AN ECONOMIC MODEL FOR ESTABLISHING PRIORITIES FOR AGRICULTURAL RESEARCH AND A TEST FOR THE BRAZILIAN ECONOMY

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ABSTRACT

Ramalho de Castro, José Prazeres. Ph.D., Purdue University, May 1974. AN ECONOMIC MODEL FOR ESTABLISHING PRIORITIES FOR AGRICULTURAL RESEARCH AND A TEST FOR THE BRAZILIAN ECONOMY. Major Professor: G. Edward Schuh.

The potential contribution of technical change to agricultural development has been recognized for some time now. However, it has only recently been fully appreciated that technical change can take alternative routes in its resource-saving effects, and that the particular route that it takes is conditioned by relative factor scarcities.

Increasing attention is being given to the problem of the management of research resources, and to the importance of allocating such resources according to criteria or some sense of priority. More particularly, policy-makers in Brazil have been giving more attention to agricultural research and to the importance of a sense of priorities in carrying out such research. Therefore, the search for criteria by means of which scarce research resources might be allocated should assist policy-makers as well as research managers.

The specific objectives of the present study were to: (1) develop an analytical framework which provides a basis for establishing agricultural research priorities, (2) develop empirical models which contain the relevant parameters and

which can be estimated from available data, or for which parameters can be taken from other sources, (3) estimate the appropriate parameters, determine changing resource scarcities, and evaluate recent technical change in Brazil, (4) draw implications and make recommendations for the allocation of research resources in Brazil.

The analytical framework is based on the concepts of consumers' and producers' surplus, on the theory of the functional distribution of income, and on a two-sector general equilibrium model. The surplus concepts provide a means of evaluating the extent to which a gain from a technological change is divided among consumers and producers. The neoclassic theory of the functional distribution of income is extended to allow an analysis for four factors of production. This is done by using a two-level production function. The two-sector general equilibrium model was developed in order to permit an analysis of the adjustment process in the factor market as well as the trends in factor shares, given a technological change in one of the sectors.

To estimate the consumers' and producers' as well as total gain the empirical model developed contains the price elasticities of demand and supply and a supply shifter as the basic parameters. Estimates of the elasticities were taken from secondary sources, while the shift in the supply function was arbitrarily set at 10 percent.

The relevant parameters for analyzing changes in the functional distribution of income are the price elasticity of demand and the elasticities of substitution. The latter was estimated through the reduced form of a two-level CES production function. Two sets of data were used for this purpose, one consisting of cross-sectional data and the other consisting of time series data.

The estimation with the time series data suggests a turning point in technology in the 1960's. The trend in the rental price of land relative to the price of labor suggests that land has become scarce relative to labor.

Six crops were selected for analysis -- cotton, sugar-cane, corn, rice, edible beans, and manioc (cassava). They accounted for 46 percent of total output from crops, and 74 percent of the total area in crops in the period 1966/1970. Cotton and sugar-cane have been exported consistently, corn and rice occasionally. Edible beans have been produced exclusively for the domestic market, while manioc in recent years appears to have a potential foreign demand.

The estimation of consumers' and producers' surpluses indicates that the consumers benefit more relative to the producers when the price elasticity of demand is low and the price supply elasticity is high, and vice-versa. The total gain increases as both elasticities increase.

The policy implications of the empirical findings have to be derived in terms of the goals established by the

policy-makers. By way of an example, if products with a low price elasticity of demand, such as corn and rice, are chosen to receive the bulk of research, the findings suggest the highest gross flow of benefits among any combination of two of the crops selected. On the other hand, the consumers will benefit more relative to the producers if research is directed to these products, technical change will have a regressive effect on labor income, and a reallocation of labor from the agricultural sector to the non-agricultural sector will be expected.

More extensive policy recommendations are made in the text, with the recommendation based on alternative sets of policy goals.

CHAPTER I

INTRODUCTION

Determining the sources of economic growth continues to be an important economic problem. Technical progress has been recognized as one of the important sources of economic growth because of the increases in efficiency or productivity of conventional resources that is associated with it. Herr[1/], for example, has pointed out that between 1930 and 1960 about 85 percent of the increase in labor productivity in United States agriculture was due to technical change, while 15 percent resulted from capital deepening in the conventional sense.[2/] Hayami and Ruttan[3/], on the other hand, have recently focused attention on the disequilibrium which exists in world agriculture. They explain 55 percent of the productivity gap between developed countries and less-developed countries by differences in technology and human capital.

[1/] Herr, W.McD., "Technological Change in the Agriculture of the United States and Australia," J.F.E. 48(2):264-271, May 1966.

[2/] Technical change in its broadest sense also represents capital deepening, but in many respects in the form of human capital. Herr's reference to capital deeping is in the traditional sense of physical capital.

[3/] Hayami, Y. and V. Ruttan, Agricultural Development: An International Perspective, Maryland, Johns Hopkins Press, 1971.

