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IMPACTS OF ALTERNATIVE TECHNOLOGIES ON PRODUCTION
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Joao Eustaquio de Lima

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George E. Rossmiller
Major professor
(George E. Rossmiller)

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IMPACTS OF ALTERNATIVE TECHNOLOGIES ON PRODUCTION AND RESOURCE ALLOCATION IN SOUTHERN BRAZILIAN AGRICULTURE, 1970-1980

By

Joao Eustaquio de Lima

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ABSTRACT

IMPACTS OF ALTERNATIVE TECHNOLOGIES ON PRODUCTION AND RESOURCE ALLOCATION IN SOUTHERN BRAZILIAN AGRICULTURE, 1970-1980

By

Joao Eustaquio de Lima

The planning of agricultural research and the implementation of technology policy require knowledge of the impacts and adjustments that take place as a result of the introduction of new technologies. In essence, the effects of improved technology can be characterized by impacts on the cost structure or the product mix of individual firms, shifts in industry demand curves for factors of production, shifts in product supply curves, and impacts on the growth and distribution of total and per capita income. The analysis of these effects provides useful information to the decision-making process in setting guidelines for research policy and in planning research activities.

The main purpose of this study has been to contribute information on the potential impacts of alternative technologies on production and resource allocation in Southern Brazilian agriculture. Specifically, the objectives of the study were:

1. To determine optimal land use and production patterns through time for farms with different sizes in the state of Rio Grande do Sul, Brazil.

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2. To evaluate the effects of introducing alternative agricultural technology on production, income, employment, resource allocation, and income distribution among different farm size groups. In this context the study focused on:
   a) Evaluating the effects of introducing high-yield varieties with higher biological potential and higher capacity to respond to fertilizer application, and
   b) Evaluating the effects of changing the level of mechanization by varying the combination of labor, animal power, and tractor requirements in production activities.

The focus of this study concerned the development of an analytical framework which could be used to analyze the potential impacts of a set of assumed varietal and mechanical technologies. High-yield crop varieties with higher capacity to respond to fertilizer application, were analyzed by means of a number of alternative assumptions with respect to yield per hectare for annual crops. High-yield varieties are supposed to facilitate substitution of fertilizer for land, thus changing resource proportion and resulting in substantial increases in output. Mechanical technology was analyzed on the basis of its effects on changes in labor, draft animal, and tractor input requirements for production activities. Tractor services were assumed to substitute for labor and draft animals, permitting more efficient combination of factors and resulting in higher returns to farm resources.

A regional model of production and resource allocation was developed to allow the observation of the time profile of optimal land

use and cropping patterns, production, farm income, and derived demand for farm inputs under a selected set of yield and mechanization assumptions. The model has three components: a) a yield component which estimates crop yields on the basis of yield-nutrient response functions; b) a resource allocation component consisting of a Recursive Linear Programming model which allocates land and other farm resources to alternative farm enterprises, and c) a production and accounting component which computes production levels and other performance criteria by commodity, farm size, and regional aggregates. The model is applied to the total area of the state of Rio Grande do Sul in Brazil.

Model results indicated that in response to technological change farmers can change, to a certain extent their land utilization, production, input demand, and income patterns over time. With the introduction of high-yield varieties and improved mechanization, the model projects significant increases in area and production of wheat and soybeans. Net returns to resources in farming can be increased significantly with improvements in crop yields and mechanization. Income of large farms showed higher projected growth rate than that of small farms. Thus, improved technology tends to increase the income gap between farm size groups over time.

This study suggests that technology policy should be based on a well-defined set of objectives. The choice of technology to be implemented would have differential impacts on the relative competitive position of the various farm enterprises and on the income accruing to the different producing groups.

Dedicated to:

my father,
JOAQUIM NORONHA DE LIMA (in memory)

and my mother,
JACINTA MARIA DE JESUS

with love and care.

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CHAPTER I

INTRODUCTION

Modernization of traditional agriculture has been an important thrust of most existing theories of agricultural development. An effective strategy for economic development depends on the capacity to generate new technologies which will contribute to growth in agricultural productivity. The strategy to modernize agriculture is usually taken as the basic means of strengthening the role of agriculture in the general process of economic development.

Thus, the concept of technological change becomes a focal theme in understanding agricultural development. Its potential contribution to development has been recognized for some time. But the study of its sources and the adjustments in the system undergoing structural changes arising from the continuous process of technological change will remain an important economic area of inquiry.

The generation and diffusion of agricultural technology is a rather complex problem. Market forces have become effective in speeding agricultural transformation, but other mechanisms such as public policies, projects, and programs have also been very efficient in increasing the technological level in agriculture. In the case of developing countries where there is a great deal of government intervention in the market system, the transformation of traditional agriculture has occurred mainly as the result of public investment in research, extension, and education.

Public investment in agricultural research generates technical knowledge which, having been diffused and adopted, has great potential as a source of increasing production and productivity in the agricultural sector. Such investments involve the use of scarce resources. The task of planning agricultural research should consider the efficient use of these resources. The objectives of agricultural research should emphasize the usefulness of its results to society and, in particular, to the rural community.

The problem of defining research objectives is a rather difficult one. Clearly, such objectives are dependent upon the general objectives of development in a country. Research priorities need to be adjusted to the goals of development. Analysis of the economic situation and knowledge of objectives and goals of an overall strategy of development can serve as a basis to adjust research priorities to development needs.

The planning of agricultural research or the implementation of agricultural research policy requires knowledge of the impacts and adjustments that take place as a result of the introduction of new technologies. Different approaches can be followed in order to carry out an analysis of research programs. One approach is to analyze a specific technological improvement after it has been introduced and its results have already occurred. Another approach is to look at the current economic situation and investigate the possible impacts and adjustments that could take place if certain well-defined types of technology were developed and introduced. This approach can deal with different objectives related to types of technology that are feasible for a region or a country. It attempts to provide useful insights into the possible impacts that are likely to happen in different parts of the agricultural sector.

This study, which applies the second approach, is concerned mainly with the impacts and adjustments in resource allocation, production, and income distribution that are most likely to occur following changes in agricultural production technology. In order to do this, a dynamic production and resource allocation model is developed which is assumed to represent the production relationships of the agricultural sector of the region. The model is then used to generate simulation results through time given changes in its structural parameters. The model is developed for one region with disaggregation in two farm size groups. The changes in structural parameters to be simulated are those which represent changes in production technology. Specifically, this involves changes in yields, fertilizer application rates, and technical coefficients related to the use of labor, animal and mechanical power.

General Problem Setting

In a general context this study is related to the economics of technological change. It is concerned with the impacts of innovations that could be generated through public investments in research and would be feasible for adoption by farmers. This approach to technological change differs from the typical one because, at least implicitly, it considers the effects of inputs such as research and extension, which are unconventional inputs of a production process.

The increasing interest in the economics of technological change after the early 1960's is, in most part, due to the recognition of the crucial role such change plays in economic growth and development.[1] This growing interest is the result of the impact of early studies which started with the observation that the gloomy predictions of the classical economists concerning growth were not corroborated by contemporary reality, at least in the developed countries.[2] The classical approach to growth neglected the fact that significant increase in labor productivity was not explained by the increase in capital per worker.[3]

An important contribution in the area of measurement of technological change was made by Robert Solow whose work laid the foundation for subsequent research in economic growth.[4] Solow

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[1]For examples of contributions which have emphasized the role of technological change in economic growth and development see: T.W. Schultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964); Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971); Zvi Griliches, "The Sources of Measured Productivity Growth: United States Agriculture, 1940-60," Journal of Political Economy 71(4):331-346, August 1963.

[2]Lester B. Lave, Technological Change: Its Conception and Measurement (Englewood Cliffs: Prentice-Hall, Inc., 1966), pp. 3-5.

[3]Robert Solow, "Technical Change and the Aggregate Production Function," Review of Economics and Statistics 30 (1957): 312-20.

[4]For a comprehensive survey of modern formal growth theories see F.H. Hahn and R.G.O. Matthews, "The Theory of Economic Growth: A Survey," Economic Journal 74 (December 1964): 779-902.

defined technological change as those increases in output per man that could not be explained by increases in capital per man. However, this increase in productivity was in fact a "residual", and for this particular reason, Solow's approach was much criticized in subsequent works on the subject.[5]

For the most part, the debates over technological change concentrated around measurement aspects. No attempt was made to redefine the concepts and to understand the process by which technical progress is induced by economic forces. After several years economists turned to different approaches which emphasized unconventional variables such as research, extension, and education as major sources of increased productivity.[6]

Over time technology became an increasingly important element affecting growth and development. This notion is demonstrated by the new theories of agricultural development which emphasize technological, institutional, and human changes. T.W. Schultz[7] argues that significant growth in productivity cannot be

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[5]Among others see T.W. Schultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964); Zvi Griliches, "The Sources of Measured Productivity Growth: United States Agriculture, 1940-60," Journal of Political Economy 71(4): 331-346, August 1963.

[6]See Robert E. Evenson, "The Contributions of Agricultural Research and Extension to Agricultural Productivity," Unpublished Ph.D. dissertation, University of Chicago, 1968; Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," American Economic Review, 54 (December 1964): 961-974; P.L. Cline, "Sources of Productivity Change in U.S. Agriculture," Unpublished Ph.D. dissertation, Oklahoma State University, 1975.

[7]T.W. Schultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964).

brought about by the reallocation of resources in traditional agriculture. Transformation is dependent on the decision to invest in agriculture to make modern high-pay-off inputs available to farmers. Mellor[8] emphasizes the process of agricultural modernization as a condition for development. He states that "a dynamic contribution to economic development from the agricultural sector and significant improvement in rural welfare depend upon the modernization of agriculture through technological change." He further suggests that there is a need to generate new inputs of technological change which increase the productivity of traditional inputs. Modernization is a process of increasing the productivity of inputs and of introducing new and improved inputs. In their important contribution to the literature of agricultural development Hayami and Ruttan[9] have treated technical and institutional changes as endogenous to the economic system, and have emphasized the process by which a new and improved factor is supplied.

The inducement of changes in technology, institutions, and human nature is an important policy variable. This process has been the preoccupation of most governments of developing countries and of international donor organizations which have invested large amounts of resources in order to induce transformations that can increase

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[8] J.W. Mellor, The Economics of Agricultural Development (Ithaca: Cornell University Press, 1966), p. 223.

[9] Y. Hayami and V.W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971).

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production of food, the efficiency of use of resources, and improve the welfare of people.

The basic problem decision-makers face in inducing transformations is the determination of the forms of investment that a government can make in agriculture in order to foster development. This point, in fact, is made by Schultz who states that "basically, this transformation is dependent on investing in agriculture. Thus it is an investment problem. But it is not primarily a problem of capital supply. It is rather a problem of determining the forms this investment must take, forms that will make it profitable to invest in agriculture."[10] This implies that the inducement of transformations in agriculture should come about through investments that can create conditions for new investments to take place. This, in turn, emphasizes the need to identify those sectors or subsectors of the agricultural economy which have a greater potential to induce changes as the result of investments.

The variable technological innovation in agriculture has become an important factor in the development process. The planning and organization of the research sector and the identification of research programs that can affect technological change is presently a significant problem. To do so requires a great deal of information about the structure of production and the major interrelationships

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[10] T.W. Schultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964), p. 4.

among markets, commodities, producing units, and other economic forces in the agricultural sector.

Problem Situation and Statement

Basically this study concerns itself with the problem of how research programs can be directed to affect technological change to increase productivity of scarce resources and increase total production of major commodities. Public investment in agricultural research generates technical knowledge that, after being diffused and adopted, will change the resource base of farmers and the structure of production of a region or a country. A whole series of impacts and adjustments will take place following the introduction of new technologies. Of particular interest are changes in the structure of use of and demand for agricultural inputs, changes in income and production patterns, and impacts on the income distribution among different farm size groups.

The problem of resource allocation to agricultural research has received increased attention over the past years. This concern may be seen as the result of: (a) the need to increase the production of food to meet increased demand due to population and income growth; (b) the increased levels of private and public investment in research; (c) the recognition of the potential contribution of technological change to development; (d) the actual level of knowledge about the generation of new technology for some specific geographical areas; (e) the absence of knowledge about the nature of returns to research investments; (f) the increased concern about a systematic way to deal with the problem of establishing research priorities, and (g) the lack of satisfactory results in respect to actual improvements in production and productivity in the agricultural sector.

These factors have contributed to the growing concern over the organization and planning of research programs in developing countries. Specifically, major reforms have taken place in the organization of research activities in Brazil in recent years.[11] The concern over the agricultural research system in Brazil arose from the importance attached to the modernization of agriculture. The performance of this system was considered very unsatisfactory in respect to generation and maintenance of a flow of research outcomes that would be able to meet the needs of the overall process of development.

The process of reform started with the analysis and diagnosis of problems of the current situation that led to the formulation of a new approach involving the institutional, administrative, and financial organization of the research system. The reorganization involved the creation of the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), an agency whose objectives were the planning and coordinating of research programs in accordance with the policies of the Federal Government in respect to technology and socio-economic development. EMBRAPA was allowed adequate administrative and financial flexibility to execute a national plan of agricultural research

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[11]See Helio Tollini, "Planning Agricultural Research: Concepts and Practice," in The Future of Agriculture: Technology, Policies and Adjustments, Collection of Papers and Reports of the Fifteenth International Conference of Agricultural Economists, Sao Paulo, Brizil, August 1973.

and to coordinate the activities of other organizations such as universities, secretaries of agriculture, and other government agencies, as well as the private sector.

The responsibility of EMBRAPA is to establish and maintain research activities throughout the country. Its orientation has been toward commodity and basic resources. It has established Regional Research Centers in different regions with the objective of concentrating efforts on major problems of each region. One example of basic resource oriented research is the case of "campos cerrados." The upland savanas, or "campos cerrados," represent extensive areas which at the present time contribute little to the economy of Brazil. A Regional Research Center has been created to develop field experiments and carry out systematic examination of the soils of the "campos cerrados" in order to create technical knowledge that would make these areas capable of supporting a much more intensive agriculture than they do at the present time.

Other Regional Research Centers have been created in major producing areas to carry out research programs related to products that are important for the regional economy. In most cases the centers concentrate research efforts on one commodity or a few related commodities.

Questions arise concerning the viability of the commodity-orientation approach because of the widely scattered distribution of production of major commodities and the difficulties of transferring technological innovations from one region to another due to marked differences in environmental conditions. This orientation can affect the relative comparative advantages among regions, induce transference of resources, and have great impacts on income distribution within the agricultural sector.

At any rate, the responsibility of the research system is to strengthen the role of agriculture in the development process. Brazil, as well as other developing countries, is facing the basic problem of increasing production of food and avoiding the debilitating effects of malnutrition. Historically, the major source of output growth in the agricultural sector has been the expansion of the frontier with incorporation of new land, labor, and associated capital. As land becomes more scarce, increases in production will have to rely more on productivity growth.

Brazil is a large country with marked diversities. Its area has been estimated at 851,000,000 hectares by the National Council of Geography, and at 846,000,000 hectares by the population census. According to the 1960 census, only 3.5 percent of the total area of the country was cultivated, and only some 30 percent of the total area of the country was counted as land in farms.[12] The 1970 census estimated the population of the country to be 94,508,000 inhabitants, and classified 44 percent as rural. The population distribution is very uneven with high concentration on the East Coast and in the Central-South region. During the 1960-70 period total population grew by about 3.0 percent per year. Rural population grew at less

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[12] G. Edward Schuh, The Agricultural Development of Brazil (New York: Praeger Publishers, Inc., 1970), p. 124.

than 1 percent per year and urban population grew at an average greater than 5 percent per year during the same period.[13] Rural-urban migration is the basic factor determining the rate of growth of the urban population.

The performance of some macroeconomic variables related to the Brazilian economy during the 1961-70 period is shown in Table I.1. The annual growth rate and the rate of inflation give a good idea of the performance of the economy during that period. The economy experienced sharp decreases in the rate of growth and high inflation rates until 1965, mainly because of a political crisis in the early 1960's which led to a revolution and the take-over by the military in March 1964. The new government initiated a set of economic policies designed to speed up economic progress and control the rate of inflation. As a result, inflation was much lower after 1965, and the rate of growth indicated a strong economic performance by the end of the decade.

Agriculture has been a major sector of the Brazilian economy. It has provided a major source of employment opportunities, produced a substantial portion of the gross national product, and has been a significant source of export earnings. For example, in 1970 agriculture generated about 15 percent of the Brazilian gross domestic

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[13]Ruy Miller Paiva, et al., Setor Agricola do Brasil (Rio de Janeiro: Editora Forense Universitaria, Ltda., 1973), p. 286.

TABLE I.1: Performance of Selected Macroeconomic Variables, Brazil, 1961-1970.

	Gross National Product			Per Capita Gross Product			Inflation	
Year	1949 Constant Prices (in million Cr$)	Real Indices 1949=100	Real Annual Growth (%)	1949 Constant Prices (in Cr$)	Real Indices 1949=100	Real Annual Growth (%)	Wholesale Price Indices 1949=100	Rate of Inflation (%)
1961	521.6	226.9	10.3	7.2	160.0	6.7	776.9	33.3
1962	549.0	238.8	5.3	7.4	163.3	2.1	1,202.4	54.8
1963	557.5	242.5	1.5	7.3	160.8	-1.5	2,139.7	78.0
1964	573.8	249.6	2.9	7.3	160.4	-0.2	3,018.0	87.8
1965	589.5	256.4	2.7	7.2	159.8	-0.4	6,245.6	55.4
1966	619.6	269.5	5.1	7.4	162.7	1.8	8,678.8	38.8
1967	649.2	28.24	4.8	7.5	165.2	1.5	11,011.4	27.1
1968	709.7	308.7	9.3	7.9	174.9	5.8	14,073.5	27.8
1969	773.6	336.5	9.0	8.4	184.7	5.6	17,207.5	22.3
1970	847.2	368.5	9.5	8.9	195.8	6.0	20,611.9	19.8

Source: <u>Anuario Estatistico Do Brasil</u>, Fundacao Instituto Brasileiro de Geografia e Estatistica, 1971.

product,[14] employed 45 percent of the population, and accounted for 77 percent of the total national exports.[15]

Average annual rates of growth of the agricultural sector have been around one-half of the corresponding figure for industry. For the years of 1968, 1969, 1970 and 1971 these rates were respectively 1.5, 6.0, 5.6, and 11.4 percent per year.[16]

Any analysis of the rates of output growth in Brazilian agriculture must deal with the sources of this growth. A number of authors have consistently found that most increases in output occurred through the incorporation of new land. For example, Schuh has concluded that analysis of the aggregate data shows that output growth resulted from the expansion of the frontier, with very little increase in resource productivity.[17] Knight also points out that Brazilian agricultural development has relied on a large supply of unexploited land and abundant agricultural man-power which made it possible to increase the area cultivated, and thus production, without a parallel effort to increase productivity in the food-production sector.[18] Patrick, in a study of the sources of growth in

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[14]Centro de Contas Nacionais, Fundacao Getulio Vargas, Rio de Janeiro, Brazil.

[15]Ruy Miller Paiva, et al., op. cit., pp. 47 and 286.

[16]G. Edward Schuh, "The Income Problem in Brazilian Agriculture," Paper prepared for the EAPA/SUPLAN of the Brazilian Ministry of Agriculture, 1973 (Mimeo).

[17]Ibid., p. 11.

[18]Peter T. Knight, Brazilian Agricultural Technology and Trade - A Study of Five Commodities (New York: Praeger Publishers Inc., 1971), p. 13.

Brazilian agriculture, has estimated that over 90 percent of the growth in output of 23 principal crops between 1948-50 and 1967-69 was attributable to expansion in area and 20 percent to yield increases, while a 12 percent decrease was attributable to changes in location and crop mix.[19]

Yields in the aggregate have remained very stable although there have been some exceptions (Table I.2). Some products such as rice, beans, coffee, and cocoa experienced decreases in yields; others, such as corn, manioc, and cotton increased less than 15 percent; wheat, Irish potatoes, and peanuts, however, showed greater increases in yields during the period.

In general, yield levels have been stable and, compared to international standards, quite low. Moreover, the aggregate analysis shows that increases in productivity have been limited to a few products. This reinforces the notion that productivity has contributed very little to the growth in output of the sector.

The setting of this study is the state of Rio Grande do Sul, the southernmost state of Brazil. In this state agriculture presents a different picture than it does in Brazil as a whole, for in general, its agriculture is more developed than that of other parts of the country due to appropriate soil and climatic conditions. Average yields and average use of modern inputs per unit of land are higher, and mechanization in the crop sector is well developed.

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[19]George F. Patrick, "Fontes de Crescimento na Agricultura Brasileira: O Setor de Culturas," in Claudio R. Contador, ed., Tecnologia e Desenvolvimento Agricola (Rio de Janeiro: IPEA/INPES, 1975), p. 9.

TABLE I.2. Average Yields of Major Brazilian Crops for Selected Years

Crops	Yields in Kg/ha				Indexes (1947-51 = 100)		
	1947-51	1956-60	1964-68	1968-70	1956-60	1964-68	1968-70
Rice	1,583	1,534	1,536	1,464	97	97	92
Corn	1,273	1,254	1,332	1,365	99	105	107
Beans	686	661	665	634	96	97	92
Manioc	13,098	12,992	14,244	14,662	99	109	112
Wheat	753	638	828	945	85	110	125
Irish Potatoes	4,790	5,406	6,633	7,098	113	138	148
Coffee	1,219	1,045	847	811	86	69	66
Cocoa	464	388	356	378	84	77	81
Sugarcane	38,402	41,403	45,161	45,551	107	118	119
Cotton	438	471	482	490	107	110	112
Peanuts	1,002	1,279	1,082	1,286	128	123	128

Source: Anuario Estatistico do Brasil, IBGE (Various issues).

The problem of technological change, from a historical point of view, is well documented by Knight in a study of five commodities in the state of Rio Grande do Sul.[20] He concludes that such technological change as occurred in Rio Grande do Sul was not sufficient to result in any statistically significant increase in land or herd productivity at the state level for five major commodities. The over-all picture was one of yield stagnation. Any yield-increasing technological change or movements along production functions appear to have been offset by declining soil fertility and the extension of cultivation to more marginal lands.

The consequences of a slow modernization process are various. Many authors believe that productivity stagnation in the agriculture sector may present a bottleneck to future economic growth. In the case of Rio Grande do Sul, Knight[21] observes that continued productivity stagnation, given the exhaustion of possibilities for further extensive expansion of output, could have adverse effects on Brazil's balance of payments and would thus help perpetuate a foreign-exchange constraint on the over-all rate of economic growth.

This study analyzes the potential impacts on production, income, employment, and income distribution of the introduction of new technologies. Such an analysis should provide knowledge useful to the decision-making process related to resource allocation to

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[20] Peter T. Knight, op. cit., Chapter 5.

[21] Ibid., p. 133.

research. In order to set guidelines for research policy and to plan research activities, information is needed as to how different technological improvements may potentially affect optimum resource allocation, employment, and income.

Research Objectives

The main purpose of this study is to examine the potential economic implications of technological change in Southern Brazilian agriculture. The analysis is accomplished by the use of a dynamic model of production and resource allocation which incorporates different farm activities and different farm size groups. The extent to which selected alternative technologies based on seed, fertilizer, and mechanization will potentially affect production, income, employment, and income distribution in the regional economy will be examined.

Specifically, the objectives of the study are:

1. To determine optimal land use and production patterns through time for farms with different sizes in the state of Rio Grande do Sul, Brazil.
2. To evaluate the effects of introducing alternative agricultural technology on production, income, employment, resource allocation, and income distribution among different farm size groups. In this context it proceeds to:
    a) Evaluate the effects of introducing high-yield varieties with higher biological potential and higher capacity to respond to fertilizer application, and

b) Evaluate the effects of changing the level of mechanization by varying the combination of labor, animal power, and tractor use.

Focus and Scope of the Study

The economic impact of technological change, as Ruttan[22] indicates can be viewed in a sequence of steps following the incorporation of new technical knowledge into production decision. First, there is impact on the cost structure or the product mix of the individual firm in which new techniques are adopted. Second, there are shifts in industry demand curves for factors of production due to change in resource use at the firm level. Third, the supply of products changes as a consequence of changes in resource use. Finally, the impact is felt in the whole economy in terms of growth and distribution of total and per capita income.

This study attempts to focus on the above aspects of technological change. It follows an ex-ante approach by asking what are the potential impacts of alternative decisions of introducing new technologies in a given region for a group of crops and by assuming that these technological innovations can be made available through investment in agricultural research in combination with favorable general economic policies.

The instrument of analysis used is a regional model of agricultural production and resource allocation. The area of study

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[22] Vernon W. Ruttan, "Research on the Economics of Technological Change in American Agriculture," Journal of Farm Economics 42(4): 735-754.

is the state of Rio Grande do Sul in Brazil. The model includes disaggregation in two farm size groups, "Small Farms" of size 0 to 100 hectares and "Large Farms" of size greater than 100 hectares. The disaggregation by farm size serves to: a) capture distributional effects of technology change, b) analyze the interdependence of different farm size groups competing for regional resources, and c) partially account for aggregation problems.

The central unit of the model is a multi-period optimum decision component composed of a Recursive Linear Programming model. This model is a sequential optimization technique allowing for changes in resource constraints, objective function elements, and input-output coefficients. First, a model is developed and tested, and is supposed to represent the basic structure of regional production. Then, this model is used to simulate and evaluate the impacts of changes in structural parameters related to yield levels and response to fertilizer, labor, animal, and tractor input-output coefficients.

The analysis includes two different tests. One so-called "explanatory test" for 1970-76 is used to "explain" actual production and land use patterns. Among other things, this test is used for validation of the model. The second test is a "projection test" for 1977-1985, which consists of conditional projection of structural changes in the model. For both tests, recursive, year-to-year estimating procedures are used to generate a solution for the following year, which has the solution for the preceding year as a point of departure.

Organization of Thesis

This thesis is organized into three major parts. Part A contains the background and description of the study. It is composed of three chapters. Chapter I consists of a formal statement of the problem and the objectives of the study. Chapter II consists of a brief review of literature. Chapter III deals with the setting of the study, including a description of the regional economy.

In Part B, which is composed of two chapters, the model formulation is explained. Chapter IV contains a description of the conceptual model of regional production and resource allocation, with emphasis on the basic structural relationships analyzed in the study. Chapter V presents the mathematical formulation of the model.

The model application and analysis are presented in Part C. In Chapter VI the empirical results are presented and discussed, with an evaluation of the model performance based on the capacity of the model to track actual results of some selected variables. Chapter VII consists of summary and conclusions, including policy implications, limitations of the analytical framework, and suggestions for further research.

CHAPTER II

REVIEW OF LITERATURE

This chapter presents a review of previous work dealing with subjects relevant to the study. The review is by no means exhaustive and consists of a summary of a series of studies with special emphasis on methodological procedures and research achievements. An attempt will also be made to point out limitations and to suggest appropriate modifications for improvements of the various approaches reviewed. The idea is to show the relationships between this study and previous works, their possible contribution to this study, and the ways in which they differ from it.

The major purpose of this chapter is to briefly review some underlying theories and some models of agricultural sector analysis that provide some background to this study. The review will scan five interrelated areas: a) formal economic growth models and theories, including technical progress; b) the role of research in the economic development process; c) approaches to empirical measurement of the impacts of research investments; d) conceptualization of types, definitions, and classification of technology, with emphasis on its production and resource use aspects, and e) formal models of agricultural sector analysis which provide the basis for the production and resource allocation model developed in this study.

Any kind of economic sector model must be based on some useful theories of economic development and growth. An overall look at the literature suggests a line of development which is relevant in this case. This line starts with modern growth models, followed by the incorporation of the concept and measurement of technical progress. Then the emphasis turns to the sources of technical progress and finally to the economic implications of technical progress in the growth process.

A point of departure for modern growth theory is the Harrod-Domar model.[1] This model is simple and is based on rather strong assumptions about the economic growth process. The model requires that employment must grow at the same rate as the labor supply to allow an economic equilibrium to exist. The consequences of this assumption is that if the economy deviates slightly from the equilibrium growth rate the consequence would be either growing unemployment or prolonged inflation, since the system has no built-in equilibrating force. Thus, in general full-employment steady growth would not be possible, unless the labor force grows at a steady rate.

The underlying assumption of fixed proportions in the combination of capital and labor in the Harrod-Domar model has been the main object of criticism.[2] The relaxation of this assumption

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[1]See F.H. Hahn and R.G.O. Matthews, "The Theory of Economic Growth: A Survey," Economic Journal, 74 (December 1964): 779-902.

[2]R.M. Solow, "A Contribution to the Theory of Economic Growth," Quarterly Journal of Economics, 70 (February 1956): 65-94.

was the basis for the development of an alternative growth model known as the neoclassical model of economic growth which is founded in an aggregate production function. The pioneer work in this area is due to Solow,[3] who presents a growth model based on a production function of the Cobb-Douglas type, with two inputs, labor and capital, and assuming constant returns to scale. In this model, factor proportions are variable and all rigidities are assumed away. Basically, the problem of extreme instability of long-run growth equilibrium is unlikely and balanced growth can be achieved in the long run. Sato has questioned the speed of adjustment in the neo-classical growth model when the system moves from one equilibrium to another. He argues that "if the adjustment period is short, disequilibrium in the economic system is easily eliminated and balanced growth is promptly achieved. But if the adjustment period is long or if factor substitution takes place at a slow rate, dis-equilibrium, such as unemployment or inflation, may last for a considerable length of time. If adjustment proceeds at a slow rate proportions in the combination of capital and labor may virtually be considered as fixed."[4] In fact, his basic conclusion is that "the adjustment process in the neo-classical system of variable proportions takes place only at an extremely slow rate." For practical purposes, at least, fixed proportions may not be a very unrealistic assumption.

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[3]R.M. Solow, "Technical Change and the Aggregate Production Function," Review of Economics and Statistics, 39 (1957): 312-320.

[4]Ryuzo Sato, "The Harrod-Domar Model vs. the Neo-classical Growth Model," The Economic Journal, 74 (294): 381-387.

One of the major impacts of the development of an alternative growth model was to stimulate a variety of studies on technological change. Solow's formulation led to a formal definition of the concept of technical progress based on shifts of the production function. The increase in output per man that could not be explained by increases in capital per man was termed technical change and could be measured by the time-varying intercept of the aggregate production function.

In earlier models of economic growth, population increase and capital accumulation were the sole factors causing growth. The neo-classical approach introduced technical progress as a source of growth. However, in Solow's first formulation, technical change, or total factor productivity change, was measured by an unexplained residual. This means that technological change is disembodied from the factors of production, and is exogenously determined outside the economic system. Residual measures of technological change give no suggestion of causal process.

Subsequent development in the field concentrated on the sources of technical change. It was recognized that technological change is really an endogenous process embodied in the factors of production. The importance of the model is its usefulness in policy recommendation. Only an understanding of the sources of productivity change could provide a set of choices for increasing its growth rate.

The recognition that the level of technological knowledge depends on the amount of resources allocated to the production of new or modification of the existing technologies brought increasing attention to some unconventional variables such as research, extension, and education as major sources of productivity growth.

Increasing attention is being given to the role of research in the development process. Research as an important element in the process of modernization of agriculture is emphasized in the works of Schultz,[5] Mellor,[6] and Hayami and Ruttan.[7] Economic aspects of agricultural research, including methodology, decision-making processes, and welfare implications of technological change are discussed in a conceptual basis by various authors in a collection of papers edited by Fishel.[8] Tweeten[9] discusses the inadequacy of existing economic analysis tools to analyze problems of research resource allocation and technical change because of incorrect assumptions about the operation of the system. He points out that research costs are easier to define and measure since they consist of monetary outlays. But, because of imperfections, costs may be a very inadequate measure of the utility that could have been derived

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[5]T.W. Schultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964).

[6]J.W. Mellor, The Economics of Agricultural Development (Ithaca: Cornell University Press, 1966).

[7]Y. Hayami and V.W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971).

[8]Walter L. Fishel, ed., Resource Allocation in Agricultural Research (Minneapolis: University of Minnesota Press, 1971).

[9]Luther G. Tweeten, "The Search for a Theory and Methodology of Research Resource Allocation," in Walter L. Fishel, ed., Resource Allocation in Agricultural Research (Minneapolis: University of Minnesota Press, 1971).

from the resources had they not been allocated to a given activity. Regarding output, many measurement problems exist. It would be useful to have a quantitative measure in terms of dollar value or physical units of increased productivity or production.

There has been a variety of approaches to the empirical measurement of returns to investment in agricultural research. Schultz[10] uses the "value of inputs saved" approach which consists in calculating the value of inputs saved by the incorporation of improved techniques. He estimates how many more resources would have been required to produce the 1950 level of agricultural output if 1910 techniques had been employed. Tweeten and Hines[11] use the same basic idea, though in a different context, to estimate the contribution of agricultural productivity to national economic growth. Their approach suggests that increased agricultural productivity has released resources to other sectors of the economy which would otherwise have been employed in the agricultural sector. The release of human resources from agricultural production allow them to be employed in other sectors where the value of their marginal products are higher. This causes national income to rise more than it would if increases in agricultural productivity had not occurred.

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[10] T.W. Schultz, The Economic Organization of Agriculture (New York: McGraw-Hill, 1953).

[11] Luther G. Tweeten and Fred K. Hines, "Contributions of Agricultural Productivity to National Economic Growth," Agricultural Science Review 3 (Second quarter 1965): 40-45.

Benefit-cost analysis has also been widely used to study returns and welfare effects of investments in research. This technique uses a partial equilibrium approach based on the concept of economic surplus. Griliches[12] calculates the rate of return to research by estimating the loss in consumer surplus to society that would occur if hybrid corn had not been developed.

A major gap in knowledge in the area of investment in agricultural research is the distributional effect of technological change. In view of the increased public concern over income distribution, more information is needed on functional and personal distribution of income. Some studies have attempted to extend the analysis of previous work based on the concept of economic surplus to investigate who benefits from certain technical changes, instead of concentration on social rates of return. Schmitz and Seckler[13] consider the distribution impacts of mechanized agriculture by analyzing the introduction of the tomato harvester. In a sense, they go beyond usual welfare analysis by investigating what happened to the labor resources saved or displaced by mechanization.

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[12]Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy 66 (October 1958): 419-431.

[13]A. Schmitz and D. Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," American Journal of Agricultural Economics 52 (November 1970): 569-577.

Ayer and Schuh[14] analyze cotton research in Brazil using the usual economic surplus concept, but then go on to evaluate the distribution of the benefits of the new technology in the form of high yield varieties developed in a major producing area. Their results show that, on the average, about 60 percent of total social gains have gone to the producer in the form of producer surplus and about 40 percent to the consumer as consumer surplus. On the production side, they conclude that because of the characteristics of the land and labor market most of the benefits go to landowners in the form of capital gains. Very little goes to the labor force, which benefits from the creation of additional employment but not from higher real wages which should reflect the increases in productivity due to the new technology. Interestingly enough, they find that one of the benefits of the research program is the maintenance of the comparative advantage of the region, by the prevention of cotton production spreading more rapidly to other areas. This shows the impacts that public investments in region and crop specific research can have in strengthening development in one region vis a vis others. As Tweeten[15] has observed, ". . . concentration of research funds in geographic areas and institutions not only provides direct

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[14] H.W. Ayer and G.E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," American Journal of Agricultural Economics 54(4): 557-569.

[15] Luther G. Tweeten, "The Search for a Theory and Methodology of Research Resource Allocation," in Walter L. Fishel, ed., Resource Allocation in Agricultural Research (Minneapolis: University of Minnesota Press, 1971), p. 57.

economic benefits but also builds a technological base in order to attract technologically oriented industry as well as more federal funds. This can generate a disparity in income among regions."

Another approach to the study of the contribution of research to productivity gains is aggregate production function and regression analysis. This approach attempts to estimate marginal returns to research by using agricultural research expenditures as a separate explanatory variable. One of the first attempts to define this relationship was made by Griliches,[16] who introduced both research and extension expenditures as explanatory variables.

Time lags in research investments can be introduced by the production function and regression analysis approach through the use of distributed lag techniques. Evenson[17] explicitly formulates this relationship by hypothesizing that the flow of returns to research resembles an inverted V. This means that the returns first increase as knowledge is generated and adopted, reach a maximum, and then decrease as the knowledge is depreciated. A recent contribution which extends Evenson's approach is presented by Cline,[18] who estimates lags in and returns to agricultural research in different regions of the United States.

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[16]Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," American Economic Review 54 (December 1964): 961-974.

[17]Robert E. Evenson, "The Contribution of Agricultural Research to Production," Journal of Farm Economics 49(5): 1415-1425, December 1967.

[18]Philip Lee Cline, "Sources of Productivity Change in United States Agriculture," unpublished Ph.D. Thesis, Oklahoma State University, 1975.

The role of agricultural research in the development process has been emphasized as a major source of production technology. The Hayami and Ruttan[19] theory of induced technological change stresses the importance of relative factor endowment in determining the efficient path to modernization and output growth. According to this theory, an important factor is production technology which, in their view, should be developed to ease production constraints determined by factor supply rigidities. Production technology facilitates the substitution of one resource for another, leading to substantial increases in output. The extent to which substitution takes place is mainly a function of the impacts the technology has on the marginal rates of substitution between pairs of inputs.

For the purpose of understanding the relationships involved in the process of technological change in respect to resource use adjustments and production response, technologies are usually classified in very broad categories. The different types of technologies can be characterized in terms of their own impact on the marginal rates of substitution among capital, labor, and land, and on yield level. At least in a conceptual basis, this problem is well understood. Difficulties arise, however, in relation to empirical analysis of basic economic and welfare aspects of one type or package of technological innovations.

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[19] Y. Hayami and V.W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971).

One of the first distinctions among types of technology was made by Heady.[20] He distinguished between "mechanical" and "biological" innovations, the former primarily labor-saving (cost-reducing), with a negligible output-increasing effect, the latter basically yield-increasing and labor-saving. Hayami and Ruttan[21] make basically the same distinction. They distinguish between "mechanical" and "biological and chemical" innovations. They also observe that, historically, mechanization has displaced labor without significant impact on yields and biological innovations have had a land-saving impact. Their classification stresses the role of fertilizer impact and the interaction between fertilizer and high-yielding crop varieties.

The development of technology in the form of high-yielding crop varieties facilitates the substitution of fertilizer for land. The critical difference between improved and indigenous varieties is that the former tend to have a larger, more sustained response to fertilizer. Traditional varieties either respond only slightly, or, in some cases, negatively to applications of fertilizers. Schuh[22] points out another aspect of the interaction between fertilizer and high-yield varieties. He observes that in

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[20]Earl O. Heady, "Basic Economic and Welfare Aspects of Farm Technological Advance," Journal of Farm Economics 21(2): 293-316

[21]Y. Hayami and V. W. Ruttan, op. cit., pp. 43-53.

[22]G. E. Schuh, "The Modernization of Brazilian Agriculture," Paper prepared for the United States National Academy of Science, 1973 (Mimeo).

addition to the effects of permitting the substitution of fertilizer for land with yield and output increases, the new technology, in the form of improved varieties, permits the introduction of an input produced in the industrial sector into the agricultural sector. If it were not for the new technology, the introduction of this input would not be feasible, since the use of the input supplied by the industrial sector would not be profitable.

Recently, De Janvry[23] classified technologies into four categories: mechanical, biological, chemical, and agronomic. The first three are consistent with earlier definitions in terms of their characterization, while agronomic refers to cultural practices and management techniques. One important point of this distinction is the consideration given to management, as a factor of production, and its relationship to technology. In many cases the decision to adopt a certain type of innovation depends on the management skills available to deal with such innovations and also on how much management time can be saved from one activity and used in other activities.

Following Seckler,[24] De Janvry finds it useful to distinguish between "on line" management and "staff" management. The former consists of the actual direction of farm activities, the process of

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[23]Alain De Janvry, "A Socioeconomic Model of Induced Innovations for Argentine Agricultural Development," Quarterly Journal of Economics, 87(3): 410-435.

[24]D. Seckler, "Reflections on Management, Scale, and Mechanization of Agriculture," Proceedings of the Western Agricultural Economics Association (Tucson, Arizona: July 1970).

conducting and coordinating tasks and operations on the farm. The latter deals with decision-making as to choice of activities and techniques, principally investment decisions, financial and fiscal administration, and commercial activities.

According to De Janvry, mechanical innovations raise the productivity of labor mainly through increases in land per worker. By reducing labor costs, they will substantially reduced on-line management requirements. Staff management requirements may increase somewhat as the firm becomes more capital-intensive. Biological innovations are fairly neutral on labor and management requirements. They are slightly capital-using and moderately yield-increasing when used outside of complete packages of techniques. Chemical innovations aim at increasing yield. They are fundamentally land-saving in permitting substitution of capital and labor for land. As capital and labor deepens, however, more on-line and staff management per unit of land are required. Finally, agronomic innovations are labor-using on-line-management-using, and land saving. Like chemicals, they are strongly yield-increasing. Packages of biological, chemical, and agronomic technologies combine the factor biases of their components and tend to be labor-using and on-line-management-using and very strongly yield-increasing.

These distinctions and characterizations of different types of technologies show how resource allocation will tend to differ with the introduction of technical innovations.[25] For example,

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[25] For an empirical analysis of employment effects of seed-fertilizer innovations see B.F. Johnston and J. Cownie, "The Seed-Fertilizer Revolution and Labor Force Absorption," American Economic Review, 59(4): 569-582.

mechanization will require less labor, more capital, less on-line management, and more staff management per unit of land. In addition, it also indicates resource productivity impacts. Mechanization considerably raises the yield per unit of labor; it generally does not lead to significant yield increases per unit of land.

Finally, the last part of this review will refer to formal models of production and resource allocation. Obviously, it is impractical to try to be complete here, due to the vast number of studies in this area. The review will basically refer to some Recursive Linear Programming studies which provide analytical framework for this study.

