relevant parameters. While the runs for the series of tests reported in this chapter included no such policies, a few of the decision parameters omitted here are tested in Chapter 10 with some of the policy runs examined there.

Initial land use conditions appear to be somewhat sensitive. Again, palm and cocoa acreages are substantially more sensitive than rubber (Runs 28-31). While initial perennial acreages have relatively little effect on per capita income (PCDINA) and food criteria (PCFNAG and PRFD), the initial amount of unused but cultivable bush land in the four ecological zones has substantial impact on those output variables (Runs 32-35). Initial bush land in the Palm Sector (Run 33) is particularly sensitive because that area has the largest and densest population, and the relative scarcity of land available for the expansion of food crops in that crop sector will be reflected in the more dramatic deviation in food prices.

Of the land allocation coefficients, the diffusion parameters are the most sensitive (Runs 36-41). As might be expected, increasing the spread of perennials into bush diminishes the potential expansion of food land, causing higher prices and lower consumption. The reverse happens when food diffusion is favored. The extreme sensitivity of

cocoa (Run 36) relative to the other perennials may be explained in two ways. First, as mentioned earlier, cocoa makes up the major part of exports and nearly all of marketing board revenues, particularly toward the end of the simulated time period as palm oil exports decline and disappear. Secondly, and more significantly, the Cocoa Sector has initially more than 2 1/2 times as much bush land available for expansion as the other perennial sectors (see base run values of Runs 32-34), a resource which is apparently tapped. Similar explanations hold for food diffusion being more sensitive in the three perennial sectors than in the Food Sector (Runs 40 and 41): there is more bush land in total in the perennial sectors than in the Food Sector alone, and since the Cocoa Sector has most of it, we might expect CIUDB(3) to cause most of the output deviations.

As for the profitability response parameters, changing the discount rate and the response thresholds has almost no effect, while the parameter controlling the response rates are fairly sensitive (Runs 42-46). A look at Figure II.6 in Chapter 3 will explain why. Since bush has zero profitability (except in the Cocoa Sector with wild palm, as explained in Chapter 3), the alternatives are far out on the PDR axis, so the response is nearly at its asymptotic maximum. Even a ten-fold increase in the threshold, i.e., shifting the curve to the right, has only a negligible effect. Decreasing the response rate, on the

Table III.11. Results of sensitivity tests of land allocation coefficients of the southern model.

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a]							
						AFORXG	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
28	TLPERM(1)	Proportion of initial traditional cocoa land (1953)	+10.0	1.1	1.0	4.69	1.10	2.06	5.06	.919	-.112	.362	10.3
29	TLPERM(3)	Proportion of initial traditional palm land (Palm Sector) (1953)	+10.0	1.1	1.0	3.71	1.33	1.42	4.08	.130	-.411	1.33	-21.7
30	TLPERM(5)	Proportion of initial traditional rubber land (1953)	+10.0	1.1	1.0	.877	.391	.550	-.0252	.519	-.168	.524	2.23
31	TLPERM(7)	Proportion of initial traditional palm land (Rubber Sector) (1953)	+10.0	1.1	1.0	1.21	.469	.434	1.36	-.130	-.131	.403	-14.4
32	TLBSH(1)	Initial bush land in the Cocoa Sector (1953) (thousand acres)	-20.	4240.	5300.	-4.02	.625	-.724	-5.04	1.62	-1.51	4.72	23.1
33	TLBSH(2)	Initial bush land in the Palm Sector (1953) (thousand acres)	-20.	1600.	2000.	-.810	3.29	1.88	-1.11	5.38	-2.87	9.68	-.172
34	TLBSH(3)	Initial bush land in the Rubber Sector (1953) (thousand acres)	-20.	1600.	2000.	-1.15	1.09	.376	-.706	1.62	-1.01	3.26	2.40
35	TLBSH(4)	Initial bush land in the Food Sector (1953) (thousand acres)	-20.	4000.	5000.	0.	.625	.405	0.	1.04	-.728	2.17	-.343

Table III.11. (cont'd.)

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a/]							
						AFORXS	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
36	CIUDB(1)	Diffusion effect of traditional cocoa on bush (info. units/acre)	+400.	.005	.001	71.1	10.2	40.5	93.8	21.7	-3.51	6.69	184.
37	CIUDB(4)	Diffusion effect of traditional palm (Palm Sector) on bush (info. units/acre)	+400.	.005	.001	9.08	8.14	7.85	12.4	13.1	-6.21	24.3	-2.06
38	CIUDB(7)	Diffusion effect of traditional rubber on bush (info. units/acre)	+400.	.01	.002	10.2	2.42	6.08	-1.59	12 2	-3.72	12.4	336.
39	CIUDB(9)	Diffusion effect of traditional palm (Rubber Sector) on bush (info. units/acre)	+400.	.005	.001	8.91	2.74	4.57	13.5	5.45	-2.92	9.14	-.773
40	CIUDB(13)	Diffusion effect of food (Food Sector) on bush (info. units/acre)	+400.	.005	.001	.270	-27.2	-19.4	.353	-35.9	36.9	-62.6	5.62
41	CIUDB(3) CIUDB(6) CIUDB(11)	Diffusion effect of food (perennial sectors) on bush (info. units/acre)	+400. +400. +400.	.0025 .0025 .0025	.0005 .0005 .0005	-3.95	-37.8	-33.5	-3.96	-44.6	51.0	-73.3	156.
42	THRB(1)	Profitability threshold of response of bush to traditional perennials	+900.	3.	.3	0.	0.	0.	-.0252	0.	0.	0.	0.

Table III.11. (cont'd.)

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a]							
						AFORXS	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
43	THRB(3)	Profitability threshold of response of bush to food	+900.	2.	.2	0.	.703	.405	0.	.844	-.542	1.44	-.601
44	SHPB(1)	Profitability rate of response of bush to traditional perennials	-90.	.06	.6	-6.01	-.625	-3.22	-7.96	-1.30	.0373	.201	5.92
45	SHPB(3)	Profitability rate of response of bush to food	-90.	.001	.01	.608	81.0	40.6	.756	109.	-37.3	315.	-2.75
46	DRB(1)	Profitability discount rate for bush to traditional perennials	+50.	.09	.06	-.0675	0.	-.0290	-.101	0.	.0187	0.	.0859
47	DLAVB(1,1) DLAVB(1,2) DLAVB(1,3)	Proportion of bush land available for traditional perennials	+100. +100. +100.	.6 .6 .6	.3 .3 .3	12.4	2.19	6.46	14.6	6.23	-2.61	7.21	-8.58
48	DLAVB(3,1) DLAVB(3,2) DLAVB(3,3)	Proportion of bush land available for food (perennial sectors)	-11.1 -11.1 -6.25	.8 .8 .75	.9 .9 .8	.0338	1.25	.752	.0252	1.49	-.970	3.14	-1.03
49	DLAVB(2,4)	Proportion of bush land available for food (Food Sector)	-11.1	.8	.9	0.	.313	.174	0.	.454	-.318	.927	-.172

Table III.11. (cont'd.)

a/ Values are at the end of a 32-year simulation run (1985).
The variables are:
AFORXS = time integral of agricultural exports
ATVAS = time integral of agricultural value added
ATRCN = time integral of agricultural net cash revenues
ATRMBS = time integral of marketing board net revenues
PCDINA = agricultural per capita disposable income
PCFNAG = nonagricultural per capita food consumption
PRFD = market price of food
TSS = measure of goodness-of-fit of time series tracking.

other hand, flattens the whole curve with much greater consequences.

Apparently, bush thresholds are of little consequence in the model. Perennial and food thresholds can be expected to be more crucial since productive uses are being compared, e.g., replanting a perennial against continuing in traditional production. This will be investigated in the next chapter.

The proportions of cultivable bush land available for perennial commodities are quite sensitive (Run 47). Proportions available for food, on the other hand, are relatively insensitive, except for the market price of food. In this case, the perennial sector proportions (Run 48) are relatively more sensitive than those of the food sector (Run 49). This, coupled with the results of Runs 28-35 might suggest the usefulness, for the purposes of this model, of obtaining accurate land use surveys.

Price Parameters

Sensitivity tests were conducted on twelve parameters of the price generation component of the southern model: five commodity marketing costs, two marketing profit margins, four export commodity FOB prices, and the rate of change of the agricultural wage rate (Table III.12).

Marketing costs appear relatively insensitive (Runs 50-54). Of the five tested,the marketing cost of food is the most sensitive. Higher food producer prices resulting

from the lower marketing costs (Run 54) result in increased production which in turn leads to lower market prices (PRFD) and higher incomes (ATRCN and PCDINA) and value added (ATVAS). Cocoa marketing costs (Run 50) are more sensitive than those for oil palm products (Runs 51 and 52), particularly for agricultural net revenues (ATRCN) and marketing board net revenues (ATRMBS) since cocoa accounts for a greater proportion of these output variables than do palm products. For example, in the last year of the base run, cocoa accounts for about 17% of agricultural net revenues while palm products contribute 12 1/2% (and food makes up about 68%). As for marketing board revenues, the main factor explaining cocoa's sensitivity relative to oil palm is that palm oil exports (through the marketing board) decline during the simulation run and eventually disappear.

Marketing profit margins of rubber and food[1/] are also rather insensitive, food being the more sensitive of the two. The more unfavorable food price to farmers (Run 54) reduces production, raises market prices and depresses value added and income, as might be expected. A trace increase in exports and marketing board revenues results from the more favorable position of export crops relative to food.

1/ Marketing profit margins for cocoa and palm products are not tested here since these are marketing board policies. See Chapter 10.

The rate of change of the agricultural wage rate (PLR) has negligible effect, the largest output deviation occurring in agricultural net revenues. Experience with adjusting the model to evaluate policies indicates, however, that the response to production campaigns, particularly the replanting of perennials, is quite sensitive to PLR[1/]. Higher wage rates lessen the relative profitability differential of the more labor intensive modern alternatives over current traditional production. This is related to the sensitivity of the response thresholds of traditional perennials and food (mentioned above in the discussion of Runs 42 and 43 [Table III.11] and investigated in the next chapter).

In general, the export price trends (WPR(i)) appear rather insensitive (Runs 56-49). However, the sensitivity of these parameters is underestimated by the tests performed here because world prices in the model are determined by recorded prices from 1953-1970; so it is only for the last 15 years of the simulation run (i.e., 1971-1985) that the WPR(i) are operative. Since this is true for all four of them, we can nevertheless make comparisons among them. We can see that changes in the export prices of cocoa and palm products are more sensitive than rubber price changes.

1/ This test was not made in the sensitivity runs for either this or the next chapter.

Table III.12. Results of sensitivity tests of price parameters of the southern model.

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a]							
						AFORXS	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
50	COSTM(1)	Cocoa marketing costs (proportion of price)	-30.	.12	.17	.101	0.	2.52	5.19	.845	.112	-.322	0.
51	COSTM(2)	Palm oil marketing costs (proportion of price)	+43.0	.10	.07	-.236	-.391	-.956	-1.31	-.715	.224	-.644	0.
52	COSTM(3)	Palm kernel marketing costs (proportion of price)	+43.0	.10	.07	-.0675	-.0782	-.434	-1.41	-.389	.112	-.282	0.
53	COSTM(4)	Rubber marketing costs (proportion of price)	+50.	.075	.05	-.0338	0.	-.145	0.	-.130	0.	0.	0.
54	COSTM(5)	Food marketing costs (proportion of price)	-50.	.05	.10	0.	.940	3.21	-.0252	2.40	1.16	-3.51	1.20
55	SRPMB(4)	Rubber marketing profit margin (proportion of price)	-50.	.05	.10	.101	0.	.318	0.	.325	.0187	-.0403	0.
56	SRPMB(5)	Food marketing profit margin (proportion of price)	+100.	.10	.05	.0337	-.939	-3.21	.0252	-2.40	-1.21	3.83	-1.20
57	PLR	Rate of change of agricultural wage rates (£/man-yr.-yr.	+20.	1.5	1.25	0.	0.	-1.50	0.	.0650	0.	.0403	0.

Table III.12. (cont'd.)

Run	Parameter Tested	Parameter Definition	Percent Change From Base Run	Test Run Value	Base Run Value	Performance Criteria[a/]							
						AFORXS	ATVAS	ATRCN	ATRMBS	PCDINA	PCFNAG	PRFD	TSS
						Base Run Value							
						2.965 billion £	12.79 billion £	3.454 billion £	.3968 billion £	15.40 £/person-yr.	535,500 Cal./person-yr.	.02483 £/lb.	1.165
						Percent Departure From Base Run							
58	WPR(1)	Proportional rate of change of cocoa world price after 1970	+400.	.005	.001	1.28	.235	.839	1.69	.650	.0560	-.161	0.
59	WPR(2)	Proportional rate of change of palm oil world price after 1970	-1100.	-.01	.001	-.405	-.391	-1.22	-.555	-1.43	.187	-.523	0.
60	WPR(3)	Proportional rate of change of palm kernel world price after 1970	+900.	.01	.001	.911	.235	.551	1.21	.910	-.0560	.161	0.
61	WPR(4)	Proportional rate of change of rubber world price after 1970	-1100.	-.01	.001	-.810	-.156	-.376	0.	-.973	0.	0.	0.

a/ Values are at the end of a 32-year simulation run (1985).
The variables are:
AFORXS = time integral of agricultural exports
ATVAS = time integral of agricultural value added
ATRCN = time integral of agricultural net cash revenues
ATRMBS = time integral of marketing board net revenues
PCDINA = agricultural per capita disposable income
PCFNAG = nonagricultural per capita food consumption
PRFD = market price of food
TSS = measure of goodness-of-fit of time series tracking.

Again, this is due to the relatively smaller role played by the latter. The palm oil world price (Run 57) would probably be more sensitive than it actually is if palm oil exports didn't decline to zero with increasing domestic demand.

Summary

We have seen how sensitivity tests provide essential information for model building and validation by flagging possible programming and modeling errors and by contributing to an understanding of the model itself as well as of the system it is simulating. Sensitivity analyses may also be used to examine potential policies and to suggest priorities for data collection. Analyses of runs testing 61 selected parameters were presented in detail to illustrate these capabilities.

Simulation Time Cycles

Two superimposed time cycles are used in the southern model. One time increment, denoted DT, is the principal computation cycle, i.e., the distance between mesh points of the numerical solution. The other increment, DTX, is the land allocation decision cycle. DTX is generally larger than DT in order to conserve computer time executing the long and complex decision mechanisms. Thus, the model is generally run with DT=.25 and DTX=1.0; that is, decisions

are made once a simulated year[1/], while other computations are made four times a year.

The model uses Euler's single step explicit method to solve differential equations (the initial value problem) numerically. Briefly, Euler's method seeks to solve a differential equation

$$u'(t) = f(t,u)$$

$$u(t_0) = u_0$$

by defining mesh points t_k, $k=0,\ldots,N$ and sequentially solving at the mesh points

$$U_{k+1} = U_k + hf(t_k,U_k).$$

If the method converges, we would have

$$\lim_{h\to 0} \max_{0\le k\le N} |u_k - U_k| = 0$$

where $u_k=u(t_k)$ is the "true" solution at t_k and U_k is the approximate, numerical solution generated [53, pp. 75-76]. (h=DT in the model.)

Generally, convergence depends on the nature of f, but in a simulation model, $f(\cdot,\cdot)$ is usually unknown; all we know is the value $f(t_k,U_k)$. The most that can be said about f is that it is bounded. An attempt will be made here,with the results of a series of runs wherein DT and

---

1/ Hence, land use transition rates are assumed constant for a year.

DTX are varied, to test the sensitivity of the computer model's behavior to changes in the simulation cycles DT and DTX and to give an indication of whether Euler's method converges to a solution for the underlying mathematical model.

Since the more rapidly f changes with t the worse the approximation for a given h (i.e., DT), the eight test runs are all made under one of the policy situations described in Chapter 10[1/]. Thus, with land transition rates and macroeconomic growth rates changing much more rapidly than in the base run (which merely projects current policies and trends), we can get a better indication of the sensitivity of the model to the computation cycles.

Two sets of runs were made. (The results of both are tabulated in Table III.13.) The first keeps the two increments, DT and DTX, equal and decreases them successively from .5 to .01 years. The second series of runs keep DT fixed at .1 years and varies the decision cycle, DTX, from 1.0 to .1 years.

Four of the output variables of Table III.13 are plotted (Figures III.1 and III.2) against DT on semi-log

---

1/ Specifically, Run 8, Table IV.1. The major differences from that run are that policies here begin in 1953 instead of 1971 and the run is for 32 years instead of 42. In addition, the southern submodel is here operating independently of the rest of the Nigeria model.

Table III.13. Results of sensitivity tests on time increments DT and DTX.

DT	DTX	Run Time (seconds)	AFORXS billion £	ATVAS billion £	ATRCN billion £	ATRMBS billion £	PCDINA £/person-yr.	PCFNAG million Cal./person-yr.	PRFD £/lb.	TSS -
.5	.5	46.5	5.226	13.97	4.369	.7351	20.40	.5509	.02243	1.410
.25	.25	89.5	5.007	13.72	4.274	.7008	20.01	.5536	.02213	1.341
.1	.1	220.	4.879	13.58	4.221	.6814	19.80	.5548	.02201	1.312
.05	.05	439.	4.819	13.54	4.198	.6725	19.70	.5548	.02201	1.300
.01	.01	2180.	4.773	13.54	4.192	.6660	19.68	.5524	.02221	1.296
.1	1.	51.3	4.730	13.89	4.255	.6619	19.77	.5342	.02337	1.241
.1	.5	70.2	4.789	13.93	4.280	.6684	19.95	.5330	.02348	1.284
.1	.2	127.	4.842	14.00	4.312	.6755	20.13	.5310	.02373	1.317
.1	.1	220.	4.879	13.58	4.221	.6814	19.80	.5548	.02201	1.312

Variable definitions:

AFORXS = time integral of agricultural exports
ATVAS = time integral of agricultural value added
ATRCN = time integral of agricultural net cash revenue
ATRMBS = time integral of marketing board net revenue
PCDINA = agricultural per capita disposable income
PCFNAG = nonagricultural per capita food consumption
PRFD = market price of food
TSS = measure of goodness-of-fit of time series tracking.

scales to emphasize changes in the outputs for proportional changes in the time increments. (The graphs are for the first set of runs, so DT=DTX.) In general, we see diminishing returns for proportional decreases in DT. This implies the numerical approximations are approaching a solution. It also implies increasing costs in computer time per unit improvement in the approximation. Figure III.3 indicates how the computer run time increases with proportional decreases in DT and DTX.

The change in the price of food (and hence, related variables such as value added and food consumption) changes direction when DT = DTX = .01 (Table III.13). The somewhat uniform behavior (i.e. showing diminishing returns throughout the decrease in DT) of the other variables may indicate that the exceptions are due to modeling or programming errors. Similarly with the substantial qualitative change in behavior when DTX $\neq$ DT (the lower half of Table III.13).

Comparing Figures III.1 and III.2 with Figure III.3, we might subjectively estimate .1 as an "optimal" value for DT. For DTX, .5 would seem reasonable. However, it is of extreme interest to reduce computer time as much as possible and still maintain a reasonable approximation, particularly considering the desirability of making large numbers of runs for policy analysis (and Monte Carlo analyses--Chapters 10 and 11). Thus, the Nigeria model

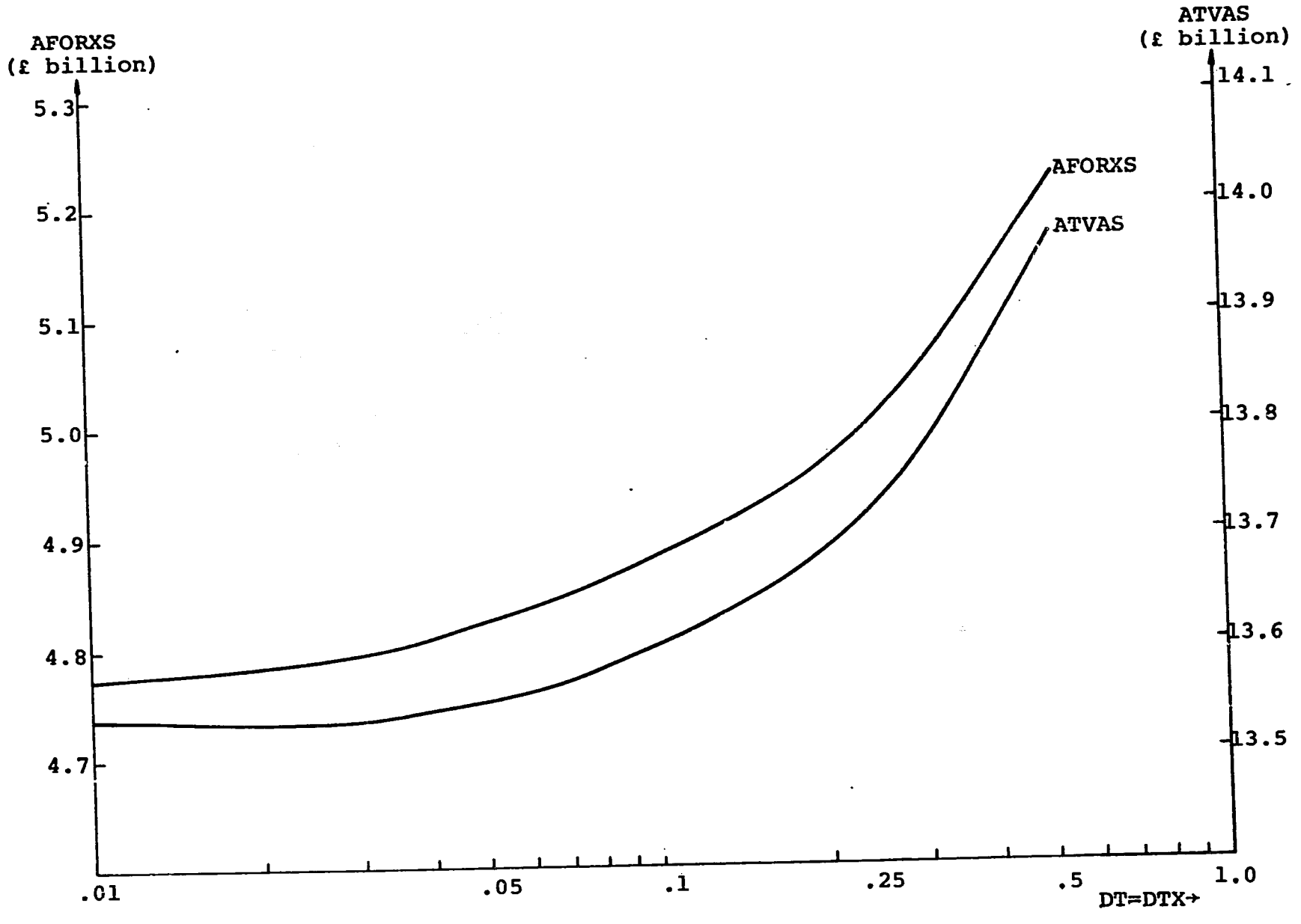


Figure III.1 Approximate solutions of agricultural exports (AFORXS) and value added (ATVAS) for different simulation cycles.

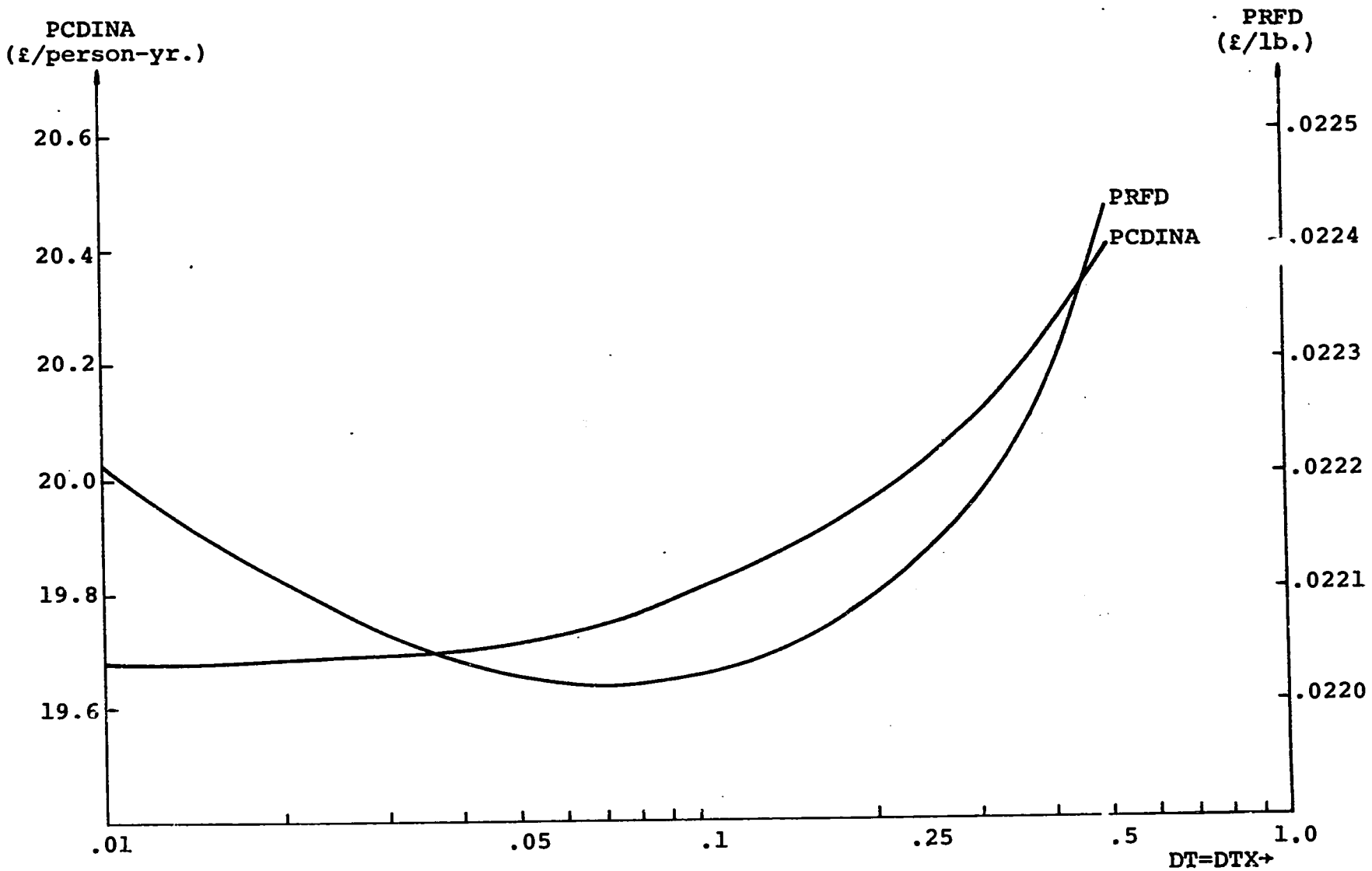


Figure III.2 Approximate solutions of per capita disposable income (PCDINA) and market price of food (PRFD) for different simulation cycles.