Activity analysis, in its various forms, has been used extensively to analyze problems in which choices and decisions are characterized by a complex set of interdependencies. The problem of optimal resource allocation under alternative technologies has been analyzed using comparative statics linear programming. Usually it involves the construction of different models with sets of input-output coefficients specified for each "technological level." Coffey[26] uses this approach to analyze the effects of the introduction of modern farming practices upon the net returns to agriculture in the Sierra region of Peru. He develops sets of input-output coefficients representing four "technological levels" for each of the crop and livestock activities included in the model. One set was

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[26] J.D. Coffey, "Impact of Technology on Traditional Agriculture: The Peru Case," Journal of Farm Economics, 49(2): 450-457.

designed to reflect the existing input-output relationships in the region. The second set was based upon the highest levels of efficiency which have been attained in the region under experimental conditions when all the recommended practices were followed. The other two sets of coefficients represented intermediate levels between the two aforementioned extremes. Three regional revenue-maximizing linear programming models were specified to correspond to the estimated resource availabilities and adjustment potentials for the years 1963-64, 1980, and 2000.

Recently, Faisal[27] used the same approach to investigate the efficient allocation of productive resources and to determine the optimal land use and production pattern in four regions of Bangladesh under two technological levels, existing agricultural technology and technology projected for 1985.

The general framework of analysis used in this study is Recursive Linear Programming. It is a form of activity analysis which takes into consideration the dynamic aspects of the decision-making problem and introduces the idea of sequential planning behavior, which seems to characterize the actual decision-making process. This approach to programming was pioneered by Day[28] who used the technique to study production response and other aspects

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[27] Mohammad Faisal, "Optimal Land and Water Use and Production Response Under Alternative Technologies in Bangladesh - A Programming Approach," Unpublished Ph.D. Dissertation, Michigan State University, 1977.

[28] Richard H. Day, Recursive Programming and Production Response (Amsterdam: North-Holland Publishing Co., 1963).

of agricultural development in the Mississippi Delta of the United States. Recursive programming incorporates the time variable in a "forward-looking" fashion. Newly acquired information is used to continually reformulate the decision-making process through time. It differs from polyperiod programming, which considers various periods within a planning horizon and takes into account backward and forward effects when solving simultaneously for all periods. As Day[29] points out, "A recursive programming problem is not solved by a single decision that claims to determine what action will be optimal in each planning period within the time horizon, as do current versions of dynamic programming. Instead, it recognizes that plans for the future must be changed during each succeeding planning period to account for the actual history of economic variables."

Heidhues[30] presents a recursive linear programming model of farm growth in Northern Germany in which the basic modeling unit is the individual farm firm. Models of regional development are presented by Singh[31] and Mudahar,[32] both applied to the Punjab area in India.

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[29] Richard H. Day, "An Approach to Production Response," Agricultural Economic Research 14(4): 134-148.

[30] Theodor Heidhues, "A Recursive Programming Model of Farm Growth in Northern Germany," Journal of Farm Economics 48(3): 668-684.

[31] I.J. Singh, "A Regional R.L.P. Model of Traditional Agriculture," Occasional Paper No. 19, Department of Agricultural Economics and Rural Sociology, Ohio State University, November 1970.

[32] M.S. Mudahar, "A Dynamic Microeconomic Analysis of the Agricultural Sector: The Punjab," Workshop Series No. 7052, Social Systems Research Institute, The University of Wisconsin, 1970.

With reference to Brazil, there is the work of Ahn[33] who used the recursive programming approach to study agricultural transformation in the wheat-producing area of Southern Brazil during the 1960-70 decade. This model is for one region with disaggregation into three farm size groups to account for aggregation problems. Basically the objective of the study was to analyze agricultural transformation during the period characterized by: (1) a shift from the traditional livestock production on extensive natural pastures to intensive cropping of wheat and soybeans and intensive livestock production on improved pasture systems, and (2) a consequent increase in mechanized crop farming.

Recursive linear programming is very appropriate to handle resource allocation problems in a systems simulation model. An example is the Korean Agricultural Sector Simulation model which has a farm resource allocation component modeled by recursive programming and is designed to study, among other things, farm mechanization problems at a regional level.[34] The component model is described

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[33]C.Y. Ahn, "A Recursive Programming Model of Regional Agricultural Development in Southern Brazil (1960-1970): An Application of Farm Size Decomposition," Unpublished Ph.D. Dissertation, The Ohio State University, 1972.

[34]G.E. Rossmiller, et al., Korean Agricultural Sector Analysis and Recommended Development Strategies, 1971-1985 (East Lansing: Michigan State University, 1972).

by de Haen and Lee[35] and by de Haen.[36] It includes 19 commodities or commodities groups and three regions. Disaggregation into farm size groups was not considered necessary, because of a land reform and a legal limitation of the maximal farm size in Korea.

In general, a recursive linear programming model has two basic sets of relationships: (1) on-farm decision structure, and (2) dynamic feedback mechanisms. The basic differences between static and recursive linear programming are the recursive feedback mechanisms which relate on-farm decisions between two points in time, say t and t+1. Most of the RLP models consider only behavioral bounds and resource-augmenting equations as dynamic feedback mechanisms. This is the same as considering the restriction elements as varying over time and placing upper and lower bounds in the level of real activities. A RLP model may include dynamic feedback mechanisms for the objective function coefficients, for the constraints elements, and for the input-output coefficients.

It is true, however, that what will determine the basic structure of a model are the objectives for which the model is built. The decision to include or exclude certain relationships and variables should be based on the problem and hypothesis under investigation.

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[35] Hartwig de Haen and J.H. Lee, "Dynamic Model of Farm Resource Allocation for Agricultural Planning in Korea - Application of Recursive Programming Within a General System's Simulation Approach," Project Working Paper 72-1, Agricultural Sector Analysis and Simulation Projects, Michigan State University, East Lansing, 1972.

[36] Hartwig de Haen, "Preliminary User's Guide to the Recursive Linear Programming Resource Allocation Component of the Korean Agricultural Sector Model," KASS Working Paper 73-2, Michigan State University, East Lansing, 1973.

In general, three major problems are present in the models reviewed above. They are: the exclusion of important resource restraints, estimation of flexibility coefficients, and aggregation problems. Theoretically, all possible restraints affecting farmers' decisions should be included in the model. These could be different types of land, labor, various kinds of machinery, and financial constraints. The accuracy of the flexibility coefficients will, in large part, determine the performance of any RLP model. With few exceptions, the methods used to estimate these coefficients have been rather simple. They are usually based on averages of past average changes or on simple regression models. More sophisticated methods should be developed based on economic as well as on non-economic variables. Aggregation bias is always a problem in regional models. One solution would be to build the model with disaggregation by homogeneous regions, farm size, and resource types.

Theoretically, a RLP model would require a distinct input-output matrix for each year of the analysis. Few recursive programming models have considered this possibility. In most models with a time-varying input-output matrix the element that varies through time is yield. Since the structure of resource combination is characterized by a dynamic process, there are reasons to consider other elements of the input-output matrix as well, for instance, changes in feed inputs for livestock activities, to account for increased efficiency in feeding practices, and changes in labor inputs over time for production activities to account for the fact that farmers tend to simplify and organize task combinations and sequences more effectively. Another possibility is to consider changes in the proportions of labor, animal, and tractor power over time to account for an increased level of mechanization.

In this study a Recursive Linear Programming model is used as the basic approach to represent resource allocation decisions of farmers in the region studied. The most important resource restraints affecting farmers' decisions are considered in the model. Flexibility coefficients are estimated based on past average changes in crop area. Disaggregation in two farm size groups is used to account for aggregation bias. The model allows for changes over time in all three components of the linear programming structure. Varying with time are all objective function coefficients, all constraint elements, and the input-output coefficients related to labor, tractor, and draft animal requirements.

In summary, this chapter presents a review of a number of works related to the present study. The review scans different interrelated areas and is intended to provide some background for analyzing the impacts of alternative technologies on production, income, and resource allocation in the agricultural sector. Even though a review of the literature for estimating research returns was presented, it should be clear that this is not the focus of this study. The basic analytical framework followed is the analysis of the potential impacts and adjustments on the production structure of the region studied that will occur if alternative varietal and mechanical technologies are introduced. A regional programming model is used for estimating the effects of technological change in production, income, and resource allocation in the region.

CHAPTER III

THE REGIONAL SETTING OF THE STUDY

The main purpose of this chapter is to present some descriptive information about the area under consideration in this study. The first part of the chapter contains some macroeconomic data on the South Region of Brazil and the states which form this region with the objective of showing the importance of the agriculture sector and the relative position of the state of Rio Grande do Sul in the regional economy. The second part summarizes the characteristics of agriculture in Rio Grande do Sul with reference to the structure of land tenure, production technology, and description and interrelationships among farm activities.

The Geographic Setting

The regional setting for this study is the state of Rio Grande do Sul, the southernmost state of Brazil. This state and the states of Parana and Santa Catarina form the South Region of Brazil. The region has an area of 577,723 km^2 which corresponds to 6.8 percent of the total area of the country. Its population in 1970 was estimated at 16.7 million habitants, about 17.6 percent of the Brazilian population. Its population density is 29.68 persons per square kilometer.[1]

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[1]Ruy M. Paiva et al., Setor Agricola do Brasil (Rio de Janeiro: Editora Forense Universitaria, Ltda., 1973), p. 278.

In 1968 the domestic income of the South Region was estimated at Cr$13,613 millions which corresponds to 17.3 percent of the domestic income of the country. Agriculture comprised 36.8 percent, industry 15.2 percent, and services 48.0 percent of the regional domestic income (Table III.1).

Table III.1: Estimated Domestic Income by Sectors, South Region of Brazil, 1968 (Cr$1,000).

States	Agriculture	Industry	Services	Total
Parana	2,101,036.1	479,746.7	2,234,678.4	4,815,461.2
Santa Catarina	705,025.4	453,251.7	918,076.5	2,076,353.6
Rio Grande do Sul	2,201,165.3	1,134,464.5	3,385,698.0	6,721,327.8
South Region	5,007,226.8	2,067,462.9	6,538,452.9	13,613,142.6

Source: Centro de Contas Nacionais IBRE-FGV.

The state of Rio Grande do Sul accounted for approximately 50 percent of the domestic income of the region in 1968. Agriculture is the second most important sector in the state's economy, accountint for 33 percent of the domestic income in 1968. Within the agricultural sector, the subsector of crops is the most important and was responsible for 69 percent of the agricultural gross product of the state in 1969 (Table III.2).

Table III.2: Agricultural Gross Product by Subsectors, South Region of Brazil, 1969 (Cr$1,000).

States	Crops	Livestock	Forestry	Total
Parana	2,561,064.4	516,522.5	57,635.1	3,135,222.0
Santa Catarina	503,411.3	340,115.0	57,381.9	900,908.2
Rio Grande do Sul	2,040,222.8	835,197.5	88,166.8	2,963,587.1
South Region	5,104,698.5	1,691,835.0	203,183.8	6,999,717.3

Source: Centro de Contas Nacionais, IBRE-FGV.

Some Characteristics of Agriculture in Rio Grande do Sul

The state of Rio Grande do Sul is one of the most important producers of agricultural products in the South Region and also in the country. It has experienced developments characteristic of the agricultural sector during the past decade, among them changing output patterns, changing technology, and a considerable variation in farm size and organization. Because of its mild and temperate climate and fertile soils, Rio Grande do Sul has significantly contributed to the agricultural output of Brazil. It has provided large amounts of beef and is the most important wheat producer in the country, accounting for about 90 percent of the country's wheat harvest in the crop year 1970-71.

Table III.3 presents some data which summarizes the changes in agricultural organization and input relationships in Rio Grande do Sul during the 1960-1970 decade. Increases in farm numbers and cultivated area represent two dimensions of frontier expansion and

Table III.3: Some Characteristics of Agriculture in Rio Grande do Sul, Brazil, 1960-1970

	1960	1970	Percent Change 1960/1970
Number of Farms	380,201	512,422	35
Cultivated Area (Ha)	3,212,698	5,298,779	65
Number of Tractors	15,169	38,317	153
Farms per Tractor	25	13	-48
Cultivated Area per Tractor (Ha)	212	138	-35
Persons Occupied in Agriculture	1,334,039	1,467,452	10
Area Cultivated per Person (Ha)	2.4	3.6	50
Persons Occupied per Tractor	88	38	-57

Source: Dale W. Adams et al., "Farm Growth in Brazil," Department of Agricultural Economics and Rural Sociology, The Ohio State University, 1975.

agricultural intensification. Farm numbers increased by only 35 percent, but a higher intensification of agriculture was achieved by a 65 percent increase in area cultivated during the 1960-1970 decade. This increase was due largely to wheat and soybean production.

Assuming numbers of tractors and their relationship to labor and cultivated area as a proxy for mechanization, it is apparent that a great transformation occurred during the 1960's. From 1960 to 1970 tractor numbers rose from 15,169 to 38,317, an increase of 153 percent. Farms per tractor decreased by 48 percent, cultivated area per tractor decreased by 35 percent, and persons occupied per tractor decreased by 57 percent during the same period. This indicates a higher level of modernization as measured by the higher proportion of capital per labor and per land in 1970 relative to 1960.

Change in employment is another aspect of the structural transformation of agriculture. From 1960 to 1970 the state of Rio Grande do Sul still showed an absolute increase of 10 percent in the number of persons employed in agriculture. When this increase is related to cultivated land, it reflects an increase from 2.4 to 3.6 cultivated hectares per person. In the aggregate, this corresponds to an increase of 50 percent in the efficiency of labor.

Data on distribution of land by farm size categories show a highly skewed distribution pattern for 1960 and 1970 (Table III.4).

Table III.4: Percent Distribution of Land by Farm Sizes, Rio Grande do Sul, Brazil, 1960 and 1970 (Percent)

Sizes (Ha)	1960		1970	
	Farms	Area	Farms	Area
0 - 10	26.26	2.33	34.61	3.58
10 - 100	66.45	30.26	58.82	32.40
100 - 1,000	6.44	31.10	5.83	35.19
1,000 - 10,000	0.81	30.12	0.63	27.50
Over - 10,000	0.02	6.19	0.00	1.33
Unclassified	0.02	--	0.11	--
TOTAL	100.00	100.00	100.00	100.00

Source: Anuario Estatistico do Brasil, IBGE.

The data show no significant improvement in the concentration of ownership from 1960 to 1970. The proportion of farms under ten hectares grew by 8.0 percent during the period. These farms constituted 34.6 percent of total farm numbers in 1970 yet held only 3.58 percent of the land area compared to the farms of 1,000 hectares or more which accounted for 0.6 percent of the farms and 28.8 percent of the area. Of course, this type of data does not reflect the varying quality of land, especially the large amount of poor land on many large farms.

Production activities in Rio Grande do Sul are rather diversified due to variations in altitude and climatic conditions. The main products are wheat, corn, soybean, rice, flax, beef and dairy cattle, sheep and hogs. Of these products the most important ones are wheat, soybean, corn, rice and beef. In the years 1965-67, Rio Grande do Sul produced 87.6 percent of Brazil's wheat, 81.7 percent of her soybeans, 18.9 percent of her corn, 18.6 percent of her rice, and 13.0 percent of her beef. Among exports, Rio Grande do Sul accounted for 84.7 percent of the rice, 85.4 percent of soybeans and soybean products, and 89.9 percent of the chilled and frozen beef exported by Brazil in the years 1965-67.[2] Thus, Rio Grande do Sul has contributed significantly to Brazilian output and trade in these five important agricultural commodities. In its wheat production it has been an important producer of an import substitute, since

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[2]Peter T. Knight, <u>Brazilian Agricultural Technology and Trade - A Study of Five Commodities</u> (New York: Praeger Publishers, Inc., 1971), p. 34.

wheat is the only major agricultural product which Brazil imports in significant quantities.

The problem of relatively low yields and slow yield increases for the main crops in Rio Grande do Sul has already been mentioned in Chapter I. Yield increase per unit of land is one of many indexes of technological change in agriculture which is commonly used, despite its faults. This index, however, is deficient in that it can be greatly affected by weather and disease incidence. Because land productivity is largely dependent on these factors, it may not show any upward movement even though technological progress has occurred to a certain extent.

The relative importance of the four major crops in Rio Grande do Sul over time is shown in Table III.5. All crops have experienced increase in cultivated area over time. Corn, an important crop for small farms, has been more or less stable or has shown a slight downward trend during the last eight years of the series. The relative importance of Rio Grade do Sul as a major producer of wheat and soybeans is clearly demonstrated by the significant increases in cultivated area with these two crops. From 1970 to 1976 the cultivated area of soybeans rose from 871,202 hectares to 3,297,000 hectares, an increase of 278 percent. The total area cultivated with these four crops corresponded to 85 percent of the total cultivated area in the state in 1970.

In terms of production, data in Table III.6 show that rice and corn have grown at much lower rates than wheat and soybeans. Production of wheat increased from 532,336 tons in 1960 to 1,500,000

Table III.5: Harvested Area for Four Field Crops, Rio Grande do Sul, 1960-1976 (Hectares)

Year	Rice	Corn	Wheat	Soybeans
1960	341,500	1,216,553	941,109	159,423
1961	355,581	1,281,604	832,176	227,155
1962	377,452	1,361,531	544,533	294,892
1963	385,338	1,403,915	600,251	318,298
1964	391,339	1,420,298	541,581	334,520
1965	449,561	1,577,577	571,111	386,452
1966	375,312	1,632,124	545,433	416,297
1967	390,813	1,626,875	658,289	490,870
1968	382,987	1,670,195	757,748	557,027
1969	409,037	1,730,130	1,072,574	649,116
1970	430,822	1,737,080	1,500,000	871,202
1971	412,322	1,722,014	N.A.	1,133,213
1972	433,684	1,717,006	N.A.	1,459,594
1973	415,934	1,507,083	1,372,952	2,217,570
1974	435,600	1,525,000	1,565,380	2,770,000
1975	470,000	1,524,138	1,898,923	3,113,286
1976	520,000	1,580,000	2,016,000	3,296,000

Source: Anuario Estatistico do Brasil - IBGE.

Note: N.A. = Not Available.

Table III.6: Production of Four Field Crops, Rio Grande do Sul, 1960-1976 (Metric Tons)

Year	Rice	Corn	Wheat	Soybeans
1960	888,675	1,582,136	532,336	188,500
1961	1,090,099	1,765,006	397,664	252,556
1962	1,169,789	1,870,590	520,695	320,755
1963	1,275,304	1,947,839	262,909	294,828
1964	1,180,661	1,773,764	477,929	275,946
1965	1,304,210	2,243,859	420,575	463,153
1966	1,167,788	2,280,929	466,289	483,339
1967	1,281,103	2,331,002	481,907	550,814
1968	1,285,605	1,971,319	665,034	423,585
1969	1,353,673	2,233,679	1,065,888	744,498
1970	N.A.	2,386,627	1,500,000	976,807
1971	N.A.	2,370,510	N.A.	1,392,917
1972	N.A.	2,234,886	N.A.	2,173,553
1973	1,433,872	2,100,808	1,535,887	2,872,060
1974	1,550,000	2,236,000	1,690,000	3,870,000
1975	1,700,000	2,67,322	1,234,300	4,688,521
1976	1,850,000	2,493,000	1,914,400	5,107,000

Source: Anuario Estatistico do Brasil - IBGE.

Note: N.A. = Not Available.

tons in 1970 and to an estimated 2,004,000 tons in 1976. Even higher increases have occurred in soybean production, which rose from 188,500 tons in 1960 to 976,807 tons in 1970 and to an estimated 5,331,000 tons in 1976. The data on physical output and cultivated area for the four field crops reinforce the point that the increased production was primarily due to the increased use of land rather than to improving yield per hectare.

One interesting aspect of the growth of area cultivated and production of these four crops is the interrelationships among them and beef production. Cropping patterns have changed significantly in the past decade due to differences in profitability of these major farm activities. Basically, what has characterized agricultural transformation in Rio Grande do Sul is a shift from the traditional range livestock production on extensive natural pastures to intensive cropping of wheat and soybeans and intensive livestock on improved pasture systems. Intensification in the use of agricultural land was made possible by a rapid increase in mechanization.[3]

During the 1960-1970 decade, price subsidy for wheat and a subsidized credit program tied with the purchase of commercial

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[3]For detailed analysis of agricultural transformation in Rio Grande do Sul see Norman Rask, "Technological Change and the Traditional Small Farmer of Rio Grande do Sul - Brazil," Occasional Paper No. 85, Department of Agricultural Economics and Rural Sociology, The Ohio State University, June 1972; C.Y. Ahn, "A Recursive Programming Model of Regional Agricultural Development in Southern Brazil (1960-1970): An Application of Farm Size Decomposition," Unpublished Ph.D. Dissertation, The Ohio State University, 1972; and Joaquim J.C. Engler, "Alternative Enterprise Combinations Under Various Price Policies on Wheat and Cattle Farms in Southern Brazil," Unpublished Ph.D. Dissertation, The Ohio State University, 1971.

inputs was largely favorable to wheat production in Rio Grande do Sul. Furthermore, high prices for soybeans in the world markets and the complementary relationship between wheat and soybeans have enhanced the competitive nature of these two crops. Soybeans can be produced in double-cropping rotation with wheat without fertilizer application, allowing fuller use of the labor and machinery inputs needed for wheat production.[4]

Cattle production has not been able to compete effectively with wheat and soybeans due to low cattle prices and the lack of direct incentives for this enterprise. As a result, wheat and soybeans have replaced extensive natural pastures and forced livestock producers to shift to a higher productive alternative cattle production system based on improved pasture systems. Rice and corn have not been significantly affected by wheat and soybeans. Soybeans have replaced corn only in some areas where land is of better quality.

Beef production has been a very important activity in Rio Grande do Sul for a long time. In terms of area occupied, it is by far the most important. Census data show that 61 percent of the agricultural area in 1970 was devoted to pastures, with 59 percent natural pasture and 2 percent cultivated pasture. The area devoted to crops was 21 percent of the total.[5]

There are significant interrelationships between beef and other activities. Rice and beef production are largely complementary

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[4]Joaquim J.C. Engler, op. cit., pp. 9-10.

[5]Anuario Estatistico do Brasil - IBGE.

activities. Natural pastures have their highest carrying capacity in the summer when rice lands are occupied, but in the winter, when carrying capacity of pastures sharply decreases rice lands are available for grazing. This combination is very appropriate, since the most important factor limiting productivity in the beef sector is the winter forage shortage. As mentioned above beef production has been replaced by wheat and soybeans because of low profitability of the cattle enterprise in comparison to wheat and soybeans.

Most rice production in Rio Grande do Sul takes place on irrigated lands. It is a fairly advanced activity in terms of its agro-technical characteristics. Productivity is somewhat correlated to the size of area planted with rice in each farm unit due to better management techniques in relation to water and fertilizer application. Mechanized land preparation is a common practice, but harvest mechanization is not very feasible due to drainage problems. Varietal improvements for rice have not provided more than 10 to 15 percent increase in yield above the indigenous varieties. Moreover, improved varieties have not been capable to efficiently use high levels of nitrogen fertilization.

Wheat production takes place on large farms with an extensive use of mechanized equipment, and on small farms with the use of animal power and large amounts of labor. Even though the land on large farms tends to be of lower quality, yields on mechanized farms average about 5 percent higher than on non-mechanized farms due to better management techniques and higher fertilization. Most varietal wit

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improvements in the past have been directed toward disease resistance, with little attention to fertilizer response.

Soybean production has increased in importance in recent years due to increased domestic and foreign demand for soybeans and soybean products. Soybeans are cultivated independently or in double cropping with wheat. When cultivated in double cropping, soybean planting has to be delayed and this causes a decrease in yield of up to 30 percent. Because of the timing of operations, mechanization is highly necessary. Production costs are lower for soybeans following wheat because of lower land preparation costs and because fertilizer is not applied.

Corn is cultivated mostly in farms of smaller size using traditional technology. It is closely associated with hog enterprises; most corn is an intermediate good in hog production. Soybeans are a potential substitute for corn in production. In some areas black and brown beans for human consumption and manioc are interplanted with corn.

The interrelationships among farm activities in terms of the timing of operations and input utilization during the year are illustrated by the calendar of operations given in Table III.7. The year is divided into three periods representing the major peak seasons in respect to input utilization. This classification is quite aggregate but should be sufficient for purpose of this study. Lack of data does not allow for a more disaggregated classification. The three periods adequately represent the peaks in labor use.

Table III.7: Calendar of Operations

Months	Rice	Corn	Wheat	Soybean/ Wheat	Soybean Independent	Summer Pasture	Winter Pasture
July						Soil Preparation and Planting	
August			Cultiavtion				
September	Soil Preparation and Planting	Soil Preparation and Planting			Soil Preparation and Planting		
October							
November			Harvesting				
December	Irrigation	Cultivation		Soil Preparation and Planting	Cultivation		
January							
February							
March	Harvesting	Harvesting			Harvesting		Soil Preparation and Planting
April				Harvesting			
May			Soil Preparation and Planting				
June							

In conclusion, this chapter shows that the state of Rio Grande do Sul is one of the most important producers of agricultural products in the South Region and also in the country. A major characteristic of its agriculture in the past fifteen years.has been a shift from the traditional range livestock production on extensive natural pastures to intensive cropping systems. Increases in crop yields have not been significant in the past. Basically, increases in production have resulted from increased use of land rather than from the improvement in yield per hectare.

PART B

THE FARM RESOURCE ALLOCATION AND PRODUCTION MODEL

CHAPTER IV

THE CONCEPTUAL APPROACH OF THE MODEL

Introduction

The agricultural production system of Rio Grande do Sul has experienced very significant changes during the past fifteen years. These changes have been related to levels and composition of resources used and output. There have been great changes in the quality and quantity of inputs used; new inputs in the form of improved seeds, fertilizer, and machinery have been introduced and used in rapidly increasing amounts. Also, real agricultural output has grown considerably, and production patterns have changed significantly, resulting in a transformation of the regional economy from range livestock production to intensive crop production.

Technological change has been a most strategic factor in the transformation of traditional agriculture. The complexity of choices involved in agricultural production is further increased when new technologies are introduced. In Rio Grande do Sul rapid increase in mechanization has been the major characteristic of technological advance. Other technologies such as biological innovations have not contributed as much as they could to the growth process. Yields per hectare and per annual remained relatively stagnant throughout the 1960's and early 1970's.

It is difficult to predict how this transformation will develop in the future. It is true, however, that the future of agriculture in Rio Grande do Sul will depend on government policies toward the agricultural sector and to market adjustments to supply and demand shifts. Despite the uncertainties in respect to market conditions, it has to be recognized that the performance of the agricultural sector will depend on the extent of government participation which alters the environment within which farmers make their decisions. As Singh and Ahn[1] point out, government intervention may occur in three ways: a) by directly controlling scarce economic and physical resources through controls over their distribution or access to them (distribution of seeds, fertilizers, or credit are examples); b) by intervention in product or factor markets either directly through the purchase or sales of inputs or outputs or indirectly through price controls and taxes (price support programs, excise and sales taxes, transportation levies, land taxes, and input price subsidies are examples); and c) through changes in the economic and social infrastructure within and with which farmers operate, thus reducing the costs of farm production or increasing (in quantity and quality) the real resource base (including knowledge) of the farm sector.

Given these considerations, three underlying assumptions are maintained in this study: a) in spite of significant changes that have occurred in the past, resource reallocation within agriculture

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[1]I. Singh and C.Y. Ahn, "A Dynamic Multi-commodity Model of the Agricultural Sector: A Regional Application in Brazil," Studies in Employment and Rural Development No. 37, IBRD, Washington, D.C., 1977, (Mimeo), p. 6.

and changes in production structure will continue in the future; b) technological change will continue as an important factor in the process of transformation and will be characterized by different types of innovations, and c) government participation in its various forms will continue as a major factor affecting the economic environment within which farmers make their decisions.

The primary objective of this study is to develop an aggregate sector level model for one region with disaggregation in two farm size groups which take into account the economic behavior of farmers as decision-makers in the agricultural sector. The basic approach is to model the activities of farm firms as behavioral decision units competing for regional resources. The model is used to project adjustments and structural changes in resource allocation and production. This chapter presents a conceptual description of the theory and logic behind the model. Detailed model formulation is presented in the next chapter.

Some Useful Concepts of Production Theory

In a broad sense, production may be defined as the transformation of inputs into outputs, and technology is the set of technical opportunities that defines the basic relationships of this transformation. Considering a process as represented by a vector of input-output coefficients, that is, a particular method or technique of converting resources into a product, technology may be defined as the complete set of processes available or potentially available for production. Processes can be defined as the different ways or sequences in which production can be carried out. A process is characterized by certain ratios of the quantities of the inputs to each other and to the quantities of each of the outputs.[2]

The concept of a production function is one of the most important in the theory of production economics. It formalizes the relationship between output and inputs in a production system. A production function is defined as "a schedule showing the maximum amount of output that can be produced from any specified set of inputs, given the existing technology."[3] The concept is associated with a particular technological process. It expresses the relation between input and output, as well as the relation among inputs themselves. It also implies that a technical maximization problem has been solved. In mathematical form it can be represented by

$$Y = f(X_1,\ldots,X_j/X_{j+1},\ldots,X_n) \qquad (1)$$

where Y is output, $X_1,\ldots,X_j$ are variable inputs and $X_{j+1},\ldots,X_n$ are fixed inputs. Specification of the variables in the production function and the form of the function are based on the nature of the process or phenomenon described by the function. The available quantities of the factors specify the values of the variables, and the maximal output specifies the value assumed by the function. The complete specification of the relationship between inputs and output defines a function or surface in the case of

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[2]R.H. Day, Recursive Programming and Production Response, (Amsterdam: North-Holland Publishing Company, 1963), pp. 61-62.

[3]C.E. Ferguson, Microeconomic Theory, 3rd ed. (Homewood, Illinois: Richard D. Irwin, Inc., 1972), p. 136.

more than one variable input. Changes in the quantity of a variable factor will define movement along the production function or surface upward or downward depending on the nature of the change.

Further elaboration of the concept of production function distinguishes between two situations of production concerning the nature of the relationships among inputs. One situation refers to those cases in which the set of technically possible factor combinations is unrestricted, allowing for continuous substitution among factors. This situation defines what is known as production under conditions of variable proportions. The ratio of input quantities may vary, and it is necessary to determine not only the level of output to produce but also the optimal proportion in which to combine inputs. The other situation involves cases in which some factors can only be combined, within the technological principle involved, in fixed ratios to each other. This situation defines what is known as production under conditions of fixed proportions. If output is expanded or contracted, all inputs must be expanded or contracted so as to maintain the fixed input ratio.

It is a truism of economic analysis that the familiar curvature of production functions is generated by changes in the scale of application of any one process.[4] Situations in which production is characterized by conditions of variable proportions are represented by continuous production functions and continuous isoquants

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[4]R. Dorfman, Application of Linear Programming to the Theory of the Firm, (Berkeley: University of California Press, 1951).

with the possibility of substitution between factors. In a case of fixed proportions, the corresponding production function has kinks at the points where the ratios of available factor quantities coincide with the technical ratios specific to the process in question.

This study is concerned with production that involves many activities. The efficient combination of activities will be determined by an established optimizing criteria. Technology choices available are assumed to be linear in nature. The analysis of production involving many activities and a linear form for the technology is presented by Koopmans[5] in a model of production in which the following circumstances or considerations are treated formally as distinct elements of the production problem: a) the purely technical possibilities of production; b) the quantitative limitations on basic resources (primary factors of production) available to the economy; c) the general goal or objective to be served by production, and d) the optimizing choice whereby the technical possibilities are exploited in a coordinated manner toward that objective.

The input structure of a given production process is represented by a column vector of coefficients, denominated technical coefficients, which defines the amounts of input used and output produced for a given unit of a process. The vector includes input coefficients and output coefficients. The set of all vectors

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[5]T.C. Koopmans, "Analysis of Production as an Efficient Combination of Activities," in T.C. Koopmans, ed. Activity Analysis of Production and Allocation (New York: John Wiley and Sons, Inc., 1951), Chapter III.

representing the processes available can be adjoined to form the technological matrix. This matrix describes the technical opportunities available for a given point in time.

Technological Change in the Linear Model

In traditional economic theory a clear distinction is made between "substitution" and "technological change." The former concept is used to designate choices related to a given production function, and the latter to changes in the production function itself. Then, technological change is simply defined as changes in one or more of the parameters of the relevant production function. This distinction is relevant in the case of production under conditions of variable proportions.[6] The concept of technological change in this context is somewhat narrow, mainly because it only encompasses production of existing commodities and use of existing resources.

Observing the variation in context in which technological change is referred to, it is clear that this concept has been given a wide range of meanings and interpretations. This shows the difficulties of defining technological change, because of the great number of relationships that it involves.

In general terms, technological change may be defined as any change in the methods of production used. Basically, the change

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[6]For a formal treatment of technological change within the context of continuous production functions see M. Brown, On the Theory and Measurement of Technological Change, (Cambridge University Press, 1966).

may result from: a) improvement in existing processes permitting commodities to be produced at lower cost; b) partial or total substitution of an old resource by a new one, and c) production of new products.

This more general view of technological change can be incorporated in a linear model of production of the type presented by Koopmans,[7] which is based on the framework of linear programming. One advantage of this approach is that it permits the analysis of different meanings of technological change and the possible interaction among them.

Basically, the problem is to deal with the changing structure of the economy which can be analyzed through changes in the structure of an input-output model. The introduction of new technology can be represented by changes in the elements of the model. Of course, a major problem is to work out a mechanism that makes these changes operational. It is necessary to understand the nature of the new structure with new technology and how the structure changes through time. Carter[8] approaches this problem by incorporating process substitution in a linear model by means of equations that describe the rate at which the input-output coefficients change as new techniques gradually replace older or average techniques.

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[7]T.C. Koopmans, op. cit.

[8]Anne P. Carter, "A Linear Programming System Analyzing Embodied Technological Change," in Anne P. Carter and A. Brody, eds. Proceedings of the Fourth International Conference on Input-Output Techniques (Amsterdam: North-Holland Publishing Company, 1970).

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In the last section a process is denoted by a vector of input coefficients and output coefficients such as yields. The combination of a number of vectors form the technological matrix which describes the technical opportunities available at one period of time. Once the structure of this matrix is understood, the basic ideas of technological change in the linear model can be introduced.

Innovation can be viewed as the existence of a new technological matrix which can differ from the previous one in several ways. The structure of the matrix changes over time as a result of changes in the technical coefficients, changes in types of scarce resources, and changes of processes. Expansion of the matrix allows for the introduction of new processes, while contraction allows for exclusion of processes which have been abandoned. The matrix can also change in order to accomodate changes in the nature of the constraints. As process or techniques of production change, new resources are developed and become a constraining element. Changes in input and output coefficients for a unit level of a process will define changes in the proportions in which resources are used and this will basically define new processes. In a real sense, innovation is a continuous process and the technological matrix is defined as a function of time.

An analysis of technological change using an approach analogous to parametric programming is presented by Simon.[9] He

[9]H.A. Simon, "Effects of Technolgoical Change in a Linear Model," in T.C. Koopmans, ed. Activity Analysis of Production and Allocation (New York: John Wiley and Sons, Inc., 1951), Chapter XV.

analyzes the effects of changing technical coefficients and resource scarcities on the economy of production activities and on income. He also emphasizes process substitution, but does not elaborate a mechanism that operationalizes the structural changes over time.

Technological change can be characterized by three components: invention, innovation, and diffusion. Invention is the process of creating new knowledge. It is of crucial importance in the growth process, but cannot be treated by existing tools of economic analysis. For this reason, treatment of technological change must include the second component. Innovation consists of the introduction of new process of production. The effects of technological change on production can be analyzed by identifying a time period in which a major innovation has been introduced. Thus, innovation may be treated as a condition of the production structure, and may be accommodated in the model by introducing new activities and new constraints pertaining to the new technology. The rate at which innovation takes place determines the ultimate effects of technological change on production. This rate is termed diffusion or the rate of adoption. It can be incorporated in the model by means of adoption patterns which show how innovations are adopted by farmers over time.

Aggregation Bias and Farm Size Considerations

One of the major problems with regional aggregate models is aggregation bias, which appears wherever aggregate relationships are modeled without explicit reference to individual decision-making units. Several approaches have been suggested to deal with this problem. The most accurate method would be to model individual farm firms as units of analysis, and then derive the aggregate estimates. This procedure would result in a bias-free estimate However, it is not usually feasible due to limited availability of resources to carry out the study. Therefore, the practical procedure is stratification of individual decision-making units into homogenous groups, according to some characteristic such as region, farm size, resource combination, etc.

Aggregation bias exists when the sum of the solutions for each of the individual firms in the set does not equal the estimate obtained by determining the optimal solution to the entire set directly. Methodological aspects of aggregation concern the conditions of similarity among individual firms permitting estimation of the aggregate response without bias. This problem has been analyzed by various authors. Day[10] establishes sufficient conditions for exact aggregation based on the requirement of "proportional heterogeneity." The conditions are: a) all firms must have identical matrices of input-output coefficients; b) the vector of net returns of every firm must be proportional to the corresponding aggregate vector, and c) the vector of resource constraints of every firm has to be proportional to the corresponding vector for the aggregate.

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[10]R.H. Day, "On Aggregating Linear Programming Models of Production," Journal of Farm Economics 45(4): 797-813.

Subsequently, Miller[11] has argued that Day's conditions are too restrictive, and states less binding requirements for exact aggregation as follows: a) all firms must have identical input-output matrices, and b) all firms must have qualitatively homogeneous output vectors, which means that all firms must have identical sets of activities in the optimum solution.

The question of less binding requirements is further analyzed by Paris and Rausser.[12] They argue that "obviously, sufficient conditions are of interest because they may indicate an easy test for LP aggregation; but on the other hand, they are of greater interest if they realistically admit the existence of empirical cases which satisfy the specified requirements." In their judgment, "it is not possible to find empirical cases which fit Day's sufficient conditions." They demonstrate that it is possible to formulate more general and less binding sufficient conditions for exact aggregation which are also empirically meaningful.

Aggregation problems arise from the fact that firms are different in respect to structural and behavioral aspects which will cause individual firms to respond differently to changes in economic conditions. Many differences among firms are due to the physical environment such as soil, topography, climate, etc. These factors are important determinants of production, but even in a homogeneous

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[11]T. A. Miller, "Sufficient Conditions for Exact Aggregation in Linear Programming Models," Agricultural Economics Research 18 (April 1966): 52-57.

[12]I. Paris and G. C. Rausser, "Sufficient Conditions for Aggregation of Linear Programming Models," American Journal of Agricultural Economics 55(4): 659-666.

environment differences in response will exist due to differences in relative factor endowments.

The importance of farm size arises from differences in response to factors such as economies of size, risk and uncertainty, technological change, and market response. Differences in farm size can explain differences in the decision-making process regarding these factors. Larger farms can make use of larger size machinery and benefit from operation of economies of scale. Depending on the size of the operational unit, different approaches can be used to deal with situations involving risk and uncertainty. Differences in size will bring about differences in the rate of adoption and adjustment to technology change, due to differences in management and access to the market. Market response is dependent on the participation in factor and product markets which is a function of the degree of commercialization of the farm firm. Differences in size cause farms to respond differently to changing market conditions due to differences in the degree of participation in the market.

These considerations are important for this study. As it is shown in Table III.4, the distribution of farm size in Rio Grande do Sul is wide and rather skewed. This results in significant differences in relative factor endowments which in turn give rise to differences in response to economic factors. This justifies the explicit treatment given in this study to different farm size groups.

General Description of Model Structure

The primary objective of this study is to analyze the effects on production, income, and employment by changing some basic farm level technology. The analytical instruments used to achieve this objective are various concepts of economic analysis and production theory incorporated in a dynamic model of production and resource allocation. The model is developed for one region with stratification in two farm size groups. The allocation problem is solved through a sequence of linear programming models, with the solution for one year recursively linked to previous years. The programming technique is known as Recursive Linear Programming. The model is developed with a great deal of flexibility, allowing for changes in its structure which represent changes in technology of production.

The model to be developed has a special characteristic which allows for model coefficients to vary over time. Most of the objective function coefficients, constraints elements, and input-output coefficients should be time variant, and shall represent changes and adjustments in the conditions under which the production decisions are made. In this study those coefficients that change as a function of technological advance, are of particular interest. Or, to put it another way, this study examines those coefficients whose changes would reflect meaningful changes in the technology opportunities open to farm firm operators.

One important characteristic of the model is its flexibility which allows it to serve as a component of a larger sector model. It is basically a decision-making component based on an optimization criterion and a set of resource and behavioral constraints. Most of the relationships considered exogenous in this model could be modeled as separate components and then linked together with this model without major difficulties.[13]

Most regional models of this nature involve a large number of relationships, allowing for the analysis of a large number of results. The basic economic problem involved is that of efficient allocation with simultaneous determination of optimum production levels of various commodities and the resource requirements to carry out such production. A model of this nature is designed to be used for three major purposes: a) explanation and basic projection of the regional structure of production, given a series of assumptions in respect to resource endowment, technology, and prices; b) projection of impacts of exogenous variables and key model parameters, and c) projection of impacts of alternative agricultural policies on the regional economy.

The modeling of farm level decision-making is a central feature of this study. It takes into account a number of characteristics of regional production. These are: a) the simultaneous aspects of decisions at the farm level; b) the multi-dimensional features of farm activities; c) the interdependencies between firm and household decisions; d) the interdependence of activities competing for a given set of inputs; e) the competition among farms for

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[13] The modelling approach of this study is similar to that developed by de Haen for the Korean Agricultural Sector Study, where resource allocation using Recursive Linear Programming is a component of a large systems model. See Hartwig de Haen, "The Resource Allocation and Production Component of the Korean Agricultural Sector Model," in G.E. Rossmiller, ed., A Systems Approach to Agricultural Sector Development Decision-Making: Building and Institutionalizing an Investigative Capacity, Agricultural Sector Analysis and Simulation Projects, Michigan State University, 1977 (Forthcoming).

the use of regional resources, and f) a wide range of technology choices available for farm operators.

The basic structure of the model, including exogenous variables and model output variables, is shown in Figure IV-1. Essentially, the model consists of three components: yield component, resource allocation component, and production and accounting component. The yield component is basically designed to compute crop yields based on fertilizer response functions. Yield rates are determined as a function of nitrogen application. The fertilizer application rate is determined based on the equimarginal principle of equating the marginal value product of the factor to the price of the factor.

The allocation component consists of a one-periodic linear programming model allocating given resources to production, an interval feedback relating previous actions to current decisions, and an external feedback establishing the interactions of the component with exogenous variables.

In the production and accounting component, production levels for crops and livestock activities are computed given land allocation and yield projections. Other results such as resource requirements, income, resource productivities, and input ratios are also computed. Results are obtained by commodity, farm size, and regional aggregates.

The structure of the linear programming problem to be solved for each time period is block diagonal with one block for each farm size and additional regional constraints (Figure IV.2). The coupling

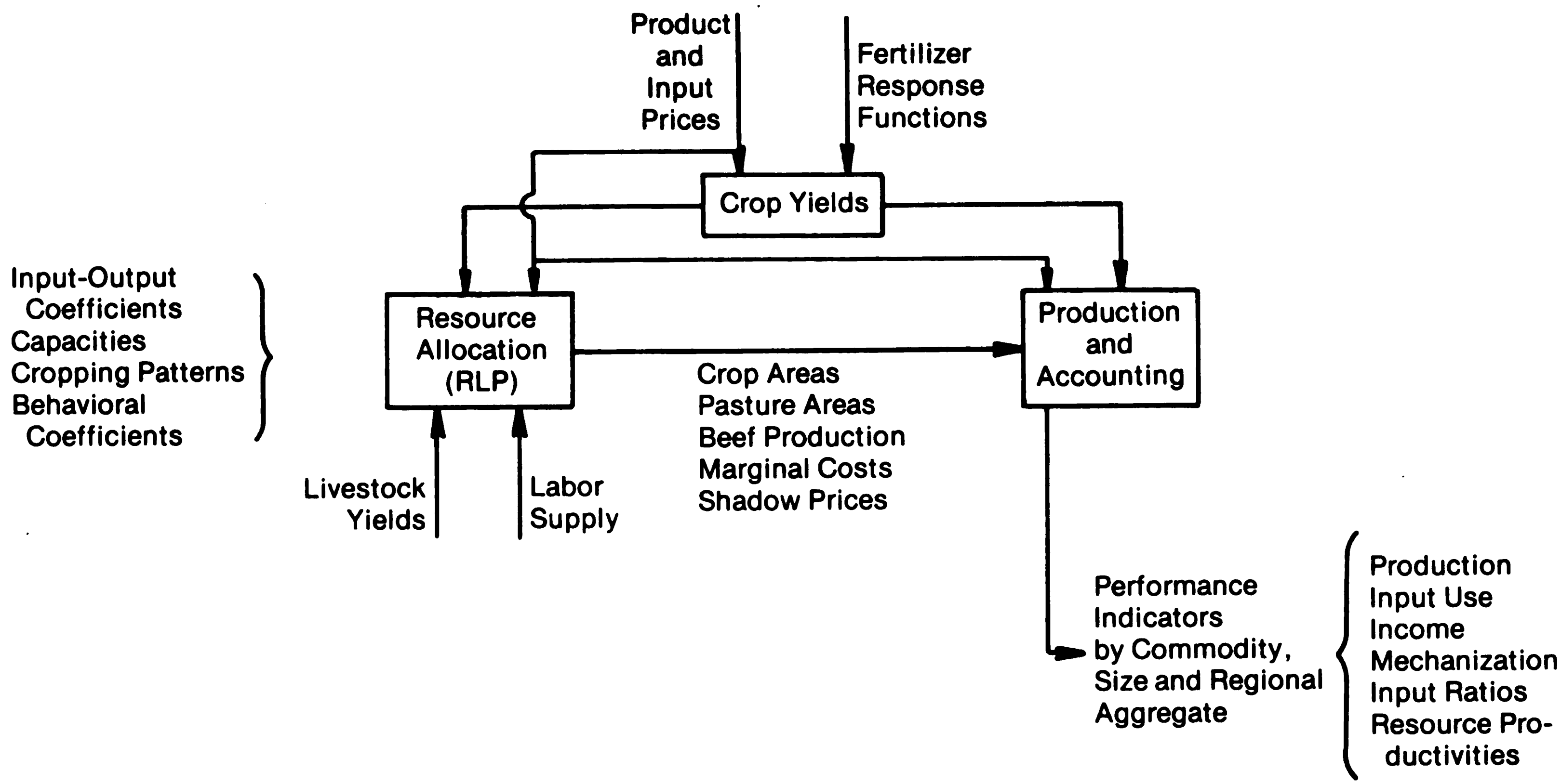

Figure IV.1: Input and Output Flows of the Model

$Z^S(t)$ +	$Z^L(t)$	$\pi(t)$
$A^S_{ij}(t)$		$B^S(t)$
	$A^L_{ij}(t)$	$B^L(t)$
$R^S_{ij}(t)$	$R^L_{ij}(t)$	$B^r(t)$

Figure IV-2: Farm Size Disaggregation for a Periodic Linear Programming Model

constraints account for interdependencies among farm size groups competing for regional resources such as supply of machinery and supply of wage labor.

A number of crucial assumptions underly the structure of the model:

1. Farmers maximize expected net returns defined as expected gross revenue minus expected variable costs.

2. The objective function for the region is the sum of the objective function for the two farm size groups.

3. Farms in each size group are assumed to meet necessary conditions for aggregation.

4. All farms are assumed to have the same degree of information and knowledge about prices and technology choices.

5. The structure of the model is the same for each farm size, i.e., same activities and same constraints.

6. Some yield rates and some input-output coefficients are different between farm sizes, reflecting differences in management and resource combination.

7. The structure of activities is assumed to remain the same over time.

Alternative Approach for Modeling Resource Allocation

In this study resource allocation is modeled using Recursive Linear Programming. Clearly, the resource allocation problem can also be modeled with the use of production functions. After production functions are estimated for each product, a programming algorithm can be developed to simultaneously solve the set of equations to determine optimum production and resource use levels which satisfy certain optimization criteria. This approach was used by Watt,[14] when he modeled a production component for Michigan's agriculture using Cobb-Douglas production functions in a recursive simultaneous solution programming algorithm.

If the resource allocation component is to be modeled by a Cobb-Douglas programming algorithm, the problem can be formulated in terms of a set of simultaneous equations in which a solution is generated for the level of activities and input use, similar to an activity analysis framework. Production functions for each commodity in each farm size group in the region are defined as follows:

$$Y_i(t) = A_i(t) \prod_{j=1}^{n} X_{ij}^{b_{ij}}(t) \qquad (2)$$

where

Y_i = expected output of i^{th} commodity

X_{ij} = j^{th} input requirement for production of i^{th} commodity

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[14]David L. Watt, "Michigan's Agricultural Production," Unpublished Ph.D. dissertation, Michigan State University, 1976.

A_i and b_{ij} = parameters

i = index commodity

j = index input

The maximization of an objective function can be incorporated together with the specification of resource and behavioral constraints. In Watt's formulation the assumptions of input supply and expected commodity demand functions, and the behavioral assumpution that input price is equated to its value of marginal product, maximize an implicit objective function defined as total revenue minus variable costs.

Basically, it seems that the same type of analysis can be carried out using either Recursive Linear or Cobb-Douglas Programming. Choice between the two approaches in this study was made based on the possibilities of incorporating technological change in the model. The production function format requires a rather high level of aggregation of outputs and inputs. Considerably more detail can be explicitly examined in the recursive programming framework which can deal with many outputs and allow for a much more specific treatment of the inputs and their combinations.

Changes in the parameters of the production function represents changes in technology. However, considerable difficulty was encountered in the attempt to connect these changes to specific and meaningful changes that could be understood in terms of variety improvements, fertilizer application, and mechanization. A further difficulty has to do with the nature of the production function. With the assumption of constant returns to scale, the sum of the elasticity coefficients has to be equal to one. If changes are introduced in one coefficient, adjustment has to be made in the others to maintain the assumption. When the coefficients change, other results, such as marginal value products, also change. Without a well-established relationship among the coefficients, only purely arbitrary changes can be analyzed.

CHAPTER V

MATHEMATICAL STRUCTURE OF THE MODEL

This chapter presents a complete description of the model developed in this study.[1] An overview of the model structure was given in Chapter IV. Here the structural equations of the model are presented. The model is composed of three components. These components are: yield, resource allocation, and production and accounting. The chapter is divided into three major sections describing the three components of the model, and two additional sections which discuss price projections and data requirements of the model.

Yield Component

One variable needed in other components of the model is yield per hectare for the crops considered. Crop yields are determined with the use of fertilizer response functions. Livestock yields are assumed constant throughout the period of model run. Crop yields are a function of a number of factors: crop variety, fertilizer application, irrigation, weather, etc. The large number of factors affecting yields and the interaction effects that can occur among them makes the task of modeling rather difficult.

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[1]The computer program of the model is given in Appendix C.

Among the various factors influencing yield, fertilizer may be considered the most important mainly because of its interaction effects with variety and also the degree of control that can be maintained over such a factor. If data is available though, adjustments can be introduced to take into account the effect of other factors.

To generate the yield rates of different crops endogenously in the model this study uses fertilizer response functions. For situations where biological technologies are crucial, it is important to introduce yield-nutrient response data in order to be able to evaluate optimum nutrient levels and the relationships among variety, fertilizer and yield. The basic data needed are experimental data on the response of yields to nutrient.

Large variation in yield is usually due to variation in the doses of a major element. The present case considers nitrogen as the basic element determining yields. The fertilizer response functions used in this model are of the non-linear quadratic form, so that the yield rates are given by

$$YLD_j(t) = YBASE_j + ALPHA_j \cdot FERT_j(t) + BETA_j \cdot FERT_j^2(t) \quad (1)$$

where

YLD = yield rate for crops determined from the response function (kg/ha)

FERT = amount of nitrogen applied for given levels of phosphorous and potassium (kg/ha)

YBASE, ALPHA, BETA = parameters of the response function

j = indexes crops ($j = 1,\ldots,4$)

The amount of fertilizer applied is a decision variable and depends on a number of factors such as capital availability, behavior of farmers in respect to improved cultural practices, and prices of products and inputs. Here optimum application rates are determined on the basis of the economizing principle of equating the marginal value product of an input to its price. Following this principle the optimum fertilizer application rate is given by

$$FERT_j(t) = \{PFER(t)/PYC_j(t) - ALPHA_j\}/2 \cdot BETA_j \qquad (2)$$

where

PFER = expected price of fertilizer (Cr$/kg)

PYC = expected price of product (Cr$/kg)

To account for the effects of mechanization and differences in farm size, the yield rates are further adjusted for incremental yield increase on mechanized areas and on larger farms. Mechanization can increase yields due to better land preparation and cultivation. Furthermore, large farms can achieve higher yield rates due to better management techniques. Thus, the final yield rate is obtained as

$$YLDA_{ijk}(t) = YLD_j(t) \cdot (1 + SYLD_{ijk}) \cdot (1 + RYLD_{ijk}) \qquad (3)$$

where

YLDA = adjusted yield rate (kg/ha)

SYLD = proportion of yield increase due to farm size (dimensionless)

RYLD = proportion of yield increase due to mechanization (dimensionless)

i = indexes farm size ($i = 1,2$)

j = indexes crops ($j = 1,\ldots,4$)

k = indexes mechanization ($k = 1,2$)

In Equation 3, yield for each crop is adjusted according to farm size and the condition of mechanization. The model includes four crops: rice, corn, wheat and soybean. Farm size is stratified into two groups: "small" representing farms of area equal or less than 100 hectares, and "large" representing farms of area greater than 100 hectares. For each crop in each size group, two levels of mechanization, traditional and modern, are considered. The former level uses draft animals, and modern uses tractors and combines.

Besides the four basic crop activities, rice, corn, wheat and soybean, the linear programming model of the resource allocation component includes soybean following wheat as an activity distinct from independent soybean. Since fertilizer response functions are only defined for the four basic crops, yield rates for soybean following wheat are determined by applying a discount factor to the yield of soybean. Usually fertilizer is not applied to soybeans when it is cultivated in double cropping with wheat. Yield can drop by as much as 30 percent due to lack of fertilizer application and delay in planting time which occurs because wheat is not harvested until passing the optimum period for planting soybeans. Thus, the yield rate for soybean following wheat is determined as

$$YLDASW_{ik}(t) = YLDAS_{ik}(t) \cdot (1 - YLDDIS) \qquad (4)$$

where

YLDASW = yield rate for soybean following wheat (kg/ha)

YLDAS = adjusted yield for soybean independent of wheat (kg/ha)

YLDDIS = yield discount factor (dimensionless)

Resource Allocation Component

This component models farmers' decision-making processes with respect to allocation and production using Recursive Linear Programming. This section describes the structure of the component only in a general way. Specific details of the model are presented in Appendix A. The section is divided into three major subsections. The first subsection presents the programming problem in its mathematical form giving a general idea of the process and relationships involved. The second describes the structure of a linear programming model for a given time t, and the third presents the linkages between different planning periods.

Mathematical Programming Model:

A recursive programming model can be defined as an infinite sequence of mathematical programming problems in which the input-output coefficients, the constraint elements and the objective function coefficients for one period of time depend on the solution of preceding programs in the sequence, with certain lag lengths, and on a vector of exogenously projected variables.

A recursive linear programming problem consists in finding the maximum $\Pi^*(t)$ of the objective functions

$$\Pi^*(t) = \underset{\overline{X}(t)}{\text{Max}}[\overline{Z}'(t)\ \overline{X}(t)] \qquad t = 1,2,\ldots,T \qquad (5)$$

subject to linear constraints

$$\underline{A}(t)\ \overline{X}(t) \leq \overline{b}(t)$$

and nonnegativity conditions

$$\overline{X}(t) \geq 0$$

where

$\Pi^*(t)$ = optimal value of the objective function in period t under the optimal plan $\overline{X}^*(t)$.

$\overline{Z}(t)$ = n-dimensional vector of objective function coefficients for period t.

$\overline{X}(t)$ = n-dimensional vector of the levels of activities for period t.

$\underline{A}(t)$ = $m \times n$ matrix of input-output coefficients for period t.

$\underline{b}(t)$ = m-dimensional vector of constraints for period t.

$*$ = indicates optimal solution.

A unique characteristic of a recursive linear programming model is a set of dynamic feedback functions which relate decisions for a period t to previous decisions and to exogenous variables.[2] These feedbacks hold for the objective function coefficients for the elements of the constraint vector and for the elements of the input-output matrix and are defined by Equations 6, 7 and 8, respectively:

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[2]See Hartwig de Haen, "The Resource Allocation and Production Component of the Korean Agricultural Sector Model," in G.E. Rossmiller, ed., A Systems Approach to Agricultural Sector Development Decision-Making: Building and Institutionalizing an Investigative Capacity, Agricultural Sector Analysis and Simulation Projects, Michigan State University, 1977 (forthcoming).

$$\bar{Z}(t) = Z[\bar{X}^*(t-1),\ldots,\bar{X}^*(t-p),\ \bar{r}^*(t-1),\ldots,\bar{r}^*(t-p),\ \bar{V}(t)] \qquad (6)$$

$$\bar{b}(t) = b[\bar{b}(0),\bar{X}^*(t-1),\ldots,\bar{X}(t-p),\ \bar{r}^*(t-1),\ldots,\bar{r}^*(t-p),\ \bar{V}(t)] \qquad (7)$$

$$\underline{A}(t) = A[\bar{X}^*(t-1),\ldots,\bar{X}^*(t-p),\ \bar{r}^*(t-1),\ldots,\bar{r}^*(t-p),\ \bar{V}(t)] \qquad (8)$$

where

$\bar{r}^*(t)$ = vector of optimal dual values (shadow prices of constraints).

$\bar{V}(t)$ = vector of exogenous variables.

p = maximum length of a lag.

To solve the model, it is necessary to obtain initial conditions for period $t = 0$ for all endogenous variables and time-varying coefficients and the time profile of the exogenous variables. The linear programming problem is solved once in each period. Clearly, this model is appropriate for incorporation in a systems simulation model because it has all the features of a recursive system which is convenient for use in a computer programming framework.

<u>Structure of a Periodic Linear Programming Model</u>:

The linear programming model for each time period t is block diagonal with one block for each farm size and a set of coupling constraints which hold for all farm sizes simultaneously. Since the structure of the model is the same for all farm sizes, complicated notation can be avoided by describing only one model for one farm size group.

The structure of a linear programming model includes three sets of relationships: a) The objective function; b) The activities, and c) The constraints. This subsection describes each of these elements composing the periodic linear programming model.

Objective Function:

The objective function represents a decision criteria which is the basis for choices among alternatives available and subject to a whole range of constraints faced by the economic unit. The optimizing principle underlying the objectives and goals of the farming operation should be the basic indication for setting the objective function, since it represents what farmers are attempting to optimize. However, this is an area of much discussion and no definite principle is agreed upon, as knowledge about behavior and expectations of farm operators is very limited. It is true, however, that in order to be able to solve the programming problem an explicit formulation of an optimizing criteria is needed.

The most commonly used specification of the objective function in programming models is the maximization of short run profits or the maximization of short-run returns to fixed resources. In this study it is assumed that farmers maximize expected short-run profits defined as expected gross revenue minus expected variable costs, that is, it is assumed that farmers maximize expected short-run returns to fixed resources. Included as fixed factors are land, family labor, and power capacities. The model also includes the following: (1) to meet requirements for home or subsistance consumption; (2) to avoid unbearable risk by taking decisions based on a safety-first principle; and (3) to maximize expected profits. In a recursive linear programming framework the subsistence consumption requirement criteria can be handled either by specifying consumption activities explicitly in the model or by defining feedback function which forces the retention of some proportion of production for home or subsistance consumption. The introduction of flexibility and adoption constraints takes care of safety and cautiousness behavior.

Typically, the objective function is defined in mathematical form as the maximization of expected yearly gross revenue minus variable costs (Equation 9). Gross revenue per hectare is expected yield times expected prices for all income producing activities. Variable costs per hectare include the cost of all inputs that are not drawn from the original resource availability and also those costs that are not charged in the model through a system of purchasing activities and appropriate transfer rows. The objective function can be expressed as follows:

$$\text{Max } \Pi(t) = \text{Max}\Big[\sum_{j=1}^{m} \sum_{w=1}^{n} P_{y_{jw}}(t) \cdot Y_{jw}(t) - \sum_{j=1}^{m} \sum_{w=1}^{n} \sum_{i=1}^{d} a_{ijw}(t) \cdot P_{x_i}(t) \cdot Y_{jw}(t)\Big] \qquad (9)$$

where

Π = profit or net return.

Y_{jw} = output j produced by method w.

$P_{y_{jw}}$ = price of output j produced by method w.

P_{x_i} = price of i^{th} input.

$a_{ijw}(t) = \frac{X_{ijw}(t)}{Y_{jw}(t)}$, the unit requirement of i^{th} input to produce output j by method w, at a given time t.

X_{ijw} = total amount of i^{th} input used to produce output j by method w.

The activities considered in the model will be described in the next subsection. In order to reduce the size of the model, income producing activities are used to produce and to sell the output. Therefore, the objective function values for these activities are defined as gross returns minus variable costs per hectare. Family labor is regarded as a fixed resource for the farm, and its cost is not priced through the objective function.

Activities:

A linear programming model can be constructed based on data from individual farm units or based on regional aggregate data. If it is constructed in an individual farm basis, aggregation can be achieved by weighting farm results by the number of farms in each category. Disregarding data requirements and time and cost of analysis, the ideal situation is to model individual farms mainly to reduce aggregation bias which can be significant in terms of model predictive power. This study uses a combination of these two approaches. Farm data is used with disaggregation in farm size groups and regional constraints are introduced for those resources which are competed for by all groups.

Since the basic unit of the model is the farm, the activities programmed must be based on the nature of the farming operation and its interdependencies with the physical and economic environment. The basis is the situation in the Southern Region of Brazil. As it is true in any other developing country, a farm in Brazil is typically a multiproduct firm with a decision-making process highly dependent on the firm-household interactions. Production, consumption and investment for the farm firm and for the family are interacting activities carried out simultaneously. Thus, the model should include these activities and the relationships among them.

Besides the characteristics of farming operations in a region, the activities and constraint structure of a linear programming model should be based on two additional considerations. The availability of data to implement the model, and the objectives for which the model is built. In many cases basic experimental or field survey data for estimating model parameters and relationships are not available for some of the elements to be included in the model. This, of course, precludes their modeling. Moreover, the model should be constructed with the necessary features which allows one to reach the objectives of the study.

Based on the above considerations, five sets of activities are included in the model. They are: a) Production of various annual crops; b) Production of natural and cultivated pasture; c) Production of beef; d) Investment in draft animal and farm machinery, and e) Seasonal labor hiring. Each of these groups of activities are discussed in detail below.

1. Production of field crops: The four major crops of the region studied are included in the model. They are: rice, corn,

wheat and soybean. Each crop is considered as an activity. Since double cropping of wheat and soybeans is a common practice in the region two distinct soybean activities are considered, namely, soybeans following wheat and soybean independent of wheat. In the basic model each activity is disaggregated by two types of technology. Traditional, using animal power, and modern, using mechanical power. The objective function coefficients for these activities are positive and are defined as gross returns minus variable costs. Included as operating costs are fertilizer, seed, transportation, variable machinery costs, and other inputs such as insecticides. Let this set of activities be denoted by P_g, g = 1,...,10.

2. Production of natural and cultivated pasture: Pasture, an intermediate product for beef production, is considered in the model as natural and cultivated. Most beef production in the area studied uses natural pasture and only a small part uses cultivated pasture. Natural pastures which are of poor quality have low production capacity. A higher productive system based on improved pasture is available, and could be used as a means of improving the competitive position of beef production relative to other activities.

Like the crop activities, cultivated pasture is also considered with two levels of technology, traditional and modern. The objective function values for these activities are negative and include the value of the variable inputs used. For natural pasture only repairs and maintenance costs are included. In addition to these costs, fertilizer, seed, and variable machinery costs are considered for cultivated pasture. Let this set of activities be denoted by F_h, h = 1,2,3.

3. Production of beef: Agricultural transformation in the area has been characterized by expansion of livestock activities to new frontiers and substitution of crop or intensive livestock activities for extensive livestock operations in those established areas. Beef production activities are considered in the model in order to capture the changes in enterprise pattern and best represent the opportunities open to farmers in operating and organizing their farms.

The model includes beef production by two methods or technologies. One uses natural pasture and the other uses cultivated pasture. The objective function coefficients are gross returns minus variable costs. Included as variable costs are bone meal, salt, and veterinary costs. This set of activities is designated by B_m, m = 1,2.

4. Investment activities: Investment in draft animal, tractor and combine is considered in the model as three distinct activities. They represent the possibilities of replacement and addition to farm animal power and machinery capacities. The investment cost of these activities are composed of depreciation and interest costs on capital. This set of activities is denoted by I_n, n = 1,2,3.

5. Seasonal labor hiring activities: The two major sources of labor for the farm are family labor and hired labor. Family labor is considered as a fixed resource for the farm and the possibility of using more than what is available on the farm is introduced by hiring activities. Due to seasonality in the use of labor, three periods of the year are considered. These are: Period 1, from July through October; Period 2, from November through February;

Period 3, from March through June. One activity is defined for each period. The cost of hiring is the market wage rate. Let H_p, $p = 1,2,3$ designate this set of activities.

In summary, if the set of all farm activities is denoted by R, then:

$$R = \{P_1,\ldots,P_{10}, F_1,\ldots,F_3, B_1,B_2,I_1,\ldots,I_3, H_1,\ldots,H_3\}.$$

An activity j in set P_g, for example, can be denoted by $j \in P_g$. The level of an activity j can be designated by $X_j = \{X_j | j \in P_g\}$, and $j \in R$ can be written to refer to an activity without specifying the set or the sets to which it belongs.

Constraints:

Decisions at the farm level are made subject to a set of financial, physical, and behavioral constraints. Within a region, different farm size groups compete for regional resources. Given the disaggregation scheme used in the resource allocation component being described here, it is necessary that the constraint structure includes: (a) constraints on farm resources for each of the two farm size groups, and (b) regional constraints which hold for all farm size groups simultaneously.

These two sets of constraints hold for one periodic static model of firm-household decisions. The dynamic properties of the model are introduced by a set of decision feedback functions which generate restraints in a recursive manner to account for the impacts of past actions on the elements of current decisions.

The inclusion of overlapping regional constraints carries the crucial assumption of resource mobility between different farm size groups. Market imperfections may exist and can preclude the mobility of certain resources. This has to be observed when deciding on the types of overlapping constraints to be included in the model.

The constraints of the model include: a) Land constraints by season; b) Labor constraints by season; c) Machinery and animal power constraints; d) Balance equations; e) Behavioral constraints, and f) Regional constraints. The first five sets of constraints are the same for each of the farm size groups. The last set include the overlapping constraints.

Before a description of each of the constraint sets is presented, some notation is developed to facilitate further reference. Denote the complete constraint set by B. This set is then partitioned in subsets representing major constraint groups, such that

$$B = \{B_g, B_h, B_m, B_n, B_p, B_r\}$$

where

B_g, g = 1,2,3: a group of constraints on available land by season.

B_h, h = 1,2,3: a group of constraints on available labor by season.

B_m, m = 1,2,3: a group of constraints on available machinery and draft animal power capacities.

B_n, n = 1,...,4: a group of balance equations.

B_p, p = 1,...,14: a group of behavioral constraints consisting of upper and lower flexibility bounds.

The right hand side elements of the inequalities are denoted by b_i. A particular constraint in set B_g, for example, can be referred by b_i, $i \in B_g$. The level of the j^{th} activity, at time t, is designated by $X_j(t)$, and the input-output coefficients are denoted by a_{ij}.

Now a description of the constraint structure of the model is presented with reference to each constraint group separately.

1. Land Constraints: Available land can be allocated to crop and pasture activities. Equation 10 assures that the amount of land allocated to different production activities do not exceed the total amount available at time t.

$$\sum_{j \in P_g} a_{ij} X_j(t) + \sum_{j \in F_h} a_{ij} X_j(t) \leq b_i(t); \; i \in B_g \tag{10}$$

where

P_g = set of crop production activities

F_h = set of pasture production activities

B_g = set of land constraints.

The model includes three land constraints: a) Summer land; b) Winter land, and c) Irrigated land. Rice is the only crop that uses irrigated land.

2. Labor Constraints: Due to the nature of farming operations, labor use is characterized by peak seasons. This makes it necessary to define labor constraints by seasons (Equation 11), which involves the use of family labor and any hired labor for each period.

$$\sum_{j\epsilon P_g} a_{ij}X_j(t) + \sum_{j\epsilon F_h} a_{ij}X_j(t) + \sum_{j\epsilon B_m} a_{ij}X_j(t) - \sum_{j\epsilon H_p} a_{ij}X_j(t)$$

$$\leq b_i(t); \; i \in B_h \qquad (11)$$

where

P_g = set of crop production activities

F_h = set of pasture production activities

B_m = set of beef production activities

H_p = set of labor hiring activities

B_h = set of labor constraints

Three constraints on human labor are considered, one for each of the following periods: Period 1, July-October; Period 2, November-February, and Period 3, March-June. Equation 11 assures that the amount of labor used by the crop, pasturing, and beef activities do not exceed the amount available on the farm plus the amount that is hired for each period at time t.

3. Machinery and Animal Power Constraints: Equation 12 defines machinery and animal power capacities. The total availability on the farm can be augmented by investment activities.

$$\sum_{j\epsilon P_g} a_{ij}X_j(t) + \sum_{j\epsilon F_h} a_{ij}X_j(t) - \sum_{j\epsilon I_m} a_{ij}X_j(t) \leq b_i(t); \; i \in B_m \qquad (12)$$

where

P_g = set of crop production activities

F_h = set of pasture production activities

I_m = set of investment activities

B_m = set of machinery and animal power constraints.

Three power sources are included in the model. They are: tractor capacity, combine capacity, and draft animal capacity. Equation 12 assures that, for a given time t, the amount used is less than or equal to the amount available plus the increases in capacity for any of the power sources.

4. Balance Equations: These equations are used to transfer resources from one activity to another and to account for intermediate-final output relationships. Intermediate outputs are produced by some activities and used by others. Balance equations allow the model to determine endogenously the proportions of the different intermediate outputs used by different activities, assuring that the amounts required to not exceed the amounts available. The same holds for a resource transfer between activities.

Two groups of balance equations are included in the model. The first group consists of two equations which account for the relationships between pasturing activities and beef production activities. All pasture produced has to be used for beef production. Equation 13 and Equation 14 define the relationship for natural pasture and cultivated pasture, respectively.

$$-a_{10,11}X_{11}(t) + a_{10,14}X_{14}(t) = 0 \qquad (13)$$

where

X_{11} = natural pasture activity

X_{14} = beef production activity using natural pasture

$$-a_{11,12}X_{12}(t) - a_{11,13}X_{13}(t) + a_{11,15}X_{15}(t) = 0 \qquad (14)$$

where

X_{12} = cultivated pasture activity using traditional technology

X_{13} = cultivated pasture activity using modern technology

X_{15} = beef production activity using cultivated pasture.

Another group of balance equations, consisting of two equations, accounts for the double cropping relationships between wheat and soybeans. Equation 15 and Equation 16 assure that the area planted with soybeans following wheat does not exceed the area planted with wheat, for two types of technology, respectively:

$$-a_{12,5}X_5(t) + a_{12,7}X_7(t) \leq 0 \qquad (15)$$

where

X_5 = wheat production activity using traditional technology

X_7 = soybean following wheat using traditional technology

$$-a_{13,6}X_6(t) + a_{13,8}X_8(t) \leq 0 \qquad (16)$$

where

X_6 = wheat production activity using modern technology

X_8 = soybean following wheat using modern technology.

5. Behavioral Constraints: The behavioral constraints included in the model consist of upper and lower flexibility constraints. Limiting year to year changes in production patterns, they are assumed to account implicitly for farmers' response to risk and uncertainty related to expansion of production activities. These constraints are defined as:

$$(1 - \underline{B}_i) \cdot X_j^*(t - 1) \leq \sum_{j \in R} X_j(t) \leq (1 + \overline{B}_i) \cdot X_j^*(t - 1); \; i \in B_p \quad (17)$$

where

$X_j(t)$ = j^{th} activity level for time t

$X_j^*(t-1)$ = optimal level for activity j at time $t-1$

$\overline{B}_i$ = estimated maximum expansion rate

$\underline{B}_i$ = estimated maximum contraction rate

R = set of activities with upper and lower bounds

B_p = set of behavioral constraints

6. Regional Constraints: The constraints described above apply to each of the farm size groups. Besides those groups, the model includes four overlapping constraints. One constraint is related to the regional supply of tractors; the other three are related to the regional supply of wage labor during the three periods considered. The general form of these constraints is given by Equation 18.

$$\sum_{s=1}^{2} \sum_{j \in I_m} a_{ijs} X_{js}(t) + \sum_{s=1}^{2} \sum_{j \in H_p} a_{ijs} X_{js}(t) \leq b_i(t); \; i \in B_r \quad (18)$$

where

I_m = set of investment activities

H_p = set of labor hiring activities

B_r = set of regional constraints

s = indexes farm size groups

Summary of the Model

The structure of the yearly linear programming model is summarized in Table V.1. A complete description of the components of the model is presented in Appendix A.

Table V.1: Summary of Activities and Constraints in the Resource Allocation Component

Constraints	Activities	Annual Crop Production	Pasture Production	Beef Production	Investment	Labor Hiring	Right Hand Side (RHS)
		$P_1,\ldots,P_{10}$	$F_1,\ldots,F_3$	B_1,B_2	$I_1,\ldots,I_3$	$H_1,\ldots,H_3$	
		$Z_1,\ldots,Z_{10}$	$Z_{11},\ldots,Z_{13}$	Z_{14},Z_{15}	$Z_{16},\ldots,Z_{18}$	$Z_{19},\ldots,Z_{21}$	
Land	Summer Winter Irrigated	A_{ij}	A_{ij}	0	0	0	$b_1 \ldots b_3$
Labor	Period 1 Period 2 Period 3	A_{ij}	A_{ij}	A_{ij}	0	A_{ij}	$b_4 \ldots b_6$
Power Capacity	Tractor Combine Draft Animal	A_{ij}	A_{ij}	0	A_{ij}	0	$b_7 \ldots b_9$
Balance Equations	Pasture/Beef Wheat/Soybean	A_{ij}	A_{ij}	A_{ij}	0	0	$b_{10} \ldots b_{13}$
Flexibility Constraints	Annual Crops Pasture	A_{ij}	A_{ij}	0	0	0	$b_{14} \ldots b_{27}$
Regional Constraints	Supply of Tractor Wage Labor	0	0	0	A_{ij}	A_{ij}	$b_{28} \ldots b_{31}$

Dynamic Feedback Mechanisms and Exogenous Variables:

Equations 6, 7 and 8 above indicate the general nature of the dynamic feedback mechanisms that relate the allocation decision problem for period t to previous decisions and to exogenous variables. The main problem now is to define explicitly dynamic feedback functions which relate the values of the objective function coefficients, constraints elements, and input-output coefficients to preceding solutions of the resource allocation problem, to variables being computed in other components of the simulation model and to exogenously projected variables. These dynamic feedback operators and linkages account for the dynamic properties of the adjustment and growth process simulated by the model. The functions defined below will be general formulations of the relationships involved. A specific formulation is presented in Appendix A.

Objective Function Coefficients:

The definition of the objective function coefficient depends on the type of activity. These coefficients are generally function of yield, product prices, input prices, and input quantities which are either exogenous to the model or projected by other components. The specification of feedback operations for these coefficients should be based on some sort of expectation model which represent farmers' anticipation of future events.

This study assumes a simple expectation model for the coefficients of the objective function. The expected coefficient for year t is equal to the coefficient of the previous year. The coefficients for crop production activities are given by the difference between gross returns and variable costs lagged by one year. For pasture activities, they are just the negative of variable costs lagged by one year. For beef production activities, they are the one year lag of gross returns minus variable costs.

The coefficients for machinery investment activities are investment costs which include depreciation and interest on capital. The model assumes a straight line depreciation defined as the difference between acquisition price and salvage value divided by the number of years of life of a machine. Interest applied to the average value of the machine is defined as acquisition price plus salvage value divided by 2. Thus, the objective function coefficients, Z_j, are given by

$$Z_j(t + 1) = \frac{Pa_j(t) - Ps_j(t)}{N_j} + \frac{Pa_j(t) + Ps_j(t)}{2} * Int(t) \qquad (19)$$

where

$j \in I_m$ = set of investment activities

Pa_j = acquisition price of j^{th} investment

P_{sj} = salvage value of j^{th} investment

Int = interest rate

N_j = number of years of life of j^{th} investment

For labor hiring activities, the objective function coefficients are simply wage rate lagged by one year. This concludes the specification of how the objective function coefficients are generated. Further details are given in Appendix A. Crop yields are projected by the yield component. Price considerations will be discussed in a separate section below.

Constraint Elements:

The elements of the constraint vector or the right-hand side of the inequalities are the farm resources. They are generated for each period through a series of recursive feedback functions. Flexibility constraints are also included as right-hand side elements.

Farm resources include land for crop and livestock production, labor and power capacities. The projection of the availabilities of these resources is made exogenously. Only the transference of capacities from one period to the other is endogenously made. In a general form, this transference of capacities can be defined by a first-order linear difference equation with endogenous and exogenous information as follows:

$$\overline{b}(t) = A(t - 1)\ H\ X^*(t - 1) + G\ \overline{b}(t - 1) + \overline{V}(t) \qquad (20)$$

where

$\overline{b}(t)$ = m-dimensional vector of capacities and numerical values of behavioral constraints

$A(t-1)$ = $m \times n$ matrix of input-output coefficients for the preceding period

$X^*(t-1)$ = n-dimensional vector of optimal activity levels for the preceding period

H = $n \times n$ diagonal transfomration matrix that transfer investment made in period $t-1$

G = $m \times m$ diagonal transformation matrix that transfer all or parts of the capacities of period $t-1$

$\overline{V}(t)$ = vector of exogenous variables.

Equation 20 represents the general process of generating the right-hand side elements. The specific procedure used for each of the elements is explained below.

Land capacity: Besides the problem of projecting aggregate land resources it is also necessary to project land distribution among farm size groups over time. Clearly, land structure is an important factor determining production response and adjustments in the agricultural sector. As the land structure changes over time, a transference of farms is made from one category to another which implies a transference of resources. When land is transferred among groups it carries a certain amount of other resources such as labor and capital.

Data on agricultural land, number of farms and land distribution are available from the Census which is taken every ten years. These data shows that the supply of land has increased substantially mainly due to incorporation of new land. Number of farms and area in each group has increased for the past four decades in absolute numbers. However, while the absolute area in each size has increased through time, in relative terms, the area in the "small" group has increased at an increasing rate, and the area in the "large" group has increased at a decreasing rate.[3]

In this study, this trend of land supply and distribution is assumed to continue over the projection period for which the model is applied. It is also assumed that land available for agricultural use will continue to increase toward an upper bound capacity of land that can be used for cultivation and pasturing

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[3]The definition of farm size groups used in this study is as follows: "small" group includes farms with 100 hectares or less; "large" group includes farms with area over 100 hectares.

activites. Furthermore, the share of each group in the total will continue according to past trends.

The procedure used to implement these assumptions involves: a) projection of total land available; b) projection of the distribution of land between the two farm size groups, and c) projection of the number of farms.

Total land available is projected using an exponential adjustment model in which the amount of land that can be allocated to farm production each year increases toward an upper bound capacity determined on the basis of the total area available in the region (Equation 21). It is assumed that this model well represents the process of land incorporation into production. It also assures that projected land available does not exceed the total capacity in the region.

$$TLAND(t) = TLAND(t-1) + DT/DEL \cdot (TLCP - TLAND(t-1)) \quad (21)$$

where

TLAND = total land available at time t (ha)

TLCP = upper bound on land capacity (ha)

DT = time increment in simulation run

DEL = average lag (years).

The total land available (TLAND) is split between the two farm size groups according to a projected percentage of participation of each group. This proportion is projected using an exponential function adjusted to the historical percentages of land in each group (Equation 22).

$$BCC1(t) = A1 \cdot EXP\ (A2 \cdot T) \qquad (22)$$

where

BCC1 = proportion of total land in one group

A1 and A2 = parameters of the function

EXP = exponential function

T = time variable

After estimating the proportion of land in one group, the total amount of land can be split between the two groups as follows:

$$ASMALL(t) = BCC1(t) \cdot TLAND(t) \qquad (23)$$

and

$$ALARGE(t) = (1 - BCC1(t)) \cdot TLAND(t) \qquad (24)$$

where

ASMALL = area available for the "small" group (ha)

ALARGE = area available for the "large" group (ha)

The number of farms in each size group was projected using, as a first approach, an exponential growth function. Some attempt was made to use a probabilistic model based on the Markov Chain Process,[4] but the nature of the data did not allow reasonable estimates through this procedure.

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[4]For the use of Markov Chains to project number of farms by classes see, for example, Ronald D. Krenz, "Projection of Farm Numbers for North Dakota with Markov Chains," Agricultural Economics Research 16(3): 77-83; Gerald W. Dean et al., "Supply Functions for Cotton in Imperial Valley, California," Agricultural Economics Research 15(1): 1-14, and Rex F. Daly et al., "Farm Numbers and Sizes in the Future," in A.G. Ball and E.O. Heady eds., Size, Structure, and Future of Farms (Ames: Iowa State University Press, 1972).

Thus, the number of farms in each group is given by

$$SNFS(t) = B1 \cdot EXP\ (C1 \cdot T) \tag{25}$$

and

$$LNFL(t) = B2 \cdot EXP\ (C2 \cdot T) \tag{26}$$

The total number of farms is then

$$TNF(t) = SNFS(t) + SNFL(t) \tag{27}$$

where

SNFS = number of farms in the small group

SNFL = number of farms in the large group

TNF = total number of farms

T = time variable

The difficulty in maintaining consistency between the number of farms and the area in each category is a major shortcoming in using an exponential growth function to project farm numbers. Using this procedure, projection is simply an extrapolation of past trends into the future. However, in the present case this may be a reasonable assumption to make, given the time horizon considered in the study and the indications that past trends of increasing farm numbers and decreasing average farm size will continue for at least a decade.

The total land available in each size group can be allocated either to summer or winter crops. This allocation is taken care of in the set up of the linear programming model. Another land restriction included in the model is irrigated land which is used only for rice, and is considered as a subset of total land. Irrigated land capacity is projected assuming a constant rate of increase which accounts for land developments (Equation 28).

$$AIRG(t) = (1 + BC1) \cdot AIRG(t - 1) \tag{28}$$

where

AIRG = irrigated land available for rice production (ha)

BC1 = rate of change (dimensionless)

Labor capacity: The seasonal capacity for a given time t depends on the capacity for time $t-1$, on the growth rate of farm population, and on the number of hours a person works per period. Labor force is projected assuming a decreasing rate for increases in farm population (Equation 29).

$$ACFPOP(t) = (1 + BT1(t)) \cdot ACFPOP(t-1) \tag{29}$$

where

ACFPOP = projected active agricultural family labor force (man-equivalent)

BT1 = annual growth rate of farm population (dimensionless)

The annual growth rate of farm population (BT1) is assumed to decrease from 0.8 percent to 0.4 percent during the period 1970-1985. The total number of family labor hours available during the i^{th} season, at time t, is given by active labor force times the number of hours a person works per period (Equation 30).

$$TFLH_i(t) = BCC2(t) \cdot ACFPOP_i(t);\ i \in B_h \qquad (30)$$

where

TFLH = total family labor available (hours)

BCC2 = working time equivalent (hours/man-equivalent/period)

B_h = set of labor constraints

The coefficient BCC2 in Equation 30 is time variant; its increase is assumed to account for learning effects which increase the efficiency of labor use. The model assumes that the working time equivalent increases continually until it reaches a maximum at the end of the simulation time horizon (Equation 31).

$$BCC2(t) = BCC2(t-1) + DT/DEL \cdot (BBAR - BCC2(t-1)) \qquad (31)$$

where

BCC2 = working time equivalent (hours/man-equivalent/period)

BBAR = upper bound on working time equivalent (hours/man-equivalent/period).