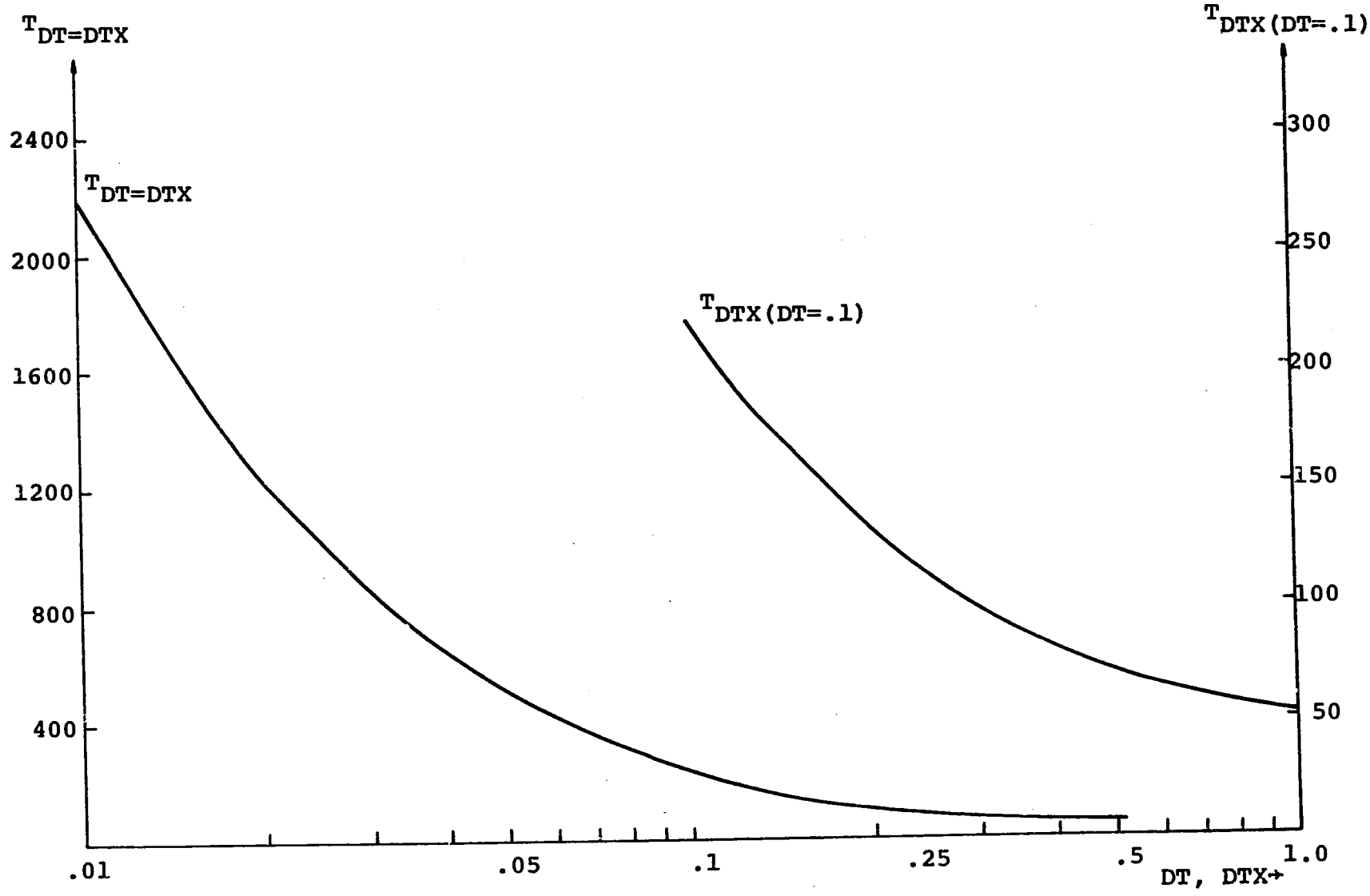


Figure III.3 Simulation run times when varying one or both simulation cycles.

as a whole and the southern submodel in particular use DT = .25 and DTX = 1.0.

P A R T IV

TOWARDS A SOLUTION

Introduction

The objective of the Nigerian Simulation Project, as specified in its USAID contract, was to investigate the feasibility of applying the systems science-simulation approach to the problems of development planning. With that in mind, the models developed by the project group--including the southern regional agricultural submodel of an agricultural economy characterized by competition between annual and perennial crops--are specifically oriented to policy development and analysis.

Chapter 10, in reporting and analyzing the results of a series of policy runs, illustrates how the model could be used in an actual planning situation[1/]. The chapter also indicates roughly how we might address considerations of the sensitivity of simulated policy projections to data uncertainty. The dissertation concludes (Chapter 11) with a discussion of needed improvements and extensions of the current model and of the form an implementation and institutionalization of the model might take.

1/ In fact, the analysis was made following limited interactions with Nigerian policy makers and agriculturalists and later fed back to them.

CHAPTER 10

Policy Formulation

A system simulation model may be used by policy makers in two principal ways. One is to sharpen his intuition and add to his understanding of the real-world system he is concerned with. As discussed in Chapter 9, this may be undertaken with sensitivity analyses. The second application--the formulation of development policies--will be discussed in this chapter.

Policy making is a process immersed in uncertainty because it concerns the future. Development policy making is submerged to uncertainty's darkest depths due to the immensely complex (and thus still imperfectly understood) process of economic development. Not only is there uncertainty concerning future states of the environment (e.g., weather, world demand for export commodities, international and domestic political alignments) but there is also uncertainty about the future behavior of the time-variant and nonlinear domestic economic system, particularly its response to policy stimuli. System simulation, by modeling specific causal and structural relationships and by projecting time paths of behavior, provides the flexibility necessary to deal with this complexity and uncertainty.

Once the political process has established the goals of development or the direction development is to take (Chapter 1, above), policies must be formulated for the attainment of those goals. (This process also involves political considerations.) As discussed in Chapter 9, it is highly desirable to develop policies which are relatively insensitive to a range of conditions reflecting the uncertainty both of future weather or world market situations, for example, and of the quality of data inputs to the model. As was suggested above, Monte Carlo techniques may be used with the simulation model to enable that kind of analysis of policy options.

Since much work remains to be done to provide the model with a Monte Carlo capability (see Chapter 11), this chapter presents an analysis of the results of a series of deterministic policy runs followed by a coarse illustration of policy sensitivity tests.

Policy Experimentation

Following initial interactions with Nigerian policy makers and experts, a series of seventeen policy experiments were defined and run with the total Nigeria model. Although this dissertation is concerned with the southern regional agricultural submodel, all 17 runs are reported for both regions and the national level. I feel this is justified on two counts. First, the policies tested have national implications, and interregional

(North-South) and intersectoral (agricultural-nonagricultural) interactions are important contributors to policy consequences. More significantly, however, the organization of the 17 runs (described below) and of the analysis is in a form particularly relevant for, and useful to, policy makers. As such, a complete presentation (as opposed to covering just the southern-related policies) provides a useful illustration of the application of the system simulation model reported here. With some adaptation, the southern (and northern) model can be implemented independently; however, at present and for Nigeria, their linkage is necessary.

Run Definitions and Organization

Policy experiments were conducted with 17 simulation runs which cover the time period 1953-1995 (Table IV.1).

The model is constrained to approximate real conditions from 1953-1965 using observed FOB (export) and producer prices for that period. The results analyzed here are for the period 1970-1995, with policy implementation beginning in 1971. The year 1970 is thus considered the starting time with simulated "initial" conditions. Projections are carried as far as 1995 in order to give the long run diffusion responses to the production campaigns time to exert their major impact.

With simulation, it is easy to build up the complexity

Table IV.1. Policy simulation runs.

Run No.	Run Sets	Run Definition
1	all	Standard Run--no modernization of production; normal export taxes and marketing board surpluses.
2	2, 3	Export taxes and marketing board surpluses cut-off at year 1970.
3	2, 3	Export taxes and marketing board surpluses phased-out from 1970-1980.
4	1	Tse-tse fly-eradication program from 1971-1981.
5	2	Production campaigns in cotton and groundnuts from 1971-1981.
6	2	Production campaign in food grains from 1971-1981.
7	2	Combines Run 5 and Run 6.
8	3	Production campaigns in cocoa new planting, cocoa replanting, rubber replanting and palm replanting from 1971-1981.
9	3	Production campaigns in cocoa new planting, cocoa replanting and palm replanting from 1971-1981.
10	3	Run 8 plus modernization of palm and rubber processing.
11	4	Combines Run 7 and Run 8.
12	4	Run 11 with production campaign in food roots in the Middle Belt from 1971-1981.
13	4	Run 11 with a further improvement in food grains technology after 1980.
14	4	Combines Run 11 and Run 2.
15	4	Combines Run 11 and Run 3.
16	5	Run 11 with half the campaign budget.
17	5	Run 11 with twice the campaign budget.

of the combinations of policies tested. Starting with runs to evaluate single policies or programs (e.g., rubber replanting), we may successively add other policies and programs (e.g., reduce marketing board and export taxes) to investigate interactive effects. In addition, a flexible output format allows us either to look at the behavior of aggregated macro-economic variables or to zero in and investigate the responses on a more micro level. The policy runs are organized to take advantage of these capabilities.

The 17 simulation runs are grouped into five sets (Table IV.1) which examine increasingly complex interactions at progressively higher levels of industry and geopolitical aggregation. All five sets include Run 1, the base run, as a standard point of reference. The base run projects likely performance under current policies, with no programs to modernize production and with export and marketing board taxes maintained at current levels.

The tsetse fly has a dramatic impact on the area where cattle can graze in good health and the corresponding size and productivity of the Nigerian cattle industry (and the income accruing to Northern Nigerians). In the first set of runs, Run 4 investigates the results of a tsetse fly eradication program budgeted for £3 million over ten years. (An eradication cost of £100/sq. mile is assumed.)

Interactions among cash crops (cotton and groundnuts) and food crops in the North are focused on in the

second set of runs, Runs 2, 3, 5, 6 and 7. Runs 2 and 3 compare the effects of cutting off export and marketing board taxes in 1970 or phasing them out over a ten-year period.

In the remaining runs of this set, these taxes are maintained at recent levels (25 percent for cotton and groundnuts) while various combinations of production campaigns are tested. The total budget for the production campaigns is assumed to be £40 million spread over a 10-year period. (See Figure II.12.) This budget pays for extension salaries, subsidies and overhead expenses. Run 5 simulates programs to increase cotton and groundnut production via extension efforts to introduce new seed varieties and improved cultural practices, improving groundnut and cotton yields to 1000 and 600 lbs./acre, respectively. In this run, groundnuts get 2/3 of the budget, while cotton gets 1/3. The same end (improved cash crop production) is sought in Run 6 via a food grains modernization program (to hopefully release land for cash crop expansion). If food production is being modernized, the model provides for cotton yields to increase as the labor pressure is eased. This reflects cotton being planted earlier in the season. New technologies in food grain production are assumed to increase yields 2 1/2 times. Here, all £40 million go to food grain programs. All three programs--cotton, groundnut and food grains--are

then combined in Run 7, where the budget is split 40 percent, 20 percent and 40 percent to groundnuts, cotton and food, respectively.

Agricultural policies and programs aimed at the southern ecological region are examined in simulation Runs 2, 3, 8, 9 and 10. Runs 2 and 3 again compare the consequences of cutting off export and marketing board taxes or, alternatively, phasing them out. Normal levels of marketing board taxes are assumed to be 20 percent for the three commodities handled by marketing boards (cocoa, palm oil and palm kernels), while export taxes for those three and rubber are 20 percent, 15 percent, 15 percent and 15 percent, respectively.

Runs 8, 9 and 10 investigate production campaigns in the perennial crops and efforts to improve the processing methods for oil palm and rubber products. The production campaigns assume a budget of £40 million over 10 years to pay for extension salaries, subsidies and overhead expenses. Run 8 involves a modest cocoa new planting program and replanting programs for cocoa, palm and rubber. The budget is split among these programs 10 percent, 30 percent, 40 percent and 20 percent, respectively. Of the 40 percent in the palm replanting program, 25 percent is used in the areas where palm competes with rubber, and 75 percent is applied to areas where palm has no perennial competitors. Run 9 attempts to highlight the interactive effects of the

oil palm-rubber competition (in comparison with Run 8) by not conducting the rubber replanting program and devoting that portion of the budget to palm replanting. The assumed yields at maturity (in lbs./acre-year) for new planted cocoa and replanted cocoa, palm and rubber are 950, 850, 6700 and 1000, respectively. The model provides for these yields to gradually increase 20% as farmers gain experience with the new methods of cultivation involved in modern production.

Finally, Run 10 adds investment in modern processing facilities for oil palm and rubber products to the programs of Run 8. For palm this means Stork hydraulic presses, while for rubber it means crumb factories. The investment rate is established at £100 thousand and £200 thousand for palm and rubber respectively, until a prespecified level of transformation has been reached (50 percent for palm and 100 percent for rubber). While rubber processing is being transformed from sheets to crumb, the model simulates a gradual increase in the domestic industrial demand for crumb rubber up to 50 percent of production.

While the first three sets of runs focus on industry- or region-specific policies, the fourth set of runs, Runs 11, 12, 13, 14, and 15, examines aggregate and interactive effects of agricultural development policies and programs in both the North and the South. Run 11 combines Runs 7 and 8 so that the following production campaigns are carried out simultaneously at the same budget levels (£40 million

in each of the North and the South) and the same commodity proportions as specified above: modernization of cotton, groundnuts and food grains in the North, and new planting of cocoa and replanting of cocoa, palm and rubber in the South.

Run 12 speculates on the impact of modernizing food production (roots and tubers) in the Middle Belt area of the North in addition to the modernization programs discussed above. In this way, we can specifically investigate the implications for regional specialization, i.e., the South specializing in perennials and relying on the North for food. The word "speculates" was used above since the modernization of root and tuber food production depends on the development of the requisite technologies, which development is not presently on the horizon.

Another speculation is made in Run 13. Running the programs specified in Run 11, a further doubling of food grains yields is assumed to diffuse over a period of four or five years after 1980 as a result of new technologies which may be developed in the next ten years by national and international research stations. Thus, modern food yields after 1980 are assumed to be potentially five times the current traditional yields experienced in northern Nigeria. This experiment investigates the potential effects on exports (due to cash crop interactions), food prices and consumption.

Finally, Runs 14 and 15 combine the production

campaigns of Run 11 with the export and marketing board tax policies of Runs 2 and 3, respectively, i.e., the alternatives of cutting off and phasing out these taxes.

The last set of runs, Runs 11, 16, and 17, examines the relative consequences of alternative levels of the campaign budgets (RMAX in Figure II.12). In this way, we can address the question of whether it would be worthwhile to intensify (or de-emphasize) modernization promotion efforts. That is, would likely gains be worth the added expenditures? Or, would the savings from decreased expenditures (saying nothing about alternative uses for the resources) be worth the projected production losses? Run 1, the standard run, has zero budgets, of course. Run 11 has budgets of £40 million each in the North and South, allocated among the programs, as indicated above. Run 16 halves this budget, while Run 17 doubles it, always with the same proportional allocations to the specific campaigns.

The following sections analyze and graphically portray the results of these 17 runs.

Policies Related to the Cattle Industry

Run 4 simulates a 10-year tsetse fly eradication program budgeted at £3 million. This analysis does not consider other livestock programs or their potential interactions with other agricultural policies and programs due

to limitations of the current model[1/].

Animal populations[2/], sales and resultant incomes all rise as might be expected (Figures IV.1 and IV.2). Fly-free grazing land (Figure IV.3) experiences a dramatic increase, and the general range condition[3/] improves substantially over the base run (Figure IV.4).

In every case, however, the gains attributed to the fly eradication program in Run 4 are temporary in the sense that these performance variables, after an initial increase, return to the same trends as experienced in the base run, although at a higher level. By 1995, the slopes of the results of Run 4 are all either the same as the slopes of Run 1 results or are approaching these slopes. Thus, the animal population (Figure IV.1) increases rapidly as new grazing areas are opened up. Once these new areas have reached their animal capacity, male and female populations grow at the same rate as in the base run. This causes

---

1/ The study by Kellogg in 1971 [26] examines some additional considerations on mortality loss, marketing costs, etc. which could be incorporated into the model for a more comprehensive analysis of this program and others related to the cattle industry.

2/ The initial (1970) cattle population assumed in the model is about five million head (Figure IV.1). Although this figure is somewhat below current estimates of Nigeria's cattle herds, the relative results of Runs 1 and 4 are still valid.

3/ "Range condition" is defined as an index of range land grass yields and reflects the effects of overgrazing. That is, its value at any time during the simulation period (1970-1975) is the ratio of grass yields at that time to grass yields at the initial time (1970).

sales and incomes (Figure IV.2) also to experience the same growth rates as in Run 1 after the initial spurt.

The amount of fly-free grazing land experiences a dramatic increase from 1975 to 1985 as a direct result of the eradication program (Figure IV.3). After 1985, however, grazing land declines at the same rate as in Run 1 due to the expansion of crop lands. Similarly, the decline in range condition due to overgrazing (Figure IV.4) is slowed substantially as new areas are opened up and the grazing pressure eases. By 1995, the cattle population is grazing even these new areas to capacity, and the range condition continues to decline at the same rate as in the base run.

The conclusion to be drawn from this is that the fly eradication program has merely "bought time." The deterioration of overgrazed ranges has been delayed, not halted (much less reversed). The loss of grazing land to crops continues in Run 4 at the same rate as in Run 1. The animal population growth rate (and hence the growth in beef and milk supplies) is the same after the eradication program as before.

This is not to say there shouldn't be a fly eradication program. This program does have substantial short run results. However, the time gained by it could be used to carry out programs which will have more long-lasting results. Indeed, other programs, such as grazing reserves, might not even be feasible without the prior elimination of the tsetse fly.

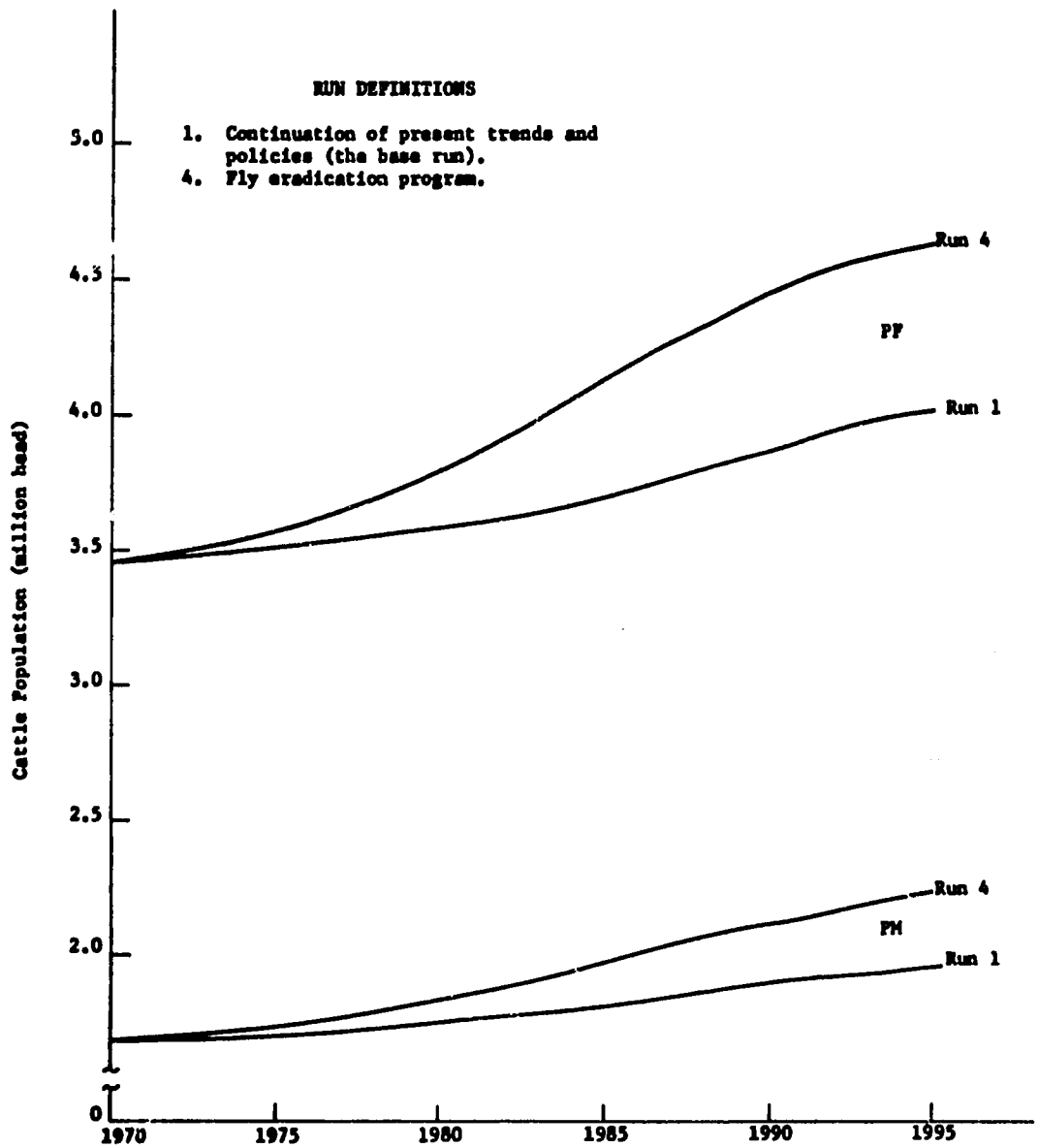


Fig. IV.1 Cattle population of males (PM) and females (PF), 1970-1995, with and without a fly eradication program.

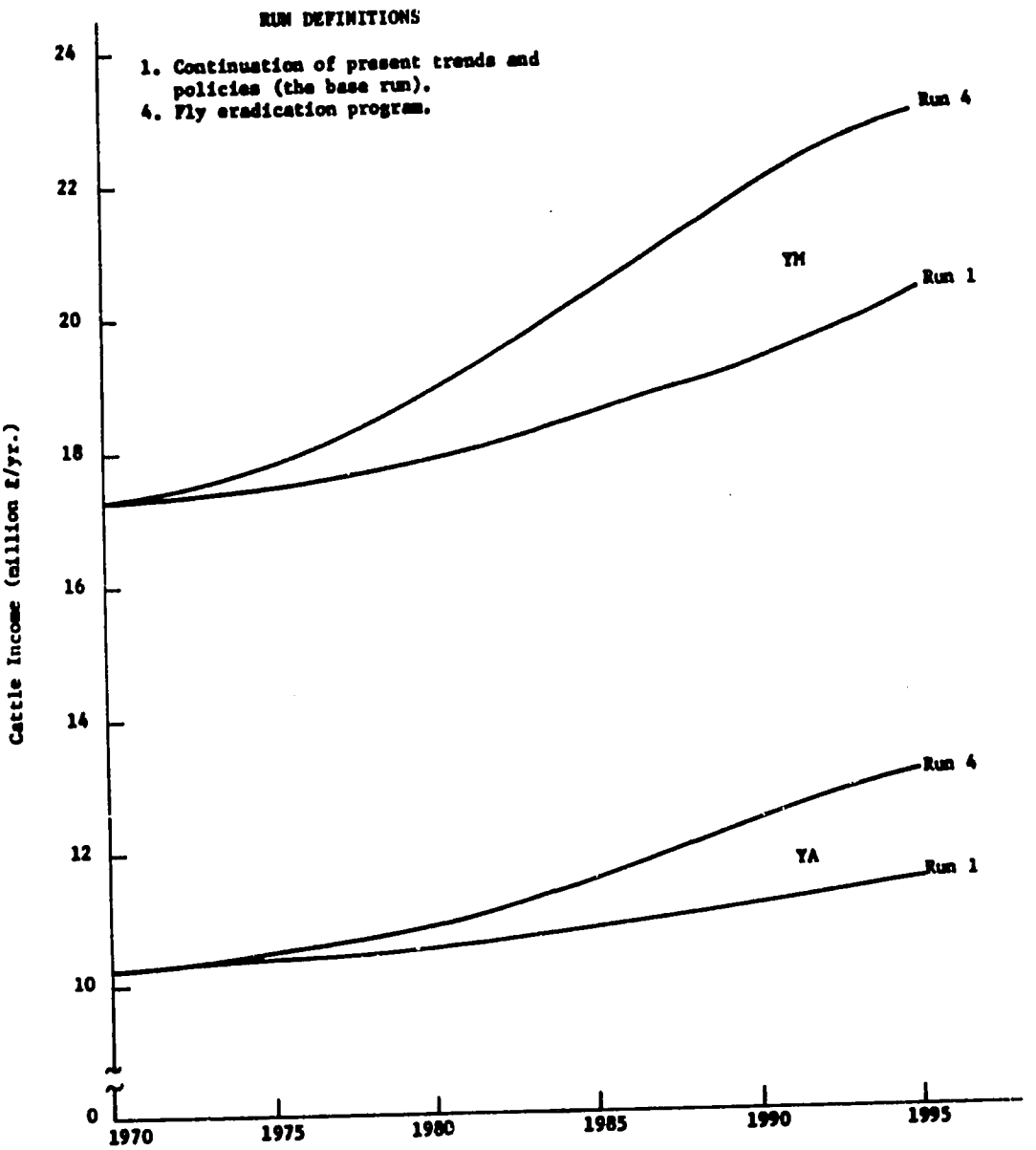


Fig. IV.2 Cattle income from animal sales (YA) and milk (YM), 1970-1995, with and without a fly eradication program.

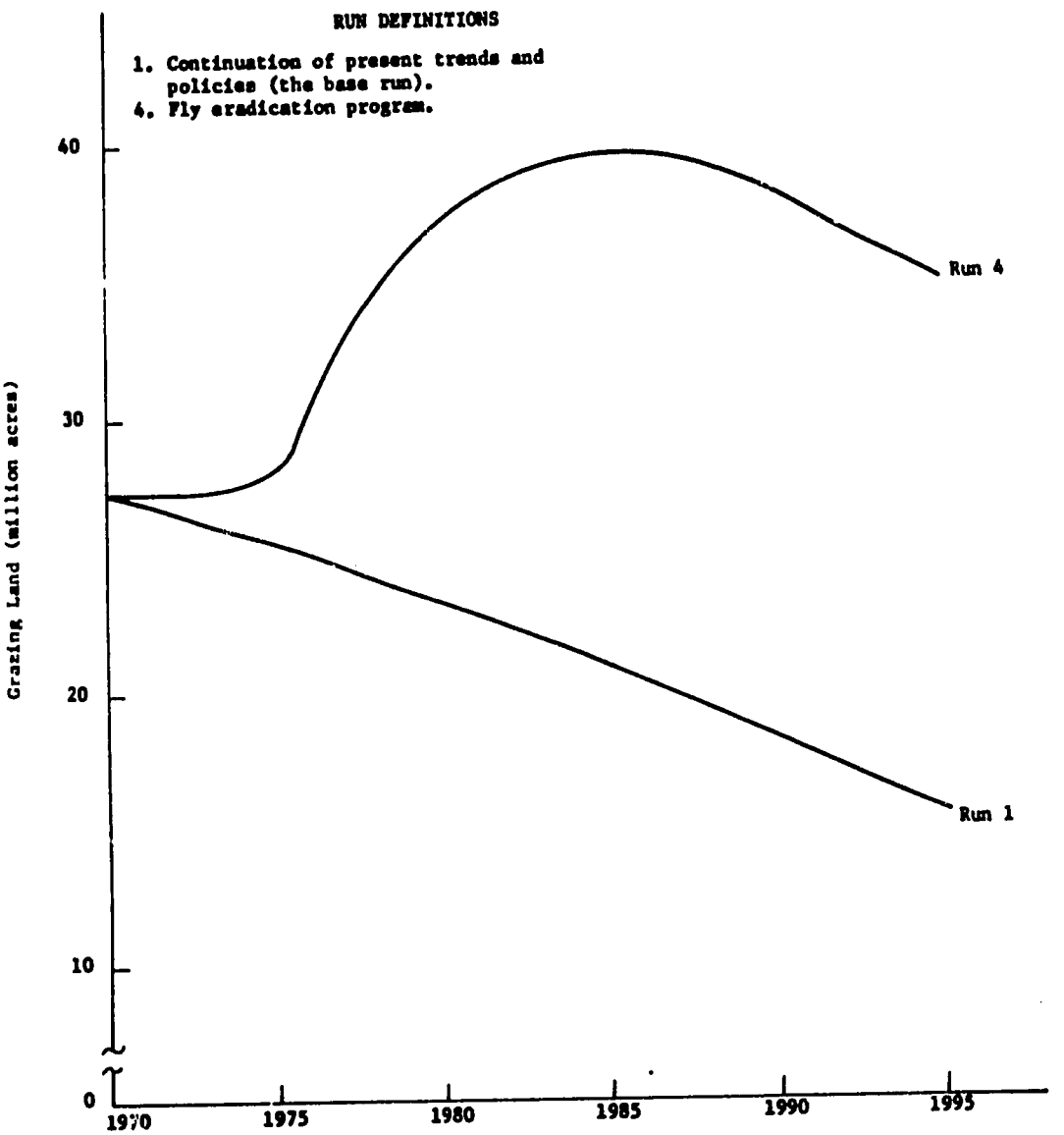


Fig. IV.3 Fly-free grazing land, 1970-1995, with and without a fly eradication program.