<u>Machinery and Animal Power Capacity</u>: The number of hours available by draft animal and machinery at time t, is the capacity available at time t-1, less depreciation on a straight line basis, plus investments made at time t-1 (Equation 32).

$$POCAP_i(t) = (1 - BCD_i) \cdot POCAP_i(t-1) + BCH_i \cdot INVP_i^*(t-1);\ i \in B_m \qquad (32)$$

where

$POCAP_i$ = capacity available of i^{th} power source (hours)

$INVP_i$ = investment in i^{th} power source (unit)

BCD_i = depreciation rate (dimensionless)

BCH_i = working capacity (hours/unit/period)

B_m = set of power constraints

<u>Flexibility Constraints</u>: The general nature of flexibility constraints is shown in Equation 17 above. Basically, these constraints establish feedback linkages through which production patterns become a function of the previous year's optimal level of the decision variables. This model includes flexibility constraints consisting of upper and lower bounds on crop and pasture areas. The hectarage bounds for year t are defined as follows:

Upper bounds:

$$X_j(t) \leq (1 + \overline{B}_i) \cdot X_j^*(t - 1) \tag{33}$$

Lower bounds:

$$X_j(t) \geq (1 - \underline{B}_i) \cdot X_j^*(t - 1) \tag{34}$$

where

$X_j(t)$ = total solution hectarage of all activities producing the j^{th} crop in year t (ha)

$X_j^*(t-1)$ = optimal solution hectarage for the j^{th} crop in year t - 1 (ha)

$\overline{B}_i$ and $\underline{B}_i$ = maximum allowable percentages of increase and decrease, respectively, from the hectarage in the preceeding year.

The flexibility coefficients, $\overline{B}_i$ and $\underline{B}_i$, define the behavioral bounds on hectarage levels. For this reason, the estimation of these coefficients is very important since they basically determine the predictive power of the model. Miller[5] presents several procedures for estimating these coefficients. In accordance with most methods suggested, flexibility coefficients were estimated from historical year to year changes in area for crops and pasture. It was quite impossible to leave out any sort of judgment in respect to expected changes and also in respect to model behavior. In some cases where the data were not available or the estimates were considered as critical to model performance, some adjustments were necessary and were made based on a judgment of the empirical situation.

One major problem with most methods of estimating flexibility coefficients is that they give coefficients which are constant over time. This means that the maximum proportion of change in the level of an activity is the same in all years regardless of the number of factors that can affect production pattern adjustments. Recently, Sahi and Craddock[6] have developed models which incorporate changes in the flexibility coefficients over time. In their models, the proportionate rate of changes are estimated as functions of several variables, such as acreage in the previous year, expected prices, expected inventories, and expected export prices.

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[5]Thomas A. Miller, "Evaluation of Alternative Flexibility Restraint Procedures for Recursive Programming Models Used for Prediction," American Journal of Agricultural Economics 54(1): 68-76.

[6]R.K. Sahi and W.J. Craddock, "Estimation of Flexibility Coefficients for Recursive Programming Models - Alternative Approaches," American Journal of Agricultural Economics 56(2): 344-350.

Regional Constraints: Two regional restraints are included in the model. These are the regional availability of tractors and the regional supply of wage labor. The regional supply of tractors is assumed to increase at a constant rate (Equation 35).

$$RST(t) = (1 + BC2) \cdot RST(t - 1) \qquad (35)$$

where

RST = regional supply of tractors (units)

BC2 = rate of change (dimensionless)

The regional availability of wage labor is determined in the same way as the availability of family labor. First, the active wage population is projected assuming a decreasing growth rate (Equation 36).

$$ACWPOP(t) = (1 + BT1(t)) \cdot ACWPOP(t - 1) \qquad (36)$$

where

ACWPOP = projected active agricultural wage labor force (man-equivalent)

BT1 = annual growth rate of farm population (dimensionless)

Then, the total hours available is given by

$$TWLH_i(t) = BCC2(t) \cdot ACWPOP_i(t); \; i \in B_r \qquad (37)$$

where

TWLH = total wage labor available (hours)

BCC2 = as defined in Equation 31

B_r = set of regional constraints

Input-Output Coefficients:

Changes in technical coefficients over time other than yields are incorporated in the model through a routine that computes new input-output coefficients before the linear programming problem is solved for each period. These changes are exogenously determined; they will include changes in labor, draft animal, and tractor hours requirements for crop activities, thereby reflecting some pattern of technological advancement. The explicit formulation of changes in these technical coefficients will be presented in Chapter VI, when discussing empirical results of the study.

Production and Accounting Component

This component is designed to carry out the accounting of the model outputs and computations of performance criteria used to analyze model results. Accounting, which is done on a yearly basis, includes land use patterns, production levels, income, resource utilization, input ratios, and resource productivities. Besides obtaining disaggregate values by farm size groups and farm enterprises, aggregated values are also obtained for the region as a whole by summing across the size groups and the enterprises.

Land Use Pattern:

Farm land allocation pattern over time is given by the activity levels from the linear programming model. It includes crops and pasture areas by size. From these results the total cultivated land with crops, ARS_s, by size is obtained as

$$ARS_s(t) = \sum_{j=1}^{4} ARCS_{js}(t) \quad (38)$$

where $ARCS_{js}$ is the area of the j^{th} crop in size s. The total utilized area, $TUAS_s$, in each size includes crop area and pasture area (Equation 39).

$$TUAS_s(t) = ARS_s(t) + ANP_s(t) + ACP_s(t) \quad (39)$$

where ANP_s and ACP_s are the areas with natural pasture and cultivated pasture in size s, respectively.

Regional aggregation for the area of a given crop, ARC_j, for cultivated land, AR_j, and for total utilized land, TUA, is given by summing the respective quantities across size as follows:

$$ARC_j(t) = \sum_{s=1}^{2} ARCS_{js}(t) \quad (40)$$

$$AR(t) = \sum_{s=1}^{2} ARS_s(t) \quad (41)$$

and

$$TUA(t) = \sum_{s=1}^{2} TUAS_s(t) \quad (42)$$

<u>Production</u>:

Once the land allocation to various production activities is determined for any given year, output levels of crops and beef production can be computed by simply multiplying activity levels by the respective yield levels. Production of a given crop in each farm size group is given by

$$PRODC_{js}(t) = ARCS_{js}(t) \cdot YLDA_{js}(t) \quad (43)$$

where

$PRODC_{js}$ = production of j^{th} crop in size s (kg)

$ARCS_{js}$ = area of j^{th} crop in size s (ha)

$YLDA_{js}$ = yield of j^{th} crop in size s (kg/ha)

Beef can be produced using natural pasture and cultivated pasture. The beef production activities in the model are given in terms of "cow units" defined as animal aggregate. Production in terms of meat is given by

$$PRODB_{js}(t) = ARP_{js}(t) \cdot (PROPS_j \cdot YFATS_j + PROPC_j \cdot YFATC_j + PROPCC_j \cdot YFATCC_j) \quad (44)$$

where

$PRODB_{js}$ = beef production in size s using pasture j (kg)

ARP_{js} = area of j^{th} pasture in size s (ha)

PROPS = proportion of fat steer output per cow unit (dimensionless)

YFATS = yield of meat per fat steer (kg/head)

PROPC = proportion of fat cow output per cow unit (dimensionless)

YFATC = yield of meat per fat cow (kg/head)

PROPCC = proportion of cull cow output per cow unit (dimensionless)

YFATCC = yield of meat per cull cow (kg/head)

The proportions and yields in Equation 44 vary according to the type of pasture used. Yields are assumed constant over time.

Regional production of a given crop, TPROD, is given by

$$TPROD_j(t) = \sum_{s=1}^{2} PRODC_{js}(t) \tag{45}$$

and total production of beef, TPROB, by

$$TPROB(t) = \sum_{j=1}^{2} \sum_{s=1}^{2} PRODB_{js}(t) \tag{46}$$

Income:

The total value of farm output, or gross income, is given by the value of crop production plus the value of beef production (Equation 47):

$$SVFO_s(t) = VPRC_s(t) + VPRB_s(t) \tag{47}$$

where $SVFO_s$ is the gross income for size s. The value of crop production, VPRC, for a given size s, is given by the summation of output times price for the various commodities (Equation 48).

$$VPRC_s(t) = \sum_{j=1}^{4} PRODC_{js}(t) \cdot PYC_j(t) \tag{48}$$

where PYC_j is the expected price of j^{th} product.

Similarly, the value of beef production, VPRB, is

$$VPRB_s(t) = PYB(t) \cdot \sum_{j=1}^{2} PRODB_{js}(t) \tag{49}$$

where PYB is the expected price of beef.

The regional value of farm output is then

$$TVFP(t) = \sum_{s=1}^{2} SVFP_s(t) \tag{50}$$

Net farm income, defined as gross income minus variable costs, is given by the value of the objective function of the linear programming model. For a given farm size s it is computed as

$$SOBJ_s(t) = \sum_{j=1}^{m} X_{js}(t) \cdot Z_{js}(t) \quad (51)$$

where X_{js} is the activity level, Z_{js} is the objective function coefficient, and m is the number of activities in each size group. The total net farm income is then

$$TOBJ(t) = \sum_{s=1}^{2} SOBJ_s(t) \quad (52)$$

Value added is a measure of the contribution of the farm sector to the economy. It is defined as the returns over cash costs incurred due to inputs originating in the non-agricultural sector. For a given size s, valued added, SVAD, is given by

$$SVAD_s(t) = SVFO_s(t) - SEXP_s(t) \quad (53)$$

where SEXP is the expenditure on non-agricultural inputs. The regional total is then

$$TVAD(t) = \sum_{s=1}^{2} SVAD_s(t) \quad (54)$$

Average gross farm income, AGI, is the total value of output divided by the number of farms in each category (Equation 55).

$$AGI_s(t) = SVFO_s(t)/SNF_s(t) \quad (55)$$

Similarly, average net farm income, ANI, is

$$ANI_s(t) = SOBJ_s(t)/SNF_s(t) \tag{56}$$

A rough measure of income distribution between farm classes can be determined by the percentage of farms and the percentage of income in each class as follows

$$PCTI_s(t) = SVFP_s(t)/TVFO(t) \cdot 100 \tag{57}$$

$$PCTF_s(t) = SNF_s(t)/TNF(t) \cdot 100 \tag{58}$$

where $PCTI_s$ and $PCTF_s$ are the percentage income and percentage of farms in class s, respectively.

Resource Utilization:

The actual demand for various inputs can be computed by enterprise and by type of input. Quantities used and expenditures on fertilizer, seed, hired labor and "other inputs" are computed here.

In general, the total amount of a certain input used is given by

$$TINP_i(t) = \sum_{j=1}^{m} \sum_{s=1}^{2} CINP_{ijs}(t) \tag{59}$$

where $CINP_{ijs}$ is the amount of input i used in crop j, for size s. The expenditure on the input is simply

$$EXINP_i(t) = TINP_i(t) \cdot PX_i(t) \tag{60}$$

where PX_i is the expected price of the i^{th} input.

The amount of fertilizer used for a given crop and size is given by

$$CFERT_{js}(t) = X_{js}(t) \cdot FERT_j(t) \qquad (61)$$

where X_{js} is the activity level and FERT is the fertilizer application rate. The regional total demand for fertilizer is then

$$TFERT(t) = \sum_{j=1}^{m} \sum_{s=1}^{2} CFERT_{js}(t) \qquad (62)$$

Similarly, the amount of seed used for each crop is

$$CSEED_{js}(t) = X_{js}(t) \cdot SEED_j \qquad (63)$$

where $SEED_j$ is the amount of seed used for j^{th} crop. The total amount used is

$$TSEED_j(t) = \sum_{s=1}^{2} CSEED_{js}(t) \qquad (64)$$

The expenditures on fertilizer and seed are given respectively by

$$EXFERT(t) = TFERT(t) \cdot PFER(t) \qquad (65)$$

and

$$EXSEED_j(t) = TSEED_j(t) \cdot PSEED_j(t) \qquad (66)$$

where PFER and PSEED are the expected prices of fertilizer and seed, respectively.

For purposes of analyzing agricultural employment, the model generates labor requirements including family and wage labor by size group and regional total. Labor use for a given size is computed as

$$SLAB_s(t) = \sum_{i=1}^{3} \sum_{j=1}^{m} X_{ijs}(t) \cdot A_{ijs} \qquad (67)$$

where

$SLAB_s$ = amount of labor used for size s

X_{ijs} = level of activity j using labor of period i in size s.

A_{ijs} = labor requirement per hectare of activity j on period i and size s.

The total labor use in the region is given by

$$TSLAB(t) = \sum_{s=1}^{2} SLAB_s(t) \qquad (68)$$

Hired labor is given by size and region as follows

$$WLAB_s(t) = \sum_{j=1}^{3} X_{js}(t) \qquad (69)$$

$$TWLAB(t) = \sum_{s=1}^{2} WLAB_s(t) \qquad (70)$$

where

X_{js} = level of labor hiring activity for period j and size s (hours)

$WLAB_s$ = amount of wage labor used for size s (hours)

TWLAB = regional amount of hired labor used (hours).

The value of wages paid by size, SWG, and for the region, TWG, is simply

$$SWG_s(t) = WLAB_s(t) \cdot WAGE(t) \qquad (71)$$

and

$$TWG(t) = \sum_{s=1}^{2} SWG(t) \quad (72)$$

Similarly, the amount of tractor, combine and draft animal hours can be computed in the same way as it is for labor.

The percentage of hired labor relative to total labor use is given by

$$PWL_s(t) = WLAB_s(t)/SLAB_s(t) \cdot 100 \quad (73)$$

and for the region by

$$PTWL(t) = TWLAP(t)/TSLAB(t) \cdot 100 \quad (74)$$

Input-Input Ratios:

Labor use per hectare for a given size is computed by

$$RLHA_s(t) = SLAB_s(t)/ARS_s(t) \quad (75)$$

For the region it is given by

$$RTLH(t) = TSLAB(t)/AR(t) \quad (76)$$

Similar ratios are computed for tractor and draft animal as well.

In addition, tractor/labor ratios and draft animal/labor ratios are computed for each size and for the region. For each size it is given by

$$TRL_s(t) = STRC_s(t)/SLAB_s(t) \quad (77)$$

$$DAL_s(t) = SDRF_s(t)/SLAB_s(t) \quad (78)$$

And for the region

$$TTRL(t) = TSTRC(t)/TSLAB(t) \quad (79)$$

$$TDAL(t) = TSDRF(t)/TSLAB(t) \quad (80)$$

where $STRC_s$, TSTRC, and DAL_s, TSDRF are tractor and draft animal hours used for a given size s and the region, respectively.

Resource Productivities:

Factor productivities for land and labor is determined as net returns divided by the amount of factor used.

Land productivity is given by

$$PDYLN_s(t) = SOBJ_s(t)/TUAS_s(t) \quad (81)$$

and

$$RPYLN(t) = TOBJ(t)/TUA(t) \quad (82)$$

where $PDYLN_s$ is land productivity in size s, and RPYLN is the regional land productivity index.

Similarly, labor productivity is computed as

$$PDYLB_s(t) = SOBJ_s(t)/SLAB_s(t) \quad (83)$$

and

$$RPYLB(t) = TOBJ(t)/TSLAB(t) \quad (84)$$

where $PDYLB_s$ is labor productivity in size s, and RPYLB is the regional labor productivity index.

Product and Input Prices Expectations

The importance of price expectation is well recognized in economic decision-making. Among the different price concepts existing, the relevant variable in decision-making is the expected price, since decisions are always made before prices are realized.

Product and input prices are needed to run the model for a projection period. Various alternatives exist to determine such prices. A simple procedure, for example, is to assume all prices constant at initial values. This is certainly an unrealistic assumption, since prices are continuously changing. Another alternative is to consider some sort of expectation model to generate future prices. This also can be an unrealistic assumption since little information exists on how farmers form expectations about future prices. A useful expectation model would require a great deal of information. Even the most complete model would be merely an attempt at projecting future prices due to all the uncertain factors involved.

Before choosing an alternative to deal with prices, a question that must be considered is the rationale for assuming prices exogenously determined in the model. It can be assumed that the region for which this model is constructed is too small to influence output and input prices. Hence, prices are exogenously given to the model, since changes in product supply and input demand in the region would not affect prices. In this study this assumption is maintained. However, it is made with reservation since, at least in the case of wheat and soybeans, changes in production may possibly affect prices due to the fact that a large proportion of the national production of these two products is provided by the region. For corn and rice this possibility is more unlikely since the region only produces a small proportion of the national output.

In order to satisfy the requirements of the model, future prices are generated by means of simple expectation models which base future price expectation on past behavior. The general mechanism used involves basically two steps. First, average prices are projected by increasing the initial prices at a constant rate of change determined from past trends. Then, expected prices are computed using a distributed lag model assumed to reflect farmers' expectations of future values. The expectation models consist of a first order distributed delay that computes expected prices as exponential averages of past values.

The average product price is projected by the following equation:

$$AVPY_j(t) = AVPYO_j \cdot (1 + T \cdot PYCH_j) \qquad (85)$$

where

AVPY = average product price (Cr$/kg)

AVPYO = product price in the beginning of period (Cr$/kg)

PYCH = rate of change of product price (dimensionless)

T = time variable

The value of PYCH and all other rates of price changes used to project prices are determined based on past price changes. These rates are assumed both to extrapolate past prices into the future, and to represent the effects of inflation and other factors which affect prices. These rates are computed by taking the average of price changes during the period 1965-1970. Comparison of actual and projected prices for the period 1970-1976 showed that the procedure used estimates prices reasonably well.

As a number of studies indicate, supply response may be viewed as an adaptation process in an uncertain world where lags in the adjustment processes exist. The quantity of a crop ready for harvesting is determined by economic and non-economic factors that operate before planting time and during growth stages. Because of uncertainty farmers are continuously adjusting to these factors. The implication of considering supply response as an adaptation process is that independent variables in supply estimates should include lagged prices to account for the effects of past values on actual quantity supplied.

Given these considerations, expected prices are computed in the model as exponential averages of projected average prices with an average delay of three years. Clearly, the determination of the average delay or adjustment coefficient of distributed lag models should be based on empirical knowledge of how farmers weight past values in future price expectations. In this study the average lag is assumed as three years. No empirical data were available to support this assumption. It is justifiable, though, given the types of products involved and the characteristics of the production process in the region.

Given the average prices, it is assumed that farmers' decisions are based on expected prices determined by an adaptive expectation model of the form

$$PY_j(t) = PY_j(t-1) + DT/DEL3 \cdot (AVPY_j(t) - PY_j(t-1)) \qquad (86)$$

where

PY = expected product price (Cr$/kg)

DEL3 = average lag (years)

The procedure described above applies to product prices. On the input side, the procedure to generate prices varies according to the nature of the input. The price of fertilizer is determined as follows:

$$PF(t) = PFO \cdot (1 + T \cdot PFCH) \qquad (87)$$

where

PF = average price of fertilizer (Cr$/kg)

PFO = fertilizer price in the beginning of period (Cr$/kg)

PFCH = rate of change of fertilizer price (dimensionless)

The value of PFCH is determined on the basis of past price changes. Next, the average price is exponentially lagged to give the expected price (Equation 88).

$$PFER(t) = PFER(t-1) + DT/DEL3 \cdot (PF(t) - PFER(t-1)) \qquad (88)$$

where

PFER = expected price of fertilizer (Cr$/kg).

The price of seed is determined from the expected product price as

$$PSEED_j(t) = PY_j(t) + PSCDIF_j \qquad (89)$$

where

PSEED = expected price of seed (Cr$/kg)

PY = expected product price (Cr$/kg)

PSCDIF = seed differential cost (Cr$/kg).

The wage rate of labor is also projected using an average rate of past changes. It is given by

$$WAGE(t) = WAGEO \cdot (1 + T \cdot WAGECH) \qquad (90)$$

where

WAGE = wage rate (Cr$/hour)

WAGEO = wage rate in the beginning of period (Cr$/hour)

WAGECH = rate of change in wage rate (dimensionless).

Acquisition prices of investment goods are also determined in the same way so that

$$PAQ_i(t) = PAQO_i \cdot (1 + T \cdot PAQCH_i) \qquad (91)$$

where

PAQ = acquisition price (Cr$/unit)

PAQO = acquisition price in the beginning of period (Cr$/unit)

PAQCH = rate of change of acquisition price (dimensionless)

Salvage values are assumed as a proportion of acquisition prices such that

$$PSL_i(t) = RT \cdot PAQ_i(t) \qquad (92)$$

where

PSL = salvage value (Cr$/unit)

RT = proportion of acquisition price determining salvage value (dimensionless)

The value of interest rate and the prices of other inputs are assumed constant, at the initial level, for the duration of the model run. Changes in these prices are assumed to have no major effects on farmers' decisions, since they only account for a small proportion of production costs.

Data Requirements and Sources

The implementation of the model requires a wide range of data which makes it necessary to use quite diverse sources. Basically, three categories of data are used in the model: a) Initial conditions, b) Constant parameters, and c) Time-varying parameters and exogenous variables. Following is a description of the data requirements and sources that fall in each category.

Initial Conditions

In order to start the first cycle of computations, it is necessary to have initial values for the constraint vector of the annual allocation model for 1970. They include land constaints, labor, draft animal and machinery capacities. The initial values for these constraint elements are derived from census data published by the Fundacao Instituto Brasileiro de Geografia e Estatistica (IBGE). The constraint vector also includes flexibility constraints for crops and pasture whose initial values are derived from historical data on cultivated area also published by IBGE.

Constant Parameters

Constant parameters used in the model are related to production technology, input application rates, prices, and rates of change. The main reason for considering these parameters as constants is lack of data needed to estimate them as time variant. Some of the parameters which are constant in time include: a) input-output coefficients for crop, pasture and beef activities; b) application rates of various crops and livestock inputs; c) livestock yields; d) flexibility coefficients, and e) various rates of change.

The input-output coefficients are derived from farm budgets contained in Engler.[7] Other sources of farm level data used are Adams et al.,[8] and Ahn.[9] Flexibility coefficients and rates of change are estimated based on historical data from IBGE.

Time-Varying Parameters and Exogenous Variables

By its very nature, the model is able only to provide conditional projection since its results depend on a given set of assumptions concerning the behavior of time-varying parameters and exogenous variables which are determined on the basis of off-line projections. Included in this category are: a) prices for product and inputs; b) labor wage rate; c) proportion of land on each farm size group; d) number of farms; e) population growth rate, and f) working time equivalent of labor. Most of these projections are based on historical data contained in various IBGE publications.

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[7]J.J.C. Engler, "Alternative Enterprise Combinations Under Various Price Policies on Wheat and Cattle Farms in Southern Brazil," Unpublished Ph.D. dissertation, The Ohio State University, 1971.

[8]Dale W. Adams et al., "Farm Growth in Brazil," Department of Agricultural Economics and Rural Sociology, The Ohio State University, 1975.

[9]C.Y. Ahn, "A Recursive Programming Model of Regional Agricultural Development in Southern Brazil (1969-1970): An Application of Farm Size Decomposition," Unpublished Ph.D. dissertation, The Ohio State University, 1972.

Data used to implement the model are contained in the computer program given in Appendix C. Detailed description of the data, including survey methods and procedures, date of collection, and number of observations can be found in the references cited in this chapter.

In summary, Chapter V presents a complete description of the model developed in this study. The major emphasis is on developing a logical framework which can be improved over time with better data and greater understanding of the structure and processes of reality. The model is composed of three components: a) a yield component which estimates crop yields given the yield-nutrient response functions; b) a resource allocation component consisting of a Recursive Linear Programming model which allocates land and other farm resources to alternative farm enterprises, and c) a production and accounting component which computes production levels and other performance criteria by commodity, farm size, and regional aggregates. The model is developed with the objective of analyzing the impacts of alternative technologies on production. However, it can be used for such other purposes as analysis of product and input pricing policies. The model has been developed and used by itself, but due to its flexibility, it can be easily linked to and used as a component of a larger sector model. Improvements on the data base and further model refinements would contribute to its usefulness in providing results applicable to policy recommendations.

PART C

MODEL APPLICATION AND ANALYSIS

CHAPTER VI

EMPIRICAL RESULTS

This chapter presents the empirical results obtained by operationalizing the model developed in this study. The structure of the model indicates that a large amount of results can be obtained from it.[1] The model permits simulation of results for alternative technology assumptions by: a) Farm size groups; b) Crops; c) Inputs, and d) Years, in detailed form. To analyze all the results for the various dimensions involved is virtually impossible. Considering the objectives of the study, analysis is limited to a few selected variables related to production, employment and input utilization, and income. Further, instead of presenting the results for all the years focus is on the projected results for 1980 only, with comparisons to the 1970 results.

According to the objectives of the study, a few situations will be analyzed in respect to the impacts and adjustments of alternative production technologies. Specifically, model application and analysis will concentrate on: a) the impacts of introducing high-yield varieties with higher response to fertilizer application, and b) the impacts of an increasing level of mechanization defined by alternative production processes through variations on the

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[1]A sample of the yearly output results is contained in Appendix B.

labor, tractor, and draft animal requirements. A description of each technology alternative and the procedures used to study each situation is presented below.

A Note on Model Operation

In the basic linear programming model of the resource allocation component production activities are programmed with two types of technology, namely, traditional, using draft animal power and modern, using mechanical power. So, originally, for each activity, two processes of production are defined and included as distinct activities in the programming model. With this set up the model would solve for the optimum combination of activities and processes over time.

In order to analyze the impacts of increasing levels of mechanization through time, the structure of the basic model is modified to include only one process for each activity. The new process is defined as a combination of the traditional and modern processes as defined in the original structure.

The modification is easily done by the computer program and basically involves the following steps: a) assign a high cost for all production activities with traditional technology; b) combine the input-output coefficients of labor, tractor, and draft animal of the traditional and modern processes in given proportions so as to define a new process for each activity, and c) assign a value zero to each input-output coefficient of the traditional activities. This procedure is conducted for every year before the allocation problem is solved. Thus, different levels of mechanization can be introduced over time by changing the proportions with which the traditional and modern processes are combined. The results presented in this chapter are based on the modified structure and are related to various assumptions in respect to yields and mechanization levels.

Technology Alternatives Designed for Experiment

The analysis of the potential impacts and adjustments arising with the introduction of high yield varieties and an increased level of mechanization is conducted by means of simulation of different technology alternatives through time. The model is used to simulate six alternatives. These are related to three yield levels and three mechanization levels. For a given alternative, simulation is conducted by providing input values for the relevant variables and maintaining the same set of assumptions in respect to model structure and exogenous variables. Choice of the values representing different technology alternatives is made based on realistic assumptions about technological innovations which could feasibly be developed through research programs and adopted during the time horizon considered.

Alternative Varietal Technology

The basic objective of agricultural research institutions is to allocate resources to research programs directed to effect technological change to increase productivity of scarce resources and increase total production of major commodities. One line of research programs often emphasized is the development of new crop varieties which give higher yield per unit of land and also uses fertilizer more efficiently.

The problem of low productivity in the agricultural sector of Rio Grande do Sul has been pointed out in previous chapters. Given the exhaustion of possibilities for further extensive expansion of output, low productivity growth rates can have adverse effects on the regional economy. With limited possibilities of expansion of cultivated area through incorporation of new lands, increases in output of one commodity will take place only at the expense of other products. Thus, sustained increases in output will have to rely more and more on productivity growth coming from an increased use of modern inputs.

Technological change based on varietal improvements will depend on farmers' decisions to adopt the innovations and to a large extent on organized activities carried on primarily in the public sector. Given the fairly low levels and low growth rates of yields, a great potential for rapid gains in agricultural productivity seems to exist in Rio Grande do Sul. More than the manipulation of the pricing system for agricultural commodities and inputs will be required for this potential to be explored. Greater attention has to be given to research, extension and rural education in order to achieve the objective of productivity growth.

Varietal and fertilizer are two integrated technologies. The interaction effects between them have been proved highly significant. It has been observed that fertilizer application to indigenous varieties shows small response. On the other hand, improved varieties tend to do just a little better than indigenous varieties if no fertilizer is applied. Improved varieties can express their higher yield potential when they can respond satisfactorily to higher levels of fertilizer application. The economic implications of this interaction effect is that high-yielding crop varieties will essentially facilitate the substitution of fertilizer for land, leading to changes in resource proportions, and to substantial increases in output.

Modeling of a research component would permit the generation of technological change endogenously in the model. The relationships between allocation of research funds to research activities and research outcomes in the form of higher productivity levels would have to be considered in the model. This consideration, however, was not included in the research objectives. Rather, a pragmatic approach is followed which consists basically of a set of assumptions about possible research outcomes that could be generated by the research sector.

A set of planned productivity gains for each crop is assumed, and viewed as tentative research administrators' decisions to develop technological innovations which would have the major impacts of increasing output per unit of land. Alternative assumptions can be seen as representing the goals and objectives in respect to technology policy. More specifically, it is assumed that: a) Research outcomes have a combination of attributes related to varietal improvement and response to fertilizer; b) Planned research outcomes are realized and come about at the beginning of the planning period in the form of increased output per unit of land, and c) Increases in yields through time occur according to a given innovation pattern which accounts for diffusion and adoption lags characteristic of the innovation process.

The modeling of the social diffusion process related to technological innovations was not in the objectives of this study. Aspects of diffusion are important in studying the impacts of technological change. The adoption rate of an innovation is a function of profitabilities, promotion and natural diffusion by "demonstration effects". This involves time for experimental station results to show up as realized productivity gains. For a given situation an adoption pattern is defined.

In order to account for innovation diffusion aspects in the model, a hypothesized adoption pattern was used which accounts for time delay in adoption and differences between experimental station and farmers' production conditions. Specifically, the percentage of land producing at higher yield rates is assumed to follow a normal distribution giving an S-shaped cumulative distribution over time. Clearly, the form of the adoption pattern is a testable hypothesis. As information becomes available different situations can be simulated by the model.

Adoption rates of high yield varieties may differ among crops. For simplicity, the same pattern is assumed for all crops. In respect to farm size, biological innovations seem to have no scale effect. However, differences in farmers' educational levels and access to markets and new technical knowledge may cause diffusion patterns to differ according to farm size. A number of studies show that larger farms tend to adopt modern farm practices before smaller farms and at a faster rate. Thus, larger farms begin using modern methods earlier and reach maximum user levels sooner. However, a lack of data and a desire for simplicity in the operation of the model, cause the same innovation pattern to be assumed for both farm size groups included in the study.

Yields are determined in the model by fertilizer response functions. The response function will change with technological advancement in terms of improved variety. In general, all parameters of the function will change as a new nutrient-response relationship is defined. Yield increases due to varietal improvements are assumed to shift the response function upward by a certain percentage of the base level. This means a change in the intercept of the function maintaining the same slope parameters. Experimental data could be used to determine new response functions. An upward shift of a quadratic response function will not change the optimum fertilizer application rate if product and input prices are the same. But this still means a higher response to fertilizer, since yield will be higher for the same amount of fertilizer applied.

The realized increase in yield at a given time is indicated by the percentage increase at the experimental station times the proportion of land producing at higher yield rates determined by the innovation pattern. It is given by

$$YBACH(t) = PROAR(t) \cdot YLDCH \qquad (1)$$

where

YBACH = actual percentage increase in yield (dimensionless)

PROAR = proportion of land producing at higher yield rates (dimensionless)

YBACH = percentage of yield increase from base level (dimensionless).

Then, the actual base yield level is determined simply as

$$YBASE_j(t) = YBASE_j(t - 1) \cdot (1 + YBACH(t)) \quad (2)$$

where

$YBASE_j$ = actual base yield level for j^{th} crop (kg/ha)

The variable YBASE determined by Equation 2 becomes the new intercept for the fertilizer response function; expected yields are determined on the basis of the optimum application rate of fertilizer:

$$YLD_j(t) = YBASE_j(t) + ALPHA_j \cdot FERT_j(t) + BETA_j \cdot FERT_j^2(t) \quad (3)$$

where

YLD_j = expected yield rate for j^{th} crop (kg/ha)

$FERT_j$ = fertilizer application rate (kg/ha)

ALPHA, BETA = parameters of the response function.

Yields are contained in the objective function coefficients. Thus, changes in yields will affect the Z_j's coefficients of the linear programming model over time. Three alternatives in respect to crop yields are analyzed: a) base yield rates determined by the original response functions; b) 30 percent increase in base level, and c) 50 percent increase in base level. Pasture and livestock yields are maintained constant throughout the period of model run.

Alternative Mechanical Technology

Mechanization is a type of technological change which depends more on individual decisions of farmers than on organized activities of the public sector. Farmers' decisions to increase the level of mechanization are functions of their financial condition and resource availabilities. Subsidized credit for the purchase of agricultural machinery has had a great impact on the rate of adoption of this type of technology in Rio Grande do Sul.

Mechanical innovations permit the substitution of land and capital for labor. It permits substitution of land for labor because a given unit of labor can till more land with mechanical power. At the same time capital is also substituted for labor. Thus, productivity of labor will increase as more capital is applied to given amounts of land.

One of the objectives of this study is to analyze the impacts of increased levels of mechanization on production and resource allocation. To reach this objective changes are introduced over time in the input-output coefficients of the linear programming model. These changes define new production processes given in terms of varying proportions of labor, draft animal, and tractor services requirements for production activities.

Originally, two production processes were defined for each crop activity, a traditional and a modern. Then, a new process is defined as a linear combination of the original processes. The combination is related to the input-output coefficients of labor, draft animal, and tractor only.

For labor of any given period the new input-output coefficients are defined as follows:

$$A^{W}_{ij}(t) = WTL \cdot A^{M}_{ij}(t) + (1 - WTL) \cdot A^{T}_{ij}(t) \qquad (4)$$

where

A^{W}_{ij} = labor requirement per hectare with new process W (hours/ha)

A^{M}_{ij} = labor requirement per hectare with modern process M (hours/ha)

A^{T}_{ij} = labor requirement per hectare with traditional process T (hours/ha)

WTL = proportion of modern process in the new process (dimensionless)

i = labor constraints

j = production activities.

Similarly, the new input-output coefficients for tractor are defined as

$$A^{W}_{ij}(t) = WTA \cdot A^{M}_{ij}(t) \qquad (5)$$

where

A^{W}_{ij} = tractor requirement per hectare with new process W (hours/ha)

A^{M}_{ij} = tractor requirement per hectare with modern process M (hours/ha)

WTA = proportion of modern process in the new process (dimensionless)

i = tractor capactity constraint

and, for draft animal as

$$A^{W}_{ij}(t) = (1 - WTA) \cdot A^{T}_{ij}(t) \qquad (6)$$

where

A_{ij}^{W} = draft animal requirement with new process W (hours/ha)

A_{ij}^{T} = draft animal requirement with traditional process T (hours/ha)

i = draft animal capacity constraint

Basically, Equations 4, 5 and 6 define a combination of processes. In order to increase the level of mechanization, it is necessary only to increase the proportions WTL and WTA. In fact, these parameters are time variant, with changes determined by an innovation pattern similar to the one used for yield. Modernization takes place over time according to an innovation pattern which gives the proportion of land using the higher technology level for a given time t. A given increase in WTL and WTA applies to a certain proportion of land. These proportions are determined as follows:

$$WTL(t) = WTL(t-1) + PRMOL(t) \cdot WTLCH \qquad (7)$$

$$WTA(t) = WTA(t-1) + PRMOL(t) \cdot WTACH \qquad (8)$$

where

PRMOL = proportion of land using new technology (dimensionless)

WTLCH = rate of increase in WTL (dimensionless)

WTACH = rate of increase in WTA (dimensionless).

Tractor mechanization substitutes for labor and draft animal. Three alternatives related to the level of mechanization are analyzed: a) a 25 percent proportion of modernization (WTL = 0.25, WTA = 0.25); b) a 50 percent proportion of modernization

(WTL = 0.50, WTA = 0.50), and c) a 75 percent proportion of modernization (WTL = 0.75, WTA = 0.75).

The model run alternatives made are summarized in Table VI.1. They include three alternatives in respect to yield, given a 50 percent proportion of combination of modern and traditional processes, and three alternatives in respect to mechanization, given base yield levels.

Table VI.1: Summary of Alternative Techonology Runs

Run No.	Alternative		Description	
1	IA.	YLDCH = 0 WTL = WTA = 0.50	(i) (ii)	Base yield levels 50 percent mechanized process
2	IB.	YLDCH = 0.30 WTL = WTA = 0.50	(i) (ii)	30 percent increase in yields 50 percent mechanized process
3	IC.	YLDCH = 0.50 WTL = WTA = 0.50	(i) (ii)	50 percent increase in yields 50 percent mechanized process
4	IIA.	YLDCH = 0 WTL = WTA = 0.25	(i) (ii)	Base yield levels 25 percent mechanized process
5	IIB.	YLDCH = 0 WTL = WTA = 0.50	(i) (ii)	Base yield levels 50 percent mechanized process
6	IIC.	YLDCH = 0 WTL = WTA = 0.75	(i) (ii)	Base yield levels 75 percent mechanized process

Simulated Model Results

This section presents the simulated impacts of alternative varietal and mechanical technologies on: a) Land use and cropping patterns; b) Production; c) Employment and input utilization, and d) Income and factor productivities. The results are for the year of 1980 with anintertemporal comparison with 1970. Thus, the focus is on the results for the eleventh year of each run with comparison with the base year. All the performance variables are given by farm size group and for the regional total. Each farm size group is to be interpreted as an aggregate of farms in that group. Net farm income in small farms, for example, means the aggregate income for all farms in the group. The results are not in a per farm basis; they are for the aggregate of farms in each group. To find average figures per farm the result has to be divided by the number of farms in the respective group. The results for varietal technology alternatives are presented first. They are followed by the results concerning mechanization.

The Impacts of Varietal Technology

The results presented here refer to alternatives IA, IB, and IC described in Table VI.1. Alternative IA refers to base yield levels, alternative IB assumes a 30 percent increase in yields, and alternative IC assumes a 50 percent increase in yields. All three alternatives assume a 50 percent level of process combination, which means that traditional and modern processes were combined in a 50 percent basis.

Land Use and Cropping Patterns:

The optimal solution for land allocation by size and crops is given by the linear programming model of the resource allocation component. The simulated impacts of alternative yield assumptions on crop and pasture areas, as given by the optimal solutions, are shown in Table VI.2.

Under alternative IA, i.e., base yields, the area cultivated with rice increases by about 72.5 percent over that of the base year for both farm size groups and for the region. The introduction of higher yield varieties would have no impact on area cultivated with rice, since the increases over the base year for alternatives IB and IC are the same as for alternative IA.

Corn area decreases by 14.6 percent in small farms, 40.0 percent in large farms, and 21.2 percent in the total, under alternative IA. The increase in yields would have impact on the area cultivated with corn in small farms and in the region, but not in large farms. Under alternative IB the corn area in small farms shows a lower decrease in relation to alternative IA, while under alternative IC it shows an increase of 8.6 percent over that of the base year. In absolute terms corn area in small farms would increase from 1,137 to 1,194 thousand hectares with a 30 percent increase in yield, and from 1,137 to 1,446 thousand hectares with a 50 percent increase in yield. This means yield impacts of 5.0 percent and 27.2 percent, respectively. For large farms no change is observed.

Model results indicate that yield increases would have significant impacts on wheat area in large farms and in the total. Under

Table VI.2: Optimal Land Use and Cropping Patterns for 1980 Under Different Yield Alternatives and a 50 Percent Mechanization Level.

	Base Year (1970)	Alternative Yield Assumptions					
		Alternative IA		Alternative IB		Alternative IC	
		Area	%Δ	Area	%Δ	Area	%Δ
Rice -S	135	233	72.6	233	72.6	233	72.6
L	315	543	72.4	543	72.4	543	72.4
T	450	776	72.4	776	72.4	776	72.4
Corn -S	1332	1137	-14.6	1194	-10.4	1446	8.6
L	467	280	-40.0	280	-40.0	280	-40.0
T	1799	1417	-21.2	1474	-18.1	1726	- 4.1
Wheat -S	279	1274	356.6	1274	356.6	1276	357.3
L	722	388	-46.3	964	33.5	963	33.4
T	1001	1662	66.0	2238	123.6	2239	123.7
Soybeans-S	304	2025	566.1	2025	566.1	2024	565.8
L	274	274	-26.7	538	43.8	567	51.6
T	678	2299	239.1	2563	278.0	2591	282.1
Cult. -S	159	1219	666.7	1162	630.8	910	472.3
Pasture L	387	232	-40.0	232	-40.0	232	-40.0
T	546	1451	165.7	1394	155.3	1142	109.1
Natural -S	3806	1890	-50.3	1890	-50.2	1890	-50.3
Pasture L	9927	9551	- 3.8	8712	-12.2	8683	-12.5
T	13733	11441	-16.7	10602	-22.8	10573	-23.0

Note: 1) S = Small Farms; L = Large Farms; T = Regional Total

2) Area in 1,000 hectares

3) %Δ means percent change from respective base year (1970) values.

all alternatives, the area in small farms shows an increase of about 357 percent from the base year level. Thus no change is observed with increase in yield. Under alternative IA, the area of wheat in large farms decreases by 46.3 percent in relation to the base year. However, going from alternative IA to IB or IC would cause an increase of about 33.5 percent. The aggregate area cultivated with wheat increases by 66.0, 123.6, and 123.7 percent under alternative IA, IB, and IC, respectively.

The changes for soybeans are similar to those for whaet. There is a substantial increase of about 566 percent for small farms under all three alternatives during the period. For large farms, alternative IA shows a decrease of 26.7 percent, while alternative IB and IC show an increase of 43.8 and 51.6 percent, respectively. For the region, soybean area would increase from 2,299 thousand hectares under alternative IA, to 2,563 thousand hectares under alternative IB, and to 2,591 thousand hectares under alternative IC.

The increase in crop yields would cause the shift of land from pasture to crops as indicated by the percentage growth rates during the period. Cultivated pasture decreases in small farms and in the region under alternatives IB and IC in relation to alternative IA. Under the same conditions natural pasture decreases for large farms and for the region. For all alternatives absolute decrease in the area with natural pasture occurs indicating the tendency for crops and intensive livestock production to substitute for natural pasture.

In summary, model results indicate that the introduction of technological change in the form of high-yielding crop varieties would have some impacts on cropping patterns for the region and in each farm size group. Wheat and soybean would experience large increases in large farms, while no change would be observed in small farms. Corn would increase in small farms. Increases in crop areas appears to come mainly from natural pasture areas.

Production:

Changes in the quantity produced are caused by changes in yield rates and land allocation. The optimal production levels simulated by the model for 1970 and 1980 under different yield alternatives are shown in Table VI.3. The data show the combined effect of yield increase and changes in land allocation. Clearly, in the case of rice differences in production are caused by yield increases only since there was no change on land allocation (Table VI.2). Rice production increases under all alternatives in about the same proportions as the respective increases in yield.

Corn production decreases for both farm size groups and for the region under alternatives IA and IB. Under alternative IC, it increases for small farms. Changes in corn production reflect changes in area observed for this crop. For the region, yield increase under alternative IC more than offsets the decrease in area cultivated, giving an increase in production of about 11 percent during the period.

Wheat and soybean production follow the same pattern observed for cultivated area. Production decreases for large farms under alternative IA, but increases in all other situations. Increases in production under alternative IB and IC are due in part to yield increases but are due mainly to changes in cropping patterns which bring more land into wheat and soybean production.

Beef production in small farms changes from 237 thousand tons in 1970 to 310 thousand tons in 1980, under alternative IA, representing an increase of 30.7 percent during the period. When crop yields are higher, the growth rate drops to 26.6 percent and 8.7 percent for alternatives IB and IC, respectively. For large farms, beef production decreases under all situations. For the region, beef production under alternative IA varies from 848 thousand tons in 1970 to 877 thousand tons in 1980. Clearly, under the conditions of the model, technological change in the form of high yield varieties would raise the profitability of crops relative to beef thus causing substitution of crops for beef in production.

Employment and Input Utilization:

The generation of employment is a major concern of development policy formulation in developing countries. When the industrial sector has a limited capability of expansion to absorb unemployed labor, the creation of employment is dependent on the possibilities of expansion in the agricultural sector. Labor use and the rate of employment growth is directly related to the form of technological change that takes place. A priori technological change in the form of biological innovations is supposed to have a positive impact on employment due to increases in production which require more labor.

The trends in employment and input utilization are basically guided by the changes in the cropping patterns described above. The yearly demand for inputs shows an increasing trend under all

Table VI.3: Optimal Production Levels for 1970 and 1980 Under Different Yield Alternatives and a 50 Percent Mechanization Level

	Alternative Yield Assumptions					
	Alternative IA		Alternative IB		Alternative IC	
	1970	1980	1970	1980	1970	1980
Rice -S	469	809	494	1018	510	1177
L	1149	1981	1210	2494	1250	2884
T	1618	2790	1704	3512	1760	4061
Corn -S	1907	1694	1941	1928	1963	2472
L	669	416	680	452	688	478
T	2576	2110	2621	2380	2651	2950
Wheat -S	298	1377	313	1704	322	1955
L	810	440	850	1352	877	1550
T	1108	1817	1163	3056	1199	3505
Soybeans-S	373	2651	394	3332	407	3847
L	462	343	487	892	504	1073
T	835	2994	881	4224	911	4920
Beef -S	237	310	237	300	237	258
L	611	567	611	526	611	518
T	848	877	848	826	848	776

Note: 1) S = Small Farms; L = Large Farms; T = Regional Total

2) Production in 1,000 tons.

alternatives (Table VI.4) that directly reflect area and production increases.

The total labor employment in the region under alternative IA increases by 25.1 percent or at the rate of about 2.5 percent per year during the period. With the introduction of tehcnological change, labor employment would raise by 38.7 percent and 40.3 percent under alternatives IB and IC, respectively. The net impact of yield increase on employment can be measured by comparing the three alternatives. Going from alternative IA to IB, total labor employment increases from 2,039 million hours to 2,260 million hours, corresponding to 10.8 percent increase. Similarly, there is a 12.1 percent net increase for alternative IC relative to alternative IA. Thus, the marginal impact of alternative IC over IB is fairly small compared to the marginal impact of alternative IB over IA. In respect to farm size groups, employment on small farms increases by about 90.0 percent during the period under all three alternatives. Thus, no major yield impact on employment would be observed. For large farms, employment decreases during the period for all alternatives, showing the tendency of larger farms to adjust to technological choices based on labor-saving modern farm power. However, when the three alternatives are compared, there is evidence that yield increases would have a greater impact on employment in large farms. The impact of alternative IB over IA is of the order of 43.5 percent. For alternative IC over IA it is 44.8 percent. Thus, some scope for expanding employment exists, especially on large farms, through technological change based on high-yielding crop varieties.

Table VI.4: Optimal Input Use for 1980 Under Different Yield Alternatives and a 50 percent Mechanization Level

Input		Base Year (1970)	Alternative Yield Assumptions					
			Alternative IA		Alternative IB		Alternative IC	
			Amount	%Δ	Amount	%Δ	Amount	%Δ
Labor	-S	812156	1543252	90.0	1547658	90.6	1587083	93.0
	L	817381	496139	-39.3	712184	-12.9	718355	-12.1
	T	1629537	2039391	25.1	2259842	38.7	2285438	40.3
Tractor	-S	3872	15255	294.0	15268	294.3	15328	295.9
	L	3644	4368	19.9	6432	76.3	6472	77.6
	T	7426	19623	164.3	21691	192.1	21800	193.6
Draft	-S	118143	202492	71.4	204300	72.9	212272	79.7
Animal	L	106209	62567	-41.1	94523	-11.0	95432	-10.1
	T	224352	265059	18.1	298823	33.2	307704	37.1
Fertilizer	S	126315	274701	117.5	278399	120.4	294736	133.3
	L	93769	74415	-20.6	116038	27.7	116038	27.7
	T	220084	349116	58.6	394437	79.2	410774	86.6

Note: 1) S = Small farms; L = Large farms; T = Regional total

2) %Δ means percent change from respective base year (1970) values.

3) Labor in 1,000 hours; Tractor in 1,000 hours; Draft animal in 1,000; Fertilizer in tons.

Model results indicate large increases in the projected amount of tractor hours used. Under alternative IA, the regional total would increase by 2.6 times, compared to a 2.9 times for alternatives IB and IC. For small farms, the results show a 3.9 fold increase over the period for all alternatives. For large farms, the increases would be only of the order of 1.2 times, under alternative IA, and 1.8 times under alternatives IB and IC. The impact of yield increase on tractor use is much higher for large farms than for small farms. For the region, alternative IB would employ 10.5 percent more tractor services than alternative IA, and alternative IC would employ 11.1 percent more than alternative IA.

The projected use of draft animal services shows an increase of 18.1 percent for the region under alternative IA, 33.2 percent under alternative IB, and 37.1 percent under alternative IC. For the regional total the impact of yield increase indicates a 12.7 percent increase for alternative IB and 16.1 percent increase for alternative IC. In respect to farm size groups, the results show increasing use on small farms and decreasing use on large farms during the period for all alternatives.

Under alternative IA, the model projects an increase in the demand for fertilizer in the region of 58.6 percent over that of the base year. This increase is the result of a 117.5 percent increase in the demand by small farms and a decrease of 20.6 percent in the demand by large farms. The impacts of yield increase can be seen by comparing the projected results for the three alternatives. This comparison shows for example, that under alternative IB the demand for fertilizer in the region is 13.0 percent higher than alternative IA, and that under alternative IC the demand is 17.7 percent higher than alternative IA.

In conclusion, the model projections of employment and input demand show substantial increases during the period considered and significant differences among the alternatives mainly due to changes in the patterns of land use. In general, small farms use from 50 to 70 percent of the total amount of each input due to a more intensive use of land in this group. Yield increases of 50 percent (alternative IC) show only marginal differences in respect to yield increases of 30 percent (alternative IB).

<u>Income and Factor Productivities</u>:

The net returns to fixed factors and factor productivities projected for 1980 under the three alternatives considered are shown in Table VI.5. Net farm income or net returns is defined as gross revenue minus variable costs. It is given by the optimum value of the objective function of the linear programming model. Land productivity is net return per hectare of total utilized land which includes crop land and pasture land. Labor productivity is defined as net returns per hour of total labor employed.

Concerning net returns by farm size, an observation should be made in reference to optimization of the objective function and the disaggregation procedure used. The definition of net returns to each group separately is not indicative of individual optimization. The model maximizes the aggregate objective function which is the sum of the individual objective functions. However, maximization of the

Table VI.5: Net Farm Income and Factor Productivities for 1980 Under Different Yield Alternatives and a 50 Percent Mechanization Level.

Item		Base Year (1970)	Alternative Yield Assumptions				
			Alternative IA	Alternative IB		Alternative IC	
			Value	Value	%Δ	Value	%Δ
Income	S	455365	4662092	5404314	15.9	5941825	27.5
	L	317477	2048463	2596690	26.8	2935995	43.3
	T	772842	6710555	8001004	19.2	8877820	32.3
Land	S	75.71	599.38	694.80	15.9	793.90	27.5
Productivity	L	26.04	181.80	230.46	26.8	260.57	43.3
	T	42.45	352.34	420.09	19.2	466.13	32.3
Labor	S	0.56	3.02	3.49	15.6	4.79	25.5
Productivity	L	0.39	4.13	3.65	-11.6	4.09	- 1.0
	T	0.47	3.29	3.54	7.6	3.88	17.9

Note: 1) S = Small farms; L = Large farms; T = Regional total

2) %Δ means percent change from respective values of Alternative IA.

3) Income in 1,000 Cruzeiros; Land Productivity in Cruzeiros per hectare; Labor Productivity in Cruzeiros per hour.

regional objective function does not necessarily imply maximization of each one separately. The separation of net returns by size group is based on the optimal values of the activities obtained after the regional objective function is maximized.

Table VI.5 includes the values for the base year and for 1980 under each alternative. Given the price relationships assumed in the model, net regional farm income increases by 8.7 times during the period, under alternative IA. Under the same alternative, it increases by 10.2 times for small farms and by 6.5 times for large farms. Basically, the higher rate of growth for small farms is due to intensification in the use of land and faster expansion of crop land in this group during this period.

According to model results, the introduction of high yield varieties would have significant impacts on net regional income. Under alternative IB net returns would be 15.9, 26.8, and 19.2 percent higher for small farms, large farms, and for the region, respectively. For alternative IC, net returns would be about 1.7 times higher than alternative IB. Large farms would experience a higher increase in net returns than small farms.

Average net land productivity measured as the ratio of total net returns to total land use is a decreasing function of farm size in all cases. Under model conditions, land productivity in alternative IA increases by 8.0 times in small farms, 7.0 times in large farms and 8.3 times for the region from the base year values. The differential impacts of yield increase on land productivity are higher for large farms due to the faster rate of transition to crop farming on larger farms and their increased use of commercial inputs under alternatives IB and IC.

Labor productivity measured as the ratio of net returns to total labor employed is higher in large farms than in small farms. Comparing alternatives IA, IB, and IC the introduction of varietal technology can be seen to have different impacts on labor productivity according to farm size. For small farms, average labor productivity would be 15.6 percent higher under alternative IB compared to alternative IA. Similarly, alternative IC would show a 25.5 percent increase in labor productivity compared to alternative IA. For large farms, labor productivity decreases by 11.6 percent and 1.0 percent for alternatives IB and IC, respectively, in regard to alternative IA. This result is due to an increase in labor employment which is more than proportional to the increase in net returns in large farms.

To summarize, model results show that net farm income and factor productivities would be enhanced with increases in crop yields. Large farms would tend to experience greater impacts relative to small farms.

The Impacts of Mechanical Technology

This section presents the results for alternatives IIA, IIB, and IIC described in Table VI.1. The objective is to show the impacts of changing labor, draft animal, and tractor requirements for production activities such that the effects of an increased level of mechanization on production and resource allocation can be analyzed. As described earlier, each alternative refers to a certain combination of traditional and modern production processes. In alternative IIA the resulting process is a combination of 0.25 modern and 0.75 traditional; for alternative IIB the combination is in a 50 percent basis and alternative IIC has a 0.25 proportion of traditional and 0.75 of modern. All three alternatives are analyzed maintaining yields at base levels, i.e., the yield levels determined by the original fertilizer response functions.

Land Use and Cropping Patterns:

Model results for crop and pasture areas under the different mechanization alternatives are shown in Table VI.6. Rice area increases by 72.6, 14.3, and 31.8 percent during the period for small farms, large farms, and the region, respectively, under alternative IIA. With a higher level of mechanization (alternative IIB or IIC), rice area would remain the same in small farms, increase by 51 percent in large farms, and increase by 31 percent in the region, relative to alternative IIA.

Area cultivated with corn would decrease by approximately the same proportions under all three alternatives for both farm size groups and the region. Thus, under model conditions of prices and behavioral constraints, no major effect would be observed on corn area with changes in the pattern of mechanization.

Area of wheat, under alternative IIA, would increase by 410 percent in small farms, decrease by 65 percent in large farms, and increase by 67 percent in the region over that of the base year. If alternative IIB is introduced, the increase in area on small farms would fall to 357 percent, and the decrease on large farms would be 46 percent. Under alternative IIC, the area on small farms remains the same

Table VI.6: Optimal Land Use and Cropping Patterns for 1980 Under Different Mechanization Alternatives and Base Yield Levels.

Crops		Base Year (1970)	Alternative Mechanization Assumptions					
			Alternative IIA		Alternative IIB		Alternative IIC	
			Area	%Δ	Area	%Δ	Area	%Δ
Rice	-S	135	233	72.6	233	72.6	233	72.6
	L	315	360	14.3	543	72.4	543	72.4
	T	450	593	31.8	776	72.4	776	72.4
Corn	-S	1332	1110	-16.7	1137	-14.6	1137	-14.6
	L	467	280	-40.0	280	-40.0	280	-40.0
	T	1799	1390	-22.7	1417	-21.2	1417	-21.2
Wheat	-S	279	1423	410.0	1274	356.6	1274	356.6
	L	722	252	-65.1	388	-46.3	1260	74.5
	T	1001	1675	67.3	1662	66.0	2534	153.1
Soybeans	-S	304	1923	532.6	2025	566.1	2025	566.1
	L	374	170	-54.5	274	-26.7	722	93.1
	T	678	2093	208.7	2299	239.1	2747	305.2
Cult.	-S	159	655	311.9	1219	666.7	1219	666.7
Pasture	L	387	232	-40.1	232	-40.1	232	-40.1
	T	546	887	62.4	1451	165.7	1451	165.7
Natural	-S	3806	2434	-36.1	1890	-50.3	1890	-50.3
Pasture	L	9927	9974	0.5	9551	- 3.8	8231	-17.1
	T	13733	12408	- 9.6	11441	-16.7	10121	-26.3

Note: 1) S = Small farms; L = Large farms; T = Regional total

2) Area in 1,000 hectares.

3) %Δ means percent change from respective base year (1970) values.

as in IIB, but would increase on large farms by 74.5 percent and in the region by 153 percent over the base year values. Thus, higher levels of mechanization tend to increase the area of wheat, with large farms experiencing larger proportion of the increases.

Projected area of soybeans follow basically the same pattern as that of wheat. For the aggregate it is 9.8 percent higher under alternative IIB than IIA, and 31.3 percent higher for alternative IIC relative to IIA. These increases would result from 5.3 and 61.2 percent increase in the area in small and large farms, respectively, under alternative IIB relative to IIA, and 5.3 and 324.7 percent under alternative IIC relative to IIA. Similar to wheat, the major proportion of the increases in soybeans goes to large farms.

Increased levels of mechanization would raise the area of cultivated area of wheat and soybeans reflect the decreases in the area with natural pasture. In the aggregate the area decreases by 9.6 percent under alternative IIA, 16.7 percent under alternative IIB, and 26.3 percent under alternative IIC from that of the base year.

Production:

Quantity produced of the various products projected by the model is shown in Table VI.7. Production impacts for the different mechanization alternatives result from changes in land use and cropping patterns determined by the optimal allocation of land among different farm activities. Rice production in the region is projected as 31.2, 72.5 and 72.5 percent higher than the base year, under

Table VI.7: Optimal Production Levels for 1980 Under Different Mechanization Alternatives and Base Yield Levels.

Products		Base Year (1970)	Alternative Mechanization Assumptions					
			Alternative IIA		Alternative IIB		Alternative IIC	
			Quantity	%Δ	Quantity	%Δ	Quantity	%Δ
Rice	-S	468906	808644	72.5	808644	72.5	808644	72.5
	L	1148820	1314349	14.4	1981176	72.5	1981176	72.5
	T	1617726	2122993	31.2	2789820	72.5	2789820	72.5
Corn	-S	1906840	1653443	-13.3	1693528	-11.2	1693528	-11.2
	L	668632	416595	-37.7	416595	-37.7	416595	-37.7
	T	2575472	2070038	-19.6	2110123	-18.1	2110123	-18.1
Wheat	-S	298022	1536978	415.7	1376617	361.9	1376617	361.9
	L	810452	285632	-64.8	439900	-45.7	1428928	76.3
	T	1109474	1822610	64.4	1816517	63.9	2805545	153.1
Soybeans	-S	373306	2486421	566.1	2651179	610.2	2651179	610.2
	L	461632	207154	-55.1	342584	-25.8	955850	107.1
	T	834938	2693575	222.6	2993763	258.6	3607029	332.0
Beef	-S	237305	242998	2.4	310123	30.7	310123	30.7
	L	610711	590377	- 3.3	567091	- 7.1	494445	-19.0
	T	848016	833375	- 1.7	877214	3.4	804568	- 5.1

Note: 1) S = Small farms; L = Large farms; T = Regional total

2) Quantity in tons.

3) %Δ means percent change from respective base year (1970) values.

alternatives IIA, IIB, and IIC, respectively. Corn production would decrease for both sizes and the region by about the same proportions under all alternatives.

According to model results quantities produced of wheat and soybeans are projected to increase significantly. This increase is due to large amounts of land being transferred into production of these two crops. For wheat, increasing the level of mechanization causes a decrease of production in small farms and very significant increases in large farms. For soybeans, production increases in both sizes for higher levels of mechanization.

Beef production on large farms would be greatly affected by increased mechanization. It would decrease by 7.1 and 19.0 percent under alternatives IIB and IIC, respectively, compared to a decrease of only 3.3 percent under alternative IIA. On small farms it would be 27.6 percent higher for alternative IIB or IIC than for alternative IIA.

Basically, according to model projections, increased mechanization would tend to shift resources away from corn and beef production in favor of rice and mostly wheat and soybeans.

Employment and Input Utilization:

Resource demands necessary to meet production levels under the various alternatives are shown in Table VI.8. The total amount that given input is used is a function of total amounts of land to which the input is applied and the unit requirements of the input per unit of land. Table VI.8 gives the demands for the inputs under conditions of changing unit requirements per hectare. For a given alternative,

Table VI.8: Optimal Input Use for 1970 and 1980 Under Different Mechanization Alternatives and Base Yield Levels.

Input		Alternative Mechanization Assumptions					
		Alternative IIA		Alternative IIB		Alternative IIC	
		1970	1980	1970	1980	1970	1980
Labor	-S	862954	1980722	812156	1543252	761358	934166
	L	869546	518095	817381	496139	765215	511610
	T	1732500	2498817	1629537	2039391	1526573	1445776
Tractor	-S	3151	7222	3782	15255	4412	22481
	L	3037	1746	3644	4368	4252	11174
	T	6188	8968	7426	19623	8664	33655
Draft	-S	126582	278711	118143	202492	109704	115710
Animal	L	113795	65543	106209	62567	98622	64398
	T	240377	344254	224352	265059	208326	180108
Fertilizer	S	126315	262131	126315	274701	126315	274701
	L	93769	57774	93769	74415	93769	138291
	T	220084	319905	220084	349116	220084	412992

Note: 1) S = Small farms; L = Large farms; T = Regional total

2) Labor in 1,000 hours; Tractor in 1,000 hours; Draft Animal in 1,000 hours; Fertilizer in tons.

the input-output coefficients of labor, tractor, and draft animal change over time in such a way as to increase the level of mechanization through substitution of tractor services for labor and draft animal services. The initial mechanization level at the beginning of the period increases from alternative IIA to IIC.

Labor employment grows at the rates of 13.0 and 4.4 percent per year for small farms and the region, respectively, under alternative IIA. For large farms employment would decrease at the annual rate of 4.0 percent, under the same alternative. Under alternative IIB, employment would grow at the annual rates of 9.0, -3.9, and 2.5 percent for small farms, large farms, and the region, respectively. If alternative IIC is introduced, employment would increase by only 2.3 percent on small farms, it would still decrease by 3.3 percent on large farms, and decrease by 0.5 percent in the region. Thus, the rate of growth of employment decreases from alternative IIA to IIC for small farms, increases slowly for large farms, and decreases for the region. This indicates that the substitution effects of tractor for labor on small farms are greater than on large farms and would come about at a faster rate.

Under alternative IIA, tractor use on small farms would increase at the annual rate of 13.0 percent, while on large farms it would decrease by 4.3 percent per year. In the aggregate it would increase by 44.9 percent or at the rate of 4.5 percent over that of the base year. Under the other alternatives these rates increase considerably. For small farms the average annual rates of growth would be 30.3 and 41.0 percent for alternative IIB and IIC, respectively. For large farms they would be positive 2.0 and 16.3 percent, and for the region 16.4 and 28.8 percent for alternative IIB and IIC, respectively.

Draft animal use presents a similar picture as that of labor. As we move from alternative IIA to IIC, the average growth rate of use decreases for small farms, increases for large farms and decreases for the region. Under alternative IIA draft animal use would increase at the rate of 12.0 percent on small farms, decrease by 4.2 percent per year on large farms, and increase by 4.3 percent in the region. On the other hand, under alternative IIC, draft animal use would increase on small farms by only 0.5 percent per year, it would decrease by 3.5 percent instead of 4.5 percent on large farms, and would decrease by 1.4 percent per year in the region.

The regional demand for fertilizer increases by 45.4, 58.6, and 87.6 percent over that of the base year for alternatives IIA, IIB, and IIC, respectively. The demand under alternative IIB is 9.1 percent higher than that of alternative IIA for 1980. Likewise, the demand under alternative IIC is 29.1 percent higher than that of alternative IIA, at the end of the projection period. Thus, model results indicate that the demand for fertilizer would increase with introduction of higher levels of mechanization.

Income and Factor Productivities:

The introduction of technological change in the form of mechanical technology has some potential for increasing net returns to fixed factors in farming through more efficient combination of resources (Table VI.9). Net regional farm income would be 14.7 percent

Table VI.9: Net Farm Income and Factor Productivities for 1980 Under Different Mechanization Alternatives and Base Yield Levels.

Item		Alternative Mechanization Assumptions				
		Alternative IIA	Alternative IIB		Alternative IIC	
		Value	Value	%Δ	Value	%Δ
Income	-S	4325008	4662092	7.8	4595719	6.3
	L	1525467	2048463	34.3	3131011	105.3
	T	5850467	6710555	14.7	7726730	32.1
Land	-S	556.04	599.38	7.8	590.84	6.3
Productivity	L	135.39	181.80	34.3	277.88	105.3
	T	307.18	352.34	14.7	405.69	32.1
Labor	S	2.18	3.02	38.5	4.92	125.7
Productivity	L	2.94	4.13	40.5	6.12	108.2
	T	2.34	3.29	40.1	5.34	128.2

Note: 1) S = Small farms; L = Large farms; T = Regional total

2) %Δ means percent change from respective values of Alternative IIA.

3) Income in 1,000 Cruzeiros; Land Productivity in Cruzeiros per hectare; Labor Productivity in Cruzeiros per hour.

higher under alternative IIB and 32.1 percent higher under alternative IIC, relative to alternative IIA. Large farms would take a larger proportion of the increase in net regional farm income. Net returns of large farms would increase by 34.3 and 105.3 percent with alternatives IIB and IIC, respectively, relative to alternative IIA. For small farms the increases would be only of the order of 7.8 and 6.3 percent.

Land productivity changes in exactly the same proportions as net returns, indicating that total utilized area increases more proportionally than net returns. Net returns per hectare are higher for small farms, even though the gap decreases from lower to higher levels of mechanization. It is 4.1, 3.3, and 2.1 times higher in small farms than in large farms, for alternatives IIA, IIB and IIC, respectively.

The index of labor productivity is about 1.3 times higher for large farms than small farms under all situations. The aggregate index for the region increases from Cr$2.34 per hour under alternative IIA to Cr$3.29 per hour under alternative IIB and to Cr$5.34 per hour under alternative IIC. This corresponds to a 40.1 percent increase from alternative IIA to IIB, and a 128.2 percent increase from alternative IIA to IIC.

Model Evaluation

The main purpose of this section is to present an evaluation of the model. This is done by two procedures. The first procedure evaluates the extent to which model results would change if prices were maintained constant at initial nominal values instead of using prices projected by the expectation models. The objective is to test if price changes would have any significant effect in determining model results. If price changes affect the results, the impacts of technology cannot be distinguished from the effects of price. The second procedure evaluates the ability of the model to track events over a given historical period. This is done by comparing the estimated model results on area and production with observed data for the period 1970-76. The purpose is to test the "goodness of fit" of the model, i.e., to evaluate how the model "explains" actual data.

Area and production of the four field crops are shown in Table VI.10 for two sets of price assumptions. Under constant prices, the commodity prices are maintained constant at initial nominal values. The results under varying prices are the same as those presented earlier in this chapter with prices projected on the basis of the expectation models. Table VI.10 presents the results for Alternative IA. The other alternatives are not shown because the results presented basically the same pattern under all alternatives.

Crop area is about the same for both price assumptions. The only differences observed are for wheat from 1976 to 1980 and for soybeans from 1978 to 1980. This shows that resource allocation is rather stable in respect to the price assumption. Thus, the price changes introduced by the expectation models had no effect on determining model results. The impacts of technology analyzed earlier in this chapter were not influenced by price changes.

Production levels with constant prices are different from those with varying prices in all cases. The reason for this is that changes in prices affect the fertilizer application rate which in turn affects

Table VI.10: Optimal Area and Production Levels Under Two Sets of Price Assumptions, Alternative IA, 1970-1980.

Year	Rice		Corn		Wheat		Soybeans	
	Constant Prices	Varying Prices	Constant Prices	Varying Prices	Constant Prices	Varying Prices	Constant Prices	Varying Prices
	Area (1,000 hectares):							
1970	450	450	1799	1799	1001	1001	678	678
1972	516	516	1890	1890	971	971	750	750
1974	579	579	1927	1927	1009	1009	902	902
1976	638	638	1739	1739	1398	1125	1166	1166
1978	703	703	1570	1570	1936	1380	1585	1613
1980	776	776	1417	1417	2683	1662	2041	2299
	Production (1,000 tons):							
1970	1618	1618	2575	2575	1108	1108	835	835
1972	1852	1854	2698	2733	1069	1072	939	948
1974	2075	2079	2747	2820	1103	1110	1137	1154
1976	2286	2293	2477	2566	1529	1233	1473	1499
1978	2520	2530	2235	2329	2118	1508	2007	2075
1980	2777	2790	2017	2110	2934	1816	2615	2994

yields. With different yields production levels change. Price changes affect the allocation of fertilizer because it is determined as a direct function of prices. The allocation of other variable resources should not be affected since it is determined as a function of the input requirements per unit of land.

Model performance can be evaluated in several ways. Probably the most common procedure is the comparison of estimated model results with historical data observed during a certain period. This procedure shows the ability of the model to track actual data. It is used here with data on area and production for the period 1970-1976.

Actual and estimated data on area and production are presented in Table VI.11. The tracking ability of the model is summarized by the Average Proportional Error (APE). The APE is calculated as follows:

$$APE = \frac{1}{n} \sum_{t=1}^{n} \frac{|E_t - A_t|}{|A_t|}$$

where

APE = average proportional error

Et = the estimated value at time t

At = the actual value at time t

n = number of years in the series

Analysis of the APE provides a rough indication of the accuracy of the model results. It gives the percentage of error of the model in estimating actual data.

In general, model tracking as shown in Table VI.11 is not very satisfactory. The model overestimates area and production of rice and corn. For wheat and soybeans model results are lower than the actual

Table VI.11: Actual and Estimated Area and Production Levels, 1970-1976.

Year	Rice Actual	Rice Estimated	Corn Actual	Corn Estimated	Wheat Actual	Wheat Estimated	Soybeans Actual	Soybeans Estimated
	Area (1,000 hectares):							
1970	431	450	1737	1799	1500	1001	871	678
1971	412	482	1722	1843	N.A.	987	1133	705
1972	434	516	1717	1890	N.A.	971	1460	750
1973	416	551	1507	1943	1373	981	2218	814
1974	436	579	1525	1927	1565	1009	2770	902
1975	470	608	1524	1831	1899	1188	3113	1018
1976	520	638	1580	1739	2016	1398	3296	1166
APE*	0.2251		0.1517		0.3309		0.5303	
	Production (1,000 tons):							
1970	N.A.	1618	2387	2575	1500	1108	977	835
1971	N.A.	1732	2371	2633	N.A.	1080	1393	878
1972	N.A.	1852	2235	2698	N.A.	1069	2173	939
1973	1434	1977	2101	2770	1536	1077	2872	1023
1974	1550	2075	2236	2747	1690	1103	3870	1137
1975	1700	2178	2367	2609	1234	1299	4688	1285
1976	1850	2286	2443	2477	1814	1529	5107	1473
APE*	0.3086		0.1514		0.2234		0.5529	

*APE = Average Proportional Error

throughout the series. A positive feature of the model is its ability to estimate the turning point in the area of wheat. This area decreases from 1970 to 1973 and then increases thereafter.

The average proportional error indicates that the estimates for corn are the most accurate, while the estimates for soybeans presented larger errors. The average error for corn is about 15 percent; for soybeans the error is over 50 percent. Clearly, the most significant projection problems of the model are related to soybeans. The model is not able to estimate the rapid increases in soybean area and soybean production observed during the past years.

There are basically two sources of errors of model estimates. These are model specification and quality of the data used in the model. Specification error could have occurred in various areas of model development. The most critical area is the specification of the linear programming model of the resource allocation component. Improvements of this model in terms of better specification of resource constraints should increase model accuracy. The quality of the data used in the model is also an important source of model error. The model uses various sources of data to estimate a number of parameters, rates of change, and initial conditions. These estimates are crucial in determining model results. Improvements in the data base should contribute a great deal to increase model performance.

In summary, the empirical results presented in Chapter VI show that introduction of alternative technologies in the form of high-yield varieties and mechanization would have impacts on production and resource allocation in the Southern Brazilian agriculture. In general, it would tend to change cropping patterns with significant shifts of resources into wheat and soybean production. Varietal technology presents a great potential for increasing labor employment in the region. Both types of technology have significant effects on increasing net farm income. Large farms tend to experience higher increases in income than small farms. This indicates that technological change would tend to increase the income gap between the two groups. Model evaluation show that the price changes introduced by the expectation models had no effect on the results. Unfortunately, model performance evaluated in terms of its ability to track actual data was not satisfactory. Improvements of model specification and data base would enhance model performance.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The purpose of this chapter, which is divided into three parts, is to present the summary and conclusions of the study. The first part gives an overview of the study with focus on the problem, objectives, and methodology. The second part presents the summary of findings, conclusions and implications for development and technology policy. Finally, the third and last section presents some limitations of the study and recommendations for further research.

Summary of Problem, Objectives and Methodology

Basically, this study deals with the problem of how research programs can be directed to affect technological change to increase productivity of scarce resources and increase total production of major commodities. Historically, the major source of output growth in the agricultural sector of the region studied has been the expansion of the frontier with incorporation of new land, labor and associated capital. Given the exhaustion of possibilities for further extensive expansion of output, increases in production will have to rely more on productivity growth in the agricultural sector.

The potential contribution of technological change to development has been recognized for some time. Yet, it will remain as an important economic problem to study its impacts and adjustment in the agricultural sector characterized by a complex structure of economic variables and interrelationships among producers, consumers, and other economic units. Technological change is, for the most part, generated by research activities carried on by the public sector. The effects of introducing new technologies can be characterized by impacts on the cost structure or the product mix of individual firms, shifts in industry demand curves for factors of production, shifts in product supply curves, and impacts on the growth and distribution of total and per capita income.

The primary objective of this study has been to examine the potential impacts of technological change in production patterns, employment and resource utilization, income and resource productivities for the agricultural sector of the state of Rio Grande do Sul, Brazil. More specifically, the analysis is concerned with the impacts of varietal and mechanical technologies. Varietal technology, in the form of high-yield crop varieties with higher capacity to respond to fertilizer application, is analyzed by means of a number of alternative assumptions in respect to yield per hectare for annual crops. Mechanized technology is analyzed on the basis of the effects of changes in labor, draft animal, and tractor input requirements for production activities. High-yield varieties are supposed to facilitate substitution of fertilizer for land, thus changing resource proportion and resulting in substantial increases in output. Tractor services are assumed to substitute for labor and draft animal, permitting more efficient combination of factors and resulting in higher returns to farm resources.

The instrument of analysis used to reach the objectives of the study is a regional, dynamic, microeconomic model of farmers' decisions with respect to resource allocation and production. The major objective of the model is to simulate the year-to-year allocation of land and other farm and regional resources on the basis of their opportunity cost in alternative uses and on the basis of relative enterprise profitability. Furthermore, the model is used to simulate the impacts of changes in structural parameters related to yield levels and response to fertilizer, labor, draft animal and tractor input-output requirements, under the condition of prespecified product and input prices relationships and initial conditions with respect to resource levels. The model provides a time profile of optimal land use and cropping patterns, production, farm income, and derived demand for farm inputs for the region and by farm size groups.

The model is applied to the whole area of the state of Rio Grande do Sul in Brazil. This state is one of the most important producers of agricultural products in the South Region and also in the country. Because of its mild and temperate climate, and adequate soil conditions, its agriculture has been largely complementary to that of the rest of Brazil. It has provided large proportions of the country's production of rice, corn, and beef, and has been the most important wheat and soybean producer in the country. Because of the wide distribution of land in the state, the model includes disaggregation of farm size in two groups: "Small Farms" including farms of size ranging from 0 to 100 hectares, and a group of "Large Farms" of size greater than 100 hectares. The disaggregation by farm size serves to: a) capture distributional effects of technology change, b) analyze the interdependence of different farm size groups competing for regional resources, and c) partially account for aggregation bias.

The model developed in this study is composed of three major components: yield component, resource allocation component, and production and accounting component. The yield component is designed to estimate crop yields based on yield-nutrient response functions. Yield rates for crops are determined by means of quadratic production functions estimated from experimental data on yield per hectare and nitrogen application.[1] The fertilizer application rate is determined on the basis of the equimarginal principle of equating the marginal value product of the factor to the price of the factor. Yield rates are further adjusted to account for the effects of mechanization and differences in farm size.

The resource allocation component consists of a Recursive Linear Programming model which allocates land and other farm resources to alternative farm enterprises based on the opportunity cost principle and on relative profitabilities.

In the production and accounting component, production levels for crops and livestock activities are computed given land allocation and yield projections. Other results such as resource requirements, income, resource productivities and input ratios are also computed.

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[1]The response functions for rice, corn, and wheat are taken from Peter T. Knight, Brazilian Agricultural Technology and Trade - A Study of Five Commodities (New York: Praeger Publishers, Inc., 1971). Due to the lack of experimental data, the response function for soybeans is graphically estimated through a scatter diagram of yield and nutrient application.

Results are obtained by commodity, farm size and regional aggregates.

Recursive Linear Programming was used as the basic approach to represent resource allocation decisions in the region. It is assumed that farmers would select a land utilization pattern which would maximize the expected net returns, subject to a range of physical and behavioral constraints. The input-output matrix of the linear programming model is block diagonal with one block for each farm size and additional regional constraints which hold for all farm sizes simultaneously.

The linear programming model is solved iteratively for each year giving optimal enterprise combinations over time by farm size. The decision rule to be satisfied is the optimization of the regional objective function defined as expected gross returns minus variable costs. The activities considered in the model are: a) Production of various annual crops; b) Production of natural and cultivated pasture; c) Production of beef; d) Investment in tractor, combine and draft animal, and e) Labor hiring by season. Crops included are: rice, corn, wheat and soybeans. Two distinct activities for soybeans are considered, namely, soybean following wheat and soybean independent of wheat. The constraints of the model include: a) Land constraints by season; b) Labor constraints by season; c) Tractor, combine, and draft animal power capacities; d) Balance equations; e) Behavioral constraints in the form of maximum and minimum hectarage for land using activities, and f) Regional constraints on tractor and wage labor supply.

Summary of Findings, Conclusions and Implications for Development and Technology Policy

This section presents a summary of the results and the major conclusions of the study. At this point model results cannot be taken as conclusive for policy recommendation since further model testing and refinement are required in addition to improvements and checks in the data used in the model. Conclusions and implications derived from model application are subject to the limitation of the data and the appropriateness of model assumptions and specification.

Model results indicate that in response to technological change farmers can change, to a certain extent, their land utilization, production, imput demand, and income patterns over time. The impacts on area allocated to the various crops are the primary effects of changing technological coefficients in the model. Impacts on other variables are in essence determined as a consequence of changes in land allocation decisions among alternative enterprises.

According to model results the introduction of technological change in the form of high-yielding varieties would have significant impacts on the area cultivated with wheat and soybeans, only minor effects on the area of corn, and no changes would be observed on the area cultivated with rice. Area of corn would increase from 5.0 to 27.0 percent in small farms and no change would occur in large farms. An increase in yields of 30 percent would increase area of wheat in large farms by about 148 percent. Area of soybeans would increase by 96 and 107 percent in large farms if yields were 30 and 50 percent higher, respectively. Increases in crop areas come about mainly at the expense of natural pasture areas. Changing technical coefficients for labor, draft animal and tractor use, so as to increase the level of mechanization, would have only marginal effects on the area of rice and corn. However, higher levels of mechanization would tend to increase the area cultivated with wheat and soybean, with large farms experiencing larger proportions of the increases. For the region, soybeans experience increases in area up to 30 percent.

Projected production levels show the effects of changes in yield rates and changes in cropping patterns that would be observed under the different technology alternatives. The model projects substantial increases in production of all crops during the 1970 - 1980 period, under all yield alternatives. Higher-yield varieties tend to have higher and more uniformily distributed impacts over all crops than mechanization (Table VII.1). In both cases wheat and soybeans experience the highest increases in production. Improved crop varieties and increased mechanization tend to raise the profitability of wheat and soybeans in greater proportions relative to other products. Furthermore, most of the increases in wheat and soybean production go to large farms. The implications of this are that large farms tend to benefit more than small farms from improved technology.

The impacts on income due to increases in the amount produced of a given commodity will depend on the price elasticity of demand for the product. If prices do not change as a consequence of increased production, income will increase for the producers of the given commodity. If prices change with changes in supply, the impacts on income will be positive if demand is elastic and vice-versa. Not much can be said about income effects for producers of individual commodities

Table VII.1: Sample of Output Results Comparing the Impacts of Varietal and Mechanical Technologies in 1980.

Item	Farm Size	Source of Technological Change	
		Varietal*	Mechanical**
Rice Production	Small	45.5	0.0
	Large	45.6	50.7
Corn Production	Small	45.9	2.4
	Large	14.9	0.0
Wheat Production	Small	42.0	-10.4
	Large	252.3	400.3
Soybean Production	Small	45.1	6.6
	Large	212.8	361.4
Beef Production	Small	-16.8	27.6
	Large	- 8.6	-16.3
Labor Employment	Small	2.8	-52.8
	Large	44.8	- 1.3
Net Farm Income	Small	27.5	6.3
	Large	43.3	105.3
Land Productivity	Small	27.5	6.3
	Large	43.3	105.3
Labor Productivity	Small	25.5	125.7
	Large	- 1.0	108.2

*Values are percent changes for Alternative IC in respect to Alternative IA.

**Values are percent changes for Alternative IIC in respect to Alternative IIA.

without knowledge of price elasticity of demand. For example, decrease in beef production will tend to lower income of beef producers if price elasticity of demand for beef is elastic.

The most important single factor influencing a developing country's ability to absorb a growing labor force into productive employment is the type of strategy pursued for developing its agricultural sector. Technology is a major factor to be considered in the development strategy. The choice of technology is an important element determining the employment effects of development. The projected annual rate of employment growth during the period of analysis ranged from 2.5 to 4.0 percent under the different yield alternatives. Improvement in yields of 30 and 50 percent would raise total labor employment by 10.8 and 12.1 percent, respectively. Almost all increases in total employment would result from higher labor use in large farms (Table VII.1). The impacts of labor displacement by mechanical technology are higher on small farms than on large farms. Moving from lower to higher levels of mechanization the rate of growth of employment decreases for small farms, increases slowly for large farms, and decreases for the region. Substitution of tractor for labor and tractor for draft animal is explicity formulated in the model. If the rate of growth of employment decreases for small farms while it increases for large farms, the substitution effects are greater for small farms than for large farms. This implies that it is easier to substitute tractors for labor in small farms than in large farms. This is mainly because small farms are abundant in labor. The majority of labor used on small farms is family labor. Most increases in employment on large farms come from hired labor. This indicates that policies which would have impacts on increasing consolidation of land would have additional impacts on increasing rural employment when these policies are combined with biological innovation programs.