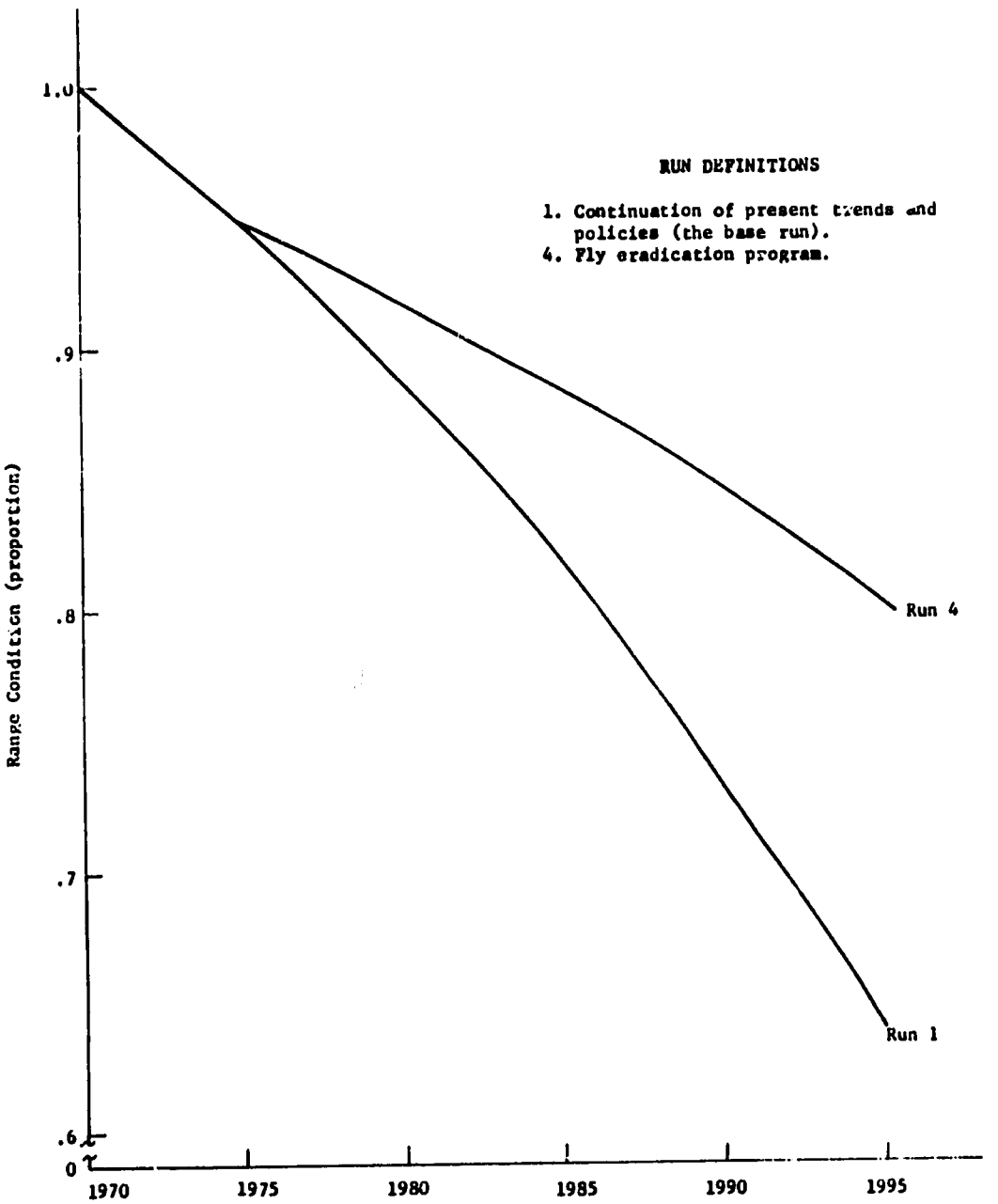


Fig. IV.4 Range condition index (the ratio of range land grass yields at a point in time to those yields at the initial time, 1970), 1970-1995, with and without a fly eradication program.

Northern Regional Policies

The set of runs which investigates the consequences of policies and programs relevant to northern Nigeria includes Runs 1, 2, 3, 5, 6 and 7 as defined above and in Table IV.1. Briefly, these runs respectively project present trends and policies (the base run), cut off marketing board and export taxes, phase out marketing board and export taxes, implement production campaigns in cotton and groundnuts, implement a campaign to modernize food grains production, and examine production campaigns in all three commodities--cotton, groundnuts and food grains.

As expected, the elimination of taxes stimulates agricultural production and incomes. Value added in agriculture improves slightly over the base run (Figure IV.5), as do exports (Figure IV.6)[1/]. The more immediate stimulus of cutting off taxes (Run 2) initially causes higher exports and value added than Run 3 (phasing out taxes), but also a slightly higher food price (Figure IV.9) for the nonagricultural population. Disposable agricultural worker incomes (Figure IV.7)[2/] markedly increased over the base run due in part to the higher producer prices for cash crops and to

---

1/ The large negative foreign exchange shown in Figure IV.6 is due primarily to projected import demands of the textile industry being charged to cotton exports. In addition, about 10-20 percent of the indicated imports is beef for consumption.

2/ Disposable income in Figure IV.7 (and Figure IV.15) includes wages earned but is net of agricultural sector debt service and interest.

slightly higher food prices[1/].

The major contributor to increased incomes, however, is the greatly increased (over the base run) cash food sales to the South to meet the higher agricultural and non-agricultural demands for food. Southern agricultural cash food demands increase as the agricultural sector reduces its desired level of subsistence in response to higher cash incomes resulting from the export crop tax reductions. In addition, Southern nonagricultural food demands rise due to the rise in nonagricultural income resulting from the greater demands for nonagricultural goods and services generated by the increased agricultural income (called multiplier effects, below).

The long run results of Run 2 are similar to those of Run 3. After 1980, when marketing board and export taxes are zero in either policy situation, food consumption by the nonagricultural population (Figure IV.10) shows a substantial rise as the increased agricultural incomes from Runs 2 and 3 begin to have their multiplier effects on nonagricultural incomes. Later, higer food prices cause nonagricultural food consumption to approach the same level as in the base run.

Figure IV.10 indicates steadily falling nonagricultural food consumption in all runs (as do Figures IV.17

1/ Food acounts for about 90 percent of agricultural value added in the North.

and IV.27 below). These results must be interpreted with caution. They represent only staple food consumption, and do not incorporate other sources of nutrition such as fish, meat, fruits and vegetables. As nonagricultural incomes rise, we might expect to see an increasing substitution of these items for the staples treated in the model.

The modernization of cotton and groudnut production (Run 5) substantially improves the performance of all the variables observed compared to both the base run and the runs eliminating taxes. Foreign exchange increased the most (Figure IV.6), about 30 percent over Run 1. Since food crops rather than export crops dominate northern agricultural production, other variables, such as value added (Figure IV.5), income (Figure IV.8) and, hence, food consumption (Figure IV.10) show a less dramatic increase. Marketing board revenues (Figure IV.7) show a 150 percent increase by 1995.

Run 6 examines a program to modernize food grains production. Indeed, foreign exchange and marketing board revenues do pick up (over the base run) as land and labor are released for cash crop production. The difference is less pronounced at the end of the run (1995) than earlier in the simulated time period as the initial reduction in total food land is gradually reversed to meet the subsistence demands of the expanding agricultural population. Throughout the time period 1970-1995, exports and marketing

board revenues in Run 6 are below those of Run 5 where cash crop production is directly transformed. This can be explained by the slower diffusion of food modernization (compared to cash crop modernization diffusion) which is built into the model. A larger promotion effort (budget) would stimulate a quicker response to food modernization and, hence, a larger effect on cash crop production.

In Run 7, promotion efforts are conducted in cotton groundnuts and food grains simultaneously. Most output variables compound the increases of Runs 5 and 6 over the base run; the results in Run 7 are more than the mere addition of these increases. Marketing board revenues (Figure IV.7) provide a striking example of this. Revenues in 1995 in Run 7 are 200 percent greater than Run 1 while revenues in Runs 5 and 6 are 150 percent and 15 percent greater, respectively. This is due to the fact that cash crop production, which has expanded onto former food land as a consequence of food modernization, is itself modernized in Run 7, further augmenting the positive results of Run 6. In addition, and more significantly in the long run, the modernization of food in conjunction with cotton and groundnuts allows more timely planting of the cash crops, resulting in even higher yields for the modern varieties than would otherwise be obtained.

Food prices are lower in Run 7 than in any other run. This effect is more than offset, however, by the

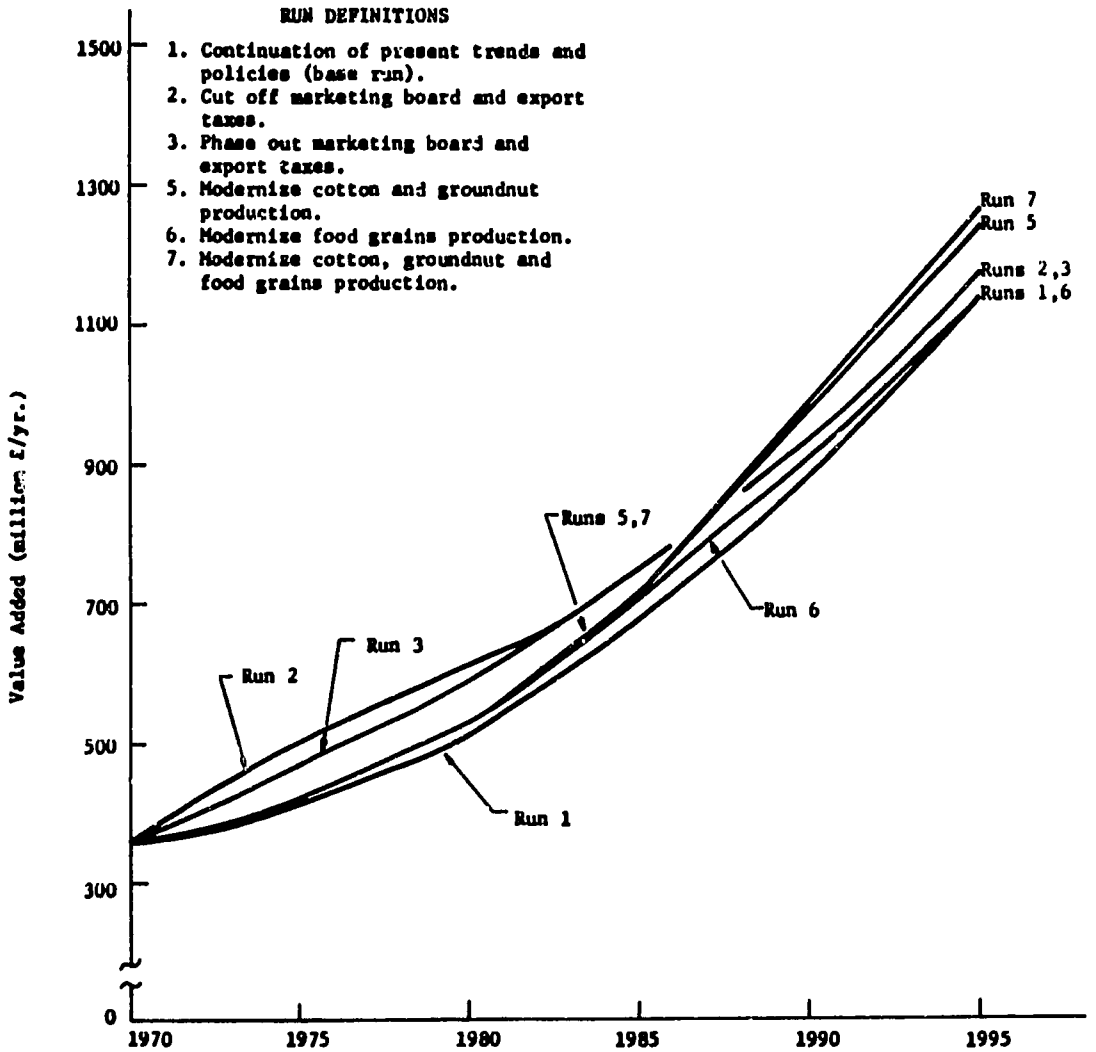


Fig. IV.5 Total value added in agriculture in the North, 1970-1995, under various policy conditions.

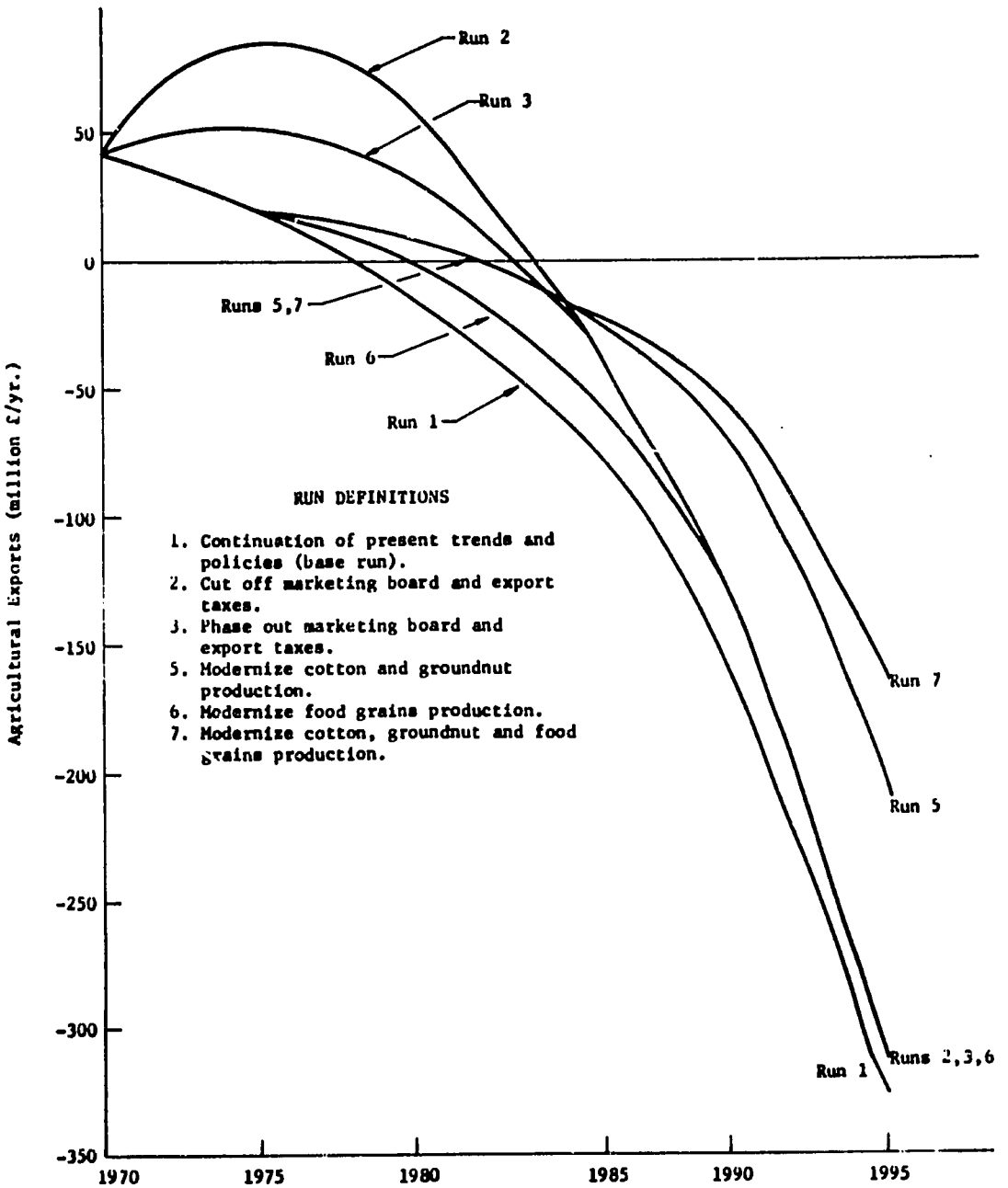


Fig. IV.6 Foreign exchange from northern agricultural exports (including imports of cotton and beef), 1970-1995, under various policy conditions.

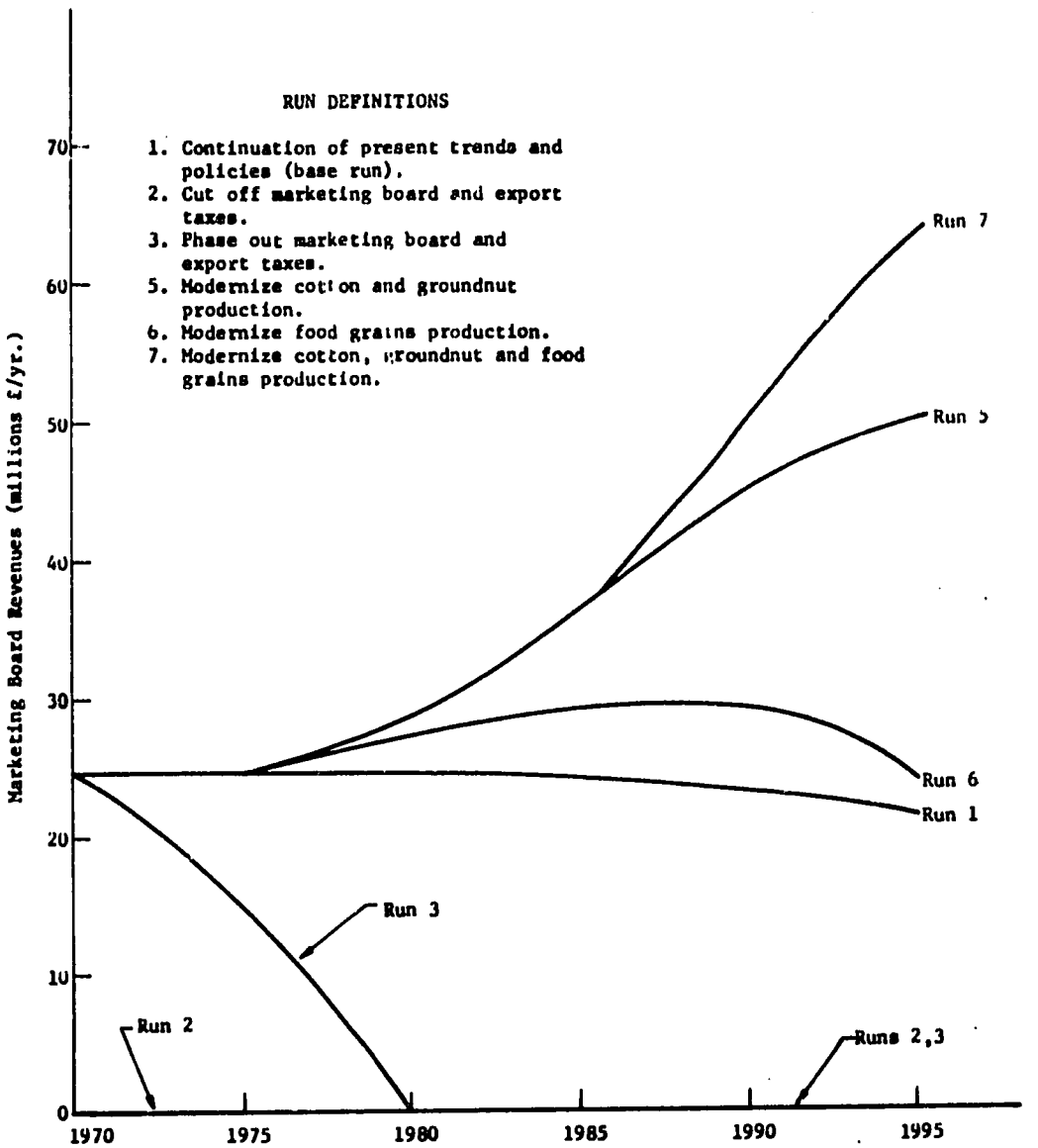


Fig. IV.7 Total marketing board net revenues from northern commodities, 1970-1995, under various policy conditions.

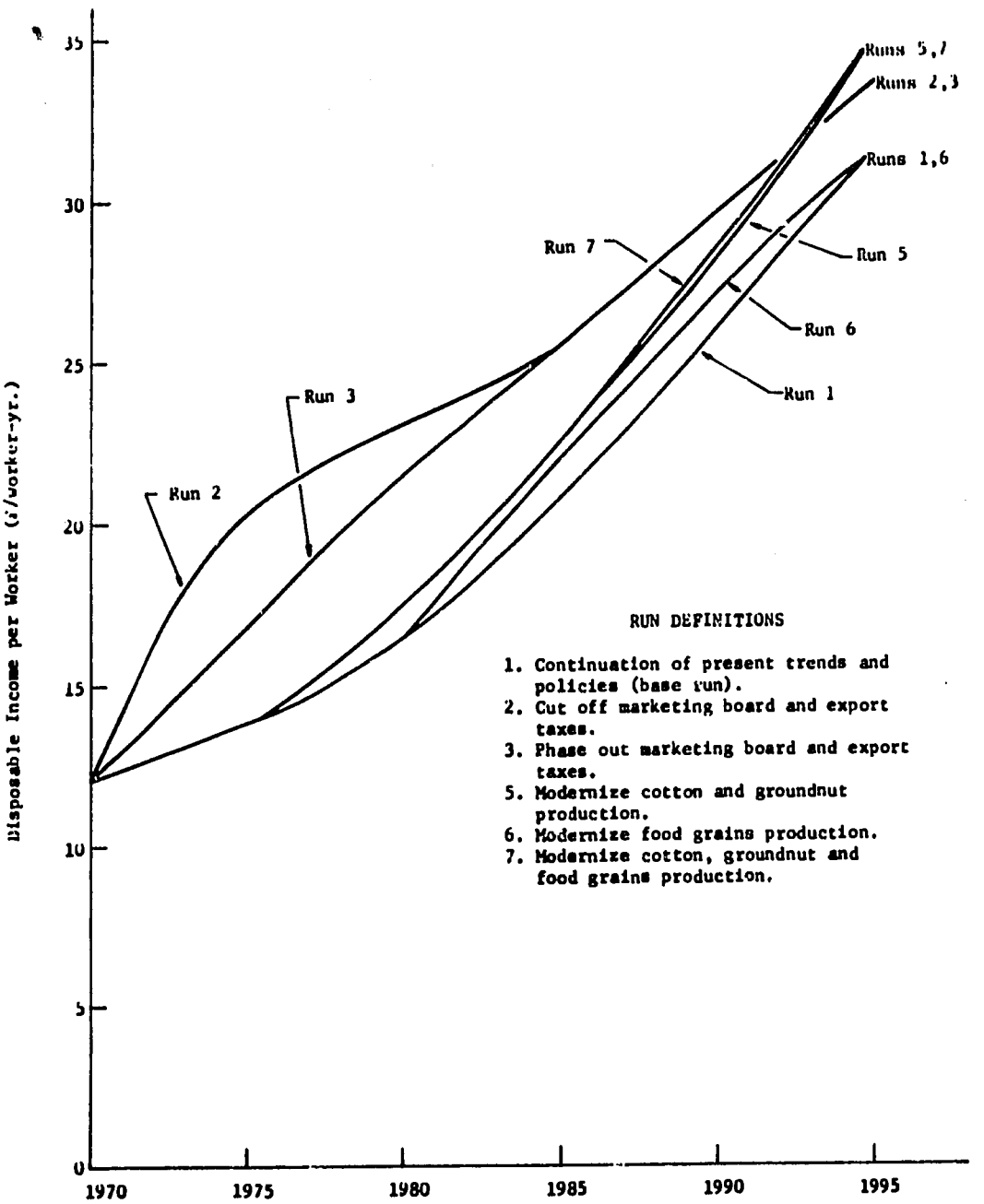


Fig. IV.8 Disposable income per agricultural worker in the North, 1970-1995, under various policy conditions.

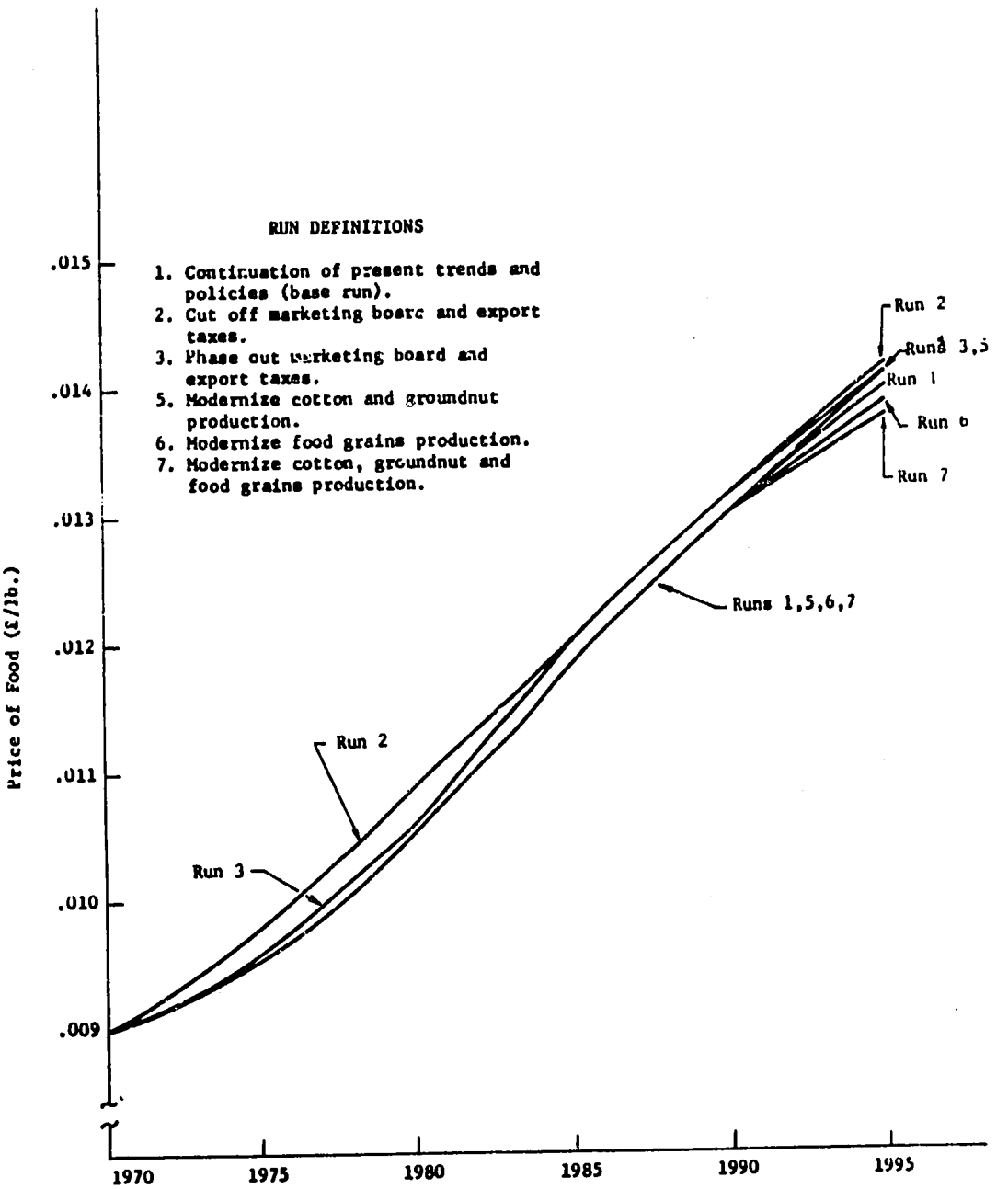


Fig. IV.9 Market price of food in the North, 1970-1995, under various policy conditions.