One phenomenon that occurs coincidentally with the modernization of traditional agriculture is a change in consumption of farm inputs, particularly purchased inputs. For instance, the demand for fertilizer in the region is projected at 349,116 tons for 1980 under the condition of base yield levels. This is an increase of 56.8 percent over that of the base year. This demand would be 13.0 and 17.7 percent higher, under the alternatives of 30 and 50 percent increases in yields, respectively. The introduction of higher levels of mechanization would raise the regional demand for fertilizer by as much as 29 percent. Thus, technological change would have significant impacts on changing the structure of farm demand for a manufactured input. This increased demand may be an incentive for development of the domestic fertilizer industry, which in turn would represent savings in foreign exchange used to import fertilizer.

In general, the group of small farms used over 50 percent of the total amount of inputs. This is due to a more intensive use of land in this group. Large farms have more extensive natural pasture area than small farms. A large proportion of cultivated area is found on small farms. Since crop production requires the use of larger amounts of inputs than beef production, more input is used on small farms. Improvements in technology tend to affect more the pattern of employment and input utilization in large farms because they will have greater potential to expand use of the various inputs. If input supply is limited there will be shifts of resources from one group of farms to another, with large farms buying up large proportion of the resources.

Some analysts have suggested that the distribution of benefits from the new technologies parallels existing resource endowments. Basically, new varieties can be adopted regardless of the size of a given farm, everything else being equal. Even though large and small operators tend to use the new technology, large farms may benefit more because they control a greater proportion of the resources. Indication of the distribution of benefits from use of new technologies is given by the rate of growth of net farm income. Net returns to resources in farming can be improved significantly with improvements in crop yields. Net regional farm income raises by 19.2 and 32.3 percent for the two alternative yield assumptions compared to the situation of base yield levels. For small farms, net returns are higher by 20 percent, and for large farms they increase by over 30 percent under alternative yield assumptions. Projected net farm income shows significant differences among the different mechanization alternatives analyzed. Net regional farm income increases by 14.7 and 32.1 percent for a 50 percent and a 75 percent mechanization alternative, respectively, compared to a 25 percent alternative. The increases for large farms would be significantly higher than those for small farms. For the above situations, the corresponding increases for small farms would be 7.8 and 6.3 percent, while for large farms they would be 34.3 and 105.3 percent (Table VII.1).

Income of large farms increases more than that of small farms for varietal and mechanical technology. However,a great difference exists when mechanical technology is introduced. Model results indicate that technological change in the form of mechanization tend to enhance income of large farms in much greater proportion than that of small farms. The implications for income distribution are clearly a tendency for the income gap between farm size groups to increase over time. The introduction of higher levels of varietal and mechanical technology would result in a higher projected growth rate of net output in large farms compared to the rate of growth in small farms. Consequently, the share of large farms in both total and net regional output would increase at the expense of small farms. Thus, large farms would tend to buy off resources and increase farm size even faster, since they would be better off by experiencing higher increases in income.

Changes in land and labor productivities show the relative factor scarcities and different technology choices among farm size groups. Land productivity is higher for small farms while labor productivity is higher for large farms. For both types of technology, land productivity increases by higher percentages in large farms (Table VII.1). Mechanical technology induces substantial increases in labor productivity in both farm sizes. Differences in factor productivity among farm sizes are possibly due to differences in the technology employed. Labor productivity, for instance, is higher in large farms which use less labor per unit of land and in turn will have lower variable costs than small farms. Thus, the choice of technology will affect resource productivity.

From the point of view of the decision-maker responsible for the allocation of funds to alternative research programs it is of interest to know which investment would give the highest pay-off. However, the concept of returns to investments has to be based on a set of criteria. In this study only varietal and mechanical technology are analyzed. The results of Table VII.1 show that there are trade-offs among criteria. The objectives of investment in research may be increased production, employment or income distribution. In order for the model to supply useful information for policy making, interaction with public decision-makers is necessary to determine their interests and the several direction of policy variables. Thus, model application can be very useful when used in interaction with decision-makers. The model can be used to analyze a whole range of situations in respect to biological and mechanical technology. Model results will indicate major direction of changes and also will provide estimates of the impacts and adjustment which will potentially occur with the introduction of alternative technologies.

This study suggests that in order to develop technology policy the interrelationships among farm size groups and crops should be taken into account. Improvements in technology for a given crop will increase its comparative advantage relative to others. With limited supply of land, increases in area cultivated with one crop is only possible at the expense of others. The introduction of technology change which affects cropping patterns should consider the consequences of changes in area of one crop due to changes in area of another crop.

Comparing the results for the various crops, the model projects large proportions of increase in area and production of wheat and soybeans, under conditions of alternative technologies. Thus, given the same improvements in technology for all crops, it appears that wheat and soybeans would tend to benefit more in comparison to other crops. This indicates that to maintain basically the same competitive relationship, greater emphasis should be given to increase productivity of the other crops.

The results of this study suggest that the type of technological change to be implemented in a region would have impacts on land use and cropping patterns, production, employment and input utilization, and income. Furthermore, the choice of technology to be generated and disseminated by research institutions should consider the adjustments and impacts that such technology improvements would have on the relative competitive position of the various farm enterprises and on the income accruing to the different producing groups.

Limitations and Suggestions for Further Research

The analytical framework used in this study is found to be feasible for analyzing the impacts of technological change with consideration of a large number of interrelationships among farm enterprises, farm size groups, and different regions. Due to the time dimension of the model, it can account for the dynamic properties of the adjustment and growth process under conditions of changes in technology. However, at the present stage the model still has several weaknesses which are the subject to further research. Several aspects of the model can be improved and extended. The most important areas for further research are:

1. Improvements of the Data Base -- The model makes use of farm level data and also secondary data collected by census statistics. Improvements of data collection and consistency checks on secondary data should receive greater attention of government agencies responsible for such tasks. The basic difficulty with the primary data is its limited availability by farm size groups. Input-output coefficients, production costs and returns should be available by farm size to allow for taking into account in the model the basic differences among farm sizes with respect to production decisions and choice of technologies. Especially in the case where the model would include several classes, basic data by size group would be essential for model performance.

2. Resource Tranference Between Farm Size Groups -- Further research should concentrate on ways of dealing with the dynamics of farm size groups. Land structure changes over time. Transference of land from one group to another will carry other resources such as labor and capital. The model should allow for the changes in structure including some mechanism to account for resource transference among groups. Also, related to land structure is the problem of projecting number of farms per farm size group in such a way as to maintain consistency between number of farms and area in each group.

3. Include More Than One Region and More Than Two Farm Sizes -- Dissaggregation in farm size groups has been found to be a very useful way of generating information. It provides a basis for analyzing the effects of scale and different factor proportions on resource allocation, and choices of technology. Besides accounting to some extent for aggregation bias, this procedure allows also the modeling of interactions among farm size groups competing for regional resources.

Analysis of model results indicates that the disaggregation into farm size groups should include a larger number of classes. Even though the stratification in two groups proved useful, it did not allow for very conclusive findings with respect to the process of resource allocation under conditions of changing resource endowments. Choice of technology is a function of resources scarcities in the farm. Only with consideration of a wider range of sizes could the effects of size and its relationships to technology choice be identified.

Extension of the model should also include more than one region. Inclusion of more than one region would be useful to study inter-regional competition, and the effects of technology change on different regions.

4. Link to Other Sector Models -- Due to the flexibility of the model and its computer program, it can be used as a separate model or in interaction with a larger sector model. Its basic function would be to serve as a decision-making component used to determine endogenously in the larger model allocation of land and other farm resources to production, based on the opportunity cost of the resources in alternative uses, and based on the relative profitability of the various farm enterprises. Further modeling effort could include other components of the agricultural sector and models of other sectors of the economy. The model developed in this study can be used as a component representing farmers' decisions with respect to resource allocation and production in a larger model.

5. Model Improvements -- Some basic improvements of the model would include: a) Incorporate financial activities and constraints;

b) Include other activities which also use farm resources; c) Incorporate other regional constraints such as fertilizer, fuel and credit; d) Include more detailed classification of labor by season, and e) Include farm machinery capacities by season. The model seems to overemphasize the role of flexibility constraints. These constraints are used to represent farmers' ability to change activity levels from year to year. Clearly, the estimation of flexibility coefficients is crucial for model behavior. However, their role should not override the role of other elements in the model. The improvements in model specification mentioned above would reduce the importance of flexbility constraints in projecting production patterns and would also improve model performance.

6. Risk and Uncertainty -- The model only deals implicitly with risk and uncertainty by means of flexibility constraints. An explicit approach would prove useful to represent farmers behavior under conditions of risk and uncertainty which characterizes the nature of the decision process.

7. Price Expectation Models -- One area of severe limitations in this study is that of product and input prices projections. Improvements of price expectation models or the modeling of demand and supply through a marketing component, thus making price expectations endogenous in the model, is considered an important area for future research related to this study.

8. Diffusion of Innovation -- In order to account for the temporal aspects of technology change, a more detailed treatment of the process of diffusion and adoption of new technologies would be an important improvement of the model.

9. Income Distribution -- The introduction of new technology would have effects on the income among regions and farm size groups. To study these impacts more than one region should be included with disaggregation in several farm size classes. More important, however, is a detailed treatment of the various sources of income at the firm-household level by farm size. This would require the inclusion of specific income earning activities in the programming model to account for the di-ferent alternatives open to farmers.

10. New Commodities -- The basic structure of the model is assumed constant over time. The same set of activities is maintained constant which means that there is no possibility of introducing new products. This may be a most realistic assumption for the region studied which has a more or less well established cropping pattern. Yet, it is still possible that a new commodity becomes viable and highly profitable in the region whose introduction could have great impacts in changing incomes.

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APPENDICES

APPENDIX A

THE STRUCTURE OF THE RECURSIVE LINEAR PROGRAMMING MODEL

The main purpose of this appendix is to describe the elements of the yearly linear programming model in a detailed form. This appendix is complementary to the model description presented in Chapter V.

The linear programming model for each year is block diagonal with one block for each of the two farm size group. In addition there is a set of overlapping equations to account for constraints which hold for all farm size groups simultaneously.

The definition of the variables in the recursive linear programming model is as follows:

<u>Activity Vector</u>[1]

$X_1^i(t)$: Production of rice using draft animal power (ha)

$X_2^i(t)$: Production of rice using mechanical power (ha)

$X_3^i(t)$: Production of corn using draft animal power (ha)

$X_4^i(t)$: Production of corn using mechanical power (ha)

$X_5^i(t)$: Production of wheat using draft animal power (ha)

$X_6^i(t)$: Production of wheat using mechanical power (ha)

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[1]For each activity i = 1,2, designates farm size groups.

$X_7^i(t)$: Production of soybeans, following wheat (double cropping), using draft animal power (ha)

$X_8^i(t)$: Production of soybeans, following wheat (double cropping), using mechanical power (ha)

$X_9^i(t)$: Production of soybeans, independent of wheat, using draft animal power (ha)

$X_{10}^i(t)$: Production of soybeans, independent of wheat, using mechanical power (ha)

$X_{11}^i(t)$: Production of range natural pasture (ha)

$X_{12}^i(t)$: Production of Cultivated pasture using draft animal power (ha)

$X_{13}^i(t)$: Production of cultivated pasture using mechanical power (ha)

$X_{14}^i(t)$: Production of beef using natural pasture (cow unit)

$X_{15}^i(t)$: Production of beef using cultivated pasture (cow unit)

$X_{16}^i(t)$: Investment in tractors (unit)

$X_{17}^i(t)$: Investment in combines (unit)

$X_{18}^i(t)$: Investment in draft animals (unit)

$X_{19}^i(t)$: Hiring labor during July-October (hours)

$X_{20}^i(t)$: Hiring labor during November-February (hours)

$X_{21}^i(t)$: Hiring labor during March-June (hours)

Constraint Vector[2]

$Y_1^i(t)$: Summer land capacity (ha)

$Y_2^i(t)$: Winter land capacity (ha)

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[2]For the constraint vector $i = 1,2$, designates farm size group constraints and r designates regional constraints.

$Y_3^i(t)$: Irrigated land capacity (ha)

$Y_4^i(t)$: Labor capacity in Period 1 (hours)

$Y_5^i(t)$: Labor capacity in Period 2 (hours)

$Y_6^i(t)$: Labor capacity in Period 3 (hours)

$Y_7^i(t)$: Tractor capacity (hours)

$Y_8^i(t)$: Combine capacity (hours)

$Y_9^i(t)$: Draft animal capacity (hours)

$Y_{10}^i(t)$: Balance equation transferring total hectares of natural pasture to beef production (ha)

$Y_{11}^i(t)$: Balance equation transferring total hectares of cultivated pasture to beef production (ha)

$Y_{12}^i(t)$: Balance equation for wheat/soybeans crop rotation using draft animal power (ha)

$Y_{13}^i(t)$: Balance equation for wheat/soybeans crop rotation using mechanical power (ha)

$Y_{14}^i(t)$, $Y_{15}^i(t)$: Flexbility constraints for rice, upper and lower bounds, respectively (ha)

$Y_{16}^i(t)$, $Y_{17}^i(t)$: Flexibility constraints for corn, upper and lower bounds, respectively (ha)

$Y_{18}^i(t)$, $Y_{19}^i(t)$: Flexibility constraints for wheat, upper and lower bounds, respectively (ha)

$Y_{20}^i(t)$, $Y_{21}^i(t)$: Flexibility constraints for soybeans, independent of wheat, upper and lower bounds, respectively (ha)

$Y_{22}^i(t)$, $Y_{23}^i(t)$: Flexibility constraints for natural pasture, upper and lower bounds, respectively (ha)

$Y_{24}^i(t)$, $Y_{25}^i(t)$: Flexibility constraints for soybeans, following wheat, upper and lower bounds, respectively (ha)

$Y_{26}^{i}(t)$, $Y_{27}^{i}(t)$: Flexibility constraints for cultivated pasture, upper and lower bounds, respectively (ha)

$Y_{1}^{r}(t)$: Regional tractor supply (unit)

$Y_{2}^{r}(t)$: Regional availability of wage labor, period 1 (hours)

$Y_{3}^{r}(t)$: Regional availability of wage labor, Period 2 (hours)

$Y_{4}^{r}(t)$: Regional availability of wage labor, Period 3 (hours)

The linear programming model is solved for each year. From one run to another the elements of the base model change as a result of previous solutions of the problem and as a function of projections made exogenously or through other components. The following section describes the mechanisms used for changing the elements of the linear programming model.

Dynamic Feedback Mechanisms

The iterative nature of the model requires a number of dynamic feedback operators to generate changes in the elements of the model over time. Following is a description of how the objective function coefficients, the constraint vector elements and the input-output coefficients are generated.

Objective Function Coefficients:

All of the objective function coefficients are time variant. The definition of the coefficient varies with the type of activity in the model.

Crop Production Activities: For these activities the objective function coefficients, $Z_{1}^{i}(t),\ldots,Z_{10}^{i}(t)$, are defined as one year lag of gross returns minus variable costs and are given by

$$Z_j^i(t+1) = YLD_j(t) \cdot (1 + SYLD_{ji}) \cdot (1 + RYLD_j) \cdot PYC_j(t) - [PFERT(t) \cdot FERT_j(t) + PSEED_j(t) \cdot SEED_j + PTRPI \cdot TRPI_j(t) + PTRPP \cdot TRPP_j(t) + OINP_j + VMC_j + CINP_j] \cdot (1 + 0.5\ RINT)$$

where

YLD = expected yield (kg/ha)

SYLD = yield differential factor due to size (proportion)

RYLD = yield differential factor due to mechanization (proportion)

PYC = average expected producer price (Cr$/kg)

FERT = fertilizer input (kg/ha)

PFERT = average expected fertilizer price (Cr$/kg)

SEED = seed input (kg/ha)

PSEED = average expected price of seed (Cr$/kg)

TRPI = amount of input transported (kg)

PTRPI = input transportation cost (Cr$/kg)

TRPP = amount of product transported (kg)

PTRPP = product transportation cost (Cr$/kg)

OINP = expenditure on other inputs (Cr$/ha)

VMC = variable machinery costs (Cr$/ha)

CINP = capital input costs (Cr$/ha)

RINT = interest rate (proportion)

Pasture Activities: These activities produce intermediary input used for beef production. Their objective function coefficients, $Z_{11}^i(t)$, $Z_{12}^i(t)$, $Z_{13}^i(t)$, are negative and contain only the variable costs lagged by one year.

$$Z_j^i(t+1) = -[RMC_j + CINP_j + PFERT(t) \cdot FERT_j + PSEED_j \cdot SSED_j + PTRPI \cdot TRPI + VMC_j] \cdot (1 + 0.5\ RINT)$$

where

RMC = repairs and maintenance costs of fences (Cr$/ha)

Beef Production Activities: The objective function coefficients for the beef production activities, $Z_{14}^i(t)$, $Z_{15}^i(t)$, are the one year lag of gross returns minus variable costs.

$$Z_j^i(t+1) = [PROPS_j \cdot YFATS_j + PROPC_j \cdot YFATC_j + PROPCC_j \cdot YFATCC_j] \cdot PYB(t) - [PBOM \cdot BOM + PSALT \cdot SALT + VETC_j] \cdot (1 + 0.5\ RINT)$$

where

PROPS = proportion of fat steers output per cow unit (dimensionless)

YFATS = yield of meat per fat steer (kg/head)

PROPC = proportion of fat cow output per cow unit (dimensionless)

YFATC = yield of meat per fat cow (kg/head)

PROPCC = proportion of cull cow output per cow unit (dimensionless)

YFATCC = yield of meat per cull cow (kg/head)

PYB = average expected price of beef (Cr$/kg)

BOM = bone meal input (kg/cow unit)

PBOM = price of bone meal (Cr$/kg)

SALT = salt input (kg/cow unit)

PSALT = price of salt (Cr$/kg)

VETC = veterinary costs (Cr$/cow unit)

Investment Activities: The investment costs of these activities, $Z^i_{16}(t)$, $Z^i_{17}(t)$, $Z^i_{18}(t)$, are composed of depreciation and interest charges on capital computed as follows:

$$Z^i_j(t+1) = [(PAQ_j(t) - PSL_j(t))/NLIF_j + (PAQ_j(t) + PSL_j(T)) \cdot 0.5\ RINT]$$

where

PAQ = acquisition price (Cr\$/unit)

PSL = salvage value (Cr\$/unit)

NLIF = number of years of life of the investment (years)

Labor Hiring Activities: For these activities the objective function coefficients, $Z^i_{19}(t)$, $Z^i_{20}(t)$, $Z^i_{21}(t)$, are simply the expected wage rate, WAGE, lagged by one year.

$$Z^i_j(t+1) = - WAGE(t)$$

This completes the specification of how the objective function coefficients are generated. In the equations above variables without a time subscript are constant over time. Crop yields are determined using fertilizer response functions. Prices are projected using simple expectation models. For a specific activity the amount of an input may be zero, when the activity does not use that input.

Constraint Vector Elements:

Projection of resource capacities are exogenous to the model. The computation of the elements of the constraint vector is described by the following equations:

Summer and Winter Land:

$$Y^i_j(t) = BCC_{ij}(t) \cdot TLAND(t);\ j = 1,2$$

where

Y_j^i = amount of j^{th} type of land available in i^{th} size (ha)

BCC_{ij} = proportion of j^{th} type of land in i^{th} size (dimensionless)

TLAND = total land available (ha)

The variable TLAND is determined as follows:

$$TLAND(t) = TLAND(t-1) + DT/DEL \cdot (TLCP - TLAND(t-1))$$

where

TLCP = upper bound on total land capacity (ha)

DT = time increment

DEL = average lag (years)

Irrigated Land:

$$Y_3^i(t) = Y_3^i(t-1) \cdot (1 + BC_{21,i})$$

where

Y_3^i = amount of irrigated land available in size i (ha)

$BC_{21,i}$ = annual rate of change (dimensionless)

Labor Capacity:

$$Y_j^i(t) = BCC_j(t) \cdot ACFPOP(t);\ j = 4,5,6$$

$$ACFPOP(t) = ACFPOP(t-1) \cdot (1 + BT1)$$

$$BCC_j(t) = BCC_j(t-1) + DT/DEL \cdot (BBAR - BCC_j(t-1))$$

where

Y_j^i = labor capacity in period j for size i (hours)

ACFPOP = projected active agricultural family labor force (man-equivalent)

BT1 = annual rate of growth of labor force (dimensionless)

BCC = working time equivalent (hours/man-equivalent/period)

BBAR = upper bound on working time equivalent (hours/man-equivalent/period)

Tractor Capacity:

$$Y_7^i(t) = Y_7^i(t-1) \cdot (1 - BC1) + BC2 \cdot X_{16}^i(t-1)$$

where

Y_7^i = tractor capacity for size i (hours)

BC1 = depreciation rate (dimensionless)

BC2 = working capacity of tractor (hours/unit)

X_{16}^i = investment in tractors (unit)

Combine Capacity:

$$Y_8^i(t) = Y_8^i(t-1) \cdot (1 - BC3) + BC4 \cdot X_{17}^i(t-1)$$

where

Y_8^i = combine capacity for size i (hours)

BC3 = depreciation rate (dimensionless)

BC4 = working capacity of combine (hours/unit)

X_{17}^i = investment in combines (unit)

Draft Animal Capacity:

$$Y_9^i(t) = Y_9^i(t-1) \cdot (1 - BC5) + BC6 \cdot X_{18}^i(t-1)$$

where

Y_9^i = draft animal capacity for size i (hours)

BC5 = depreciation rate (dimensionless)

BC6 = working capacity of animal (hours/unit)

X_{18}^i = investment in draft animals (unit)

Balance Equations:

$$Y_{10}^i(t) = 0$$

$$Y_{11}^i(t) = 0$$

$$Y_{12}^i(t) = 0$$

$$Y_{13}^i(t) = 0$$

Flexibility Constraints:

$$Y_j^i(t) = X_j^i(t-1) \cdot (1 + BC_j)$$

where

Y_j^i = upper and lower bounds on crop and pasture hectarage (ha)

X_j^i = optimum level of the activity in the previous period (ha)

BC = flexibility coefficients (dimensionless)

Regional Supply of Tractors:

$$Y_1^r(t) = Y_1^r(t-1) \cdot (1 + BT6)$$

where

Y_1^r = regional availability of tractors (unit)

BT6 = annual growth rate of tractor supply (dimensionless)

Regional Availability of Wage Labor:

$$Y_j^r(t) = BCC_j(t) \cdot ACWPOP(t); \quad j = 2,3,4$$

$$ACWPOP(t) = ACWPOP(t-1) \cdot (1 + BT2)$$

where

Y_j^r = regional wage labor availability in period j (hours)

ACWPOP = projected active agricultural wage labor force (man-equivalent)

BT2 = annual rate of growth of labor force (dimensionless)

BCC = as defined above.

Input-Output Coefficients:

Some of the input-output coefficients are constant over the whole projection period. Others vary through time and are exogenously changed for each year reflecting changes in production processes. The changes are related to requirements of labor, draft animal and tractor hours for the various production activities. Since the definition of these changes are simple and rather specific their description is given in the first part of Chapter VI, when presenting the procedures used for model application in analyzing the inpacts of alternative production technologies.

Data used to implement the model are contained in the computer program given in Appendix C. The definition of the variables and coefficients in the program is the same as in Appendix A.

APPENDIX B

A SAMPLE OF THE YEARLY OUTPUT RESULTS OF THE MODEL

TABLE 1. RESOURCE ALLOCATION, CONSTRAINTS, ALTERNATIVE 1, 1978.

NO.	NAME	TYPE*	VALUE USED	SLACK	SHADOW PRICE
SMALL FARMS(0-100HA)					
1	SUMMER LAND	(+)	5702.0 TH HA	1150.9 TH HA	0.00 CR$/HA
2	WINTER LAND	(+)	6314.6 TH HA	838.2 TH HA	0.00 CR$/HA
3	IRRIG. LAND	(+)	135.0 TH HA	7.9 TH HA	0.00 CR$/HA
4	LABOR PRD 1	(+)	632858.6 TH HR	278639.6 TH HR	0.00 CR$/HR
5	LABOR PRD 2	(+)	40054.7 TH HR	471243.5 TH HR	0.00 CR$/HR
6	LABOR PRD 3	(+)	190039.9 TH HR	721259.2 TH HR	0.00 CR$/HR
7	TRACTOR CAP.	(+)	3151.4 TH HR	42395.8 TH HR	0.00 CR$/HR
8	COMBINE CAP.	(+)	717.6 TH HR	21393.6 TH HR	0.00 CR$/HR
9	DFT ANIM CAP	(+)	126581.7 TH HR	562635.4 TH HR	0.00 CR$/HR
10	BAL NAT PAST	( )	0.0 TH HA	0.0 TH HA	-65.59 CR$/HA
11	BAL CUL PAST	( )	0.0 TH HA	0.0 TH HA	-142.54 CR$/HA
12	BAL SOYW TRD	(+)	0.0 TH HA	0.0 TH HA	0.00 CR$/HA
13	BAL SOYW MOD	(+)	-245.1 TH HA	245.1 TH HA	0.00 CR$/HA
14	MAX RICE	(+)	135.0 TH HA	0.0 TH HA	-509.47 CR$/HA
15	MIN RICE	(-)	45.9 TH HA	24.5 TH HA	0.00 CR$/HA
16	MAX CORN	(+)	1332.2 TH HA	0.0 TH HA	-68.90 CR$/HA
17	MIN CORN	(-)	847.8 TH HA	242.2 TH HA	0.00 CR$/HA
18	MAX WHEAT	(+)	278.9 TH HA	0.0 TH HA	-289.55 CR$/HA
19	MIN WHEAT	(-)	137.3 TH HA	85.8 TH HA	0.00 CR$/HA
20	MAX SOYBEAN	(+)	270.0 TH HA	0.0 TH HA	-178.80 CR$/HA
21	MIN SOYBEAN	(-)	103.9 TH HA	83.1 TH HA	0.00 CR$/HA
22	MAX NAT PAST	(+)	3806.2 TH HA	0.0 TH HA	-38.79 CR$/HA
23	MIN NAT PAST	(-)	1903.1 TH HA	951.6 TH HA	0.00 CR$/HA
24	MAX SOY/WHT	(+)	33.8 TH HA	0.0 TH HA	-123.66 CR$/HA
25	MIN SOY/WHT	(-)	13.0 TH HA	10.4 TH HA	0.00 CR$/HA
26	MAX CUL PAST	(+)	158.6 TH HA	0.0 TH HA	-87.89 CR$/HA
27	MIN CUL PAST	(-)	79.3 TH HA	39.6 TH HA	0.00 CR$/HA
LARGE FARMS(>100HA)					
28	SUMMER LAND	(+)	11377.1 TH HA	815.7 TH HA	0.00 CR$/HA
29	WINTER LAND	(+)	12192.9 TH HA	0.0 TH HA	-35.27 CR$/HA
30	IRRIG. LAND	(+)	315.0 TH HA	18.3 TH HA	0.00 CR$/HA
31	LABOR PRD 1	(+)	49995.0 TH HR	0.0 TH HR	-.89 CR$/HR
32	LABOR PRD 2	(+)	49995.0 TH HR	0.0 TH HR	-.89 CR$/HR
33	LABOR PRD 3	(+)	49995.0 TH HR	0.0 TH HR	-.89 CR$/HR
34	TRACTOR CAP.	(+)	3036.8 TH HR	43475.2 TH HR	0.00 CR$/HR
35	COMBINE CAP.	(+)	1411.1 TH HR	21168.1 TH HR	0.00 CR$/HR
36	DFT ANIM CAP	(+)	47718.7 TH HR	0.0 TH HR	-.08 CR$/HR
37	BAL NAT PAST	( )	0.0 TH HA	0.0 TH HA	-42.06 CR$/HA
38	BAL CUL PAST	( )	0.0 TH HA	0.0 TH HA	-134.63 CR$/HA
39	BAL SOYW TRD	(+)	0.0 TH HA	0.0 TH HA	0.00 CR$/HA
40	BAL SOYW MOD	(+)	-628.8 TH HA	628.8 TH HA	0.00 CR$/HA
41	MAX RICE	(+)	315.0 TH HA	0.0 TH HA	-150.61 CR$/HA
42	MIN RICE	(-)	200.4 TH HA	57.3 TH HA	0.00 CR$/HA
43	MAX CORN	(+)	467.1 TH HA	103.8 TH HA	0.00 CR$/HA
44	MIN CORN	(-)	467.1 TH HA	0.0 TH HA	325.83 CR$/HA
45	MAX WHEAT	(+)	722.3 TH HA	393.2 TH HA	0.00 CR$/HA
46	MIN WHEAT	(-)	722.3 TH HA	0.0 TH HA	53.18 CR$/HA
47	MAX SOYBEAN	(+)	280.4 TH HA	124.6 TH HA	0.00 CR$/HA
48	MIN SOYBEAN	(-)	280.4 TH HA	0.0 TH HA	182.72 CR$/HA
49	MAX NAT PAST	(+)	9927.1 TH HA	2473.5 TH HA	0.00 CR$/HA
50	MIN NAT PAST	(-)	6072.9 TH HA	1927.1 TH HA	0.00 CR$/HA
51	MAX SOY/WHT	(+)	93.5 TH HA	41.5 TH HA	0.00 CR$/HA
52	MIN SOY/WHT	(-)	93.5 TH HA	0.0 TH HA	174.73 CR$/HA
53	MAX CUL PAST	(+)	387.5 TH HA	129.2 TH HA	0.00 CR$/HA
54	MIN CUL PAST	(-)	387.5 TH HA	0.0 TH HA	222.36 CR$/HA
REGIONAL CONSTRAINTS					
55	SUP TRACTOR	(+)	0.0 TRC UNIT	3.8 TRC UNIT	0.00 CR$/UNIT
56	WAGE LABOR 1	(+)	415790.1 TH HR	505623.7 TH HR	0.00 CR$/HR
57	WAGE LABOR 2	(+)	54747.9 TH HR	866665.9 TH HR	0.00 CR$/HR
58	WAGE LABOR 3	(+)	249023.5 TH HR	672390.2 TH HR	0.00 CR$/HR

* (+) = LESS THAN OR EQUAL
(-) = GREATER THAN OR EQUAL
( ) = EQUAL

TABLE 2. RESOURCE ALLOCATION, ACTIVITIES, ALTERNATIVE 1, 1970.

NO.	NAME	OPTIMUM VALUE		OBJECTIVE COEFFICIENT		MARGINAL COST	
SMALL FARMS(0-100 HA)							
1	RICE TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
2	RICE MOD	135.0	TH HA	509.47	CR$	.00	CR$/HA
3	CORN TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
4	CORN MOD	1332.2	TH HA	68.90	CR$	.00	CR$/HA
5	WHEAT TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
6	WHEAT MOD	278.9	TH HA	289.55	CR$	.00	CR$/HA
7	SOY/WHT TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
8	SOY/WHT MOD	33.8	TH HA	123.66	CR$	.00	CR$/HA
9	SOYBEAN TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
10	SOYBEAN MOD	270.0	TH HA	178.80	CR$	0.00	CR$/HA
11	NATURAL PAST	3806.2	TH HA	-6.79	CR$	.00	CR$/HA
12	CUL PAST TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
13	CUL PAST MOD	158.6	TH HA	-54.64	CR$	.00	CR$/HA
14	BEEF NAT PAS	1522.5	TH CU	113.97	CR$	.00	CR$/UNIT
15	BEEF CUL PAS	126.9	TH CU	178.17	CR$	.00	CR$/UNIT
16	INV TRACTOR	0.0	TRC UNIT	-3480.00	CR$	-3480.00	CR$/UNIT
17	INV COMBINE	0.0	COM UNIT	-8700.00	CR$	-8700.00	CR$/UNIT
18	INV DFT ANIM	0.0	ANI UNIT	-56.01	CR$	-199.98	CR$/UNIT
19	HIRE LABOR 1	0.0	TH HR	-.89	CR$	-.89	CR$/HR
20	HIRE LABOR 2	0.0	TH HR	-.89	CR$	-.89	CR$/HR
21	HIRE LABOR 3	0.0	TH HR	-.89	CR$	-.89	CR$/HR
LARGE FARMS(>100HA)							
22	RICE TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
23	RICE MOD	315.0	TH HA	548.60	CR$	.00	CR$/HA
24	CORN TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
25	CORN MOD	467.1	TH HA	68.90	CR$	.00	CR$/HA
26	WHEAT TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
27	WHEAT MOD	722.3	TH HA	312.28	CR$	-.00	CR$/HA
28	SOY/WHT TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
29	SOY/WHT MOD	93.5	TH HA	133.66	CR$	-.00	CR$/HA
30	SOYBEAN TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
31	SOYBEAN MOD	280.4	TH HA	193.09	CR$	-.00	CR$/HA
32	NATURAL PAST	9927.1	TH HA	-6.79	CR$	.00	CR$/HA
33	CUL PAST TRD	0.0	TH HA	************	CR$	*****************	CR$/HA
34	CUL PAST MOD	387.5	TH HA	-54.64	CR$	-.00	CR$/HA
35	BEEF NAT PAS	3943.3	TH CU	113.97	CR$	.00	CR$/UNIT
36	BEEF CUL PAS	310.0	TH CU	178.17	CR$	.00	CR$/UNIT
37	INV TRACTOR	0.0	TRC UNIT	-3480.00	CR$	-3480.00	CR$/UNIT
38	INV COMBINE	0.0	COM UNIT	-8700.00	CR$	-8700.00	CR$/UNIT
39	INV DFT ANIM	27.5	ANI UNIT	-56.01	CR$	.00	CR$/UNIT
40	HIRE LABOR 1	415790.1	TH HR	-.89	CR$	0.00	CR$/HR
41	HIRE LABOR 2	54747.9	TH HR	-.89	CR$	0.00	CR$/HR
42	HIRE LABOR 3	249323.5	TH HR	-.89	CR$	0.00	CR$/HR

MAXIMUM OBJECTIVE FUNCTION (MI CR$) = 725.78
NUMBER OF ITERATIONS = 14
NUMBER OF INVERSIONS = 3
CP TIME (SECS) = 7.65

TABLE 3. VARIOUS OUTPUT RESULTS, ALTERNATIVE 1, 1978.

ITEM	SMALL FARMS	LARGE FARMS	TOTAL
LAND USE (HA)			
TOTAL UTILIZED AREA	6014646.	12192867.	18207513.
CROP AREA	2049837.	1878237.	3928074.
RICE	134982.	314958.	449940.
CORN	1332200.	467135.	1799335.
WHEAT	278869.	722253.	1001122.
SOYBEAN	303786.	373891.	677677.
CULTIVATED PASTURE	158592.	387519.	546111.
NATURAL PASTURE	3836217.	9927111.	13733328.
MECHANIZATION (HA)			
MECHANIZED AREA	2208429.	2265756.	4474185.
PERCENT	100.00	100.00	100.00
NON-MECHANIZED AREA	0.	0.	0.
PERCENT	0.00	0.00	0.00
BEEF PRODUCTION (TON)			
USING CULTIVATED PASTURE	26745.	65351.	92096.
USING NATURAL PASTURE	210560.	545360.	755920.
TOTAL VALUE OF PRODUCTION (TH CR3)	229395.	590354.	819749.

TABLE 4. AREA, YIELD, AND PRODUCTION, ALTERNATIVE 1, 1978.

CROP	SMALL FARMS			LARGE FARMS			TOTAL		
	AREA (HA)	YIELD (KG/HA)	PROD (TON)	AREA (HA)	YIELD (KG/HA)	PROD (TON)	AREA (HA)	YIELD (KG/HA)	PROD (TON)
RICE	134982.	3474.	468936.	314958.	3648.	1148820.	449940.	3561.	1617726.
CORN	1332200.	1431.	1906840.	467135.	1431.	668632.	1799335.	1431.	2575472.
WHEAT	278869.	1069.	298022.	722253.	1122.	810452.	1001122.	1395.	1108474.
SOYBEAN	303786.	1229.	373306.	373891.	1235.	461632.	677677.	1232.	834938.

TABLE 5. UTILIZATION OF AGRICULTURAL INPUTS, ALTERNATIVE 1, 1970.

SIZE AND CROPS	FERTILIZER QUANTITY (TH KG)	FERTILIZER VALUE (TH CR$)	SEED QUANTITY (TH KG)	SEED VALUE (TH CR$)	VALUE OF OTHER INPUTS (TH CR$)	TOTAL EXPEND. (TH CR$)
SMALL FARMS(0-100HA)						
RICE	4412.00	4339.66	22946.94	12085.39	3374.55	19768.99
CORN	99494.82	97173.27	15986.40	12043.09	13322.90	122538.36
WHEAT	13445.03	13131.31	25099.21	17485.09	3775.89	34392.28
SOYBEAN	5791.48	5656.34	42530.04	18004.38	9113.58	32774.30
CULT. PASTURE	3171.84	3097.93	3171.84	1585.92	0.00	4683.75
LARGE FARMS(>100HA)						
RICE	10294.67	10054.46	53542.86	28199.24	7873.95	46127.65
CORN	34887.79	34073.74	5605.62	4222.90	4671.35	42967.99
WHEAT	34821.76	34009.25	65002.77	45285.26	9779.31	89073.82
SOYBEAN	6014.23	5873.90	52344.74	22159.27	11216.73	39249.90
CULT. PASTURE	7750.38	7569.54	7750.38	3875.19	0.00	11444.73
REGIONAL TOTAL	220083.99	214948.70	0.00	164945.73	63127.35	443021.78

TABLE 6. EMPLOYMENT AND INCOME, ALTERNATIVE 1, 1970.