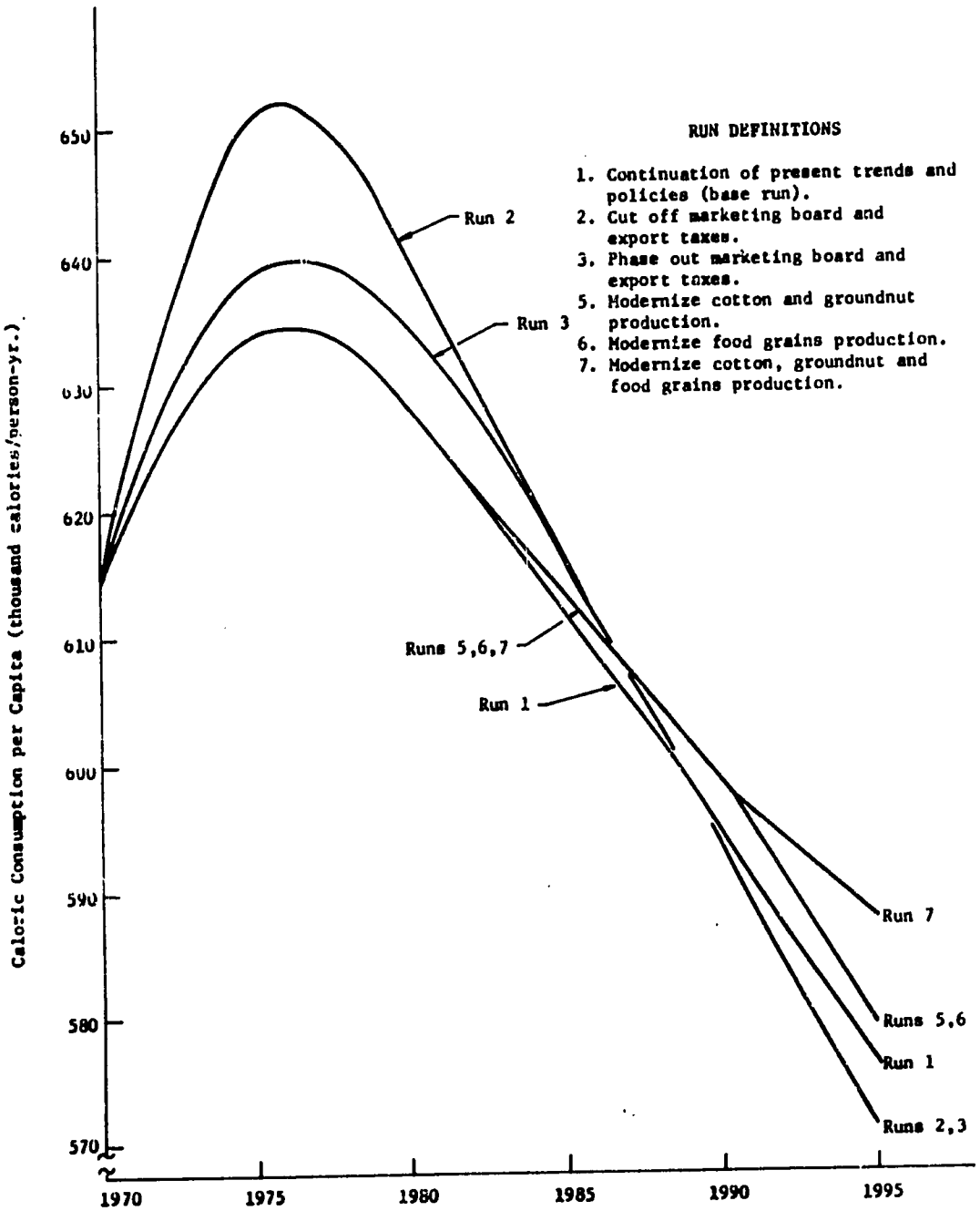


Fig. IV.10 Caloric consumption (of staples) per capita of the northern nonagricultural population, 1970-1995, under various policy conditions.

increased productivity of food so that value added and income are slightly higher in Run 7 than Run 5. The lower food prices coupled with increased nonagricultural income result in higher nonagricultural food consumption (Figure IV.10).

Southern Regional Policies

The set of runs which investigates the consequences of policies and programs relevant to southern Nigeria includes Runs 1, 2, 3, 8, 9, and 10 as defined earlier and in Table IV.1. Briefly, these runs respectively project present trends and policies (the base run), cut off marketing board and export taxes, phase out these taxes, implement production campaigns in all three perennial commodities (cocoa, palm and rubber), implement production campaigns in cocoa and palm only, and implement the same programs as Run 8 simultaneously with investments to modernize and transform palm and rubber processing capacities (to Stork presses and crumb factories, respectively). Run 10 also assumes the domestic demand for crumb rubber increases gradually to 50 percent of production.

The most striking observation that can be made about Runs 2 and 3 (cutting off and phasing out taxes) is not that the long run results are virtually identical, for taxes are eventually zero in both cases. Nor is it that incomes, value added, exports, etc. are initially higher than the other runs and consistently higher than the base

run--the reduction in taxes represents an immediate increase in producer prices, whereas there is a delay involved for the perennial modernization programs to show results. This delay is due to the natural gestation and maturation lags of the perennials and the longer lags before the innovations are diffused beyond the direct promotion results. The most striking observation concerning the behavior shown in Runs 2 and 3 is that value added, exports and income (Figures IV.11, IV.12 and IV.15) are relatively higher initially in Run 2 than in Run 3; while later in the simulated time period (after about 1978), they are relatively higher in Run 3 than in Run 2, finally approaching the same steady state levels in both runs. Run 2 should indeed have higher results initially since producer price increases are immediate. The short term supply (harvest) response is sharp initially, and then tapers off, ultimately returning to normal levels as farmers gradually come to regard the higher prices as "normal." Exports begin to increase again after 1980 (Figure IV.12) as the long term supply (planting) response to the higher prices becomes increasingly dominant, finally tapering off again as acreage has expanded to its limit (as in the base run) and production from aging traditional trees falls.

In Run 3, prices rise steadily over a 10-year period while taxes are being phased out. Thus, the harvest response is lower than in Run 2. However, it lasts longer

since the new price (achieved when taxes have finally been eliminated) is not seen as "normal" by the farmers until later. Therefore, while exports in Run 2 taper off, the harvest and planting responses reinforce each other in Run 3. Eventually, however, the acreage limits are reached, the natural aging process decreases yields, and the long run results of Runs 2 and 3 are virtually the same (Figures IV.11, IV.12, IV.14, IV.15).

Although long run exports, when taxes are removed, are virtually the same as in the base run (due to capacity limits and aging traditional trees), the higher prices keep long run value added and income per worker (Figures IV.11 and IV.15) higher than the base run. Per worker income falls during the latter part of the runs because the labor force is growing faster than income.

The increased agricultural incomes, via multiplier effects on nonagricultural incomes, cause a higher consumption (in Runs 2 and 3 than in Run 1) of staple calories by the nonagricultural population through most of the simulated time period (Figure IV.17). As incomes stabilize in the long run, however, the higher food prices associated with Runs 2 and 3 result in lower nonagricultural staple food consumption.

Comparing Runs 8 and 10 (production campaigns in the three major perennial commodities without and with modernization of palm and rubber processing), some

interesting observations can be made. Value added (Figure IV.11) and marketing board revenues (Figure IV.13) are higher in Run 10 than in Run 8 due to the increased technical efficiency of oil palm and rubber processing facilities. While palm oil exports are also substantially improved (Figure IV.14), total exports (Figure IV.12) are lower due to the assumption in Run 10 that the domestic demand for rubber increases to 50 percent of production over a 15-year period, thus reducing rubber exports (which don't pass through a marketing board, thus not diminishing marketing board revenues). Indeed, exports are initially higher in Run 10 while domestic rubber demand is still low.

In spite of this increased production, incomes in Run 10 are lower than in Run 8 (Figure IV.15). The reason is that palm oil processing with the Stork hydraulic presses, while technically more efficient (i.e., more oil is extracted per pound of fruit), is economically inefficient. That is, the increased processing costs outweigh the revenue from increased production, thus making palm processing unprofitable[1/]. The centralized crumb rubber factories, on the other hand, prove to be substantially more efficient--economically as well as technically--than the traditional

---

1/ The transformation of processing takes place in the model irregardless of its profitability. It is carried out solely by an exogenous (policy) investment. The model's rudimentary processing component would have to be expanded to more realistically simulate investment decisions (Chapter 4).

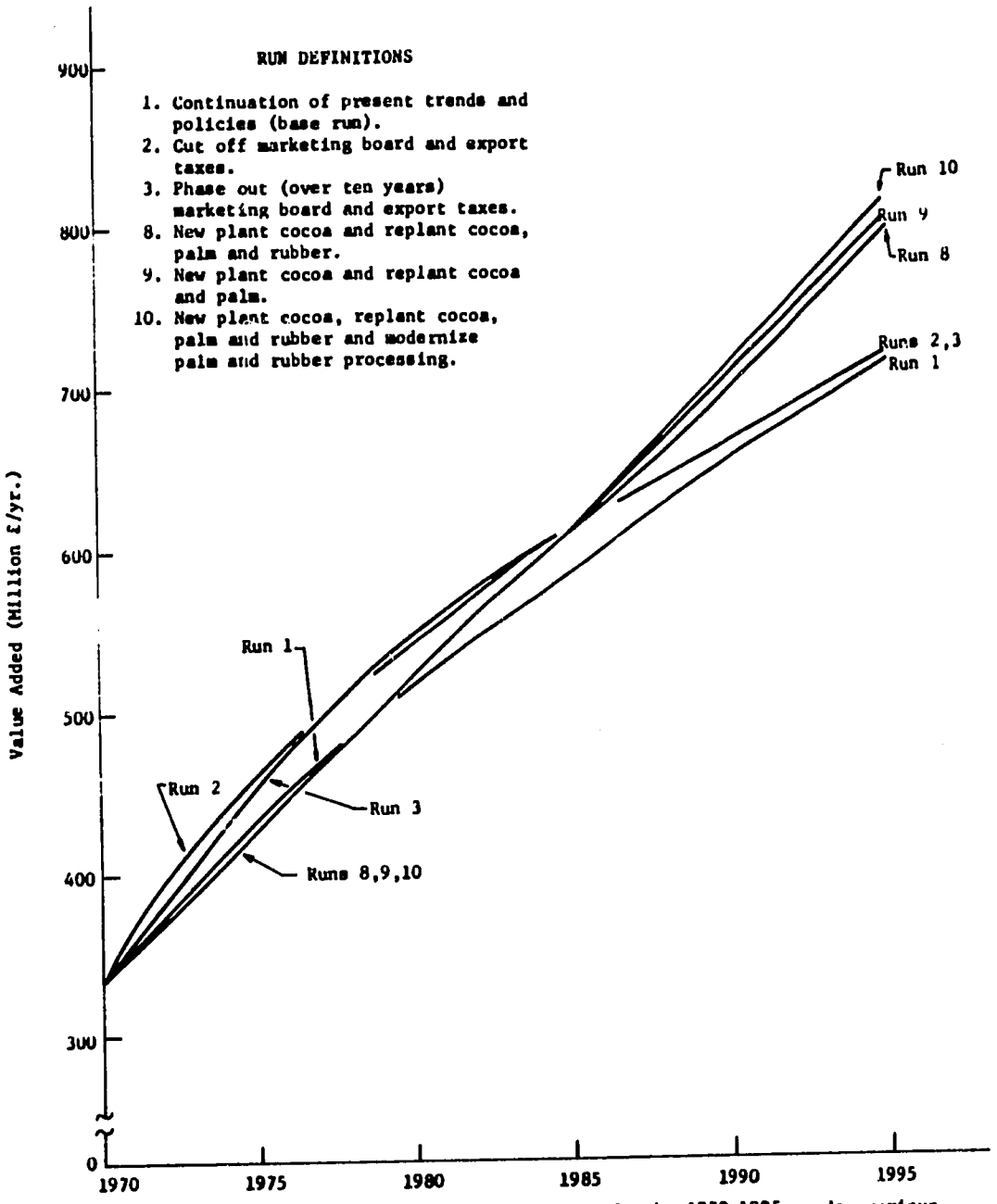


Fig. IV.11 Total value added in agriculture in the South, 1970-1995, under various policy conditions.

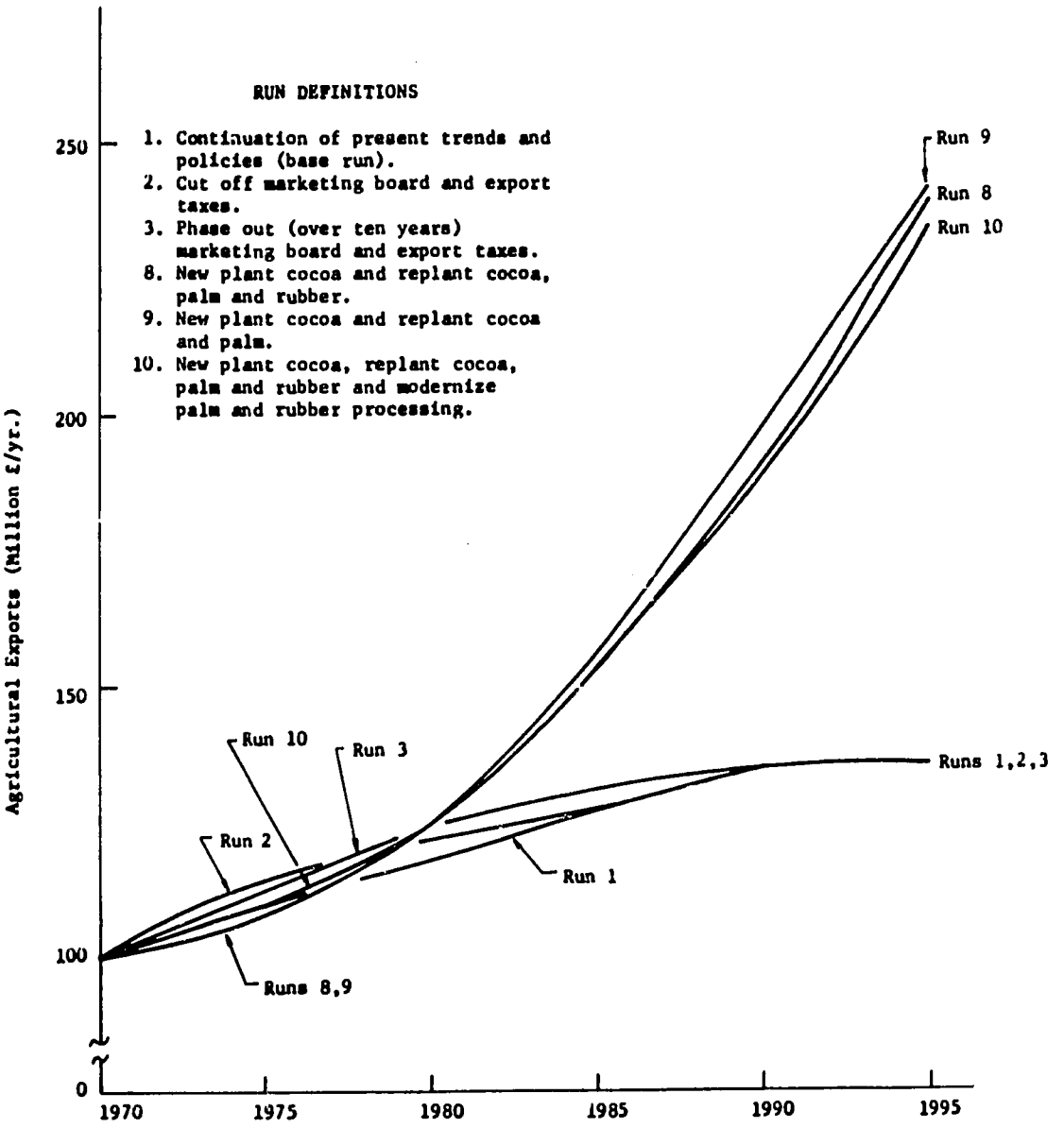


Fig. IV.44 Foreign exchange from southern agricultural exports, 1970-1995, under various policy conditions.

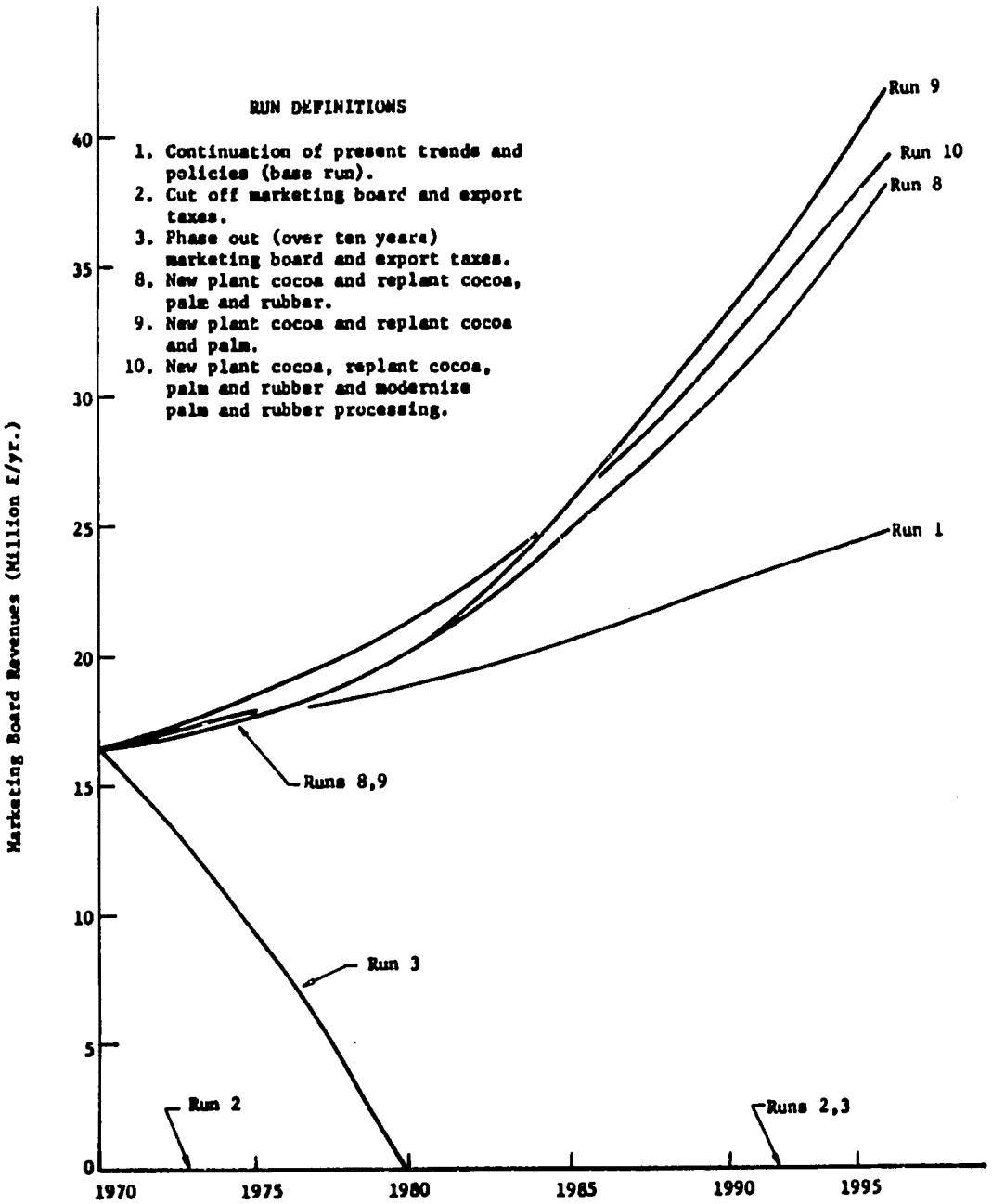


Fig. IV.13 Total marketing board net revenues from southern commodities, 1970-1995, under various policy conditions.

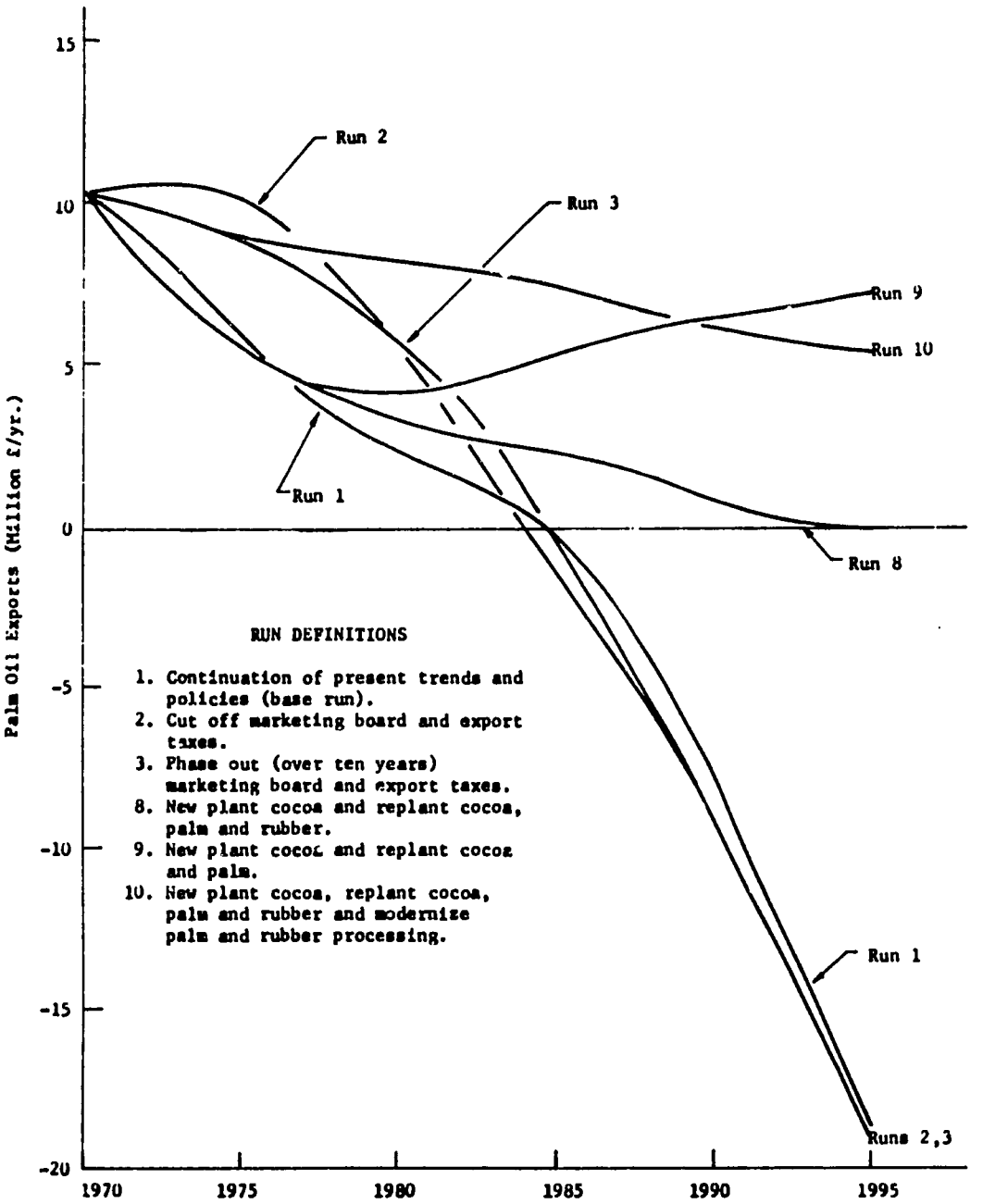


Fig. IV.14 Foreign exchange from palm oil exports, 1970-1995, under various policy conditions.

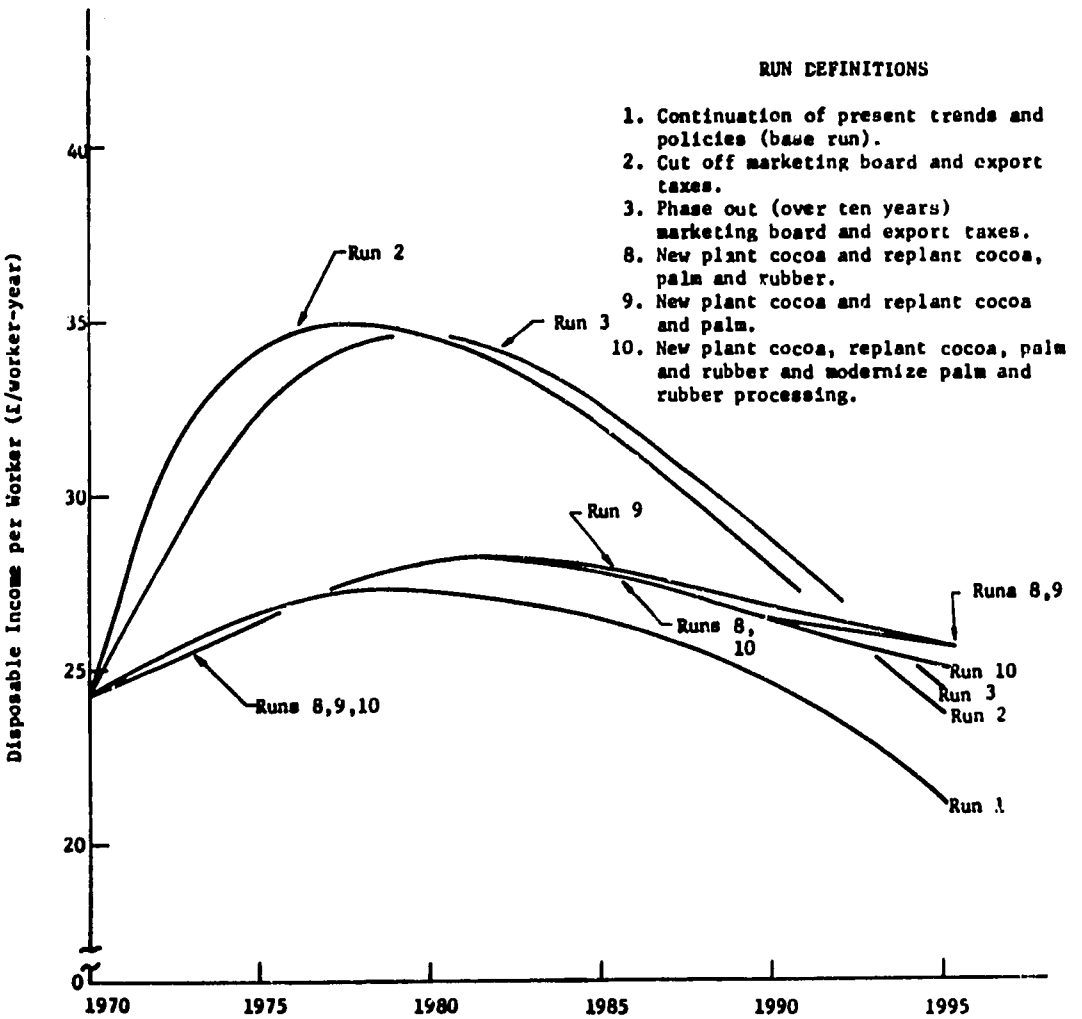


Fig. IV.15 Real disposable income per agricultural worker in the South, 1970-1995, under various policy conditions.

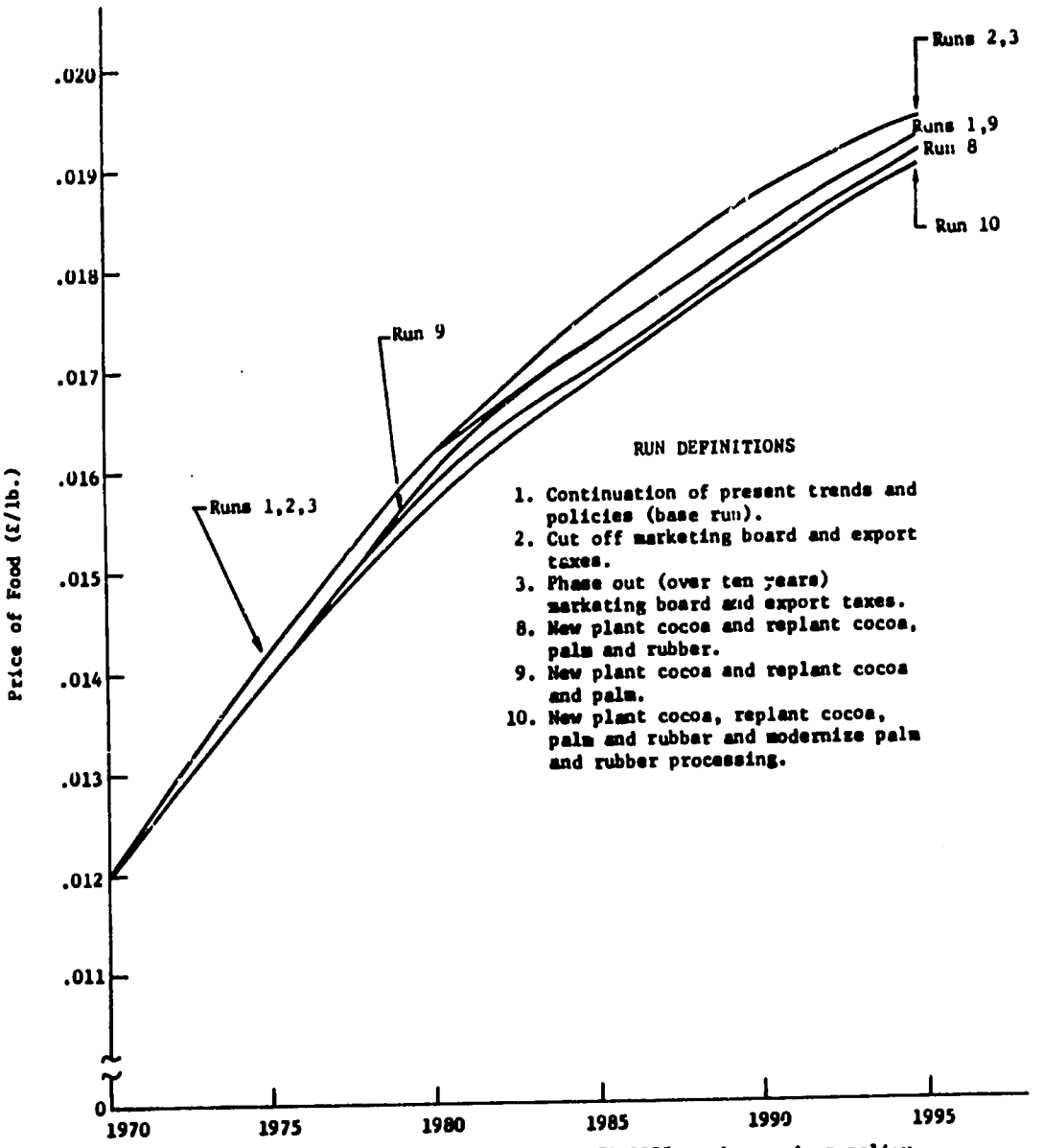


Fig. IV.16 Market price of food in the South, 1970-1995, under various policy conditions.

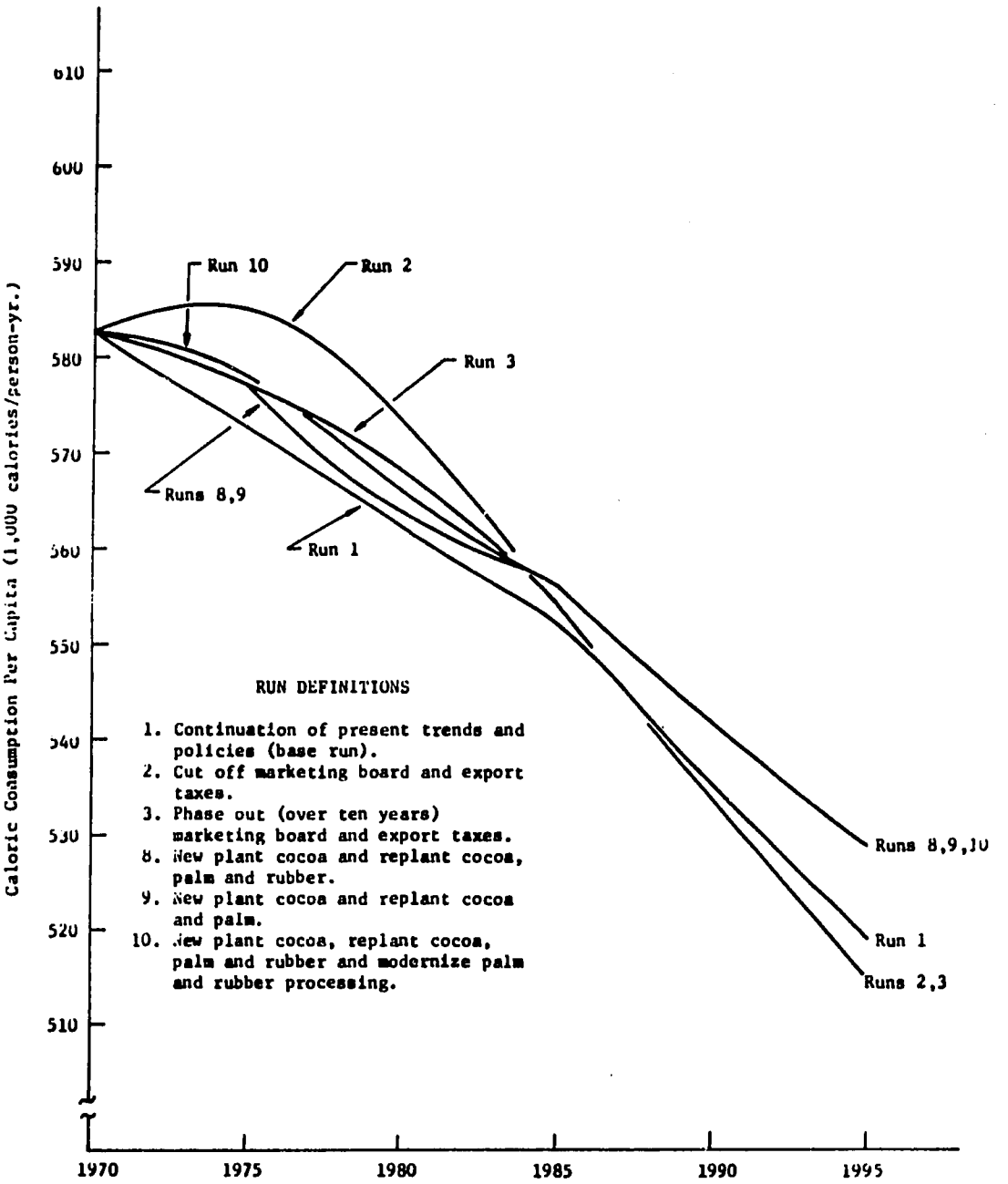


Fig. IV.17 Caloric consumption (of staples) per capita of the southern nonagricultural population, 1970-1995, under various policy conditions.

sheet-making facilities operated on the village level.

Run 9 was an experiment to investigate the consequences of increasing the palm replanting effort at the expense of rubber in the crop sector where the two perennials compete. Indeed, palm oil exports do improve substantially over Run 8 (Figure IV.14). Value added and total exports are also higher in spite of the still traditional rubber production.

It is interesting to note that value added, exports, marketing board revenues and income per worker all are lower in Runs 8 and 9 than in the base run for about the first six to eight years of the simulated time period (1976-1978) before rising to substantially improved levels. This is due to the replanting programs removing trees from production and the gestation lag which occurs before the new trees come into production.

Nonagricultural food consumption is higher in Runs 8, 9 and 10 than in the other runs (Figure IV.17) due to the multiplier effects of increased agricultural incomes (Figure IV.15) on nonagricultural incomes and due to slightly lower food prices (Figure IV.16).

Policies Viewed on the National Level

The fourth set of runs, Run 1, 11, 12, 13, 14 and 15, examines the results of agricultural development policies and programs at the national level. Briefly, Run 1 projects present trends and policies (the base run); Run 11

implements production campaigns in cotton, groundnuts, food grains, cocoa, palm and rubber; Run 12 implements a program to modernize food roots in the Middle Belt in addition to the above programs; Run 13 investigates the effects of, in addition to the programs of Run 11, the diffusion of a further doubling of food grains yields beginning after 1980; Run 14 implements the programs of Run 11 with a cut-off of taxes; and Run 15 does the same as Run 14 except with a phase-out of taxes.

Coupled with the modernization programs, the elimination of marketing board and export taxes substantially enhances the results of the modernization programs in the presence of these taxes. Figures IV.24 and IV.25 indicate that, while both total exports and total imports increase in Runs 14 and 15 compared to Run 11, exports experience a relatively greater rise, leaving Nigeria with a more favorable balance of payments. Similar increases are seen in other variables, such as GDP (gross domestic product, assuming marketing board and export tax revenues are not put to productive use), value added in agriculture, and agricultural exports (Figures IV.18 through IV.21 and IV.23).

Nonagricultural food consumption is higher in Runs 11, 14 and 15, with modernization, than in the base run (Figure IV.27). This is due to the multiplier effect of increased agricultural income on nonagricultural income,

i.e., increasing agricultural demand for consumer goods from the nonagricultural sector.

Run 12 was an attempt to speculate on the consequences of increased production of food root crops in the Middle Belt (assuming improved technology to be available). The indications are that the South would tend to specialize in exports while importing food from the North. Shipments of food increase about 56 percent by 1995 over Run 11. However, this results in much lower food prices (Figure IV.26) rather than the substitution of perennial production for food production; Southern agricultural exports remain virtually the same as Run 11 (Figure IV.21). This can be attributed to the current model's limitations, specifically the one which constrains the transfer of food land to perennial production (Table II.1, Chapter 3). Without this restriction, we would see a move to export specialization in the South in the presence of a secure food supply from the North. The lower food prices do lead to a dramatically higher level of food consumption by the nonagricultural population (Figure IV.27).

An interesting observation can be made concerning agricultural value added and gross domestic product (GDP) (Figures IV.18, IV.19 and IV.23). Such a large proportion of value added and GDP is derived from food production (about 80 percent for agricultural value added and 30 percent for GDP) that these variables at current prices

are depressed in Runs 11 and (particularly) 12 due to lower food prices (Figure IV.26). In "real" terms (i.e., relative to food prices in the base run), Runs 12 and 11 would show even greater improvements over Run 1, with Run 12 probably taking the lead.

Modern food grains yields in the North were gradually doubled in Run 13 over a four to five-year period after 1980 (i.e., to five times the current traditional yields) to investigate the consequences of the introduction and diffusion of new technologies expected to be developed during the 1970's. The results show that exports (Figure IV.20) and marketing board revenues (Figure IV.22) do improve substantially over Run 11 after 1980. Value added also increases slightly (Figure IV.18). However, by the end of the simulated time period, the results of Run 13 and Run 11 become quite similar. The initial increase in cash crop acreage, resulting from labor and land freed from subsistence food production, is later reduced as the population continues to expand and more food land is required. Value added in Run 13 (Figure IV.18) eventually falls below that of Run 11 because of the somewhat lower food prices. The effect on southern exports is nil (Figure IV.21), while the lower food prices cause southern value added to fall slightly and nonagricultural food consumption to rise.

Note that value added in the North rises more than twice as fast as in the South (Figures IV.18 and IV.19).

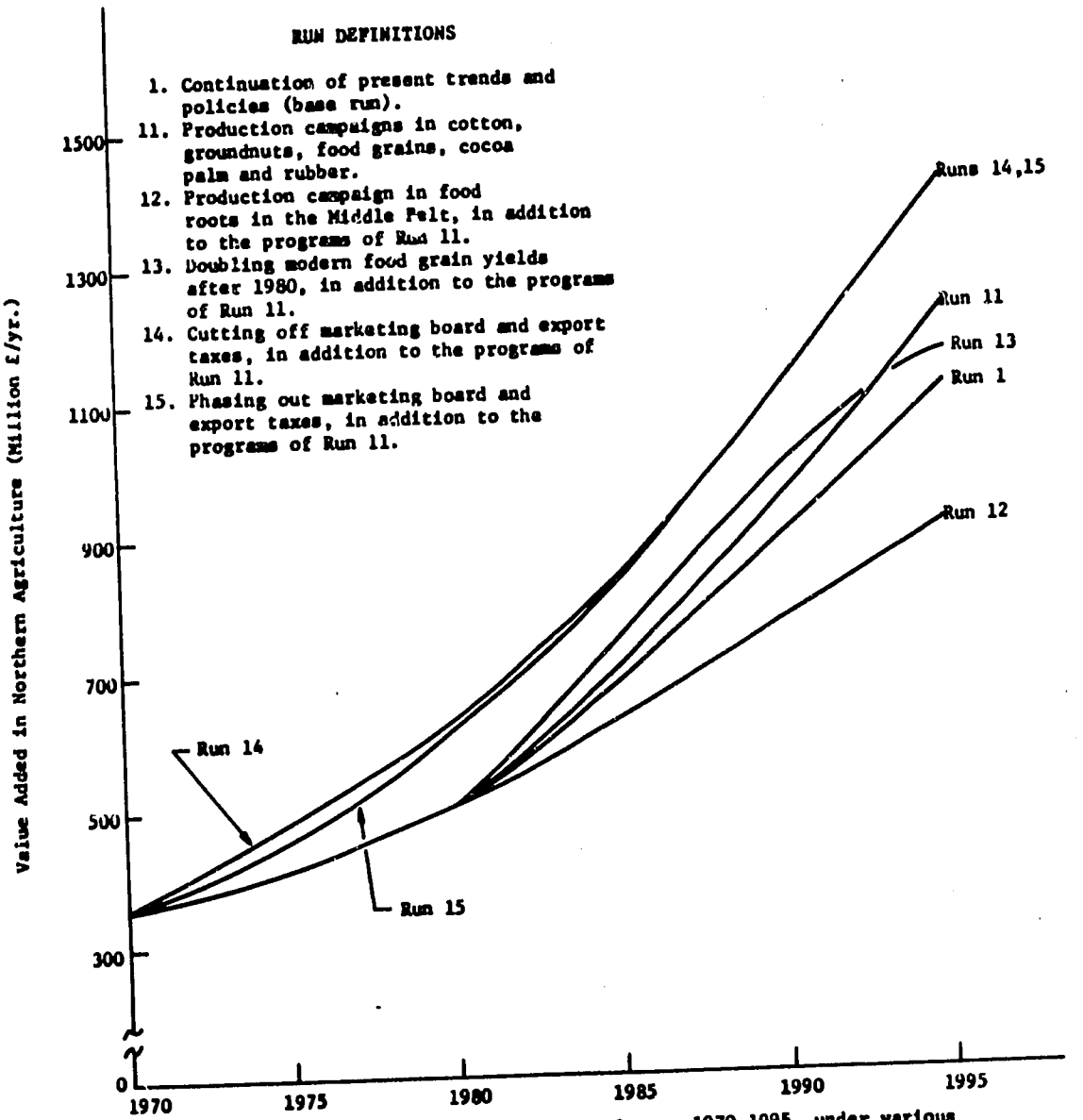


Fig. IV.18 Total value added in northern agriculture, 1970-1995, under various policy conditions.

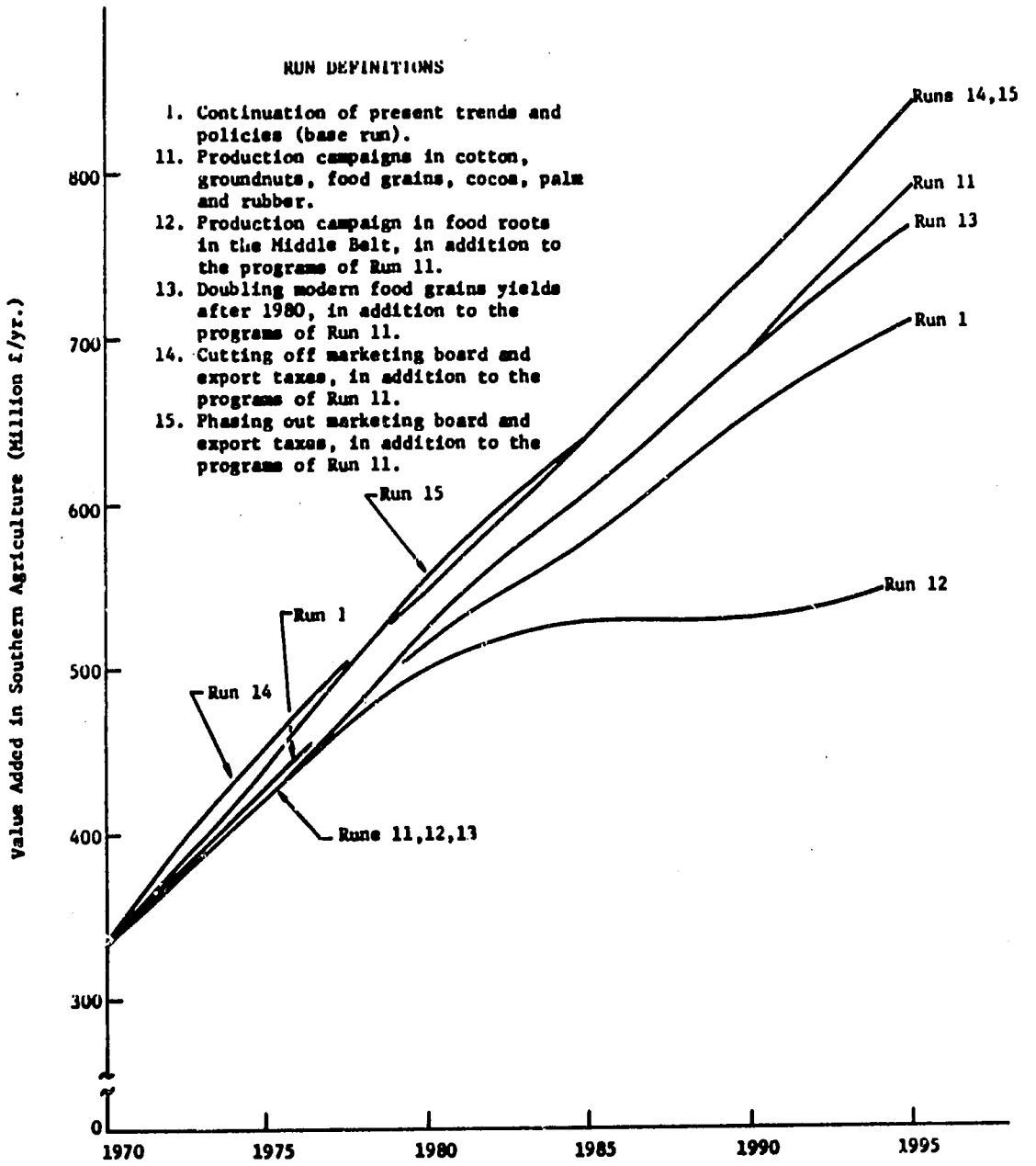


Fig. IV.19 Total Value added in southern agriculture, 1970-1995, under various policy conditions.

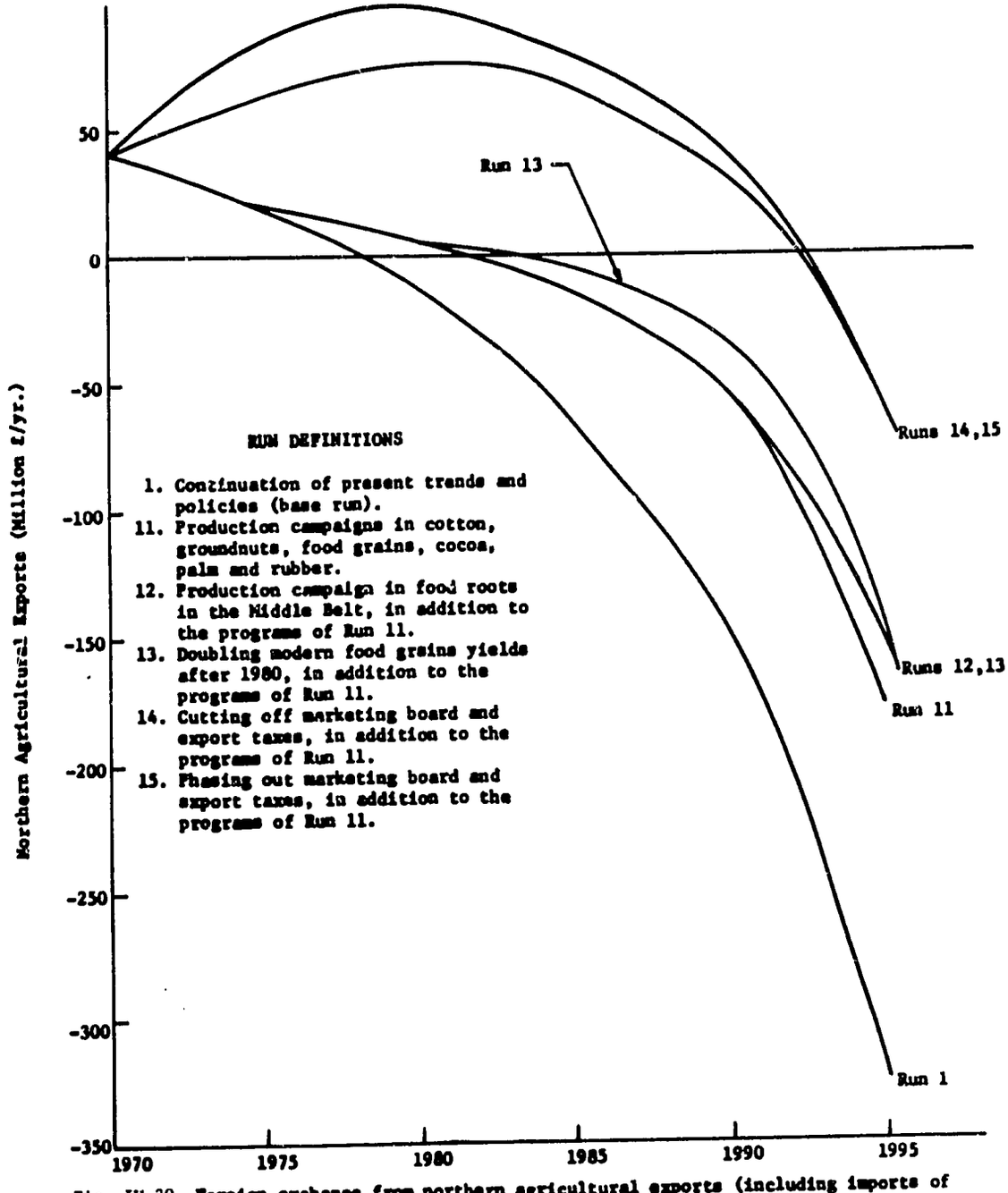


Fig. IV.20 Foreign exchange from northern agricultural exports (including imports of cotton and beef), 1970-1995, under various policy conditions.

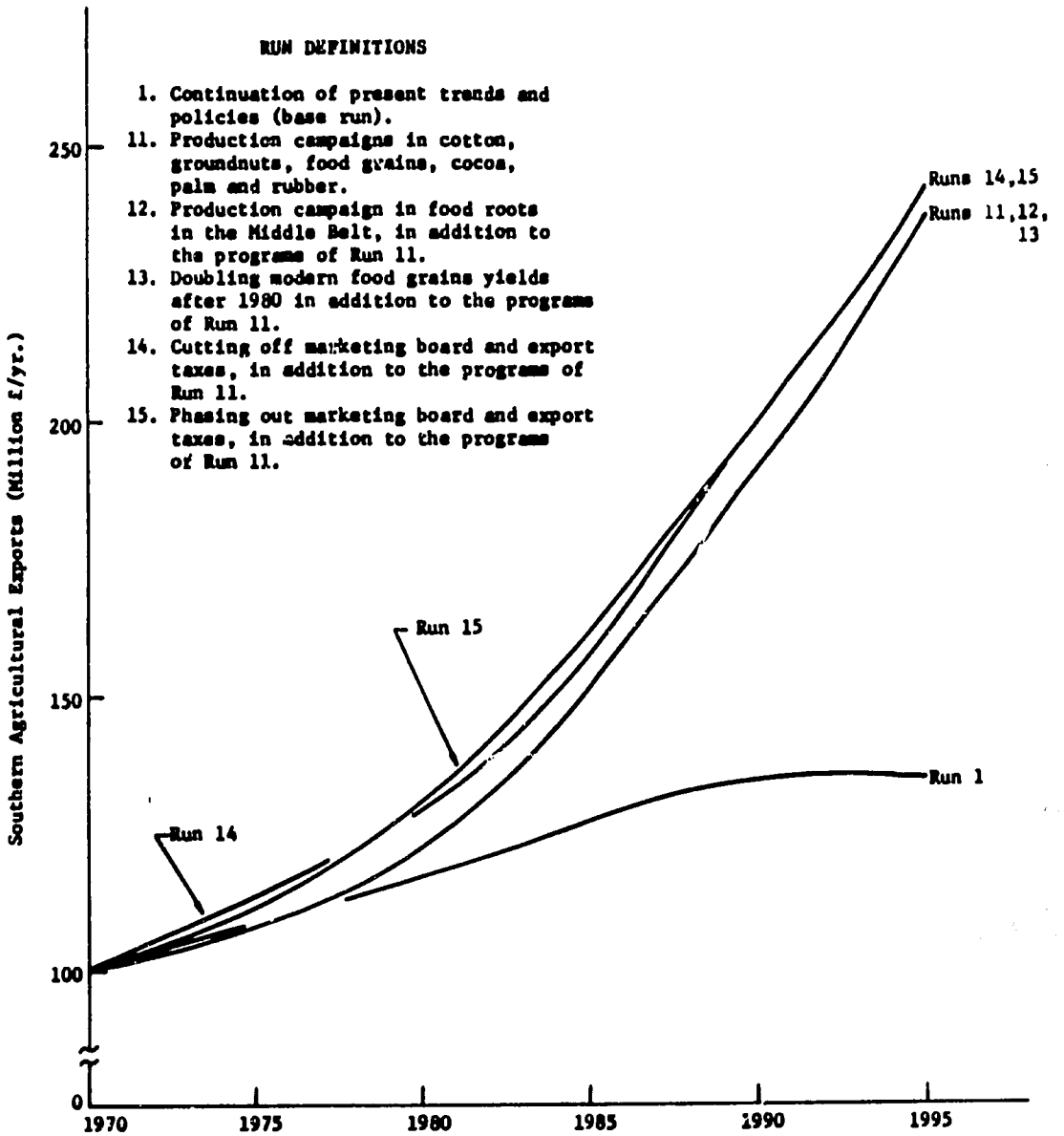


Fig. IV.21 Foreign exchange from southern agricultural exports, 1970-1995, under various policy conditions.

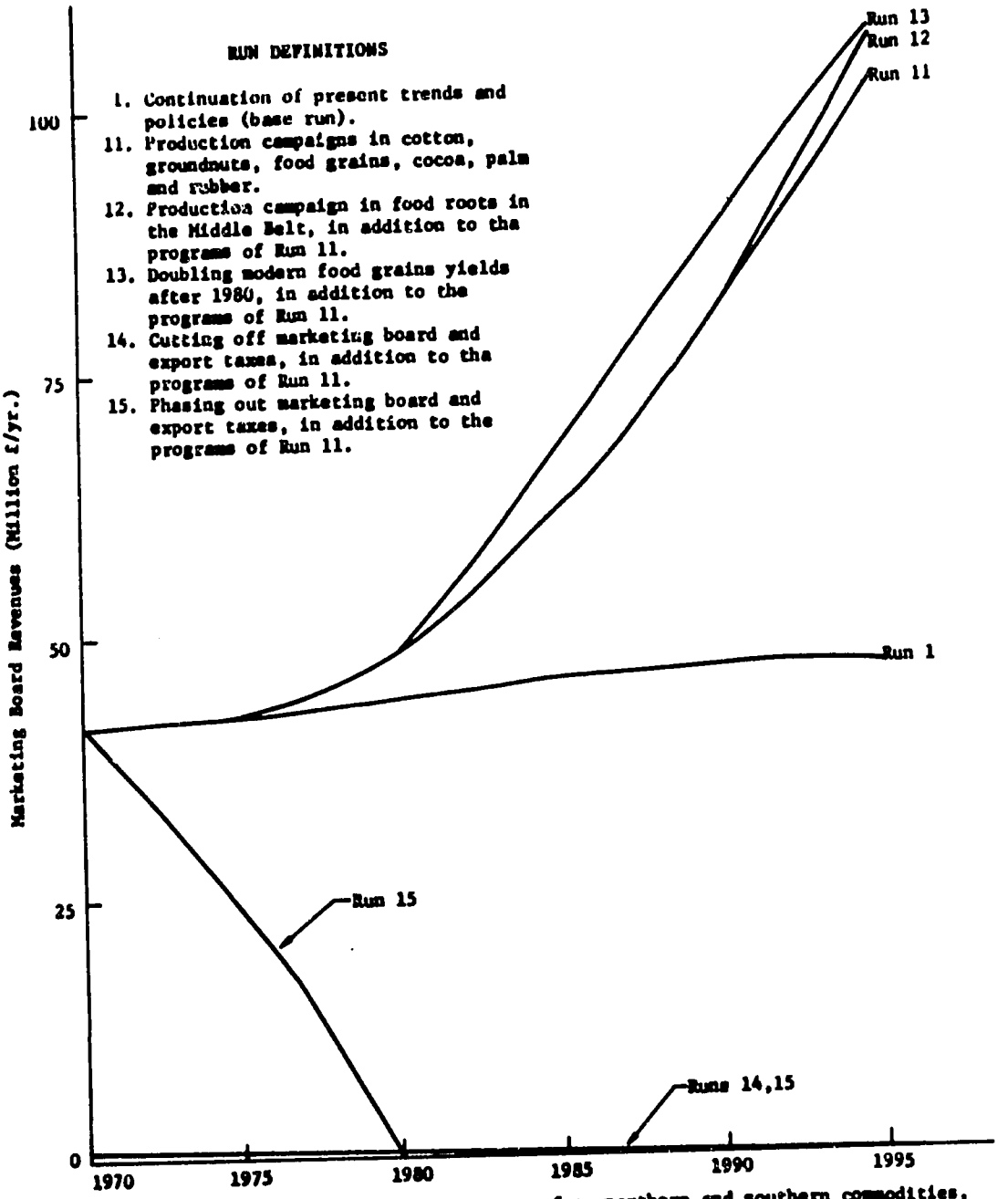


Fig. IV.22 Total marketing board net revenues from northern and southern commodities, 1970-1995, under various policy conditions.