ITEM	SMALL FARMS	LARGE FARMS	REGIONAL TOTAL
LABOR USE (TH HR)	862953.	869546.	1732500.
TRACTOR USE (TH HR)	3151.	3037.	6188.
DRAFT ANIMAL (TH HR)	126582.	113795.	240377.
HIRED LABOR (TH HR)	0.	719561.	719561.
VALUE WAGES PAID (TH CR$)	0.	640410.	640410.
RATIO HIRED/TOTAL (PCT)	0.00	82.75	41.53
LABOR HOURS PER HECTARE	421.	463.	441.
TRACTOR HOURS PER HECTARE	2.	2.	2.
DRAFT ANIMAL HOURS PER HECTARE	62.	61.	61.
DRAFT ANIMAL/LABOR RATIO	.1467	.1309	.1387
TRACTOR/LABOR RATIO	.0037	.0035	.0036
GROSS FARM INCOME (TH CR$)	872797.	1474795.	2347592.
NET FARM INCOME (TH CR$)	455365.	270417.	725783.
VALUE ADDED (TH CR$)	658639.	1245931.	1904570.
LAND PRODUCTIVITY (CR$/HA)	75.71	22.18	39.86
LABOR PRODUCTIVITY (CR$/HOUR)	.53	.31	.42
GROSS INCOME PER FARM (CR$)	1791.61	46323.21	4523.35
NET INCOME PER FARM (CR$)	934.74	8493.79	1398.44
PERCENT OF INCOME IN CLASS	37.18	62.82	100.00
PERCENT OF FARMS IN CLASS	93.87	6.13	100.00

APPENDIX C

COMPUTER PROGRAM

```
      PROGRAM RGSPLP(OUTPUT,INPUT,TAPE6=OUTPUT,TAPE5=INPUT)              GPIJ       2
      COMMON /LPAC/   A(58,42), Y(58), Z(42), OBJ, X(62), IX(58),        LPAC       2
     1                PI(58), IOUT(4), S(100), ACT(100), NP, NPB, NRP,   GPIG       3
     2                NC, NCB                                            LPAC       4
      COMMON /CNTRLC/ DT, DEL, DELT, IYF, NYR, YEAR, YEARO,              GPIG       1
     1                IALT,LUCUT,LUIN,TIMLP,IDBG,                        JFLD       1
     2                YLDCH,WTL,WTA,WTLCH,WTACH                          JFLD       2
C                                                                        RGSRLP     4
C          INITIALIZATION                                                RGSPLP     5
C                                                                        RGSPLP     6
      IYR = 0                                                            RGSRLP     7
      CALL CNTRL                                                         RGSPLP     8
      CALL INA                                                           RGSPLP     9
      CALL IPY                                                           RGSRLP    10
C                                                                        RGSPLP    11
C          SIMULATION THROUGH TIME                                       RGSPLP    12
C                                                                        RGSPLP    13
      DO 50 IYR=1,NYR                                                    RGSRLP    14
      YEAR = YEAR + DT                                                   RGSPLP    15
C          LINEAR PROGRAMMING MODEL                                      RGSRLP    16
      CALL LPRUN                                                         RGSRLP    17
C          DETERMINE PRICES, YIELDS, ETC.                                RGSPLP    18
      CALL IPY                                                           RGSRLP    19
C          OUTPUT FROM MODEL                                             RGSPLP    20
      CALL ACCTG (Y,NPB,ACT,NCB,A,OBJ,NP,NC,Z,IYR)                       GPIK       9
      CALL PRTOUT                                                        GPIF       3
   50 CONTINUE                                                           RGSRLP    23
      END                                                                RGSRLP    24
```

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      SUBROUTINE ACCTG (Y,NPB,X,NCB,A,OBJ,NR,NC,Z,IYR)                   GPIK      10
C                                                                        GPIH       2
C          ACCOUNTING ROUTINE - PERFORMANCE CRITERIA                     GPIH       3
C                                                                        GPIH       4
      COMMON /BINPC/  BOM, PBOM, SALT, PSALT, VETC(2), PPOPC(2),         BINPC      2
     1                PPOPCC(2), PPOPS(2), YFATC(2), YFATCC(2),          BINPC      3
     2                YFATS(2) , AVPYR, PYRCH                            BINPC      4
      COMMON /CINPC/  ALPHA(5), AVPYC(5), BETA(5), CINP(5), CINPP(2),    CINPC      2
     1                FERT(5), FERTP, PF, PFCH, PFERP, PFERT(5),         CINPC      3
     2                PFEFTP, POI(5), OINP(5), PSEED(5), PSEEDP,         CINPC      4
     3                FTRPI(5), FTRPIP, FTRPP(5), FMC(2), SEED(5),       CINPC      5
     4                SEEDP, VMC(13,2), VMCP, FSCOIF(5), YBASE(5),       GPID       1
     5                FYCH(5), YLDCIS                                    GPIC       1
      COMMON /SYSVC/  ACFPOP(2), ACHPOP, PYB, FYC(5), RINT,              GPID       2
     1                FYLC(2), SYLD(5,2), TLAND, TLCP,                   SYSVC      3
     2                WAGE, YLD(5)                                       SYSVC      4
      COMMON /ACCVAR/ APCS(6,2),APS(2),TUAS(2),APC(5),AR,TUA,            ACCVAR     2
     1                AMES(2),ATS(2),TAM,TAT,PAMES(2),PATS(2),           ACCVAR     3
     2                PRODB(2,2),VPRB(2),RPRODB(2),RVPRB,AYLD(4,2),      ACCVAR     4
     3                SWYLD(2),STYLD(2),PRODC(4,2),TARC(4),TPRCD(4),     ACCVAR     5
     4                PRAM,PRAT,TYLD(4),                                 ACCVAR     6
     5                CFERT(5,2),EXFERT(5,2),CSEED(5,2),EXSEED(5,2),     ACCVAR     7
     6                COINP(5,2),TEXP(5,2),                              ACCVAR     8
     7                TFERT,TVFT,TSEED,TVSD,TVCIP,TOTEXP,                ACCVAR     9
     8                SLAB(2),STRC(2),SCOB(2),SDRF(2),                   ACCVAR    10
     9                TSLAB,TSTRC,TSCOB,TSDRF,                           ACCVAR    11
     *                WLAB(2),TWLAB,SWG(2),TWG,PWL(2),PTWL,              ACCVAR    12
     A                PLHA(2),PTHA(2),PDHA(2),                           ACCVAR    13
     B                PTLH,PTTH,PTDH,                                    GPIK       1
     C                VPRC(2),FVPRC,SVFO(2),TVFO,                        GPIK       2
     D                RAL(2),TEL(2),TDAL,TTRL,                           GPIK       3
     E                SOBJ(2),TOBJ,SEXP(2),SVAD(2),TVAD,                 GPIK       4
     F                PDYLN(2),PDYLB(2),FPYLN,FPYLB,                     GPIK       5
     G                SNF(2),TNF,                                        GPIK       6
     H                AGI(2),ANI(2),RAGI,RANI,                           GPIK       7
     I                PCTI(2),PCTF(2),RPCTI,RPCTF                        GPIK       8
      DIMENSION Y(NRB,3), X(NCB,2), A(NR,NC), Z(NCB,2)                   GPIK      11
      DO 20 I=1,2                                                        GPIH      10
C          CROPS AND PASTURE AREAS BY SIZE                               GPIH      11
      APCS(1,I) = X(1,I) + X(2,I)                                        GPIH      12
      APCS(2,I) = X(3,I) + X(4,I)                                        GPIH      13
      APCS(3,I) = X(5,I) + X(6,I)                                        GRIH      14
      APCS(4,I) = X(7,I) + X(8,I) + X(9,I) + X(10,I)                     GPIH      15
      APCS(5,I) = X(12,I) + X(13,I)                                      GPIH      16
      APCS(6,I) = X(11,I)                                                GRIH      17
C                                                                        GPIH      18
C          CULTIVATED LAND BY SIZE                                       GRIH      19
      APS(I) = 0.                                                        GPIH      20
      DO 10 J=1,4                                                        GPIH      21
   10 APS(I) = APS(I) + APCS(J,I)                                        GPIH      22
C                                                                        GRIH      23
C          TOTAL UTILIZED AREA BY SIZE                                   GPIH      24
```

```
      TUAS(I) = ARS(I) + ARCS(5,I) + ARCS(6,I)
C
   20 CONTINUE
C
C          REGIONAL CROP AREA
      DO 30 J=1,6
   30 ARC(J) = ARCS(J,1) + ARCS(J,2)
C
C          REGIONAL CULTIVATED AREA
      AR = ARS(1) + ARS(2)
C
C          REGIONAL TOTAL UTILIZED AREA
      TUA = TUAS(1) + TUAS(2)
C
C          MECHANIZED AREA BY SIZE
      DO 60 I=1,2
      AMES(I) = 0.
      DO 40 J=2,10,2
   40 AMES(I) = AMES(I) + X(J,I)
      AMES(I) = AMES(I) + X(13,I)
      ATS(I) = 0.
      DO 50 K=1,9,2
   50 ATS(I) = ATS(I) + X(K,I)
      ATS(I) = ATS(I) + X(12,I)
C          PERCENTAGES
      PAMES(I) = AMES(I) / (AMES(I) + ATS(I)) * 100.
      PATS(I) = ATS(I) / (AMES(I) + ATS(I)) * 100.
   60 CONTINUE
C          REGIONAL MECHANIZED AREA
      TAM = AMES(1) + AMES(2)
      TAT = ATS(1) + ATS(2)
      PRAM = TAM/(TAM + TAT) * 100.
      PRAT = TAT /(TAM + TAT) * 100.
C          BEEF PRODUCTION BY SIZE
      DO 80 I=1,2
      DO 79 J=1,2
      PRODB(J,I) = X(J+13,I) * (PROPS(J)*YFATS(J) + PROPC(J)*YFATC(J)
     1             + PROPCC(J)*YFATCC(J) )
   79 CONTINUE
C          VALUE OF PRODUCTION
      VPRB(I) = (PRODB(1,I) + PRODB(2,I)) * PYB
   80 CONTINUE
C          REGIONAL TOTAL
      DO 90 J=1,2
   90 RPRODB(J) = PRODB(J,1) + PRODB(J,2)
      RVPRB = VPRB(1) + VPRB(2)
C
C          AREA, YIELD AND PRODUCTION
      DO 110 I=1,2
C                AVERAGE YIELDS BY SIZE
C          RICE
      AVLD(1,I) = (YLD(1) *(1.+SYLD(1,I)) *(1.+RYLD(1)) * X(1,I)
     1            + YLD(1) *(1.+SYLD(1,I)) *(1.+RYLD(2)) * X(2,I) )
     2            / (X(1,I) + X(2,I))
C          CORN
      AVLD(2,I) = (YLD(2) *(1.+SYLD(2,I)) *(1.+RYLD(1)) * X(3,I)
     1            + YLD(2) *(1.+SYLD(2,I)) * (1.+RYLD(2)) * X(4,I))
     2            / (X(3,I) + X(4,I))
C          WHEAT
      AVLD(3,I) = (YLD(3) * (1.+SYLD(3,I)) * (1.+RYLD(1)) * X(5,I)
     1            + YLD(3) * (1.+SYLD(3,I))* (1.+RYLD(2)) * X(6,I) )
     2            / (X(5,I) + X(6,I))
C          SOYBEAN
      SWYLD(I) = (YLD(4) * (1.+SYLD(4,I)) * (1.+RYLD(1)) * X(7,I)
     1            + YLD(4) * (1.+SYLD(4,I)) * (1.+RYLD(2)) * X(8,I) )
     2            / (X(7,I) + X(8,I))
      SIYLD(I) = (YLD(5) * (1.+SYLD(5,I)) * (1.+RYLD(1)) * X(9,I)
     1            + YLD(5) * (1.+SYLD(5,I)) * (1.+RYLD(2)) * X(10,I) )
     2            / (X(9,I) + X(10,I))
      AVLD(4,I) = (SWYLD(I) * (X(7,I) + X(8,I)) + SIYLD(I) *
     1             (X(9,I) + X(10,I))) / ARCS(4,I)
C
C                PRODUCTION
      DO 100 J=1,4
  100 PRODC(J,I) = AVLD(J,I) * ARCS(J,I)
C
  110 CONTINUE
C                REGIONAL TOTAL PRODUCTION AND AREA
      DO 120 J=1,4
      TAPC(J) = ARCS(J,1) + ARCS(J,2)
      TPROD(J) = PRODC(J,1) + PRODC(J,2)
```

```
      TYLD(J) =(AYLD(J,1) + AYLD(J,2)) / 2.
  120 CONTINUE
C
C          UTILIZATION OF, AND EXPENDITURE ON AGRICULTURAL INPUTS
C
      DO 200 I=1,2
C               FERTILIZER
      DO 130 J=1,3
  130 CFERT(J,I) = FERT(J) * ARCS(J,I)
      CFERT(4,I) = FERT(5) * ( X(9,I) + X(10,I) )
      CFERT(5,I) = FERTP * ARCS(5,I)
      DO 135 J=1,5
  135 EXFERT(J,I) = CFERT(J,I) * PFER
C               SEED
      DO 140 J=1,3
  140 CSEED(J,I) = SEED(J) * ARCS(J,I)
      CSEED(4,I) = 2. * SEED(4) * ARCS(4,I)
      CSEED(5,I) = SEEDP * ARCS(5,I)
      DO 145 J=1,4
  145 EXSEED(J,I) = CSEED(J,I) * PSEED(J)
      EXSEED(5,I) = CSEED(5,I) * PSEEDP
C               OTHER INPUTS
      DO 150 J=1,3
  150 COINP(J,I) = OINP(J) * ARCS(J,I)
      COINP(4,I) = 2. * OINP(4) * ARCS(4,I)
      COINP(5,I) = 000.00
C               TOTAL EXPENDITURE
      DO 160 J=1,5
  160 TEXP(J,I) = EXFERT(J,I) + EXSEED(J,I) + COINP(J,I)
  200 CONTINUE
C
C               REGIONAL TOTAL
      TFERT = 0.
      DO 210 I=1,2
      DO 210 J=1,5
  210 TFERT = TFERT + CFERT(J,I)
      TVFT = 0.
      DO 220 I=1,2
      DO 220 J=1,5
  220 TVFT = TVFT + EXFERT(J,I)
      TSEED = 000.00
      TVSD = 0.
      DO 230 I=1,2
      DO 230 J=1,5
  230 TVSD = TVSD + EXSEED(J,I)
      TVOIP = 0.
      DO 240 I=1,2
      DO 240 J=1,5
  240 TVOIP = TVOIP + COINP(J,I)
      TOTEXP = 0.
      DO 250 I=1,2
      DO 250 J=1,5
  250 TOTEXP = TOTEXP + TEXP(J,I)
C
C          LABOR AND POWER USE
C
      DO 300 I=1,2
      SLAB(I) = 0.
      STPC(I) = 0.
      SCOB(I) = 0.
      SDRF(I) = 0.
      DO 300 J=1,15
      DO 290 K=4,6
  290 SLAB(I) = SLAB(I) + X(J,I) * A(K,J)
      STPC(I) = STPC(I) + X(J,I) * A(7,J)
      SCOB(I) = SCOB(I) + X(J,I) * A(8,J)
      SDRF(I) = SDRF(I) + X(J,I) * A(9,J)
  300 CONTINUE
C               REGIONAL TOTAL
      TSLAB = SLAB(1) + SLAB(2)
      TSTPC = STPC(1) + STPC(2)
      TSCOB = SCOB(1) + SCOB(2)
      TSDRF = SDRF(1) + SDRF(2)
C               HIRED LABOR
      DO 320 I=1,2
      WLAB(I) = 0.
      DO 320 J=19,21
  320 WLAB(I) = WLAB(I) + X(J,I)
      THLAB = WLAB(1) + WLAB(2)
C               VALUE OF WAGES PAID
      DO 321 I=1,2
```

```
  321 SHG(I) = WLAB(I) * WAGE                                  GRIH      187
      THG = SHG(1) + SHG(2)                                    GRIH      188
C         PERCENT OF HIRED LABOR                               GRIH      189
      DO 322 I=1,2                                             GRIH      190
  322 PHL(I) = WLAB(I) / SLAB(I) * 100.                        GRIH      191
      PTHL = TWLAB / TSLAB * 100.                              JELA        1
C     LABOR, TRACTOR AND DRAFT ANIMAL HOURS PER HECTARE        GRIH      193
      DO 323 I=1,2                                             GRIH      194
      FLHA(I) = SLAB(I) /ARS(I)                                GRIH      195
      PTHA(I) = STRC(I) / ARS(I)                               GRIH      196
      FDHA(I) = SDRF(I) / ARS(I)                               GRIH      197
  323 CONTINUE                                                 GRIH      198
      PTLH = TSLAB / AR                                        GRIH      199
      RTTH = TSTRC / AR                                        GRIH      200
      PTDH = TSDRF / AR                                        GRIH      201
C                                                              GRIK       12
C         ANIMAL AND TRACTOR/LABOR RATIOS                      GRIK       13
C                                                              GRIK       14
      DO 330 I=1,2                                             GRIK       15
      DAL(I) = SDRF(I) / SLAB(I)                               GRIK       16
      TRL(I) = STRC(I) / SLAB(I)                               GRIK       17
  330 CONTINUE                                                 GRIK       18
      TDAL = TSDRF / TSLAB                                     GRIK       19
      TTRL = TSTRC / TSLAB                                     GRIK       20
C                                                              GRIK       21
C     VALUE OF CROP PRODUCTION                                 GRIK       22
C                                                              GRIK       23
      DO 340 I=1,2                                             GRIK       24
      VPRC(I) = 0.                                             JELA        2
      DO 340 J=1,4                                             GRIK       25
  340 VPRC(I) = VPRC(I) + PROCC(J,I) * PYC(J)                  JELA        3
      RVPRC = VPRC(1) + VPRC(2)                                GRIK       27
C                                                              GRIK       28
C         TOTAL VALUE OF FARM OUTPUT - GROSS INCOME            GRIK       29
C             (CROPS AND LIVESTOCK)                            GRIK       30
      DO 345 I=1,2                                             GRIK       31
  345 SVFO(I) = VPRC(I) + VPRB(I)                              GRIK       32
      TVFO = RVPRC + RVPRB                                     GRIK       33
C                                                              GRIK       34
C         NET FARM INCOME                                      GRIK       35
C                                                              GRIK       36
      DO 350 I=1,2                                             GRIK       37
      SOBJ(I) = 0.                                             GRIK       38
      DO 350 J=1,NCB                                           GRIK       39
      SOBJ(I) = SOBJ(I) + X(J,I) * Z(J,I)                      GRIK       40
  350 CONTINUE                                                 GRIK       41
      TOBJ = SOBJ(1) + SOBJ(2)                                 GRIK       42
C                                                              GRIK       43
C         VALUE ADDED                                          GRIK       44
C                                                              GRIK       45
      DO 360 I=1,2                                             GRIK       46
      SEXP(I) = 0.                                             GRIK       47
      DO 360 J=1,5                                             GRIK       48
      SEXP(I) = SEXP(I) + TEXP(J,I)                            GRIK       49
  360 CONTINUE                                                 GRIK       50
      DO 365 I=1,2                                             GRIK       51
  365 SVAD(I) = SVFO(I) - SEXP(I)                              GRIK       52
      TVAD = TVFO - TOTEXP                                     GRIK       53
C                                                              GRIK       54
C         LAND AND LABOR PRODUCTIVITIES                        GRIK       55
C                                                              GRIK       56
      DO 370 I=1,2                                             GRIK       57
      FDYLN(I) = SOBJ(I) / TUAS(I)                             GRIK       58
      PDYLB(I) = SOBJ(I) / SLAB(I)                             GRIK       59
  370 CONTINUE                                                 GRIK       60
      FPYLN = TOBJ / TUA                                       GRIK       61
      FPYLB = TOBJ / TSLAB                                     GRIK       62
C                                                              GRIK       63
C         NUMBER OF FARMS                                      GRIK       64
C                                                              GRIK       65
      SNF(1)=199990. * EXP(0.287345 * (0.1*FLOAT(IYR) + 3.0))  GRIK       66
      SNF(2)= 26156. * EXP(0.063464 * (0.1*FLOAT(IYR) + 3.0))  GRIK       67
      TNF = SNF(1) + SNF(2)                                    GRIK       68
C                                                              GRIK       69
C         AVERAGE FARM INCOME                                  GRIK       70
C                                                              GRIK       71
      DO 380 I=1,2                                             GRIK       72
      AGI(I) = SVFO(I) / SNF(I)                                GRIK       73
  380 ANI(I) = SOBJ(I) / SNF(I)                                GRIK       74
      RAGI = TVFO / TNF                                        GRIK       75
      RANI = TOBJ / TNF                                        GRIK       76


C                                                              GRIK       77
C         PERCENTAGES OF INCOME AND FARMS IN EACH CLASS        GRIK       78
C                                                              GRIK       79
      DO 390 I=1,2                                             GRIK       80
      PCTI(I) = SVFO(I) / TVFO * 100.                          GRIK       81
  390 PCTF(I) = SNF(I) / TNF * 100.                            GRIK       82
      FPCTI = 100.                                             GRIK       83
      FPCTF = 100.                                             GRIK       84
      RETURN                                                   ACCTG       3
      END                                                      ACCTG       4
```

```
      SUBROUTINE ASET
C
C         ASET COMPUTES TIME VARYING COEFFICIENTS OF A
C
      COMMON /LPAC/    A(58,42), Y(58), Z(42), OBJ, X(60), JX(59),
     1                 PI(58), IOUT(4), S(100), ACT(100), NR, NRB, NRR,
     2                 NC, NCB
      COMMON /CNTRLC/ DT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,
     1                 IALT,LUOUT,LUIN,TIMLP,IDBG,
     2                 YLOCH,WTL,WTA,WTLCH,WTACH
      DIMENSION PRMOL(3)
      DATA PRMOL / 0.20, 0.40, 0.30 /
C
      IF(WTLCH.EQ.0.) GO TO 5
      IF(YEAR.NE.1970.) GO TO 2
      WTL = WTL + WTLCH * PRMOL(1)
      WTA = WTL
      GO TO 5
    2 IF(YEAR.NE.1975.) GO TO 3
      WTL = WTL + WTLCH * PRMOL(2)
      WTA = WTL
      GO TO 5
    3 IF(YEAR.NE.1980.) GO TO 5
      WTL = WTL + WTLCH * PRMOL(3)
      WTA = WTL
    5 CONTINUE
C
      A( 4, 1) = 400.0
      A( 5, 1) =  11.0
      A( 6, 1) = 118.4
      A( 9, 1) =  80.0
      A( 4, 2) =   6.5
      A( 5, 2) =  11.0
      A( 6, 2) =   3.0
      A( 7, 2) =   5.5
      A( 8, 2) =   1.0
      A( 4, 3) = 462.0
      A( 6, 3) =  50.0
      A( 9, 3) =  84.0
      A( 4, 4) =   7.0
      A( 6, 4) =  50.0
      A( 7, 4) =   6.0
      A( 5, 5) = 118.4
      A( 6, 5) = 366.9
      A( 9, 5) =  71.0
      A( 5, 6) =   3.0
      A( 6, 6) =   6.0
      A( 7, 6) =   5.0
      A( 8, 6) =   1.0
      A( 5, 7) = 318.6
      A( 6, 7) =  82.8
      A( 9, 7) =  59.0
      A( 5, 8) =   4.5
      A( 6, 8) =   3.0
      A( 7, 8) =   3.5
      A( 8, 8) =   1.0
      A( 5, 9) = 370.0
      A( 6, 9) = 130.2
      A( 9, 9) =  76.0
      A( 4,10) =   6.5
      A( 6,10) =   3.0
      A( 7,10) =   5.5
      A( 8,10) =   1.0
      A( 4,12) = 397.0
      A( 9,12) =  23.7
      A( 4,13) =   3.0
      A( 7,13) =   5.5
C
C         COMBINE TRAD-MOD COEFFICIENTS
C
C     LABOR
C
      A(4,2) = WTL * A(4,2) + (1.-WTL) * A(4,1)
      A(6,2) = WTL * A(6,2) + (1.-WTL) * A(6,1)
      A(4,4) = WTL * A(4,4) + (1.-WTL) * A(4,3)
      A(5,6) = WTL * A(5,6) + (1.-WTL) * A(5,5)
      A(6,6) = WTL * A(6,6) + (1.-WTL) * A(6,5)
```

```
      A(5,8) = WTL * A(5,8) + (1.-WTL) * A(5,7)
      A(6,8) = WTL * A(6,8) + (1.-WTL) * A(6,7)
      A(4,10)= WTL * A(4,10)+ (1.-WTL) * A(5,9)
      A(6,10)= WTL * A(6,10)+ (1.-WTL) * A(6,9)
      A(4,13)= WTL * A(4,13)+ (1.-WTL) * A(4,12)
C
C     TRACTOR
C
      DO 10 J=2,11,2
   10 A(7,J) = WTA * A(7,J)
      A(7,13)= WTA * A(7,13)
C
C     DRAFT ANIMAL
C
      DO 20 J=1,9,2
   20 A(9,J+1) = (1.-WTA) * A(9,J)
      A(9,13) = (1.-WTA) * A(9,12)
C
C          ELIMINATES COEFFICIENTS OF TRADITIONAL ACTIVITIES
C
      DO 80 I=1,NRB
      DO 80 J=1,9,2
   80 A(I,J) = 0.0
      A( 1,12) = 0.0
      A( 2,12) = 0.0
      A( 4,12) = 0.0
      A( 9,12) = 0.0
      A(11,12) = 0.0
      A(26,12) = 0.0
      A(27,12) = 0.0
      A(9,18) = -2400.
C
C          DUPLICATE BLOCK
      DO 50 I=1,NRB
      DO 50 J=1,NCB
   50 A(I+NRB, J+NCB) = A(I,J)
      RETURN
      END
```

```
      SUBROUTINE BSET
C
C          BSET COMPUTES BT, THE TIME-VARYING B COEFFICIENTS, AND BCC
C
      COMMON /CNTRLC/ DT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,
     1                IALT,LUCUT,LUIN,TIMLP,IDBG,
     2                YLOCH,WTL,WTA,WTLCH,WTACH
      COMMON /BCFC/   A1, A2, BBAR, BC(21,2), BCC(6,2),
     1                BT(6), DB, KB, SB, VBT(4,6)
C
      DO 20 I=1,6
   20 BT(I) = TABEL(VBT(1,I),KB,SB,DB,YEAR)
C
      BCC(1,1) = A1 * EXP(A2*(.1*FLOAT(IYR)+3.))/100.
      BCC(1,2) = 1. - BCC(1,1)
      BCC(2,1) = BCC(1,1)
      BCC(2,2) = BCC(1,2)
```

```
C
      BCC(4,1) = BCC(4,1) + (DT/DEL)*(BBAR-BCC(4,1))
      BCC(5,1) = BCC(4,1)
      BCC(6,1) = BCC(4,1)
      DO 30 I=4,6
   30 BCC(I,2) = BCC(I,1)
C
      RETURN
      END
```

```
      SUBROUTINE CNTRL                                                  CNTRL      2
C                                                                       CNTRL      3
C         CONTROL PARAMETERS INITIALIZED                                CNTRL      4
C                                                                       CNTRL      5
      COMMON /CNTRLC/ CT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,             GRIG       1
     1                IALT,LUOUT,LUIN,TIMLP,IDBG,                       JFLD       1
     2                YLDCH,WTL,WTA,WTLCH,WTACH                         JFLD       2
C                                                                       CNTRL      7
      LUIN = 5                                                          GRIG       3
      READ(LUIN,100) NYR,IALT,IDBG,YLDCH,WTL,WTA,WTLCH,WTACH            JFLD       3
  100 FORMAT(3I2,5F5.2)                                                 JFLD       4
      YEAR0 = 1970.                                                     CNTRL      9
      YEAR = YEAR0 - 1.                                                 CNTRL     10
      DEL = 16.                                                         GRIA       1
      DEL3 = 3.                                                         CNTRL     12
      DT = 1.                                                           CNTRL     13
      TIMLP = 0.                                                        GRIG       5
      LUOUT = 6                                                         GRIG       6
      RETURN                                                            CNTRL     14
      END                                                               CNTRL     15
```

```
      SUBROUTINE INA                                                    INA        2
C                                                                       INA        3
C         INA INITIALIZES THE CONSTANT ELEMENTS OF A                    INA        4
C                                                                       INA        5
      COMMON /CNTRLC/ CT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,             GRIG       1
     1                IALT,LUOUT,LUIN,TIMLP,IDBG,                       JFLD       1
     2                YLDCH,WTL,WTA,WTLCH,WTACH                         JFLD       2
      COMMON /LPAC/   A(58,42), Y(58), Z(42), OBJ, X(60), JX(58),       LPAC       2
     1                PI(58), IOUT(4), S(100), ACT(100), NR, NRB, NRR,  GRIG       3
     2                NC, NCB                                           LPAC       4
      COMMON /TXTC/   TEXTR(7,58), TEXTC(7,42), TEXTB(5,3)              TXTC       2
      DO 10 I=1,NR                                                      INA        8
      DO 10 J=1,NC                                                      INA        9
   10 A(I,J) = 0.                                                       INA       10
C                                                                       INA       11
      A( 1, 1) = 1.                                                     INA       12
      A( 2, 1) = 1.                                                     INA       13
      A( 3, 1) = 1.                                                     INA       14
      A(14, 1) = 1.                                                     INA       15
      A(15, 1) = 1.                                                     INA       16
      A( 1, 2) = 1.                                                     INA       17
      A( 2, 2) = 1.                                                     INA       18
      A( 3, 2) = 1.                                                     INA       19
      A(14, 2) = 1.                                                     INA       20
      A(15, 2) = 1.                                                     INA       21
      A( 1, 3) = 1.                                                     INA       22
      A( 2, 3) = 1.                                                     INA       23
      A(16, 3) = 1.                                                     INA       24
      A(17, 3) = 1.                                                     INA       25
      A( 1, 4) = 1.                                                     INA       26
      A( 2, 4) = 1.                                                     INA       27
      A(16, 4) = 1.                                                     INA       28
      A(17, 4) = 1.                                                     INA       29
      A( 2, 5) = 1.                                                     INA       30
      A(12, 5) =-1.                                                     INA       31
      A(18, 5) = 1.                                                     INA       32
      A(19, 5) = 1.                                                     INA       33
      A( 2, 6) = 1.                                                     INA       34
      A(13, 6) =-1.                                                     INA       35
      A(18, 6) = 1.                                                     INA       36
      A(19, 6) = 1.                                                     INA       37
      A( 2, 7) = 1.                                                     INA       38
      A(12, 7) = 1.                                                     INA       39
      A(24, 7) = 1.                                                     INA       40
      A(25, 7) = 1.                                                     INA       41
      A( 2, 8) = 1.                                                     INA       42
      A(13, 8) = 1.                                                     INA       43
      A(24, 8) = 1.                                                     INA       44
      A(25, 8) = 1.                                                     INA       45
      A( 1, 9) = 1.                                                     INA       46
      A( 2, 9) = 1.                                                     INA       47
      A(20, 9) = 1.                                                     INA       48
```

```
      A(21, 9) = 1.
      A( 1,10) = 1.
      A( 2,10) = 1.
      A(20,10) = 1.
      A(21,10) = 1.
      A( 1,11) = 1.
      A( 2,11) = 1.
      A(10,11) =-1.
      A(22,11) = 1.
      A(23,11) = 1.
      A( 1,12) = 1.
      A( 2,12) = 1.
      A(11,12) =-1.
      A(26,12) = 1.
      A(27,12) = 1.
      A( 1,13) = 1.
      A( 2,13) = 1.
      A(11,13) =-1.
      A(26,13) = 1.
      A(27,13) = 1.
      A( 4,14) = 3.3
      A( 5,14) = 3.3
      A( 6,14) = 3.3
      A(10,14) = 2.5
      A( 4,15) = 3.7
      A( 5,15) = 3.7
      A( 6,15) = 3.7
      A(11,15) = 1.25
      A( 7,16) =-2400.
      A(55,16) = 1.
      A( 8,17) =-2000.
      A( 9,18) =-1200.
      A(10,18) = 2.5
      A( 4,19) =-1.
      A(56,19) = 1.
      A( 5,20) =-1.
      A(57,20) = 1.
      A( 6,21) =-1.
      A(58,21) = 1.
      DO 50 I=1,NRB
      DO 50 J=1,NCB
   50 A(NRB+I,NCB+J) = A(I,J)
C
      DO 60 I=1,NRB
      DO 60 J=1,NCB
   60 A(2*NRB+I,NCB+J) = A(2*NRB+I,J)
C
C
C           DUPLICATE TEXT
C
      DO 98 I=1,7
      DO 92 J=1,NRB
   92 TEXTR(I,J+NRB) = TEXTR(I,J)
      DO 94 J=1,NCB
   94 TEXTC(I,J+NCB) = TEXTC(I,J)
   98 CONTINUE
      RETURN
      END
```

```
      BLOCK DATA INB
C
C           TIME SERIES PROJECTIONS OF B COEFFICIENTS
C
      COMMON /BCFC/    A1, A2, BBAR, BC(21,2), BCC(6,2),
     1                 BT(6), DE, KB, SB, VBT(4,6)
C
C           CONSTANT B
      DATA BC /
     1     .10,      2400.,       .10,     2000.,       .10,      1200.,
     2    .104,     -.093,      .079,     -.050,      .340,     -.195,
     3    .300,     -.100,      .414,     -.050,      .100,     -.200,
     4    .100,     -.100,       .02,
     5     .10,      2400.,       .10,     2000.,       .10,      1200.,
     6    .104,     -.093,      .078,     -.050,      .340,     -.195,
     7    .300,     -.100,      .414,     -.050,      .100,     -.200,
     8    .100,     -.100,       .02/
C           TIME-VARYING B
C                         1970        1975        1980        1985
      DATA VBT /
     1                    .008,       .006,       .005,       .004,
     2                    .008,       .006,       .005,       .004,
     3                    .008,       .006,       .005,       .004,
     4                    .008,       .006,       .005,       .004,
     5                    .008,       .006,       .005,       .004,
     6                     .05,        .05,        .05,        .05/
C
      DATA KB, SB, DB / 4, 1970., 5./
C
      DATA A1, A2 / 25.781 , .1122 /
      DATA BBAR / 1000. /
C
      DATA ((BCC(I,J),I=4,6),J=1,2) / 6*800./
C
      END
```

```
      BLOCK DATA INCON                                                  INCON      2
C                                                                       INCON      3
C         INITIAL CONDITIONS                                            INCON      4
C                                                                       INCON      5
      COMMON /BINPC/  BOM, PBOM, SALT, PSALT, VETC(2), PROPC(2),        BINPC      2
     1                PROPCC(2), PROPS(2), YFATC(2), YFATCC(2),         BINPC      3
     2                YFATS(2) , AVPYB, PYBCH                           BINPC      4
      COMMON /CINPC/  ALPHA(5), AVPYC(5), BETA(5), CINP(5), CINPP(2),   CINPC      2
     1                FERT(5), FERTP, PF, PFCH, PFEP, PFERT(5),         CINPC      3
     2                PFERTP, POI(5), OINP(5), PSEED(5), PSEEDP,        CINPC      4
     3                PTRPI(5), PTRPIP, PTRPP(5), PMC(2), SEED(5),      CINPC      5
     4                SEEDP, VMC(10,2), VMCP, PSCDIF(5), YBASE(5),      GRID       1
     5                PYCH(5), YLDDIS                                   GRIC       1
      COMMON / INVC/  XLIF(3), PAQ(3), PSL(3), PAQCH(3), WAGECH         GRIC       2
      COMMON /SYSVC/  ACFPOP(2), ACHPOP, PYB, PYC(5), PINT,             GRID       2
     1                PYLD(2), SYLD(5,2), TLAND, TLCP,                  SYSVC      3
     2                WAGE, YLD(5)                                      SYSVC      4
      COMMON /CNTRLC/ DT, DEL, DELT, IYR, NYP, YEAR, YEARO,             GRIG       1
     1                IALT,LUOUT,LUIN,TIMLF,IOBG,                       JELD       1
     2                YLDCH,WTL,WTA,WTLCH,WTACH                         JELD       2
C                                                                       INCON     11
C         CONSTANT PARAMETERS                                           INCON     12
C                                                                       INCON     13
C         PARAMETERS OF FERTILIZER RESPONSE FUNCTIONS                   INCON     14
      DATA ALPHA /  20.39,      19.29,       5.61,       0.00,       6.00/  INCON 15
      DATA BETA  /  .2537,      .0865,      .0360,      .0000,      .0500/  INCON 16
      DATA YBASE /  2913.,       405.,       631.,         0.,      1105./  GRID   8
C         CAPITAL INPUTS                                                INCON     18
      DATA CINP / 77.45,  480. /                                        INCON     19
      DATA CINPP / 4.93, 9.86 /                                         INCON     20
C         RATE OF CHANGE IN PRODUCT AND FERTILIZER PRICES               INCON     21
      DATA PYCH /     .2311,      .2221,      .1782,      .0000,      .2495/  INCON 22
      DATA PFCH, PYBCH / .12, .1090 /                                   INCON     23
C         YIELD DISCOUNT FOR SOYBEANS AFTER WHEAT                       INCON     24
      DATA YLDDIS / .3 /                                                INCON     25
C         TOTAL LAND CAPACITY                                           INCON     26
      DATA TLCP / 19045744. /                                           INCON     27
C         FERTILIZER RATE - CULTIVATED PASTURE                          INCON     28
      DATA FERTP / 100. /                                               INCON     29
C         YIELD DIFFERENTIAL FOR SIZE AND MECHANIZATION                 INCON     30
      DATA PYLD  / 0.0, .05 /                                           GRID       9
      DATA SYLD /        .00,        .00,        .00,        .00,        .00,  INCON 32
     1                   .09,        .00,        .05,        .05,        .05/  GRID  10
C         CROP INPUTS - RATES AND PRICES                                INCON     34
      DATA OINP /    25.00,      10.00,      13.54,      15.00,      15.00/  INCON 35
      DATA SEED /     170.,        12.,        90.,        70.,        73./  INCON 36
      DATA VMC /      0.00,      37.48,       0.00,      29.34,       0.00,  GRID  11
     1               35.11,       0.00,      29.11,       0.00,      37.39,  GRID  12
     2                0.00,      37.48,       0.00,      29.34,       0.00,  GRID  13
     3               35.11,       0.00,      29.11,       0.00,      37.39/  GRID  14
      DATA POI /        1.,         1.,         1.,         1.,         1./  INCON 38
      DATA PTRPI /    .014,       .014,       .014,       .014,       .014/  INCON 39
      DATA PTRPP /    .014,       .014,       .014,       .014,       .014/  INCON 40
      DATA SEEDP / 20. /                                                INCON     41
      DATA PSEEDP / .50 /                                               INCON     42
      DATA PTRPIP / .014 /                                              INCON     43
      DATA VMCP / 9.74 /                                                INCON     44
      DATA PMC / 1.54, 3.88 /                                           INCON     45
C         CHANGE RATES - ACQUISITION COSTS AND WAGES                    INCON     46
      DATA PAQCH / .2137,  .2128,  .2128 /                              INCON     47
      DATA WAGECH / .2280 /                                             INCON     48
C         BEEF PARAMETERS                                               INCON     49
      DATA PROPC  /    .06,   .12/                                      INCON     50
      DATA PROPCC /    .09,   .11/                                      INCON     51
      DATA PROPS  /    .18,   .25/                                      INCON     52
      DATA YFATC  /   400.,  420./                                      INCON     53
      DATA YFATCC /   370.,  390./                                      INCON     54
      DATA YFATS  /   450.,  470./                                      INCON     55
      DATA PBOM / .40 /                                                 GRIC       4


      DATA BOM / 8. /                                                   GRIC       5
      DATA PSALT / .15 /                                                GRIC       6
      DATA SALT / 12. /                                                 GRIC       7
      DATA VETC  /    5.00,  6.00/                                      INCON     60
C         INVESTMENT - EXPECTED LIFE                                    INCON     61
      DATA XLIF /  10.,  10.,  5. /                                     INCON     62
C         INTEREST RATE                                                 GRIA       2
      DATA PINT / .10 /                                                 GRIA       3
C                                                                       INCON     63
C         INITIAL CONDITIONS                                            INCON     64
C                                                                       INCON     65
C         INITIAL PRICES - CROPS AND FERTILIZER                         INCON     66
      DATA PYC    /      .24,        .15,        .44,        .24,        .24/  INCON 67
      DATA AVPYC  /      .29,        .16,        .49,        .28,        .28/  INCON 68
      DATA PF     /    1.25/                                            INCON     69
      DATA PFEP   /     .94/                                            INCON     70
      DATA PYB    /     .90/                                            INCON     71
      DATA AVPYB  /    1.10/                                            INCON     72
C         INVESTMENT                                                    INCON     73
      DATA PAQ /    24000.,     60000.,       366./                     INCON     74
      DATA PSL /     2400.,      6000.,      36.60/                     INCON     75
C         WAGES                                                         INCON     76
      DATA WAGE /        .89/                                           INCON     77
C         SEED DIFFERENTIAL COST                                        INCON     78
      DATA PSCDIF /      .27,        .60,        .24,        .17,        .17/  INCON 79
      END                                                               INCON     80
```

```
      BLOCK DATA INTXT
C
C          TEXT FOR OUTPUT
C
      COMMON /TXTC/   TEXTR(7,58), TEXTC(7,42), TEXTB(5,3)
      DIMENSION DTXTR(7,27,3), DTXTC(7,21,2)
      EQUIVALENCE (TEXTR,DTXTR), (TEXTC,DTXTC)
      DATA ((DTXTR(I,J,1),I=1,7),J=1,10)  /
     1     4HSUMM, 4HER L, 4HAND , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     2     4HWINT, 4HER L, 4HAND , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     3     4HIRRI, 4HG. L, 4HAND , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     4     4HLABO, 4HR PE, 4HD 1 , 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     5     4HLABO, 4HR PE, 4HD 2 , 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     6     4HLABO, 4HR PE, 4HD 3 , 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     7     4HTRAC, 4HTOR , 4HCAP., 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     8     4HCOMB, 4HINE , 4HCAP., 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     9     4HDFT , 4HANIM, 4H CAP, 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     *     4HBAL , 4HNAT , 4HPAST, 4HTH H, 4HA   , 4HCRS/, 4HHA  /
      DATA ((DTXTR(I,J,1),I=1,7),J=11,20)  /
     1     4HBAL , 4HCUL , 4HPAST, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     2     4HBAL , 4HSOYW, 4H TRD, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     3     4HBAL , 4HSOYW, 4H MOD, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     4     4HMAX , 4HRICE, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     5     4HMIN , 4HRICE, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     6     4HMAX , 4HCORN, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     7     4HMIN , 4HCORN, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     8     4HMAX , 4HWHEA, 4HT   , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     9     4HMIN , 4HWHEA, 4HT   , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     *     4HMAX , 4HSOYB, 4HEAN , 4HTH H, 4HA   , 4HCRS/, 4HHA  /
      DATA ((DTXTR(I,J,1),I=1,7),J=21,27)  /
     1     4HMIN , 4HSOYB, 4HEAN , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     2     4HMAX , 4HNAT , 4HPAST, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     3     4HMIN , 4HNAT , 4HPAST, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     4     4HMAX , 4HSOY/, 4HWHT , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     5     4HMIN , 4HSOY/, 4HWHT , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     6     4HMAX , 4HCUL , 4HPAST, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     7     4HMIN , 4HCUL , 4HPAST, 4HTH H, 4HA   , 4HCRS/, 4HHA  /
      DATA ((DTXTR(I,J,3),I=1,7),J=1,4)  /
     1     4HSUP , 4HTRAC, 4HTOR , 4HTPC , 4HUNIT, 4HCRS/, 4HUNIT,
     2     4HWAGE, 4H LAB, 4HOR 1, 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     3     4HWAGE, 4H LAB, 4HOR 2, 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     4     4HWAGE, 4H LAB, 4HOR 3, 4HTH H, 4HR   , 4HCRS/, 4HHR  /
      DATA ((DTXTC(I,J,1),I=1,7),J=1,10)  /
     1     4HRICE, 4H TRD, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     2     4HRICE, 4H MOD, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     3     4HCORN, 4H TRD, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     4     4HCORN, 4H MOD, 4H    , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     5     4HWHEA, 4HT TR, 4HD   , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     6     4HWHEA, 4HT MO, 4HD   , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     7     4HSOY/, 4HWHT , 4HTRD , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     8     4HSOY/, 4HWHT , 4HMOD , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     9     4HSOYB, 4HEAN , 4HTRD , 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     *     4HSOYB, 4HEAN , 4HMOD , 4HTH H, 4HA   , 4HCRS/, 4HHA  /
      DATA ((DTXTC(I,J,1),I=1,7),J=11,21)  /
     1     4HNATU, 4HRAL , 4HPAST, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     2     4HCUL , 4HPAST, 4H TRD, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     3     4HCUL , 4HPAST, 4H MOD, 4HTH H, 4HA   , 4HCRS/, 4HHA  ,
     4     4HBEEF, 4H NAT, 4H FAS, 4HTH C, 4HU   , 4HCRS/, 4HUNIT,
     5     4HBEEF, 4H CUL, 4H FAS, 4HTH C, 4HU   , 4HCRS/, 4HUNIT,
     6     4HINV , 4HTRAC, 4HTOR , 4HTPC , 4HUNIT, 4HCRS/, 4HUNIT,
     7     4HINV , 4HCOMB, 4HINE , 4HCOM , 4HUNIT, 4HCRS/, 4HUNIT,
     8     4HINV , 4HDFT , 4HANIM, 4HANI , 4HUNIT, 4HCRS/, 4HUNIT,
     9     4HHIRE, 4H LAB, 4HOR 1, 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     *     4HHIRE, 4H LAB, 4HOR 2, 4HTH H, 4HR   , 4HCRS/, 4HHR  ,
     A     4HHIRE, 4H LAB, 4HOR 3, 4HTH H, 4HR   , 4HCRS/, 4HHR  /
      DATA TEXTB  /
     1     4HSMAL, 4HL FA, 4HRMS(, 4H)=10, 4HDHA),
     2     4HLARG, 4HE FA, 4HRMS(, 4H >10, 4HDHA),
     3     4HREGI, 4HONAL, 4H CON, 4HSTRA, 4HINTS/
C
      END
```