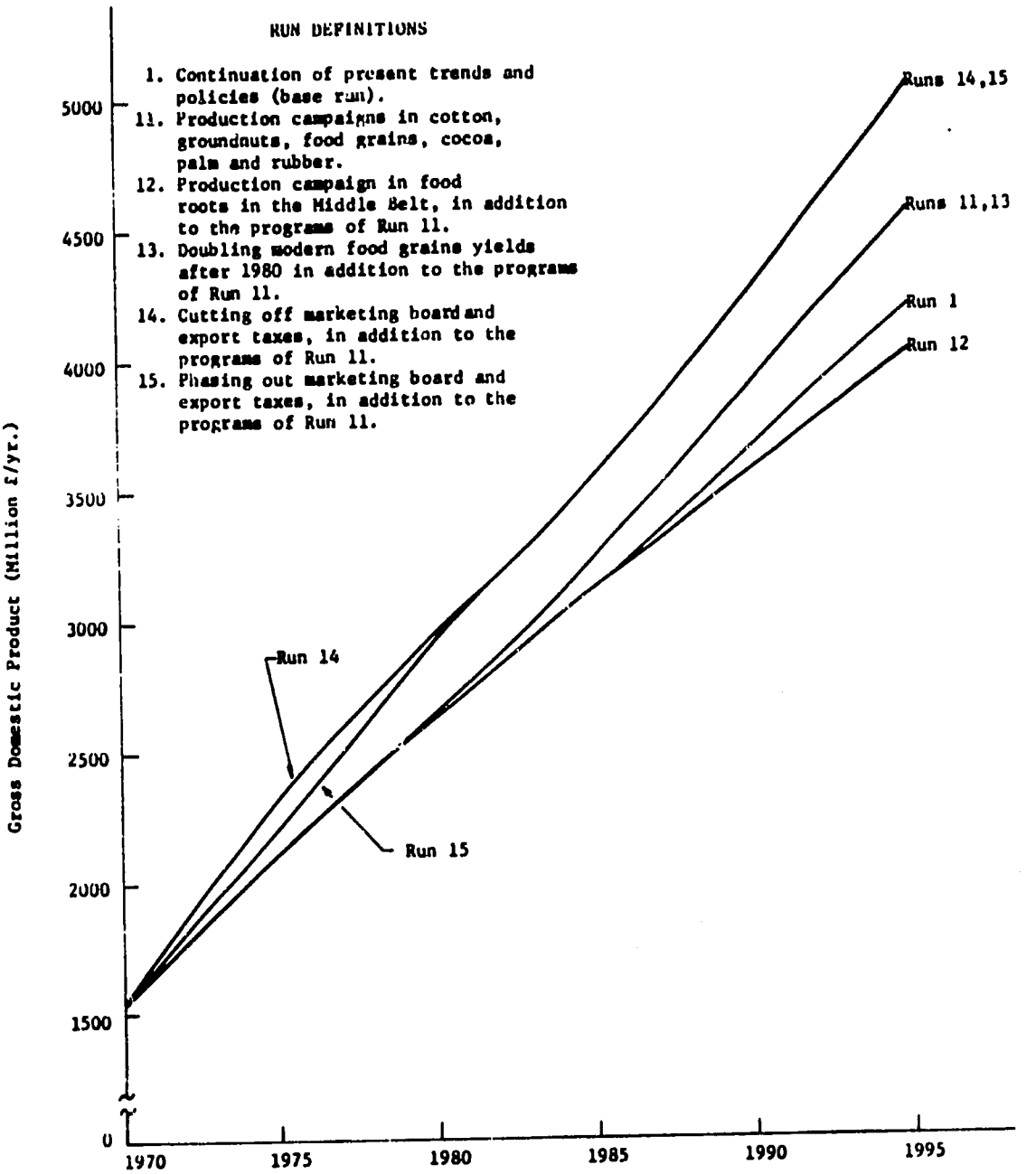


Fig. IV.23 Gross domestic product (assuming marketing board and export taxes are not put to productive use), 1970-1995, under various policy conditions.

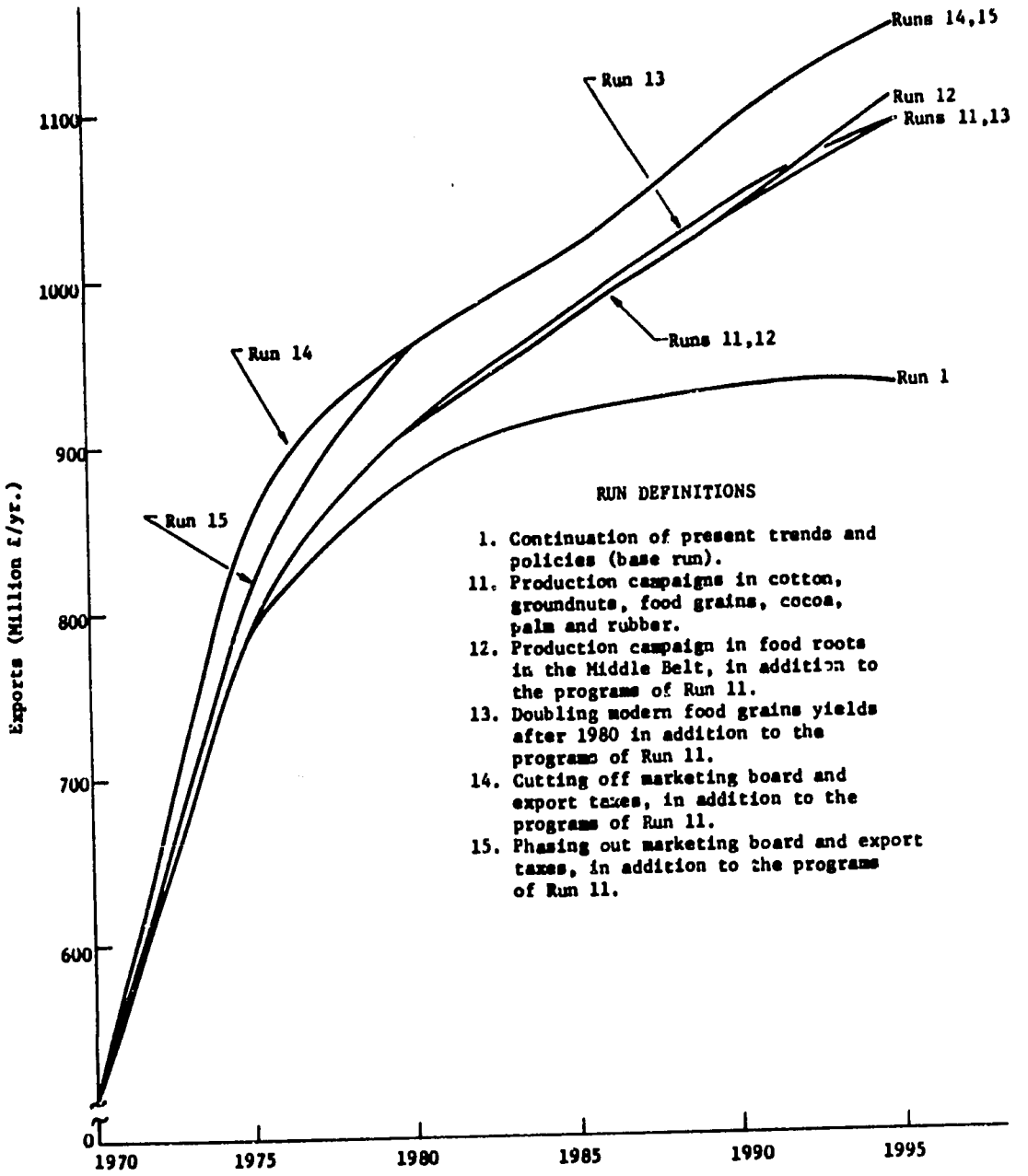


Fig. IV.24 Total exports (agricultural and nonagricultural), 1970-1995, under various policy conditions.

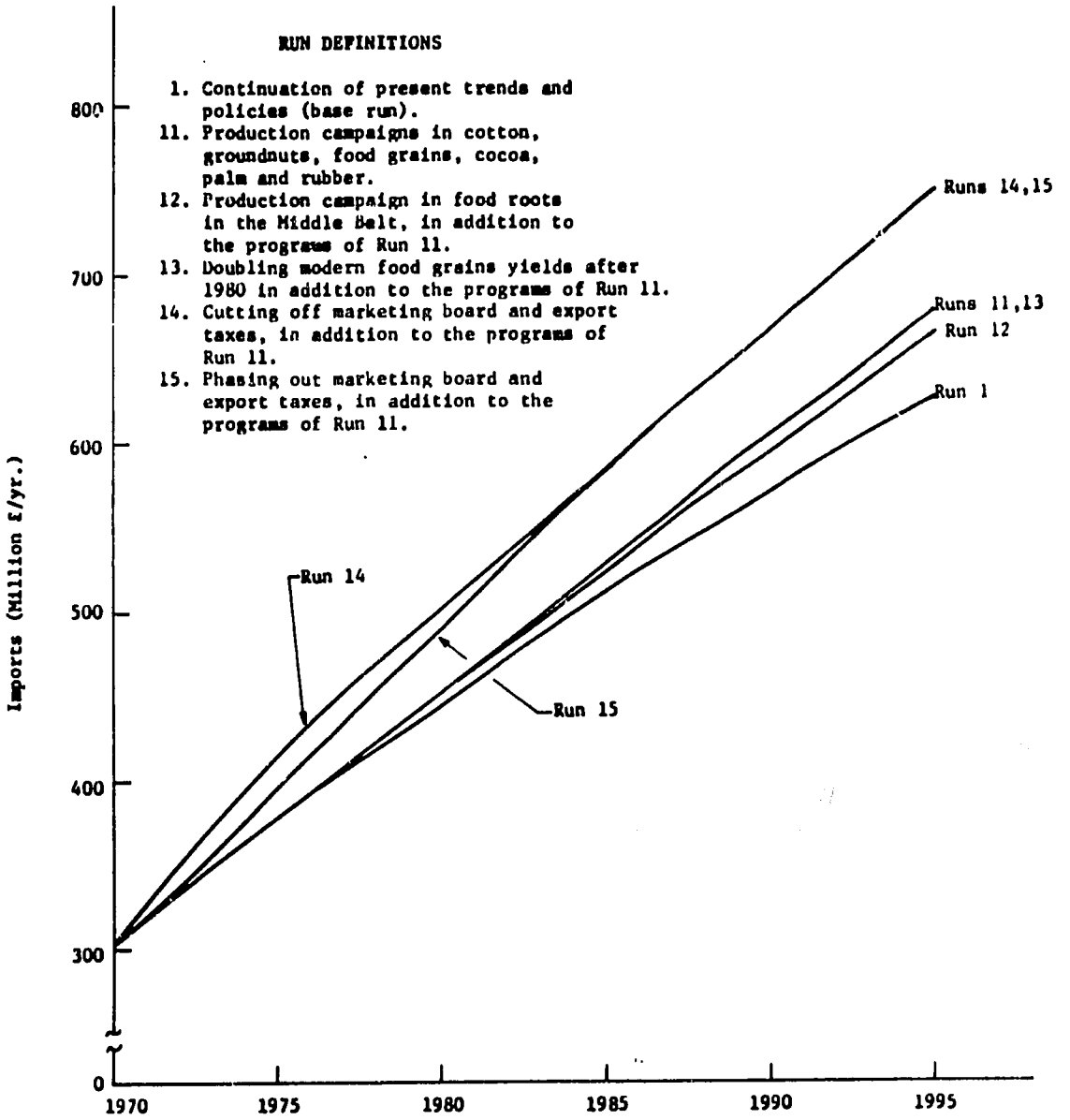


Fig. IV.25 Total imports, 1970-1995, under various policy conditions.

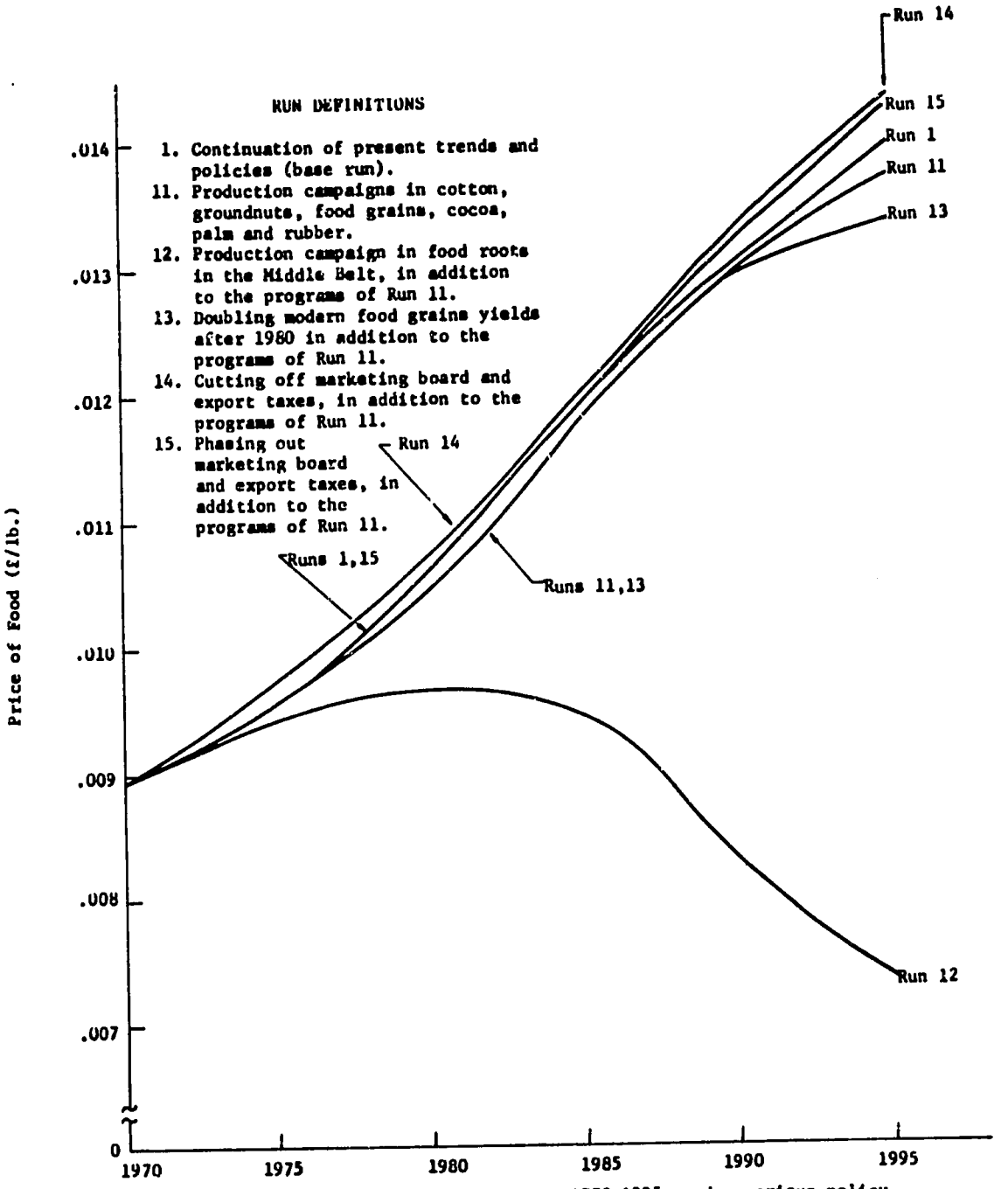


Fig. IV.26 Market price of food in the North, 1970-1995, under various policy conditions.

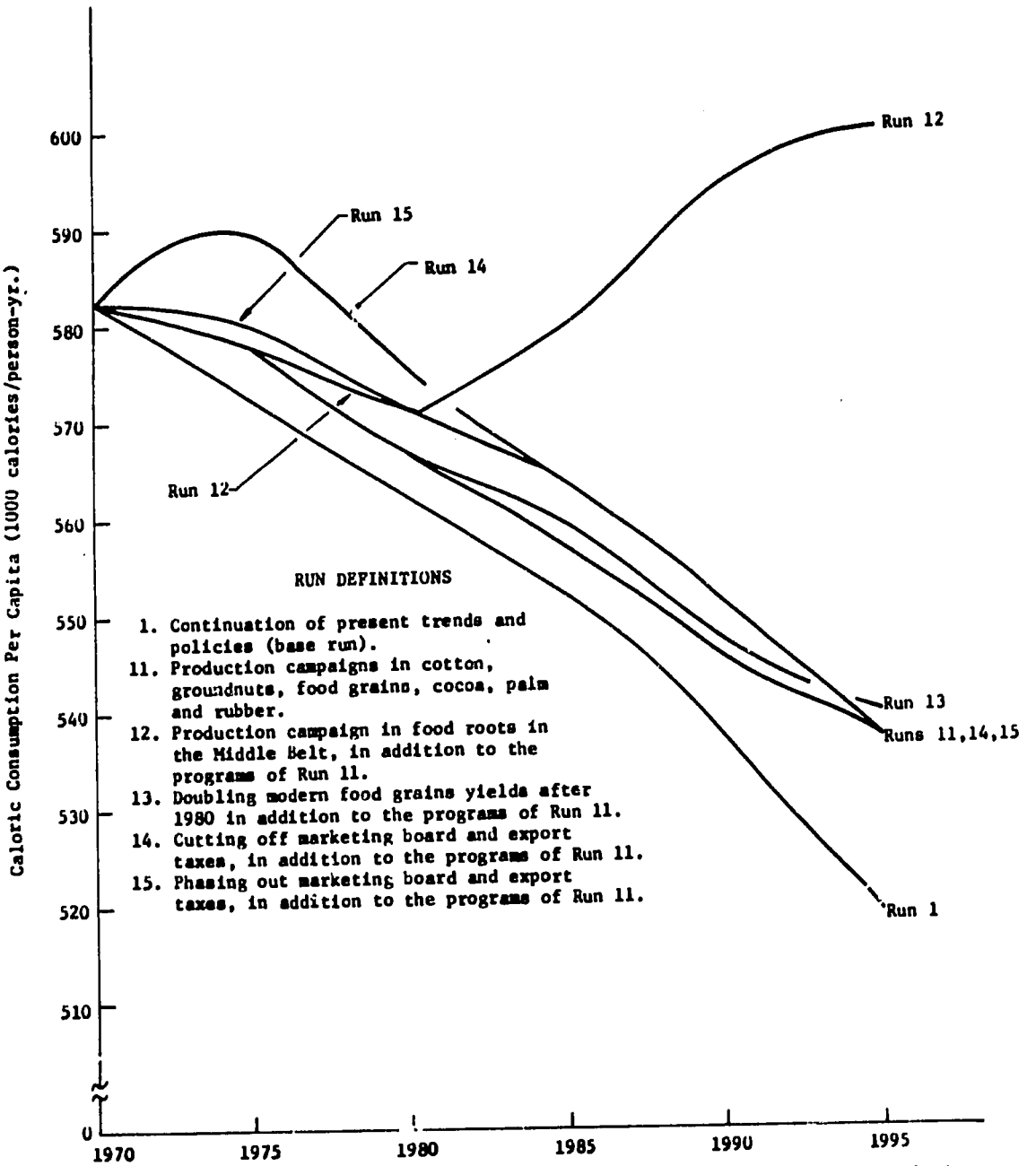


Fig. IV.27 Caloric consumption (of staples) of the southern nonagricultural population, 1970-1995, under various policy conditions.

This is due to the much more dominant role food plays in northern agriculture. In the base run, food accounts for over 90 percent of value added in the North and only about 75 percent in the South. Rising food prices and steady or falling export prices account for the rapid rise in northern value added compared to the South.

Varying Production Campaign Budget Levels

The fifth set of runs, Runs 1, 11, 16 and 17, investigates the relative effects of various levels of production campaign budgets. Run 1 is the base run where no campaigns are carried out. Run 16 spends £20 million on five programs in the South--30 percent to each of cocoa replanting and palm replanting where palm doesn't compete with other perennials (essentially the eastern states), 20 percent to rubber replanting, 10 percent to cocoa new planting, and 10 percent to palm replanting where palm competes with rubber--and £20 million on three programs in the North--40 percent to each of groundnut and food grains modernization and 20 percent to cotton modernization. Run 11 budgets £40 million in each region for the same programs in the same proportions, and Run 17 doubles the budget again to £80 million, still for the same programs and in the same proportions.

Exports (Figure IV.28) and marketing board revenues (Figure IV.29) are the variables which most directly reflect increased export production resulting from the modernization

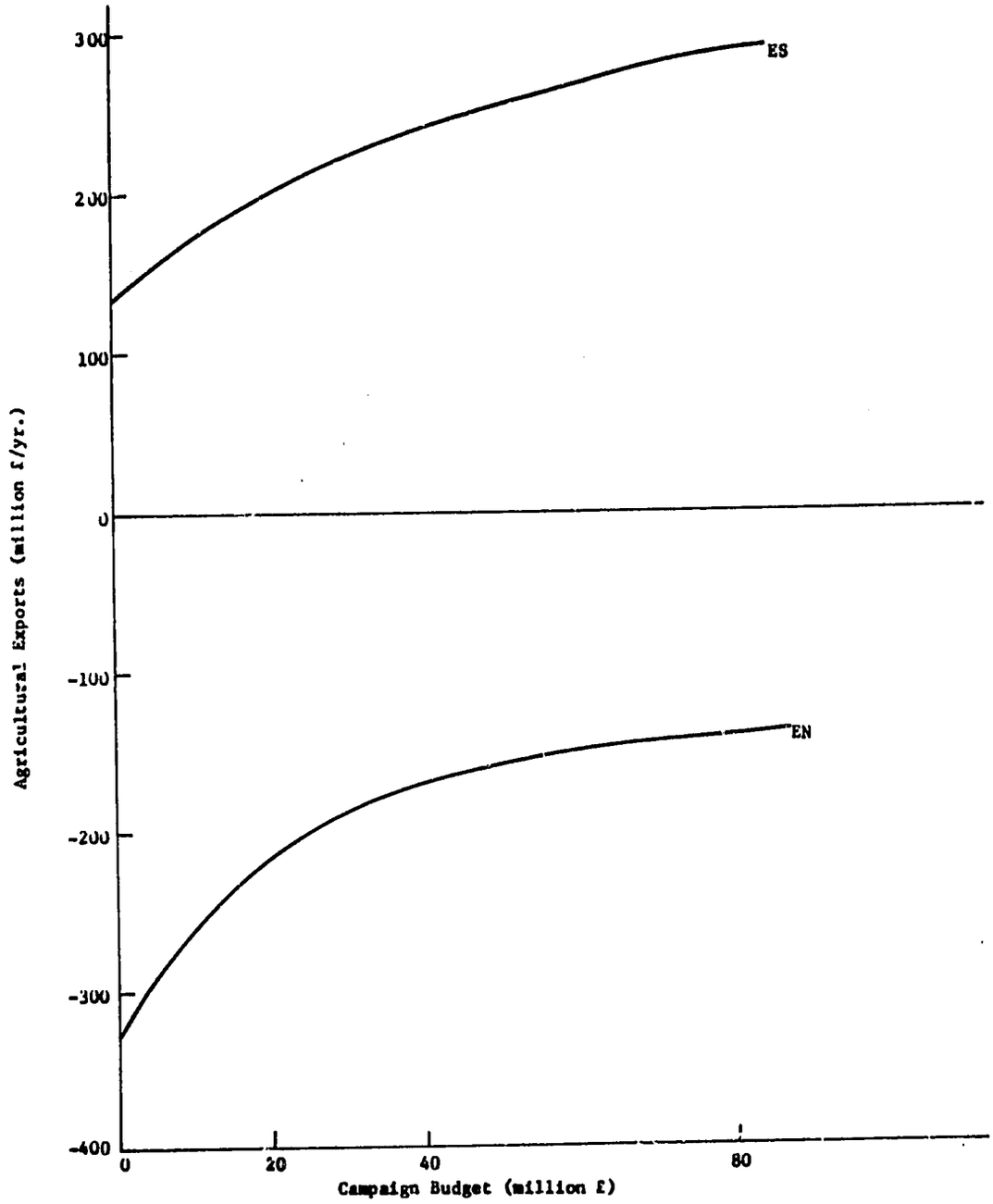


Fig. IV.28 Agricultural exports in the North (including beef and cotton imports) (EN) and South (ES), in 1995, under varying production campaign budgets.

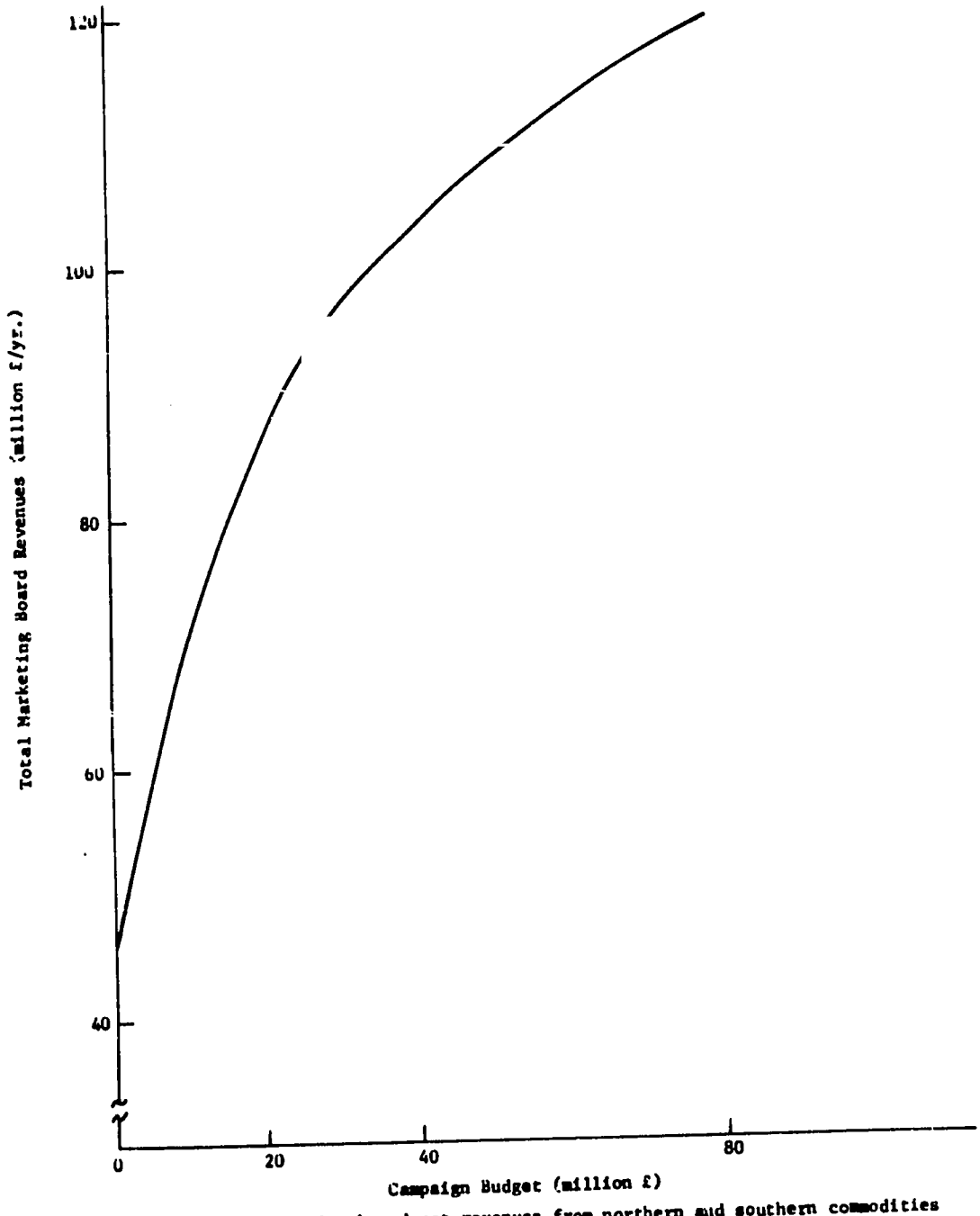


Fig. IV.29 Total marketing board net revenues from northern and southern commodities in 1995 under varying production campaign budgets.

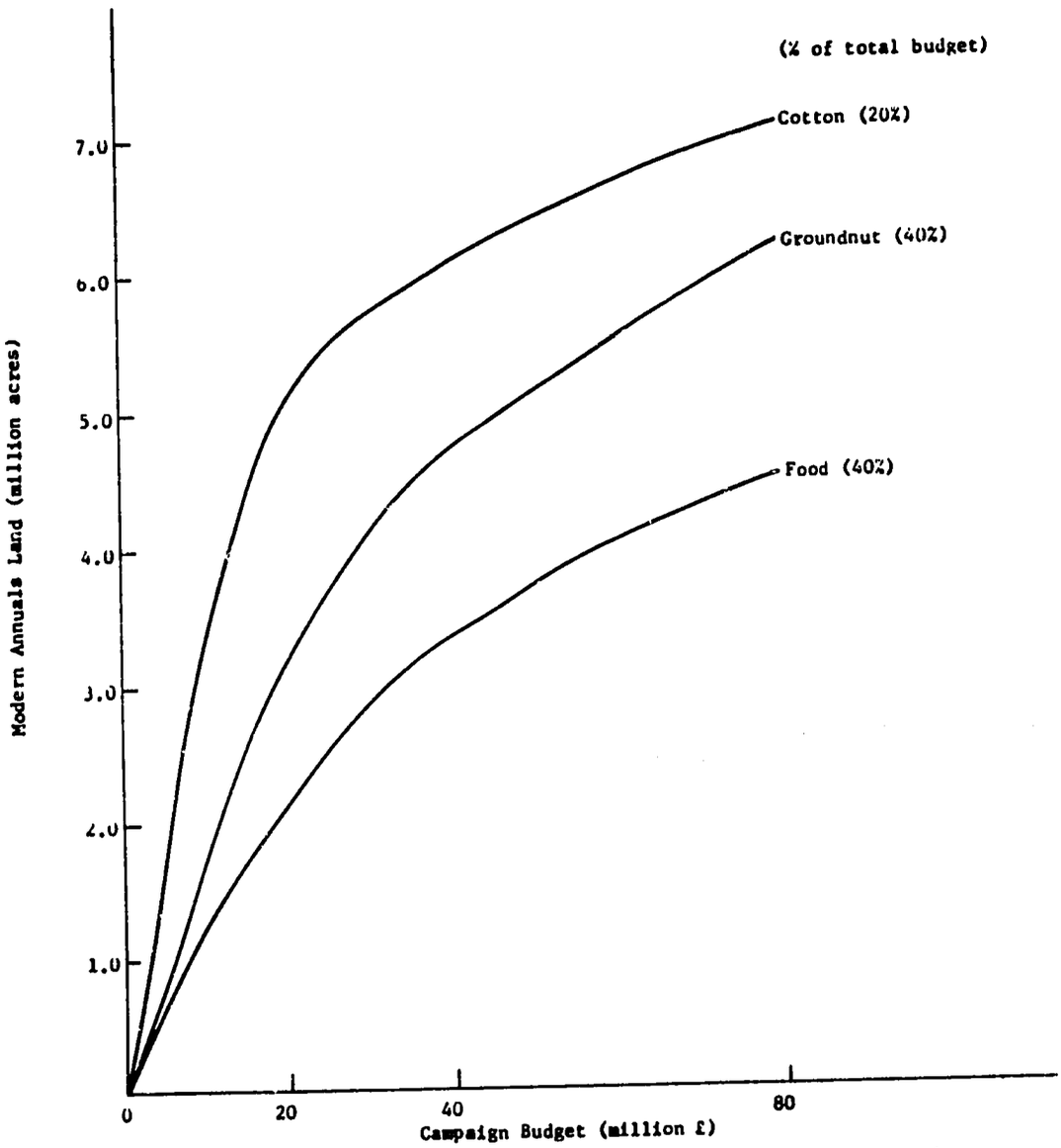


Fig. IV.30 Modern annuals cotton, groundnut and food land in 1995 under varying production campaign budgets.

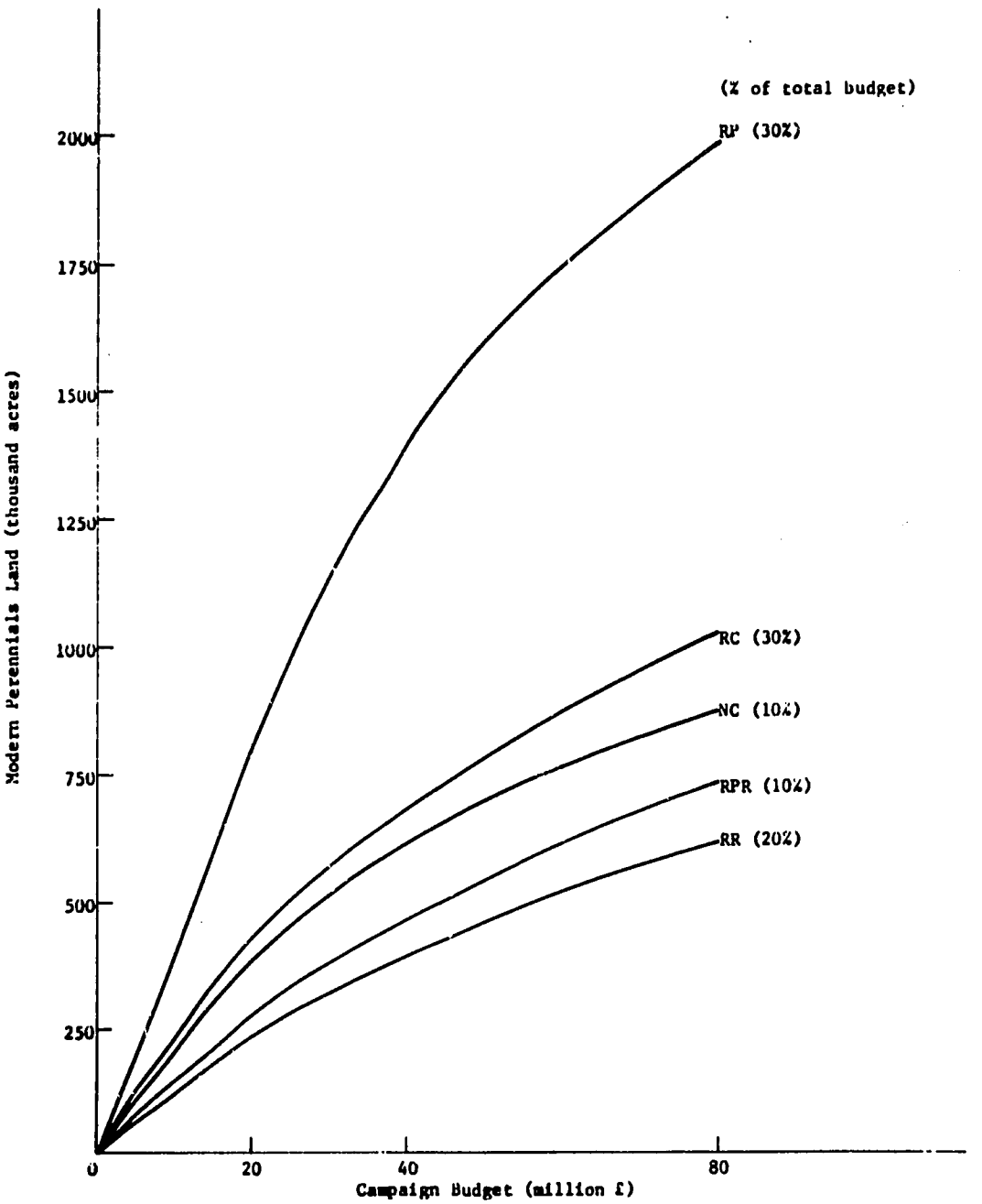


Fig. IV.31 Modern perennials land in new planted cocoa (NC), replanted cocoa (RC), replanted palm where no other perennial competition (RP), replanted palm where rubber competition (RPR) and replanted rubber (RR) in 1995 under varying production campaign budgets.

programs. Interestingly, they indicate diminishing returns for larger campaign efforts. Thus, increasing the modernization budget from £20 million to £40 million increases foreign exchange and marketing board revenues by about £70 million and £14 million, (or £3.5 and £.7 per pound of increased budget), respectively. A further doubling of the effort (i.e., another £40 million) would only return an additional £75 million and £17 million in foreign exchange and marketing board revenues (or about £1.9 and £.4 per pound of increased budget), respectively.

Figures IV.30 and IV.31 portray the acreage of each crop in modern production in 1995 resulting from various levels of production campaign budgets. All commodities exhibit the same diminishing returns in foreign exchange and marketing board revenues discussed above.

Conclusions

The major conclusion to be drawn from the above results is that a technological transformation of agricultural export crop production is necessary for sustained growth[1/]. Other development policies show only short run benefits which are eventually eaten up by continued population growth, by activated land constraints and by declining

---

1/ This conclusion is of course dependent on the model's validity and is limited to the policies and programs tested. It is not inconceivable that there may be some other route to sustained growth than the one indicated here.

yields of aging perennials. This was true of the tsetse fly eradication program, where initial gains were later lost to a growing cattle population and to expanding crop acreages. It was also true of the elimination of marketing board and export taxes, where land constraints and declining yields in the South eventually nullified positive results of the higher producer prices. And it was also true of the food grains modernization programs in the North, where an expanding population eventually reversed the gains made in the increased availability of land and labor for export crop production. Only production campaigns to modernize the production of export crops with the introduction of high-yielding seed variates and improved cultural practices had beneficial consequences which were maintained in the long run.

Other conclusions can be made from the analysis concerning interregional and intersectoral interactions. North-South shipments of food do play a substantial role in supplying the southern population, and the indications are that there exists a potential for regional specialization, wherein the northern Middle Belt area (where roots and tubers--the primary components of southern staple consumption--can be grown) would grow food for a South which would specialize in export perennial crop production.

Interactions between the nonagricultural and agricultural sectors are also strong and indicate that

agricultural development can also lead to growth in the nonagricultural sector. For example, rising agricultural incomes mean an increasing demand for nonagricultural consumer and investment goods which means more employment and higher incomes in the nonagricultural sector. This in turn means greater nonagricultural demands for agricultural products (food and raw materials) and thus more agricultural income. And so it goes. This is the multiplier effect referred to in the analysis[1/].

A final observation that can be made from the above policy analysis concerns the production campaign budget levels. Specifically, they show diminishing marginal returns. That is, as the campaigns are intensified (the budgets are incremented), resulting increments in output criteria (such as exports) become less and less.

Policy Sensitivity

Each of the three southern regional production campaigns examined in the last section (Runs 8, 9 and 10; Table IV.1) were tested for sensitivity to 29 land allocation parameters. Many other parameters could have also been investigated, including those tested in Chapter 9, but the 29 were chosen for illustrative purposes because they are directly related to the policies under consideration.

1/ See [4] for a fuller discussion of this phenomenon.

The consequences of parameter variations on the results of the three policy runs are examined in terms of three output criteria--accumulated agricultural exports (AFORXS), accumulated agricultural value added (ATVAS), and accumulated marketing board revenues (ATRMBS).

The policy runs used here are exactly the same as Runs 8, 9 and 10 of the last section with one major exception--here, the southern submodel was run independently of the rest of the Nigeria model and thus without interregional and intersectoral interactions[1/]. The results reported here (Table IV.2) are thus somewhat distorted in the absence of shipments of food from the North. For example, the 1995 price of food in the base run (Run 1) of the last section was .0193 £/lb. (Figure IV.15), while here it turned out to be .0519 £/lb.! Similar exaggerations occur when comparing the price of food in Runs 8, 9 and 10 here and in the last section. Nevertheless, if the results given below are not comparable with those of the previous analysis, they are comparable among the three policy stipulations here and thus serve their illustrative purposes.

The results are tabulated in Table IV.2 for AFORXS, ATVAS and ATRMBS, respectively. A quick look at the table will show that variations in the proportions of traditional

---

1/ The current model does not provide for these interactions to be exogenously supplied when a regional submodel operates alone. Such provision is on the agenda for further development.

Table IV.2. Results of policy sensitivity tests under three policy situations.

Run	Parameter Tested	Parameter Definition	Test Run Value	Base Run Value	Performance Criteria: Agricultural Exports (AFORXS) (billion £) — Policy Runs[a] 8	9	10	Agricultural Value Added (ATVAS) (billion £) — Policy Runs[a] 8	9	10	Marketing Board Revenues (ATRMBS) (billion £) — Policy Runs[a] 8	9	10
0	Base run	-	-	-	3.704	3.767	3.685	21.29	21.43	20.81	.6012	.6174	.6195
1	CIUDT(2,1)	Diffusion parameter for replanting cocoa (info. units/acre)	.01	.005	3.742	3.805	3.72[illegible]	21.09	21.23	20.63	.6080	.6242	.6262
2	CIUDT(2,2)	Diffusion parameter for replanting palm (Palm Sector) (info. units/acre)	.006	.003	3.836*	3.912*	3.873*	20.77	20.91	20.37	.6248	.6435	.6534
3	CIUDT(2,3)	Diffusion parameter for replanting rubber (info. units/acre)	.02	.01	3.701	3.767	3.681	21.09	21.43	20.63	.6011	.6174	.6192
4	CIUDT(2,4)	Diffusion parameter for replanting palm (Rubber Sector) (info. units/acre)	.006	.003	3.732*	3.843*	3.746*	21.07	21.30	20.63	.6063*	.6312*	.6306*
5	CIUDB(2)	Diffusion parameter for new planting cocoa (info. units/acre)	.004	.002	3.953	4.013	3.929	21.39	21.53	20.92	.6459	.6617	.6635
6	CIUDB(5)	Diffusion parameter for new planting palm (Palm Sector) (info. units/acre)	.004	.002	3.718	3.792	3.688	21.33	21.49	20.82	.6037*	.6220*	.6206*
7	CIUDB(8)	Diffusion parameter for new planting rubber (info.units/acre)	.004	.002	3.710	3.767	3.688	21.27	21.43	20.79	.6011	.6174	.6197
8	CIUDB(10)	Diffusion parameter for new planting palm (Rubber Sector) (info. units/acre)	.004	.002	3.711	3.795	3.686	21.29	21.47	20.81	.6027*	.6226*	.6197*
9	CEFF	Extension agent promotion efficiency (acres/agent-yr.)	750.	500.	3.840	3.902	3.822	21.23	21.47	20.77	.6223	.6418	.6422
10	THRT(2,1)	Profitability response threshold for replanting cocoa	.45	.3	3.595	3.658	3.575	21.30	21.44	20.81	.5815	.5978	.5998
11	THRT(2,2)	Profitability response threshold for replanting palm (Palm Sector)	.45	.3	3.703	3.764	3.684	21.29	21.43	20.81	.6010	.6168	.6194

Table IV.2. (cont'd.)

Run	Parameter Tested	Parameter Definition	Test Run Value	Base Run Value	Performance Criteria: Agricultural Exports (AFORXS) (billion £) Policy Runs[a] 8	9	10	Agricultural Value Added (ATVAS) (billion £) Policy Runs[a] 8	9	10	Marketing Board Revenues (ATRMBS) (billion £) Policy Runs[a] 8	9	10
12	THRT(2,3)	Profitability response threshold for replanting rubber	.45	.3	3.680	3.767	3.676	21.50*	21.43*	21.01*	.6017	.6174	.6207
13	THRT(2,4)	Profitability response threshold for replanting palm (Rubber Sector)	.45	.3	3.703	3.762	3.684	21.29	21.43	20.81	.6011	.6166	.6194
14	SHPT(2,1)	Profitability rate of response for replanting cocoa	.1	1.	3.563	3.626	3.545	21.37	21.52	20.88	.5759	.5922	.5943
15	SHPT(2,2)	Profitability rate of response for replanting palm (Palm Sector)	.1	1.	3.625	3.661	3.621	21.70	21.71	21.00	.5926	.5986	.6081
16	SHPT(2,3)	Profitability rate of response for replanting rubber	.1	1.	3.681	3.767	3.676	21.49*	21.43*	21.00*	.6016	.6174	.6206
17	SHPT(2,4)	Profitability rate of response for replanting palm (Rubber Sector)	.1	1.	3.689*	3.669*	3.664*	21.42	21.58	20.88	.5983	.5996	.6157
18	THRB(2)	Profitability response threshold for new planting perennials	5.	.5	3.704	3.767	3.683	21.29	21.43	20.80	.6012	.6174	.6192
19	SHPB(2)	Profitability rate of response for new planting perennials	.03	.3	3.650*	3.703*	3.673*	21.25	21.37	20.79	.5915	.6059	.6164
20	DRT(2)	Profitability discount rate for replanting perennials	.09	.06	3.503*	3.524*	3.512*	21.79*	21.65*	21.13*	.5697	.5736	.5911
21	DRB(2)	Profitability discount rate for new planting perennials	.105	.07	3.704	3.767	3.681	21.29	21.43	20.80	.6012	.6174	.6188
22	CLAVT(2,1)	Land availability proportion for replanting cocoa (promotion)	.7	.8	3.704	3.767	3.685	21.29	21.43	20.81	.6012	.6174	.6195
23	CLAVT(2,2)	Land availability proportion for replanting palm (Palm Sector) (promotion)	.7	.8	3.704	3.767	3.685	21.29	21.43	20.81	.6012	.6174	.6195

Table IV.2. (cont'd.)

Run	Parameter Tested	Parameter Definition	Test Run Value	Base Run Value	Performance Criteria: Agricultural Exports (AFORXS) (billion £) Policy Runs[a] 8	9	10	Agricultural Value Added (ATVAS) (billion £) Policy Runs[a] 8	9	10	Marketing Board Revenues (ATRMBS) (billion £) Policy Runs[a] 8	9	10
24	CLAVT(2,3)	Land availability proportion for replanting rubber (promotion)	.7	.8	3.704	3.767	3.685	21.29	21.43	20.81	.6012	.6174	.6195
25	CLAVT(2,4)	Land availability proportion for replanting palm (Rubber Sector) (promotion)	.7	.8	3.704	3.767	3.685	21.29	21.43	20.81	.6012	.6174	.6195
26	DLAVT(2,1)	Land availability proportion for replanting cocoa (diffusion)	.8	.9	3.704	3.767	3.685	21.29	21.43	20.81	.6012	.6175	.6195
27	DLAVT(2,2)	Land availability proportion for replanting palm (Palm Sector) (diffusion)	.8	.9	3.704	3.766	3.683	21.30	21.44	20.82	.6012	.6173	.6192
28	DLAVT(2,3)	Land availability proportion for replanting rubber (diffusion)	.8	.9	3.704	3.767	3.685	21.29	21.43	20.81	.6012	.6174	.6195
29	DLAVT(2,4)	Land availability proportion for replanting palm (Rubber Sector) (diffusion)	.8	.9	3.704	3.765	3.684	21.29	21.44	20.81	.6012	.6172	.6194

* Indicates results reordered from base run.
a/ Policy run definitions are in Table IV.1.

perennial lands have negligible effect on any of the three output variables in any of the policy situations (Runs 22-29). Similarly, the discount rate for evaluating the profitability of replanted perennials is the most sensitive parameter tested (Run 20). Diffusion parameters for replanting perennials (Runs 1-4) and the parameters regulating the replanting profitability response rates (Runs 14-17) are also relatively sensitive.

We can see that for a few of the sensitivity runs (marked with a "*" in the table), the relative order of the output variables in the three policy situations has changed from the order of the base values. For example, in the base runs (i.e., the policy runs with no parameter changes), agricultural exports are ordered (from highest to lowest) as Policy 9-Policy8-Policy 10. In Runs 2 and 4, on the other hand--where the diffusion response parameters for replanting palm in the Palm and Rubber Sectors, respectively, are tested --the order is Policy 9-Policy 10-Policy 8. The implication is that the parameters whose test runs are marked with a "*" in Table IV.2 are the most crucial[1/] for the evaluation of alternative policies. Thus, efforts to improve estimates of their values would apparently be justified.

The three policy situations examined are relatively stable in the face of parameter variations. Runs 5 and 20 generate the largest deviations from base values of

---

1/ Of the 29 tested here; others, not tested, may be similarly important or even more so.

agricultural exports and marketing board revenues under all three policy conditions. Runs 2 and 20 give the largest deviations of value added under the three policies, except for Policy 9 where Run 15 replaces Run 20. These deviations are tabulated in Table IV.3 as percentages of base values. Value added varies less than 2 1/2% in either direction in all three cases, while exports and marketing board revenues vary less than 6 3/4% and 7 1/2%, respectively, in either direction. In addition, the relatively few cases of a reordering of policy results (marked by "*" in Table IV.2) suggest stable policies.

Table IV.3.

Greatest deviations of three output variables from 29 parameter variations under three policy situations (percent of base values).

Output Variables \ Policy Situations		Policy 8	Policy 9	Policy 10
Agricultural Exports (AFORXS)	Run 5	6.72	6.53	6.63
	Run 20	-5.42	-6.45	-4.69
Agricultural Value Added (ATVAS)	Run 2	-2.44	-2.42	-2.11
	Run 20*	2.35	1.31	1.54
Marketing Board Revenues (ATRMBS)	Run 5	7.43	7.18	7.10
	Run 20	-5.24	-7.08	-4.59

* Except Policy 9, where Run 15 is tabulated.

Summary

This chapter has presented a detailed analysis of some agricultural development policy options which have been under consideration in Nigeria. The analysis was organized to illustrate how a system simulation model such as the one presented here could be used as part of the development-planning and policy-formulation process. We may conclude that while detailed considerations of policy sensitivity and stability in the face of uncertain parameters must await the development of a Monte Carlo capability in the model, the present model can provide at least some useful information in this regard. Of particular significance is the model's ability to project the consequences of a variety of policy combinations whose interactive and dynamic effects may then be analyzed.

CHAPTER 11

Summary and Conclusions

This study concludes with a summary of the foregoing chapters, and conclusions are drawn concerning the practical utility of the present model. This is followed by a discussion of further work which can and should be done on the model if it is to be successfully and usefully implemented. Finally, a brief sketch is given of the form such an implementation would take.

Summary

Agricultural development is viewed as a complex process involving the dynamic interactions of economic, political and social subsystems. Necessarily simplified analytical models have been found wanting in comprehensiveness and detail to be of significant use for either explanation or prediction of system behavior. Analog simulation models which might have been sufficient in this regard were too cumbersome and impractical [21]. Since Forrester's introduction of industrial dynamics techniques in 1961 [16], much work has been done on the modeling of industries and regional and national economies (e.g., [22, 33, 36]).

With this background, and building upon the foundation laid by the Consortium analysis of Nigeria's

agricultural sector [24], a research team at Michigan State University, under contract to the United States Agency for International Development, developed a digital computer system simulation model of Nigeria's agricultural economy with links to the nonagricultural sector (Figure I.1) [35]. The Nigeria model includes two regional agricultural submodels, a nonagricultural submodel and components which model the demography of Nigeria and the interregional trade in food.

The agricultural economy of southern Nigeria, as well as that of many other tropical areas, is characterized by competition between perennial and annual commodities for scarce productive resources. The southern regional submodel presented in this dissertation considers five commodities: cocoa, oil palm, rubber, food and tobacco. Because of the importance of tree crops in the South, perennials are modeled as dynamic populations distributed over time and productivity (Chapter 2). Eight perennial populations are defined, four traditional and four modern. The productivity dimension of each population is lumped into five production cohorts (Figure II.3)--gestation, rising yields, maximum yields, declining yields, and old age. The maturation time through each cohort is assumed to be a random variable following a gamma distribution (Figure II.4) modeled deterministically as a series of distributed delays (Chapters 2 and 3).

Land use transition rates are based on perceived relative profitability differentials of the alternatives available in each of four ecological zones. Decisions are influenced by government promotion efforts, if any, and by farmer-to-farmer diffusion (Chapter 3). Given technological coefficients and the allocation of land, production, processing and marketing are carried out for cocoa, oil palm, rubber, food and tobacco. Supplies are price responsive in two ways: by a short run harvest response and by the longer run land allocation decisions (Chapter 4). Prices of export commodities are derived from exogenous world prices and national tax policies, while endogenous demand-supply relationships determine domestic prices for food and palm oil (Chapter 5). Finally, the agricultural sector budget is accounted, and output criteria are generated (Chapter 7).

There are three direct policy entry points in the model: commodity production campaigns can be specified, marketing board and export tax policies can be regulated, and income taxes can be levied (Chapter 6). The model's applicability to policy formulation was demonstrated in Chapter 10, where the results were analyzed of a series of 17 runs examining progressively more complex combinations of policy options which have recently been considered in Nigeria. The major conclusion drawn from these runs, <u>given the model's assumptions</u>, is that a technological transformation of agriculture (incorporating both improved inputs and improved cultural practices) is necessary for

substantial and sustained economic growth.

In attempting to come to grips with the uncertainty arising from the necessary use of some poor and questionable data, an investigation was made in Chapter 10 into the stability and sensitivity of policies to variations in the values of selected parameters. While the results suggest relative policy stability for most of the parameters varied--that is, little deviation, in general, in the absolute and relative levels of output criteria under the various policy conditions examined--changes in some of the parameters, particularly those affecting the supply and demand of palm oil, caused appreciable output deviations and even a re-ordering of output values in the three policy situations considered. In any case, many more such tests would be necessary to more fully treat the data uncertainty problem. This might be done by running the model in a Monte Carlo mode (discussed below), where many parameter variations would be treated simultaneously and stochastically and output statistics would be generated.

Sensitivity analyses, discussed in Chapter 9, may serve three purposes. First, they provide an indirect way to test policy options. One or several parameters could be changed to reflect a particular policy goal and the consequences thus simulated. Secondly, sensitivity analyses may indicate logical or theoretical inconsistencies in the model and may also add to one's understanding of and insights into both the model and the corresponding real system. This

application of sensitivity tests was illustrated in Chapter 9. Finally, the results of sensitivity tests can suggest data collection priorities by indicating those parameters which are of greatest consequence to the performance of the model. For example, the results of the tests reported in Chapter 9 show that initial land usage patterns and parameters affecting the supply and demand of palm oil and food are quite sensitive, suggesting the value of collecting data in these areas.

Data needs of the model are discussed in Chapter 8. Tuning the model to track recorded time series is presented as one approach both to treating parameters for which no (or only poor) data exist and to assuring some correspondence to the real system. General validation procedures then interact iteratively on a continuing basis with the model-building process by evaluating the model's behavior and assumptions against theory, empirical evidence and knowledgeable intuition.

Conclusions

From the sensitivity and policy analyses of Chapters 9 and 10, we can conclude that, although the model as presented here needs further work, it can, even in its present form, provide important contributions to three broad aspects of the development-planning and policy-making process: understanding the socio-economic system, formulating development policies and focusing research activities.

These aspects are somewhat overlapping; for example, both research and an increased understanding of the problem certainly contribute to improved policy formulations.

Understanding the System

Detailed analyses of the behavior of the model (the simulated system) under a range of assumptions (particularly data) and policy conditions provide a comprehensive view of the complex and dynamic socio-economic system under study. This, combined with the model-building process itself--particularly the identification of causal and structural relationships--can contribute substantially to an improved understanding of and sharpened intuitions regarding the development process in general as well as the particular socio-economic system itself--Nigeria's in this case. This was demonstrated in Chapter 9 where sensitivity tests pinpointed sensitive parameters and where the analyses carried out to explain the consequences of parameter changes highlighted complex interactions of the simulated system.

Insofar as the simulated system faithfully represents relevant behavioral patterns of the real system, this heightened understanding can be a valuable asset in reducing some of the uncertainty policy makers necessarily face.

Policy Formulation

A more direct input to the policy-making process is the capability of the model to explore the consequences and implications of a wide range of development policy options.

We saw in Chapter 10 how the model projects time paths of relevant output variables under alternative and increasingly complex combinations of policies. Thus, using the same data available and used for more traditional (e.g., paper-and-pencil) type projections, the model takes account of many more complex policies and interactions than can be done by hand or with a desk calculator. In this way, a good deal of the uncertainty concerning the system's response to various policies can be reduced.

Another important application of the model to policy formulation is in dealing with the uncertainty inherent in the quality of the available data. Sensitivity tests were conducted in Chapter 10 where key parameters were varied in each of three policy situations. While those few runs could hardly be called a complete analysis, they do illustrate how the model can be used to evaluate the sensitivity of policies to data uncertainty. This is information essential in the search for stable policies, that is, policies which will have the intended results even though projections were based on poor data.

Research Activities

A third contribution the model can make to development planning is as a focus for research activities. There are primarily three ways in which use of the model can provide a central theme to coordinate and guide research. First, sensitivity analyses will suggest data collection priorities to improve the available estimates of the most

important parameters and coefficients of the model. In some cases, new survey and estimation methods may have to be devised to accomplish the task. For example, tests in Chapter 9 indicate the sensitivity of the parameters controlling the rates of innovation and other information diffusion among farmers. New techniques may have to be found to estimate these parameters.

Another area of research which the model's application will motivate is investigations into structural relationships among and the behavior of component elements of the socio-economic system These efforts will be necessary to continually improve and keep up to date the model's assumptions and representations of the real system and to keep it relevant to the needs and concerns of policy makers in a changing world.

Finally, technological research may be suggested by policy runs which speculate on the likely consequences of the introduction of an innovation which may not actually be developed at the moment. Of course, the projected consequences would have to indicate that the expense of undertaking such research and development is warranted.