```
      BLOCK DATA INV                                                      INV
C                                                                         INV
C         INV CONTAINS THE INITIAL VALUES OF Y(1970) AND T(TYPE)          INV
C                                                                         INV
      COMMON /LPAC/   A(58,42), Y(58), Z(42), CBJ, X(60), JX(58),         LPAC
     1                PI(58), IOUT(4), S(100), ACT(100), NF, NPB, NRP,    GRIG
     2                NC, NCB                                             LPAC
      COMMON /LPBC/   T(58), IFIX(25), TOL(5), E(60,60), ERR(4), TMP(60)  LPBC
C                                                                         INV
      DATA Y( 1) , T( 1) /   5824945., 1H+ /                              INV
      DATA Y( 2) , T( 2) /   5824945., 1H+ /                              INV
      DATA Y( 3) , T( 3) /    142843., 1H+ /                              INV
      DATA Y( 4) , T( 4) / 655927280., 1H+ /                              INV
      DATA Y( 5) , T( 5) / 655927280., 1H+ /                              INV
      DATA Y( 6) , T( 6) / 650927280., 1H+ /                              INV
      DATA Y( 7) , T( 7) /  40932480., 1H+ /                              INV
      DATA Y( 8) , T( 8) /  14996000., 1H+ /                              INV
      DATA Y( 9) , T( 9) / 488195460., 1H+ /                              INV
      DATA Y(10) , T(10) /         0., 1H  /                              INV
      DATA Y(11) , T(11) /         0., 1H  /                              INV
      DATA Y(12) , T(12) /         0., 1H+ /                              INV
      DATA Y(13) , T(13) /         0., 1H+ /                              INV
      DATA Y(14) , T(14) /    134982., 1H+ /                              INV
      DATA Y(15) , T(15) /    110440., 1H- /                              INV
      DATA Y(16) , T(16) /   1332200., 1H+ /                              INV
      DATA Y(17) , T(17) /   1089992., 1H- /                              INV
      DATA Y(18) , T(18) /    278869., 1H+ /                              INV
      DATA Y(19) , T(19) /    193063., 1H- /                              INV
      DATA Y(20) , T(20) /    270032., 1H+ /                              INV
      DATA Y(21) , T(21) /    186945., 1H- /                              INV
      DATA Y(22) , T(22) /   3806217., 1H+ /                              INV
      DATA Y(23) , T(23) /   2854663., 1H- /                              INV
      DATA Y(24) , T(24) /     33754., 1H+ /                              INV
      DATA Y(25) , T(25) /     23363., 1H- /                              INV
      DATA Y(26) , T(26) /    158592., 1H+ /                              INV
      DATA Y(27) , T(27) /    118944., 1H- /                              INV
      DATA Y(28) , T(28) / 109735800., 1H+ /                              INV
      DATA Y(29) , T(29) / 109735800., 1H+ /                              INV
      DATA Y(30) , T(30) /    333330., 1H+ /                              INV
      DATA Y(31) , T(31) /  35789040., 1H+ /                              INV
      DATA Y(32) , T(32) /  35789040., 1H+ /                              INV
      DATA Y(33) , T(33) /  35789040., 1H+ /                              INV
      DATA Y(34) , T(34) /  44186400., 1H+ /                              INV
      DATA Y(35) , T(35) /  22342000., 1H+ /                              INV
      DATA Y(36) , T(36) /  35789040., 1H+ /                              INV
      DATA Y(37) , T(37) /         0., 1H  /                              INV
      DATA Y(38) , T(38) /         0., 1H  /                              INV
      DATA Y(39) , T(39) /         0., 1H+ /                              INV
      DATA Y(40) , T(40) /         0., 1H+ /                              INV
      DATA Y(41) , T(41) /    314959., 1H+ /                              INV
      DATA Y(42) , T(42) /    257693., 1H- /                              INV
      DATA Y(43) , T(43) /    570943., 1H+ /                              INV
      DATA Y(44) , T(44) /    467135., 1H- /                              INV
      DATA Y(45) , T(45) /   1115477., 1H+ /                              INV
      DATA Y(46) , T(46) /    722253., 1H- /                              INV
      DATA Y(47) , T(47) /    405048., 1H+ /                              INV
      DATA Y(48) , T(48) /    290418., 1H- /                              INV
      DATA Y(49) , T(49) /  12400596., 1H+ /                              INV
      DATA Y(50) , T(50) /   8000000., 1H- /                              INV
      DATA Y(51) , T(51) /    135016., 1H+ /                              INV
      DATA Y(52) , T(52) /     93473., 1H- /                              INV
      DATA Y(53) , T(53) /    516692., 1H+ /                              INV
      DATA Y(54) , T(54) /    337519., 1H- /                              INV
      DATA Y(55) , T(55) /      3836., 1H+ /                              INV
      DATA Y(56) , T(56) /  89280800., 1H+ /                              INV


      DATA Y(57) , T(57) /  89280800., 1H+ /                              INV
      DATA Y(58) , T(58) /  89280800., 1H+ /                              INV
C                                                                         INV
      END                                                                 INV
```

```
      SUBROUTINE IPY
C
C          IPY COMPUTES INPUT PRICES AND RATES, OUTPUT PRICES,
C          FERTILIZER APPLICATION RATES, AND YIELDS
C
      COMMON /CNTRLC/ DT, DEL, DEL3, IYR, NYR, YEAR, YEARS,
     1                 IALT,LUCUT,LLIN,TIMLP,IORG,
     2                 YLDCH,WTL,WTA,WTLCH,WTACH
      COMMON /SYSVC/  ACFPOP(2), ACHPOP, PYB, PYC(5), RINT,
     1                 FYLD(2), SYLD(5,2), TLAND, TLCP,
     2                 WAGE, YLD(5)
      COMMON /CINPC/  ALPHA(5), AVPYC(5), BETA(5), CINP(5), CINPP(2),
     1                 FERT(5), FERTP, PF, PFCH, PFER, PFERT(5),
     2                 PFERTP, FOI(5), CINP(5), PSEED(5), PSEEDP,
     3                 FTRPI(5), PTRPIP, PTRPP(5), FMC(2), SEED(5),
     4                 SEEDP, VMC(10,2), VMCP, PSCDIF(5), YBASE(5),
     5                 PYCH(5), YLDDIS
      COMMON /BINPC/  POM, PBCM, SALT, PSALT, VETC(2), PROPC(2),
     1                 PROPCC(2), PROPS(2), YFATC(2), YFATCC(2),
     2                 YFATS(2) , AVPYB, PYBCH
      COMMON / INVC/  XLIF(3), PAQ(3), PSL(3), PAQCH(3), WAGECH
      COMMON /LPAC/   A(58,42), Y(58), Z(42), C3J, X(60), JX(58),
     1                 PI(58), IOUT(4), S(100), ACT(100), NF, NRB, NRR,
     2                 NC, NCB
      IF(IYR .GT. 0) GO TO 10
C          INITIALIZE POPULATION
      ACFPOP(1) = Y(4) / 800.
      ACFPOP(2) = Y(31) / 800.
      ACHPOP = Y(56) / 800.
      GO TO 50
   10 CONTINUE
C          CROPS
C
C          DISTRIBUTED LAG FERTILIZER PRICES
      PFER = PFER + (PF-PFER)*(DT/DEL3)
      DO 20 I=1,5
      IF(I.EQ. 4) GO TO 20
C          DISTRIBUTED LAG PRODUCT PRICES
      PYC(I) = PYC(I) + (AVPYC(I)-PYC(I))*(DT/DEL3)
C          EXPECTED PRODUCT PRICES
      AVPYC(I) = AVPYC(I) + DT*PYCH(I)*AVPYC(I)
   20 CONTINUE
      PF = PF + DT*PFCH*PF
C
      PYC(4) = PYC(5)
C          BEEF PRICE
      PYB = PYB + (AVPYB-PYB)*(DT/DEL3)
      AVPYB = AVPYB + DT*PYBCH*AVPYB
C          PRICES - ACQUISITION AND SALVAGE
      DO 40 I=1,3
      PAQ(I) = PAQ(I) + DT*PAQCH(I)*PAQ(I)
   40 PSL(I) = PAQ(I) * .1
C          WAGE RATE
      WAGE = WAGE + DT*WAGECH*WAGE
   50 CONTINUE
      DO 60 I=1,5
      IF(I .EQ. 4) GO TO 60
C          INPUT-OUTPUT PRICE RATIOS
      R = PFER / PYC(I)
C          FERTILIZER APPLICATION RATES
      FERT(I) = (ALPHA(I)-R) / (2.*BETA(I))
C          YIELD RATES
      YLD(I) = YBASE(I) + ALPHA(I)*FERT(I) - BETA(I)*FERT(I)**2
C          FERTILIZER PRICES
      PFERT(I) = PFER
C          SEED PRICES
      PSEED(I) = PYC(I) + PSCDIF(I)
   60 CONTINUE
      YLD(4) = YLD(5) * (1.- YLDDIS)
      FERT(4) = 0.0
      PFERT(4) = PFERT(5)
      PSEED(4) = PSEED(5)
C          FERTILIZER PRICE - PASTURE
      PFERTP = PFER
      RETURN
      END
```

```
      SUBROUTINE LPRUN
C
C         EXECUTIVE SUBROUTINE OF RLF MODEL
C
      COMMON /CNTRLC/ DT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,
     1                IALT,LUOUT,LUIN,TIMLP,IDBG,
     2                YLOCH,WTL,WTA,WTLCH,WTACH
      COMMON /LPAC/   A(58,42), Y(58), Z(42), OBJ, X(60), JX(58),
     1                PI(58), IOUT(4), S(100), ACT(100), NR, NRB, NRR,
     2                NC, NCB
      COMMON /LPBC/   T(58), IFIX(25), TOL(5), E(60,60), EFR(4), TMP(60)
C
      CALL ASET
      CALL ZSET(Z,NCB)
C         YSET IS NOT CALLED IN THE INITIAL YEAR
      IF(IYR .EQ. 1) GO TO 20
      CALL BSET
      CALL YSET(Y,NRB,ACT,NCB)
C         SCALING
   20 IF(IDBG .EQ. 0) GO TO 25
      CALL ARPRT(A,NR,NC,1,NR,1,NC)
      CALL ARPRT(Y,1,NR,1,1,1,NR)
      CALL ARPRT(Z,1,NC,1,1,1,NC)
   25 DO 30 I=1,NC
   30 Z(I) = -Z(I)
      DO 35 I=1,NR
   35 Y(I) = Y(I) / 10000.
C         SOLVE LP MODEL
      CALL SECOND (T1)
      CALL DULPLX(A,T,Y,Z,IFIX,TOL,OBJ,X,JX,PI,E,EFR,IOUT,TMP,S)
      CALL SECOND (T2)
      TIMLP = T2 - T1
C
C         SCALING
      OBJ = - OBJ * 10000.
      DO 60 I=1,NC
   60 Z(I) = -Z(I)
      DO 70 I=1,NR
      PI(I) = -PI(I)
      Y(I) = Y(I) * 10000.
   70 X(I) = X(I) * 10000.
      NT = NR + NC
      DO 80 I=1,NT
   80 S(I) = -S(I)
C
      DO 85 I=1,NT
   85 ACT(I) = 0.
      DO 90 I=1,NR
   90 ACT(JX(I)) = X(I)
C
      IF(IOUT(1) .EQ. 1) RETURN
      CALL ARPRT(A,NR,NC,1,NR,1,NC)
      CALL ARPRT(Y,1,NR,1,1,1,NR)
      CALL ARPRT(Z,1,NC,1,1,1,NC)
      STOP
      RETURN
      END
```

```
      SUBROUTINE PPTOUT
C
C         OUTPUT ROUTINE - ANNUAL TABLES
C
      COMMON /CNTRLC/ DT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,
     1                IALT,LUOUT,LUIN,TIMLP,IDBG,
     2                YLOCH,WTL,WTA,WTLCH,WTACH
      COMMON /TXTC/   TEXTR(7,58), TEXTC(7,42), TEXTB(5,3)
      COMMON /LPAC/   A(58,42), Y(58), Z(42), OBJ, X(60), JX(58),
     1                PI(58), IOUT(4), S(100), ACT(100), NR, NRB, NRR,
     2                NC, NCB
      COMMON /LPBC/   T(58), IFIX(25), TOL(5), E(60,60), EFR(4), TMP(60)
      COMMON /ACCVAR/ AFCS(5,2),APS(2),TUAS(2),AFC(5),AP,TUA,
     1                AMFS(2),ATS(2),TAM,TAT,PAMFS(2),PATS(2),
     2                PROD3(2,2),VPR3(2),PFROD8(2),FVPR8,AYLD(4,2),
     3                SHYLD(2),STYLD(2),PRODC(4,2),TAPC(4),TPROD(4),
     4                PRAM,PRAT,TYLD(4),
     5                CFERT(5,2),EXFERT(5,2),CSEED(5,2),EXSEED(5,2),
     6                COINP(5,2),TEXP(5,2),
     7                TFERT,TVFT,TSEED,TVSD,TVCIP,TOTEXP,
     8                SLAB(2),STEC(2),SCOB(2),SOPF(2),
     9                TSLAB,TSTEC,TSCOB,TSOPF,
     A                WLAB(2),THLAB,SWG(2),THG,PWL(2),PTWL,
     B                RLHA(2),STHA(2),ROHA(2),
     C                FTLH,RTTH,PTOH,
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```
     C                  VPRC(2),FVPRC,SVFO(2),TVFO,
     D                  CAL(2),TPL(2),TCAL,TTPL,
     E                  SOBJ(2),TOBJ,STXP(2),SVAC(2),TVAD,
     F                  PDYLN(2),PDYLB(2),RPYLN,RPYLB,
     G                  SNF(2),TNF,
     H                  AGI(2),ANI(2),RAGI,RANI,
     I                  PCTI(2),PCTF(2),RPCTI,RPCTF
      ITAB = 0
C
C         RESOURCE ALLOCATION - CONSTRAINTS
C
      ITAB = ITAB + 1
      WRITE(LUOUT,100) ITAB,IALT,YEAR
      IROW = 0
      DO 10 I=1,3
      WRITE(LUOUT,101)  (TEXTB(J,I),J=1,5)
      DO 10  J=1,NPB
      IF(I.EQ.3  .AND. J.GT.NPB) GO TO 15
      IROW = IROW + 1
      USE = Y(IROW) - ACT(NC+IROW)
      WRITE(LUOUT,102) IROW,(TEXTR(K,IROW),K=1,3),T(IROW),USE,
     1     (TEXTR(K,IROW),K=4,5),ACT(NC+IROW),(TEXTR(K,IROW),K=4,5),
     2     PI(IROW),(TEXTR(K,IROW),K=6,7)
   10 CONTINUE
   15 WRITE(LUOUT,103)
C
C         RESOURCE ALLOCATION - ACTIVITIES
C
      ITAB = ITAB + 1
      WRITE(LUOUT,110)ITAB,IALT,YEAR
      ICOL = 0
      DO 20 I=1,2
      WRITE(LUOUT,101)  (TEXTB(J,I),J=1,5)
      DO 20  J=1,NCB
      ICOL = ICOL + 1
      WRITE(LUOUT,111) ICOL,(TEXTC(K,ICOL),K=1,3),ACT(ICOL),
     1     (TEXTC(K,ICOL),K=4,5),Z(ICOL),S(ICOL),
     2     (TEXTC(K,ICOL),K=6,7)
   20 CONTINUE
      WRITE(LUOUT,112) OBJ,IOUT(2),IOUT(4),TIMLP
C
C         VARIOUS OUTPUT RESULTS
C
      ITAB = ITAB + 1
      WRITE(LUOUT,120) ITAB,IALT,YEAR
      WRITE(LUOUT,121) TUAS(1), TUAS(2), TUA, ARS(1), ARS(2), AR,
     1                 ARCS(1,1), ARCS(1,2), ARC(1),
     2                 ARCS(2,1), ARCS(2,2), ARC(2),
     3                 ARCS(3,1), ARCS(3,2), ARC(3),
     4                 ARCS(4,1), ARCS(4,2), ARC(4),
     5                 ARCS(5,1), ARCS(5,2), ARC(5),
     6                 ARCS(6,1), ARCS(6,2), ARC(6)
      WRITE(LUOUT,122) AMES(1), AMES(2), TAM, PAMES(1), PAMES(2), PRAM,
     1                 ATS(1), ATS(2), TAT, PATS(1), PATS(2), PRAT
      WRITE(LUOUT,123) PROCB(2,1), PROCB(2,2), RPROCB(2),
     1                 PROCB(1,1), PROCB(1,2), RPROCB(1),
     2                 VPRB(1), VPRB(2), RVPRB
C
C         AREA, YIELD, AND PRODUCTION
C
      ITAB = ITAB + 1
      WRITE(LUOUT,130) ITAB, IALT, YEAR
      WRITE(LUOUT,131) ARCS(1,1), AYLD(1,1), PRODC(1,1),
     1                 ARCS(1,2), AYLD(1,2), PRODC(1,2),
     2                 TARC(1), TYLD(1), TPROD(1),
     3                 ARCS(2,1), AYLD(2,1), PRODC(2,1),
     4                 ARCS(2,2), AYLD(2,2), PRODC(2,2),
     5                 TARC(2), TYLD(2), TPROD(2),
     6                 ARCS(3,1), AYLD(3,1), PRODC(3,1),
     7                 ARCS(3,2), AYLD(3,2), PRODC(3,2),
     8                 TARC(3), TYLD(3), TPROD(3),
     9                 ARCS(4,1), AYLD(4,1), PRODC(4,1),
     *                 ARCS(4,2), AYLD(4,2), PRODC(4,2),
     A                 TARC(4), TYLD(4), TPROD(4)
C
C         UTILIZATION OF AGRICULTURAL INPUTS
C
      ITAB = ITAB + 1
      WRITE(LUOUT,140) ITAB,IALT,YEAR
      WRITE(LUOUT,101) (TEXTB(J,1),J=1,5)
      WRITE(LUOUT,141) CFERT(1,1), EXFERT(1,1), CSEED(1,1), EXSEED(1,1),
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```
     1           COINP(1,1),  TEXP(1,1),
     2           CFERT(2,1),  EXFERT(2,1), CSEED(2,1), EXSEED(2,1),
     3           COINP(2,1),  TEXP(2,1),
     4           CFERT(3,1),  EXFERT(3,1), CSEED(3,1), EXSEED(3,1),
     5           COINP(3,1),  TEXP(3,1),
     6           CFERT(4,1),  EXFERT(4,1), CSEED(4,1), EXSEED(4,1),
     7           COINP(4,1),  TEXP(4,1),
     8           CFERT(5,1),  EXFERT(5,1), CSEED(5,1), EXSEED(5,1),
     9           COINP(5,1),  TEXP(5,1)
      WRITE(LUOUT,101)  (TEXTR(J,2),J=1,5)
      WRITE(LUOUT,141)  CFERT(1,2),  EXFERT(1,2), CSEED(1,2), EXSEED(1,2),
     1           COINP(1,2),  TEXP(1,2),
     2           CFERT(2,2),  EXFERT(2,2), CSEED(2,2), EXSEED(2,2),
     3           COINP(2,2),  TEXP(2,2),
     4           CFERT(3,2),  EXFERT(3,2), CSEED(3,2), EXSEED(3,2),
     5           COINP(3,2),  TEXP(3,2),
     6           CFERT(4,2),  EXFERT(4,2), CSEED(4,2), EXSEED(4,2),
     7           COINP(4,2),  TEXP(4,2),
     8           CFERT(5,2),  EXFERT(5,2), CSEED(5,2), EXSEED(5,2),
     9           COINP(5,2),  TEXP(5,2)
      WRITE(LUOUT,142)TFERT,TVFT,TSEED,TVSD,TVOIP,TOTEXP
C
C        EMPLOYMENT AND INCOME
C
      ITAB = ITAB + 1
      WRITE(LUOUT,150) ITAB, IALT, YEAR
      WRITE(LUOUT,151) SLAB(1), SLAB(2), TSLAB,
     1                 STRC(1), STRC(2), TSTRC,
     2                 SORF(1), SORF(2), TSORF
      WRITE(LUOUT,152) HLAB(1), HLAB(2), THLAB,
     1                 SHG(1), SHG(2), THG,
     2                 PHL(1), PHL(2), PTHL
      WRITE(LUOUT,153) PLHA(1), PLHA(2), PTLH,
     1                 PTHA(1), PTHA(2), PTTH,
     2                 PDHA(1), PDHA(2), PTDH
     3                 ,DAL(1),DAL(2),TDAL,
     4                 TPL(1),TPL(2),TTPL
      WRITE(LUOUT,160) SVFO(1),SVFO(2),TVFO,
     1                 SOBJ(1),SOBJ(2),TOBJ,
     2                 SVAD(1),SVAD(2),TVAC,
     3                 PDYLN(1),PDYLN(2),RPYLN,
     4                 PDYLB(1),PDYLB(2),RPYLB,
     5                 AGI(1),AGI(2),RAGI,
     6                 ANI(1),ANI(2),RANI,
     7                 PCTI(1),PCTI(2),RPCTI,
     8                 PCTF(1),PCTF(2),RPCTF
  100 FORMAT(1H1,5HTABLE,I9,36H, RESOURCE ALLOCATION, CONSTRAINTS, ,
     1       11HALTERNATIVE,I4,1H,,F7.0 / 1X,92(1H-) / /
     2       T2,3HNO.,T10,4HNAME,T26,5HTYPE*,T40,10HVALUE USED,
     3       T61,5HSLACK,T82,12HSHADOW PRICE / 1X,92(1H-) )
  101 FORMAT(/,1X,5A4 / )
  102 FORMAT(I4,5X,3A4,5X,1H(,A1,1H),3X,2(-3PF12.1,1X,2A4),
     1       0PF12.2,1X,2A4)
  103 FORMAT(1X,92(1H-) /
     1       30H * (+) - LESS THAN OR EQUAL    /
     2       30H   (-) - GREATER THAN OR EQUAL /
     3       30H   ( ) - EQUAL                 )
C
  110 FORMAT(1H1,5HTABLE,I8,35H, RESOURCE ALLOCATION, ACTIVITIES, ,
     1       11HALTERNATIVE,I4,1H,,F7.0 / 1X,90(1H-) /
     2       T30,7HOPTIMUM,T49,9HOBJECTIVE,T71,8HMARGINAL /
     3       T2,3HNO.,T10,4HNAME,T32,5HVALUE,T47,11HCOEFFICIENT,
     4       T75,4HCOST / 1X,93(1H-) )
  111 FORMAT(I4,5X,3A4,-3PF15.1,1X,2A4,0PF12.2,4H CR$,3PF17.2,1X,2A4)
  112 FORMAT(1X,90(1H-) /
     1       39H MAXIMUM OBJECTIVE FUNCTION (MI CR$) =,-6PF10.2 /
     2       23H NUMBER OF ITERATIONS =,I3 /
     3       23H NUMBER OF INVERSIONS =,I3 /
     4       17H CP TIME (SECS) =, 0PF6.2 )
  120 FORMAT(1H1,5HTABLE,I8,37H, VARIOUS OUTPUT RESULTS, ALTERNATIVE,
     1       I4,1H,,F7.0 / 1X,99(1H-) /
     2       T19,4HITEM,T46,11HSMALL FARMS,T66,11HLARGE FARMS,
     3       T89,5HTOTAL / 1X,99(1H-) )
  121 FORMAT(1H0,13HLAND USE (HA),//,6X,19HTOTAL UTILIZED AREA,15X,
     1       3(F15.0,5X),/,6X,9HCROP AREA,25X,3(F15.0,5X),/,11X,
     2       4HRICE,25X,3(F15.0,5X),/,11X,4HCORN,25X,3(F15.0,5X) /
     3       11X,5HWHEAT,24X,3(F15.0,5X),/,11X,7HSOYBEAN,22X,
     4       3(F15.0,5X),/,6X,19HCULTIVATED PASTURE,16X,3(F15.0,5X),/,
     5       6X,15HNATURAL PASTURE,19X,3(F15.0,5X) )
  122 FORMAT(1H0,18HMECHANIZATION (HA),//,6X,15HMECHANIZED AREA,19X,
     1       3(F15.0,5X),/,11X,7HPERCENT,22X,3(F15.2,5X),/,
```

```
     2        6X,19HNON-MECHANIZED AREA,15X,3(F15.0,5X),/,
     3        11X,7HPERCENT,22X,3(F15.2,5X) )
 123  FORMAT(1H0,21HBEEF PRODUCTION (TON),//,
     1        6X,24HUSING CULTIVATED PASTURE,10X,3(-3PF15.0,5X),/,
     2        6X,21HUSING NATURAL PASTURE,13X,3(-3PF15.0,5X),/,
     3        6X,25HTOTAL VALUE OF PRODUCTION,9H (TH CRS),3(-3PF15.0,5X)/
     4        1X,99(1H-) )
 130  FORMAT(1H1,5HTABLE,I4,31H. AREA, YIELD, AND PRODUCTION, ,
     1        11HALTERNATIVE,I4,1H.,F7.0 / 1X,120(1H-) /
     2        T16,20HS M A L L  F A R M S,T56,20HL A R G E  F A R M S,
     3        T102,9HT O T A L, / ,
     4        3X,4HCROP,T14,4HAREA,T24,5HYIELD,T34,4HPROD,
     5        T54,4HAREA,T64,5HYIELD,T74,4HPROD,
     6        T94,4HAREA,T104,5HYIELD,T114,4HPROD, / ,
     7        T14,4H(HA),T23,7H(KG/HA),T34,5H(TON),
     8        T54,4H(HA),T63,7H(KG/HA),T74,5H(TON),
     9        T94,4H(HA),T103,7H(KG/HA),T114,5H(TON), /,1X,
     *        120(1H-) )
 131  FORMAT(1H0,/,1X,4HRICE,5X,2F10.0,-3PF10.0,2(10X,0PF10.0,0PF10.0,
     1        -3PF10.0),
     2        //,1X,4HCORN,5X,0P2F10.0,-3PF10.0,2(10X,0PF10.0,0PF10.0,
     3        -3PF10.0),
     4        //,1X,5HWHEAT,4X,0P2F10.0,-3PF10.0,2(10X,0PF10.0,0PF10.0,
     5        -3PF10.0),
     6        //,1X,7HSOYBEAN,2X,0P2F10.0,-3PF10.0,2(10X,0PF10.0,0PF10.0,
     7        -3PF10.0),
     8        //,1X,120(1H-)  )
 140  FORMAT(1H1,5HTABLE,I8,38H. UTILIZATION OF AGRICULTURAL INPUTS, ,
     1        11HALTERNATIVE,I4,1H.,F7.0 / 1X,110(1H-) /
     2        T5,14HSIZE AND CROPS,T27,19HF E R T I L I Z E R,
     3        T63,7HS E E D,T82,14HVALUE OF OTHER,T101,5HTOTAL, /,
     4        T25,8HQUANTITY,T41,5HVALUE,T55,8HQUANTITY,T71,5HVALUE,
     5        T86,6HINPUTS,T100,7HEXPEND., / ,1X,110(1H-), / ,
     6        1X,T25,7H(TH KG),T40,8H(TH CRS),T55,7H(TH KG),
     7        T70,8H(TH CRS),T85,8H(TH CRS),T100,8H(TH CRS),/)
 141  FORMAT(5X,4HRICE,11X,6(-3PF13.2,2X),
     1        /,5X,4HCORN,11X,6(-3PF13.2,2X),
     2        /,5X,5HWHEAT,10X,6(-3PF13.2,2X),
     3        /,5X,7HSOYBEAN,8X,6(-3PF13.2,2X),
     4        /,5X,13HCULT. PASTURE,2X,6(-3PF13.2,2X) )
 142  FORMAT(1H0,//,1X,14HREGIONAL TOTAL,5X,6(-3PF13.2,2X),
     1        /,1X,110(1H-) )
 150  FORMAT(1H1,5HTABLE,I8,25H. EMPLOYMENT AND INCOME, ,
     1        11HALTERNATIVE,I4,1H.,F7.0 / 1X,90(1H-),//,
     2        T13,7HI T E M,T36,11HSMALL FARMS,T56,
     3        11HLARGE FARMS,T74,14HREGIONAL TOTAL, / ,
     4        1X,90(1H-),/)
 151  FORMAT(1H ,17HLABOR USE (TH HR),12X,3(-3PF15.0,5X),/,
     1        1X,19HTRACTOR USE (TH HR),10X,3(-3PF15.0,5X),/,
     2        1X,20HDRAFT ANIMAL (TH HR),9X,3(-3PF15.0,5X),// )
 152  FORMAT(1H ,19HHIRED LABOR (TH HR),10X,3(-3PF15.0,5X),/,
     1        1X,25HVALUE WAGES PAID (TH CRS),4X,3(-3PF15.0,5X),/,
     2        1X,23HRATIO HIRED/TOTAL (PCT),6X,3(0PF15.2,5X),// )
 153  FORMAT(1H ,23HLABOR HOURS PER HECTARE,5X,3(F15.0,5X),/,
     1        1X,25HTRACTOR HOURS PER HECTARE,4X,3(F15.0,5X),/,
     2        1X,30HDRAFT ANIMAL HOURS PER HECTARE,F14.0,5X,2(F15.0,5X),
     3        / ,1X,24HDRAFT ANIMAL/LABOR RATIO,5X,3(F15.4,5X),/,
     4        1X,19HTRACTOR/LABOR RATIO,10X,3(F15.4,5X),// )
 160  FORMAT(1H ,26HGROSS FARM INCOME (TH CRS),3X,3(-3PF15.0,5X),/,
     1        1X,24HNET FARM INCOME (TH CRS),5X,3(-3PF15.0,5X),/,
     2        1X,20HVALUE ADDED (TH CRS),9X,3(-3PF15.0,5X),/,
     3        1X,26HLAND PRODUCTIVITY (CRS/HA),3X,3(0PF15.2,5X),/,
     4        1X,29HLABOR PRODUCTIVITY (CRS/HOUR),3(0PF15.2,5X),/,
     5        1X,27HGROSS INCOME PER FARM (CRS),2X,3(0PF15.2,5X),/,
     6        1X,25HNET INCOME PER FARM (CRS),4X,3(0PF15.2,5X),/,
     7        1X,26HPERCENT OF INCOME IN CLASS,3X,3(0PF15.2,5X),/,
     8        1X,25HPERCENT OF FARMS IN CLASS,4X,3(0PF15.2,5X),/,
     9        1X,90(1H-) )
      RETURN
      END
```

```
      BLOCK DATA RLPDAT
C
C          PARAMETERS FOR PLP
C
      COMMON /LPAC/   A(58,42), Y(58), Z(42), OBJ, X(60), JX(58),
     1                PI(58), IOUT(4), S(100), ACT(100), NR, NRB, NRR,
     2                NC, NCR
      COMMON /LPBC/   T(59), IFIX(25), TOL(5), E(60,60), EFR(4), TMP(60)
C
      DATA NR,NRB,NRR,NC,NCR / 58,27,4,42,21 /
C
      DATA IFIX / 58, 42, 58, 42, 1, 100, 100, 100, 1, 0,
     1            0, 1, 1, 0, 60, 42, 0, 6HBRASIL, 7*0 /
C
      DATA TOL / 1.0E-7, -1.0E-4, 1.0E-4, 1.0E-10, 1.0E6 /
C
      DATA JX /     1,   3,   4,   5,   6,   7,   9,  11,  13,  14,
     1             15,  23,  24,  25,  27,  29,  31,  32,  34,  35,
     2             36,  42,  43,  45,  47,  48,  49,  50,  51,  54,
     3             57,  59,  61,  63,  64,  65,  67,  69,  70,  72,
     4             74,  76,  77,  78,  81,  82,  84,  85,  88,  90,
     5             91,  92,  94,  96,  97,  98,  99, 100/
      END
```

```
      SUBROUTINE YSET(Y,NPB,X,NCB)
C
C          YSET UPDATES Y, THE VECTOR OF CONSTRAINTS
C
      COMMON /CNTRLC/ CT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,
     1                IALT,LUCUT,LUIN,TIMLP,ICBG,
     2                YLDCH,WTL,WTA,WTLCH,WTACH
      COMMON /BCFC/   A1, A2, BBAR, BC(21,2), BCC(6,2),
     1                BT(6), DB, KB, SB, VPT(4,6)
      COMMON /SYSVC/  ACFPOP(2), ACHPOP, PYB, PYC(5), RINT,
     1                RYLC(2), SYLC(5,2), TLANC, TLCP,
     2                WAGE, YLC(5)
      DIMENSION Y(NPB,3),X(NCB,2)
C          TOTAL AVAILABLE LANC
      TLAND = Y(1,1) + Y(1,2)
      TLAND = TLAND + (DT/DEL)*(TLCP-TLAND)
C          POPULATION
      ACFPOP(1) = ACFPOP(1) * (1.+BT(1))
      ACFPOP(2) = ACFPOP(2) * (1.+BT(1))
      ACHPOP = ACHPOP * (1.+BT(2))
C          CONSTRAINTS BY SIZE
      DO 80 I=1,2
C          LAND - SUMMER AND WINTER
      DO 10 J=1,2
   10 Y(J,I) = BCC(J,I) * TLAND
C          IRRIGATED LAND
      Y(3,I) = Y(3,I) * (1.+BC(21,I))
C          LABOR CAPACITY
      DO 20 J=4,6
   20 Y(J,I) = ACFPOP(I) * BCC(J,I)
C          TRACTOR CAPACITY
      Y(7,I) = Y(7,I) * (1.-BC(1,I)) + X(16,I) * BC(2,I)
C          COMBINE CAPACITY
      Y(8,I) = Y(8,I) * (1.-BC(3,I)) + X(17,I) * BC(4,I)
C          DRAFT ANIMAL CAPACITY
      Y(9,I) = Y(9,I) * (1.-BC(5,I)) + X(18,I) * BC(6,I)
C          BALANCE EQUATIONS
      Y(10,I) = 0.
      Y(11,I) = 0.
      Y(12,I) = 0.
      Y(13,I) = 0.
C          FLEXIBILITY CONSTRAINTS
C         RICE
      Y(14,I) = (X(1,I)+X(2,I)) * (1.+BC(7,I))
      Y(15,I) = (X(1,I)+X(2,I)) * (1.+BC(8,I))
C         CORN
      Y(16,I) = (X(3,I)+X(4,I)) * (1.+BC( 9,I))
      Y(17,I) = (X(3,I)+X(4,I)) * (1.+BC(10,I))
C         WHEAT
      Y(18,I) = (X(5,I)+X(6,I)) * (1.+BC(11,I))
      Y(19,I) = (X(5,I)+X(6,I)) * (1.+BC(12,I))
C         SOYBEANS
      Y(20,I) = (X(9,I)+X(10,I)) * (1.+BC(15,I))
      Y(21,I) = (X(9,I)+X(10,I)) * (1.+BC(16,I))
C         PASTURE - NATURAL
      Y(22,I) = X(11,I) * (1.+BC(17,I))
      Y(23,I) = X(11,I) * (1.+BC(18,I))
C         SOYBEANS AFTER WHEAT
      Y(24,I) = (X(7,I)+X(8,I)) * (1.+BC(13,I))
      Y(25,I) = (X(7,I)+X(8,I)) * (1.+BC(14,I))
C         PASTURE - CULTIVATED
      Y(26,I) = (X(12,I)+X(13,I)) * (1.+BC(19,I))
      Y(27,I) = (X(12,I)+X(13,I)) * (1.+BC(20,I))
   80 CONTINUE
C          REGIONAL CONSTRAINTS
C          SUPPLY OF TRACTORS
      Y(1,3) = Y(1,3) * (1.+BT(6))
C          WAGE LABOR
      DO 90 I=2,4
   90 Y(I,3) = ACHPOP * BCC(4,1)
      RETURN
      END
```

```
      SUBROUTINE ZSET(Z,NCB)
C
C          ZSET COMPUTES THE OBJECTIVE FUNCTION COEFFICIENTS
C
      COMMON /CNTRLC/  DT, DEL, DEL3, IYR, NYR, YEAR, YEAR0,
     1                 IALT,LUOUT,LUIN,TIMLP,IDBG,
     2                 YLDCH,WTL,WTA,WTLCH,WTACH
      COMMON /CINPC/   ALPHA(5), AVPYC(5), BETA(5), CINP(5), CINPP(2),
     1                 FERT(5), FERTP, PF, PFCH, PFER, PFERT(5),
     2                 PFERTP, POI(5), OINP(5), PSEED(5), PSEEDP,
     3                 PTRPI(5), PTRPIP, PTRPP(5), RMC(2), SEED(5),
     4                 SEEDP, VMC(10,2), VMCP, PSCDIF(5), YBASE(5),
     5                 PYCH(5), YLDDIS
      COMMON /BINPC/   BOM, PBOM, SALT, PSALT, VETC(2), PROPC(2),
     1                 PROPCC(2), PROPS(2), YFATC(2), YFATCC(2),
     2                 YFATS(2) , AVPYB, PYBCH
      COMMON / INVC/   XLIF(3), PAQ(3), PSL(3), PAQCH(3), WAGECH
      COMMON /SYSVC/   ACFPOP(2), ACHPOP, PYB, PYC(5), RINT,
     1                 RYLD(2), SYLD(5,2), TLAND, TLCP,
     2                 WAGE, YLD(5)
      DIMENSION Z(NCB,2)
C          SIZE (1-SMALL, 2-LARGE)
      DO 90 I=1,2
C          CROP ACTIVITIES      (J-CROP,  K-TRAD(1)/MOD(2) )
      DO 20 J=1,5
      DO 20 K=1,2
      JSUB = 2*(J-1) + K
   20 Z(JSUB,I) = YLD(J) * (1.+SYLD(J,I)) * (1.+RYLD(K)) * PYC(J)
     1           - (PFERT(J)*FERT(J) + PSEED(J)*SEED(J)
     2           + PTRPI(J)*(FERT(J)+SEED(J)) + PTRPP(J)*(YLD(J)*
     3           (1.+SYLD(J,I))*(1.+RYLD(K))) + POI(J)*OINP(J)
     4           + VMC(JSUB,I) + CINP(J)) * (1.+0.5*RINT)
C          PASTURE ACTIVITIES
      Z(11,I) = -(RMC(1) + CINPP(1)) * (1.+.5*RINT)
      Z(12,I) = -(RMC(2) + CINPP(2) + PFERTP*FERTP + PSEEDP*SEEDP +
     1           PTRPIP*(FERTP+SEEDP)) * (1.+.5*RINT)
      Z(13,I) = Z(12,I) - VMCP * (1.+0.5*RINT)
C          BEEF ACTIVITIES
      Z(14,I) = (PROPS(1)*YFATS(1) + PROPC(1)*YFATC(1) + PROPCC(1)
     1           *YFATCC(1)) * PYB - (PBOM*BOM + PSALT*SALT + VETC(1))
     2           * (1.+.5*RINT)
      Z(15,I) = (PROPS(2)*YFATS(2) + PROPC(2)*YFATC(2) + PROPCC(2)
     1           *YFATCC(2)) * PYB - (PBOM*BOM + PSALT*SALT + VETC(2))
     2           * (1.+.5*RINT)
C          INVESTMENT ACTIVITIES
      DO 40 J=1,3
   40 Z(J+15,I) = -((PAQ(J)-PSL(J))/XLIF(J)+(PAQ(J)+PSL(J))*
     1           .5*RINT)
C          LABOR ACTIVITIES
      DO 50 J=19,21
   50 Z(J,I) = -WAGE
C
   90 CONTINUE
C
C          PRICING-OUT ACTIVITIES WITH TRADITIONAL TECHNOLOGY
C
      DO 120 I=1,2
      DO 100 J=1,9,2
      Z(J,I) = -0.1000E+20
  100 CONTINUE
      Z(12,I) = -0.1000E+20
  120 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE ARPRT (ARRAY,MM,NN,MLC,MHI,NLC,NHI)
      DIMENSION ARRAY (MM,NN), TEMP(8),INDEX(8)
C
C               THIS ROUTINE IS DESIGNED TO PRINT OUT
C               SELECT NONZERO PORTIONS OF A GIVEN ARRAY
C
      INTEGER TAPE6
      DATA TAPE6 /6/
      WRITE (TAPE6,1001)
      DO 300 I=MLC,MHI
      WRITE (TAPE6,1002) I
      K = 0
      DO 200 J = NLC,NHI
      IF (ARRAY(I,J)) 100,200,100
  100 K = K + 1
      TEMP(K) = ARRAY(I,J)
      INDEX(K)=J
      IF (K-8) 200,150,150
  150 WRITE (TAPE6,1003) (INDEX(L),TEMP(L),L=1,K)
      K = 0
  200 CONTINUE
      IF (K) 300,300,250
  250 WRITE (TAPE6,1003) (INDEX(L),TEMP(L),L=1,K)
  300 CONTINUE
      RETURN
 1001 FORMAT (1H1,50X,32HMATRIX PRINT OF NONZERO ELEMENTS)
 1002 FORMAT (1H ,3HROW,I5)
 1003 FORMAT (8(1X,I3,1H),G11.4))
      END
```

```
      FUNCTION TABEL(VAL, K, SMALL, DIFF, XARG)
C DELLAPATIONS
      DIMENSION VAL(K)
C
C EXECUTION
C
      DUM = XARG - SMALL
      IF(DUM.LT.0.) DUM = 0.
      IF(DUM.GT.FLOAT(K-1)*DIFF) DUM = FLOAT(K-1)*DIFF
      I = 1. + DUM/DIFF
      IF(I.EQ.K) I = K-1
      TABEL = VAL(I) + ((VAL(I+1)-VAL(I))/DIFF)*(DUM-FLOAT(I-1)*DIFF)
C
      RETURN
      END
```