In summary, a system simulation model such as has been presented here can be a useful and valuable tool in the battle against uncertainty in the development-planning process, providing a comprehensive view of a complex, dynamic system while at the same time facilitating policy experimentation and motivating research. Such models are

characterized by a high initial cost (reflecting the costs of data acquisition and modeling) but a relatively low recurrent (user) cost as the model is used to explore a myriad of policy options.

Improvements and Extensions of the Model

A simulation model of human systems can never be "completed". This is particularly true if the model is to be applied in practical policy-making situations. Aside from the truism that "you can't model everything," data can be sharpened, structural and causal relationships must be continually verified in a changing world, and even the problem definition which delimits the model and specifies its constraints may have to be revised from time to time in response to the evolving needs of planners and policy makers. The latter case could require a major model expansion or reemphasis. It is an economic truism that any modification of the model, including the improvements and extensions discussed below, will incur costs for modeling and programming which will have to be weighed against the expected returns of increased model flexibility and relevance before a decision is made to go ahead with the modification.

A number of areas in the current southern model can be identified as needing further attention to improve the model's performance. These are discussed below as "improvements". Preliminary experiences with the southern model, operating as part of the total Nigeria model, have suggested possible extensions to enable it to better address some of

the major problems of economic development. These will also be discussed.

Improvements

There are several aspects of the southern model which need further development and verification. First, it is not certain that the model of the domestic palm oil price mechanism (Equation 5.4) adequately or even realistically represents the actual operation of that market. In particular, the link between the domestic market price and the marketing board price is not clear. Since the competition for palm oil between foreign and domestic markets makes this a fairly sensitive commodity in the model, further research and eventual modification of this aspect of the model may be indicated.

A second area that could call for further work is the treatment of the modernization of processing. As pointed out in Chapter 10, the model currently simulates the transformation of agricultural processing irregardless of the profitability of the supposedly "modern" technology; all that is necessary for modernization to be carried out is a policy of exogenous investment in modern capacity (Equation 4.15). Thus, in Run 10 of the 17 runs analyzed in Chapter 10, oil palm processing was converted from hand presses to Stork hydraulic presses even though farmers were losing money on it. If policy makers and planners feel this is an area which they would like to investigate more fully, then revisions of the model will be necessary.

The land use alternatives specified in each of the four ecological zones (or crop sectors--Figures I.3 and II.2) may also do with some confirmation. Table II.1 lists the potential alternatives omitted from consideration in the model. These omissions are based on assumptions concerning the relative significance of the alternatives and on considerations of model simplification and efficiency. However, further evidence may indicate a greater importance for some of the omitted alternative land uses (e.g., food land being planted in traditional perennials), in which case the model will have to be modified.

Related to this possible shortcoming of the model is the question of whether the entire set of "logical alternatives" in Table II.1 is too restrictive. There is currently in Nigeria interest in the possibilities of introducing and expanding the production of other tree crop commodities, e.g., kola and coffee, in areas where cocoa is marginal. If the model were to be developed further to handle such additional perennials, however, it may also be necessary to redefine the ecological zones in which land allocation decisions take place (Figure II.2).

A major feature of the model which needs theoretical and empirical verification is the land use decision mechanism (Chapter 3). One question arises concerning the realism of relating <u>all</u> decisions--even those pertaining to <u>traditional</u> land uses--to a diffusion curve (Equation 3.8) which is usually considered descriptive of the diffusion of <u>innovations</u>.

Another aspect of the decision mechanism which is unrealistic is the effective lack of constraints on land allocations. First, the capital constraint on land use decisions (Equations 3.13 and 7.12) is virtually inactive in the model and does not effectively represent the actual constraints Nigerian farmers seem to be facing. Additional research is necessary to better understand the nature of this problem before further modeling work can be done on it. It may well be that this phenomenon cannot be handled meaningfully until the model can deal with the question of income distribution, discussed below.

A second constraint, one which is not in the model at all, is the availability of labor. Based on pre-civil war conditions, the model assumes there will be no shortage of agricultural labor; any such shortage in the indigenous southern population will be met by seasonal migration from the North. Actually, the availability of agricultural labor <u>is</u> a problem in Nigeria today, and in other developing countries as well, so that the assumption of no labor constraint is a serious limitation of the model. Thus, it may be desirable, if the model is to be implemented, to give high priority to modifying the model to realistically reflect actual labor constraints on land allocation and production decisions.

A less serious shortcoming is the lack of constraints on other inputs, primarily fertilizers and other chemicals and seeds and seedlings. If it is felt the availability of

these inputs is a real problem to be assessed, it wouldn't be too difficult to enable the model to do so.

Two examples of other structures of the southern model which may bear further verification are the subsistence level adjustment mechanism and the use of exponentially weighted price averages. First, it may be questioned whether Equations 4.1-4.3--in assuming the functional relationship shown in Figure II.9 between food market stability, food price level and cash crop income on the one hand and, on the other, the level at which the agricultural population will want to feed itself--realistically, or even adequately, determine the agricultural subsistence level.

Secondly, further information may indicate weaknesses in the assumption that, in making their decisions, the _expected_ prices that farmers project are exponentially weighted averages of recent prices (Equation 5.8). Research findings may even suggest promising alternative formulations. Another question which might be raised concerns the use of exponential price _averages_, instead of the price in a reference _year_, as a base for determining the harvest supply response (Equation 4.6).

Finally, this model, and indeed _any_ model, may always be improved by improving the data that go into it. As has been discussed, the model itself may help in this endeavor by indicating those parameters to which the simulated behavior of the model is most sensitive.

Extensions

There are two categories of possible extensions of the model, both of which would add to the model's relevance and usefulness to development planning and policy making. The first involves enabling the model to address some of the major practical and theoretical problems of economic development. The other category of model extensions is of a technical nature and would increase the model's flexibility to deal with a wider range of planning needs.

In the initial, problem definition phase of the Nigerian Simulation Project, interactions with Nigerian researchers and officials helped identify areas of concern to agricultural development planners which the model could relevently address. Some of these included: 1) extension efforts to increase export and other cash crop production, which would thus improve both government's balance of payments posture and cash incomes to the private agricultural sector; 2) marketing board pricing policies, where there was a question of trade-offs between public revenues (which could ostensibly be used to finance development projects) and private income; 3) promotion of improvements in and modernization of the cattle industry (e.g., tstse fly eradication and the creation of grazing reserves) to increase production and consumption of beef and milk; and 4) efforts to increase food production to maintain and improve the nutrition of the agricultural and growing urban populations.

The last item is one direction in which the model might be extended further. In placing emphasis on export production, food is treated in a very aggregate way. Non-staples are not considered at all[1/], while staples are aggregated into a composite (defined in Chapter 3), and their nutritional value is treated solely in terms of Calories. On the other side of the coin, the model determines only the population's demand--urban and rural, cash and subsistence--for staple Calories (assumed to be about 80% of total caloric needs). Other nutritional factors, such as proteins and vitamins, are ignored. These limitations of the model were cited in Chapter 10 to explain the apparent unfavorable nutritional future of urban Nigeria projected in the policy runs analyzed in that chapter (Figures IV.10, IV.16 and IV.27).

Currently in Nigeria, however, and in many other developing countries as well, the problems of nutrition are increasingly in the forefront of policy issues [38]. If these concerns persist and deepen, and if it is thus deemed worthwhile to expand the model, perhaps substantially, to assist in the formulation of policy solutions, the model could be extended to treat individual food crops and a wider range of nutritional indicators.

1/ Domestic palm oil consumption is computed, but only as it competes with exports. It is not considered for its contribution to nutrition. Similarly, beef and milk are viewed from the standpoint of production; consumption demand is not treated endogenously in the model.

Another concern of economic development, a problem often made more acute by the development process itself, is the issue of the distribution of income [11]. At present, the model distributes income between the agricultural and nonagricultural sectors, between traditional and modern sectors within the nonagricultural economy [4], and geographically by region and ecological zone within the agricultural sector (Chapter 7). However, as discussed above and in Chapter 7, it may be desirable to also distinguish, within the agricultural sector, between large farmers with the educational and material resources to take full advantage of modern agricultural technology and small farmers barely above subsistence and struggling to enter the cash economy. To the extent that the inclusion of this distinction would enable the model to more realistically simulate the production and consumption decisions of the agricultural sector, the model's applicability to the analysis of policy consequences would be enhanced. In addition, this dimension of income distribution would be an important output criterion for evaluating alternative policies. Further research on the linkages between income distribution patterns and agricultural decision making is necessary, however, before the model can be extended to include this phenomenon.

A third possible problem area which would call for an extension of the model, and one of growing concern to researchers and policy makers (e.g., [18]), is the question of rural-urban migration and urban unemployment. This problem,

like income distribution, also seems to accompany development, and it may be an even more crucial issue for its implications for social and political stability. However, although some significant theoretical and empirical research has been conducted in this area, there is yet no general agreement on the principal motivations and mechanisms governing rural-urban migration. Is it rural-urban wage differentials? Or education? Or rural unemployment? Or is it the bright city lights? Perhaps some combination of these and other factors all play a role and, if so, what is that combination and how do they work together to motivate or inhibit rural-urban migration. Although questions such as these should ideally be answered to provide a theoretical and empirical foundation for building realistic models, the problem will not wait. Thus, it may be necessary to construct an interim model, or alternative models, which may be used temporarily to deal with the problem. Indeed, such models will probably even prove useful in an iterative process of developing and testing theories of migration.

A final development problem which the model might be extended to address is inflation. Not only is inflation of particular concern to developing countries for its effects on investment, consumption and terms of trade but also, if it continues rampant and uncontrolled, for its likely consequences for economic, social and political stability. This is another area toward which, in spite of the lack of strong theoretical agreement on causal relationships and

dynamic behavior, modeling efforts may have to be directed.

We have discussed extensions of the model which may be indicated to increase its relevance as an aid in dealing with the problems of economic development. There are also a few extensions, technical in nature, which can add to its range and depth of application to policy formulation.

One such extension has already been discussed in Chapters 8, 9 and 10--running the model in a Monte Carlo stochastic mode rather than deterministically. In this way, probability distributions (reflecting data uncertainty) would be specified for key parameters, initial conditions and coefficients of the model; a number of simulation runs (on the order of a hundred) would be made, each drawing samples from these distributions; and output statistics would be generated. As discussed in earlier chapters, such Monte Carlo runs could be useful both to deal with data problems and to evaluate the relative stability and sensitivity of policy alternatives in the face of uncertainty.

However, there are a number of problems which must be evaluated and solved before a Monte Carlo capability for the model would be feasible. First, there is the problem of defining the parameter probability distributions. This is not insurmountable. Indeed, it has already been done for the northern regional submodel [35, Chapter 4]. There is another potential difficulty, however, which may prove more intractable in terms of statistical methods and complicated computer programming requirements: it may not

make sense to sample from all the probability distributions independently. In particular, we might require the model to maintain for each sample a "reasonable" goodness-of-fit of time series tracking (Chapter 8). That is, although individual parameters and initial conditions may vary, they should all vary in such a way as to maintain internal consistency so the model still simulates the same system.

A third problem of using Monte Carlo techniques--the computer execution time necessary to make hundreds of simulation runs--may be handled by the second possible technical extension of the model to be discussed, namely, the use of response surfaces. A response surface is an explicit functional relationship between a vector of relevant output variables and the parameters and initial conditions which have been given probability distributions. Thus, samples from the distributions would be "plugged" into this vector function to determine an observation of the output variables, bypassing the need to make simulation runs of the model. Response surfaces can also be used for policy analysis if policy parameters and variables are included among the independent variables of the function.

A look at the generalized response surface function will suggest a limitation of the method:

$$Y_t = F_t(\alpha, \beta, \pi)$$

where

Y_t = a vector of output variables at time t

F_t = a vector function

α = a vector of parameters

β = a vector of initial conditions

π = a vector of policy instruments.

The problem is that a different surface would have to be generated for each point in time which may be of interest as a terminal time. Ideally, a dynamic surface would be generated as an explicit function of time, i.e.,

$$Y(t) = F(\alpha,\beta,\pi,t).$$

Another difficulty is the generation of the response surface itself. In preliminary work in this area, Turnquist and Manetsch, working with the cattle component of the northern submodel, used Monte Carlo simulation runs to generate output observations to which they fitted multivariate polynomials [51]. They found there was a trade-off between the computer time saved in using the surface and the time required to generate it in the first place, so that, given the computer time required to fit the surface, the simulation run time would determine whether it is cheaper to generate a response surface or to use Monte Carlo runs of the whole simulation model. In connection with the problem of generating the surface, a new surface would have to be generated every time the model itself was modified!

As a final extension to be discussed here, it could be technically feasible to enable the model to operate in an optimization mode, perhaps by using gradient search techniques on response surfaces. However, it is questionable whether this would be a relevant tool for the policy maker.

Without common denominators for the many and varied goals of development, an objective function may not exist. It has been suggested [46] that decision making in general (i.e., not just for economic development) is more a process of "satisficing" than of optimizing. That is, decision makers seek satisfactory results within acceptable limits. Uncertainty about available alternatives and about the likely consequences of alternatives and the decision maker's ignorance of his own subjective welfare function make optimization virtually impossible.

Implementation

The theme of this dissertation has been more than the presentation of a system simulation model and of results of model tests. I have continually emphasized how the model could be of use to planners and policy makers as a tool and methodology with which to get a handle on hundreds of complex interactions in order to project consequences of policy options and to sharpen insights into the socio-economic system of interest. I conclude here with a brief discussion of where this approach would fit into the policy-making process.

Figure IV.32 is a schematic representation of policy making as a problem-solving process[1/]. At the top is the problem definition phase. The diagram emphasizes the

---

1/ This discussion is drawn and extended from concepts presented in [1] and [29]. The diagram is adapted from Ladipo's paper.

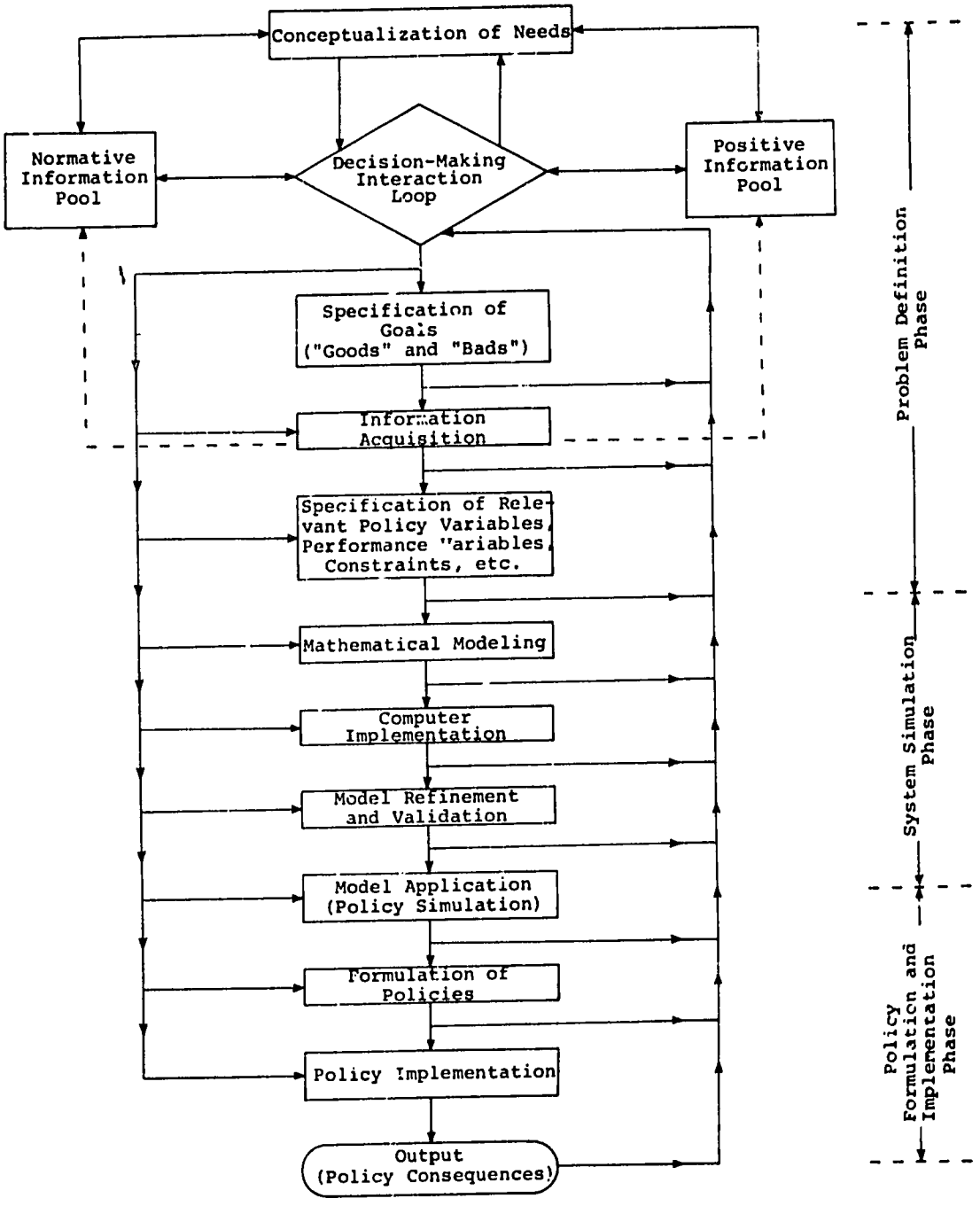


Figure IV.32 System simulation and the policy-making process.

interactions and resources that come to bear in defining the problem. The actors consist of decision makers, members of their staff, and outside consultants and researchers--each with a conceptualization of the problems and needs of society. This conceptualization is based on cultural background and norms and on positive information about contemporary conditions.

The interaction loop is the center of the process, where the actors exchange views and information on perceived needs and suggested prescriptions. This creative interaction concretely specifies the goals to be attained, defines the problem in terms of constraints, controllable inputs, environmental inputs and relevant output criteria, and finally identifies a collection of relevant policy issues to be explored. The problem definition phase also requires normative and non-normative (positive) information on the state of the system (economy, society, environment). These information pools are continually being modified and expanded as new information is sought and acquired in light of the agreed-upon goals and objectives. Such information may then suggest modifications in the goals or later stages of the policy-making process.

The system simulation phase has been the subject of earlier chapters of this paper. Usually, it is missing from the process, its place taken by paper-and-pencil projections, recursive or linear programming techniques, or merely intuitive and seat-of-the-pants methods of analyzing and

evaluating potential policies.

Perhaps the most important feature of this process is the continual iterative feedback from each stage through the interaction loop where decision makers, consultants and staff members evaluate what has been learned and, if necessary, modify earlier stages. For example, on the basis of model testing, another pass through the modeling stage may be called for. Or, experiences with applying the model to analyze alternative policies may suggest changes in the goals or in the set of relevant policy variables, which might then require additional modeling. In addition, events (including the consequences of earlier policies) continue to take place in the world and may generate new ideas and perceived needs which will be conceptualized by the actors in the policy-making process and fed into the process from the top (Figure IV.32).

The final point to be made here concerns the relationship between the model and the decision maker. The policy decision maker, in evaluating simulated results, must be aware of the assumptions and simplifications built into the model, and he must appreciate limitations that exist vis-à-vis the questions the model is capable of addressing. Furthermore, the model described is principally an economic model which will indicate the likely economic consequences of alternative policies; it was not designed to directly answer social or political questions. The policy-making process must still be responsive to the political pressures and social interests which are indispensable components of that

same process. In short, a simulation model, while potentially an integral and important part of the decision-making process, will not replace the decision maker. It will, however, give him more information, help to identify new and economically feasible policy options, and sharpen his intuition, thus making for better decisions.

BIBLIOGRAPHY

1. Asimow, Morris, Introduction to Design (Englewood Cliffs: Prentice Hall, Inc., 1962).

2. Bertalanffy, Ludwig von, General System Theory: Foundations, Development, Applications (New York: George Braziller, 1968).

3. Buck, R. Creighton, Advanced Calculus (New York: McGraw-Hill Book Company, 1965).

4. Byerlee, Derek R., Agricultural Development and Urban Unemployment: A Simulation Analysis of the Nigerian Economy, unpublished Ph. D. dissertation (Corvallis: Oregon State University, 1972).

5. Chandrasekhar, Sripati and Charles W. Hultman, eds., Problems of Economic Development (Boston: D. C. Heath and Co., 1967).

6. Colm, Gerhard and Theodore Geiger, "Country Programming as a Guide to Development" in Robert E. Asher, ed., Development of the Emerging Countries: An Agenda for Research (The Brookings Institution, 1962).

7. Coulman, George A., Seth R. Reice and Ramomahan Tummala, "A Systems Analytic Approach to Single Species Population Dynamics", paper presented at the 69th A.I.Ch.E. National Meeting in Cincinnati, Ohio, 1971.

8. Day, Richard H., "On Simulation", discussion presented to the Econometric Society, Dec. 28, 1969 and to be published in M.D. Intrilegator, ed., Frontiers of Quantitative Economics (Amsterdam: North-Holland Publishing Co., forthcoming).

9. Dutton, John M. and William H. Starbuck, "Computer Simulation Models of Human Behavior: A History of an Intellectual Technology", IEEE Transactions on Systems, Man, and Cybernetics, SMC-1:128-171, 1971.

10. Eakman, J. M., A. G. Fredrickson and H. M. Tsuchiya, "Statistics and Dynamics of Microbial Cell Populations" in M. R. Sfat, ed., Bioengineering and Food Processing, Chemical Engineering Progress Symposium Series, Vol. 62, pp. 37-49, 1966.

11. Essang, Sunday M., The Distribution of Earnings in the Cocoa Economy of Western Nigeria: Implications for Development, unpublished Ph.D. dissertation (East Lansing: Michigan State University, 1970).

12. Federal Office of Statistics, Census of Population 1963 (Lagos: FOS, 1963).

13. Federal Office of Statistics, Annual Abstract of Statistics, 1966 (Lagos: FOS, 1966).

14. Federal Office of Statistics, Rural Economic Survey of Nigeria: Farm Survey--1964/65 (Lagos: FOS, 1966).

15. Food and Agriculture Organization of the United Nations, Agricultural Development in Nigeria, 1965-1980 (Rome: FAO, 1966).

16. Forrester, Jay W., Industrial Dynamics (Cambridge: M.I.T. Press, 1961).

17. Güsten, Rolf, Studies in the Staple Food Economy of Western Nigeria (Munich: Weltforum Verlag, 1968).

18. Harris, J. R. and Michael P. Todaro, "Migration, Unemployment and Development", American Economic Review, LX:126-142, 1970.

19. Himmelblau, David M. and Kenneth B. Bischoff, Process Analysis and Simulation: Deterministic Systems (New York: John Wiley & Sons, Inc., 1968).

20. Holland, Edward P., "Principles of Simulation" in Richard J. Ward, ed., The Challenge of Development: Theory and Practice (Chicago: Aldine Publishing Co., 1967).

21. Holland, Edward P. with Robert W. Gillespie, Experiments on a Simulated Underdeveloped Economy: Development Plans and Balance-of-Payments Policies (Cambridge: The M.I.T. Press, 1963).

22. Holland, Edward P., et al., Dynamic Models for Simulating the Venezuelan Economy, mimeo (New York: The Simulmatics Corporation, 1966).

23. Howard, Warren D., "The Computer Simulation of a Colonial Socio-Economic System", Proceeding of the 1961 Western Joint Computer Conference, 19:613-22, 1961.

24. Johnson, Glenn L., Orlin J. Scoville, George K. Dike and Carl K. Eicher, Strategies and Recommendations for Nigerian Rural Development 1969/1985, CSNRD-33 (East Lansing: Michigan State University, 1969).

25. Johnston, Bruce F. and John W. Mellor, "The Role of Agriculture in Development" in [5].

26. Kellogg, Earl D., A Temporal and Spatial Model to Assist in Evaluating Investments in the Nigerian Beef Distribution System, unpublished Ph.D. dissertation (East Lansing: Michigan State University, 1971).

27. Kharkar, Anilkumar N., "Theoretical Development of a Mechanistic Model for the Dynamics of Populations", mimeo, Department of Chemical Engineering, Michigan State University, 1971.

28. Kriesel, H. C., Cocoa Marketing in Nigeria, CSNRD-21 (East Lansing: Michigan State University, 1969).

29. Ladipo, O. O., "Simulation and Interaction as a Means of Studying Normative Questions", class paper, Michigan State University, May 1971.

30. Laurent, C. K., Investment in Nigerian Tree Crops: Smallholder Production, CSNRD-18 (East Lansing: Michigan State University, 1968).

31. Llewellyn, Robert, FORDYN--An Industrial Dynamics Simulator (Raleigh: North Carolina State University, 1965).

32. Manetsch, Thomas J., "Transfer Function Representation of the Aggregate Behavior of a Class of Economic Processes", IEEE Transactions on Automatic Control, AC-11:693-698, 1966.

33. Manetsch, Thomas J., "The United States Plywood Industry --A Systems Study", IEEE Transactions on Systems Science and Cybernetics, SSC-3:92-101, 1967.

34. Manetsch, Thomas J. and Gloria Page, "A Simulation Model of the Nigerian Agricultural Economy: The Modernization Executive Component", Project Working Paper 70-1, Department of Agricultural Economics, Michigan State University, 1970.

35. Manetsch, Thomas J., et al., A Generalized Simulation Approach to Agricultural Sector Analysis With Special Reference to Nigeria, Final Report to USAID (East Lansing: Michigan State University, 1971).

36. Mathis, Kary, An Economic Simulation Model of the Cacao Industry of the Dominican Republic, International Programs Information Report No. 69-2 (College Station: Texas A & M University, 1969).

37. National Agricultural Development Committee, Report of the Study Group on Coca, Kola, Coffee and Cashew (Lagos: Federal Department of Agriculture, June 1971).

38. National Agricultural Development Committee, Report of the Study Group on Food Crops and Pastures (Lagos: Federal Department of Agriculture, June 1971).

39. National Agricultural Development Committee, Report of the Study Group on the Oil Palm (Lagos: Federal Department of Agriculture, June 1971).

40. National Agricultural Development Committee, Report of the Study Group on Rubber (Lagos: Federal Department of Agriculture, June 1971).

41. Okurume, Godwin, The Food Crop Economy in Nigerian Agricultural Policy, CSNRD-31 (East Lansing: Michigan State University, 1969).

42. Phillips, A. W., "Mechanical Models in Economic Dynamics", Economica, 17:283-305, 1950.

43. Pugh, Alexander L., III, DYNAMO User's Manual, 2nd ed. (Cambridge: The M.I.T. Press, 1963).

44. Purvis, Malcolm J., Report on a Survey of the Oil Palm Rehabilitation Scheme in Eastern Nigeria, 1967, CSNRD-10 (East Lansing: Michigan State University, 1968).

45. Rogers, Everett M., Diffusion of Innovations (New York: The Free Press, 1962).

46. Simon, Herbert A. and James G. March, Organizations (New York: John Wiley and Sons, Inc., 1958).

47. Smith, O. J. M. and H. F. Erdley, "An Electronic Analogue for an Economic System", Electrical Engineering, 71:362-66, 1952.

48. Stolper, Wolfgang F., Planning Without Facts: Lessons in Resource Allocation From Nigeria's Development (Cambridge: Harvard University Press, 1966).

49. Takahashi, Yasundo, Michael J. Rabins and David M. Auslander, Control and Dynamic Systems (Reading: Addison-Wesley Publishing Co., 1970).

50. Thodey, Alan Robert, Analysis of Staple Food Price Behavior in Western Nigeria, unpublished Ph.D. dissertation (Urbana: University of Illinois, 1969).

51. Turnquist, Mark and Thomas J. Manetsch, "The Uses of Monte Carlo Techniques and Response Surface Methodology in Complex Simulation Models", Project Working Paper 71-1, Department of Agricultural Economics, Michigan State University, 1971.

52. Wangersky, P. J. and W. J. Cunningham, "Time Lag in Population Models", Cold Spring Harbor Symposia on Quantitative Biology, 22:329-338, 1957.

53. Wendroff, Burton, Theoretical Numerical Analysis (New York: Academic Press, 1966).

54. Western Nigeria Ministry of Agriculture and Natural Resources, Tree Crop Planting Projects (Ibadan: WNMANR, 1963).

55. Western State Ministry of Agriculture and Natural Resources, "Proposed Cocoa Project", mimeo, July 1969.

56. Western State Ministry of Agriculture and Natural Resources, Western State Smallholders' Oil Palm Project (Ibadan: WSMANR, Dec. 1969).