The relative importance of agricultura in most low-income countries and/or regions is apparent, since from 50 to 80 percent of the labor force in those countries is engaged in agricultural activities and from 40 to 60 percent of the GNP comes from this sector. This suggests that agriculture can, or in many cases will have to be, a major source of the resources for the expansion of the non-farm sector of the economy. Improvements in the productivity of agricultural resources will enable agriculture to contribute to the economic development of the country and/or to the development of regions within a country. Hayami and Ruttan[1/], in their recent important contribution to the agricultural development literature, had as their central proposition "that an efficient economic development strategy, particularly during the early stages of economic growth, depends critically on the achievement of rapid technical change, leading to productivity growth in agriculture."

The Role of Technical Change in Agriculture And Its Income Distribution Effects

Kaldor[2/] has recently observed that "the demand for new knowledge is derived from the contribution it is expected to

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1/ Hayami, Y. and V. Ruttan, op. cit., p. 2.

2/ Kaldor, Donald R., "Social Returns to Research and the Objectives of Public Research," in Walter L. Fishel (ed.), Resource Allocation in Agricultural Research, Minneapolis, University of Minnesota Press, 1971.

make to the achievement of individual and collective goals or to the solution of private and public problems." If one accepts this proposition, new technology is treated as an input in the development process, and not as an end in itself. Moreover, technology is seen to have an instrumental role in attaining a larger set of goals and objectives.

One way to understand the importance of technical change in agriculture as a basis for economic development is to consider the role of agriculture in economic development.[1/] It is generally recognized that agriculture has at least five major roles to play in the course of economic development: (1) to supply food for the total population; (2) to supply capital to the economy, especially for expansion of the nonfarm sector; (3) to supply labor for the expansion of non-farm activities; (4) to supply exchange earnings in order that inputs critical to the development process can be purchased from abroad; and (5) to provide a market for the products of the non-farm sector.[2/] Technological change has been recognized as a powerful means of strengthening agriculture in regard to each of these factors.

[1/] One could speak of the contribution of agriculture to economic development instead of its role. However, we prefer to put the emphasis on the role of agriculture, following Schuh, who has observed that "by referring to the role of agriculture rather than its contributions we stress the interrelation and interaction between the farm and non-farm sectors, and perhaps avoid developing an agricultural fundamentalist syndrome." See, Schuh, G.E., Lecture Notes on Agricultural Development, Department of Agricultural Economics, Purdue University, 1972 (mimeo).

[2/] For a more detailed discussion of these roles, see Schuh, G.E., op. cit., Chapter II.

Technical progress in all its aspects is difficult to define and to measure precisely, but its essential quantitative characteristic is to shift the production function (embodying all previously known techniques), thereby enabling greater output to be produced with the same volume of conventional inputs, or the same output with fewer inputs.[1/] Clearly, if all of the increase in agricultural output has to come from increases in traditional inputs, i.e., more land and/or labor, it is unlikely that the agricultural sector could make a significant contribution to general economic development. Moreover, it should be noted that there are conflicts between some of the roles of agriculture as described above. For example, if all of the agricultural surplus[2/] is siphoned off as capital for the nonfarm sector, there is not much potential left for agriculture as a market for goods and services produced by the non-farm sector. Hence, if the government uses some device to take away the producer surplus from the agricultural sector to expand the nonfarm sector, there will be less income left in that sector to buy goods and services from the nonagricultural sector.

[1/] Kennedy, Charles and A.P. Thirlwall, "Surveys in Applied Economics: Technical Progress," The Economic Journal, 82(325): 11-72, March 1972.

[2/] An agricultural surplus is here defined in the Nicholl's sense of the difference between agricultural output and the consumption of the agricultural population. See Nicholls, W.H., "An 'Agricultural Surplus' as a Factor in Economic Development," Journal of Political Economy 71(1): 1-29, February 1963.

However, at a given point in time the critical contributions which agriculture can make to the general development of the economy can be identified. Four alternative sets of goals may be specified for the agricultural sector according to the stage of development of the economy, the particular development model the government is implemementing, and the specific economic policies it uses to implement this model. These sets of goals include: (1) to increase the total net income of the agricultural sector, (2) to increase employment and the income of labor employed in the agricultural sector, (3) to increase consumer welfare by providing food at lower real prices, and (4) to maximize the contribution of agriculture to the growth of the economy as a whole.

To accomplish each of these goals requires different kinds of technical change, which in turn have different income distribution impacts. But Bonnen[1/] has recently observed that (unfortunately) we know very little about the process by which technological change works its distributional effects, and seem to be greatly deficient in institutional arrangements to contend with the problem.

[1/] Bonnen, James T., "The Absence of Knowledge of Distributional Impacts: An Obstacle to Effective Policy Analysis and Decision," in Haveman, Robert H. and Julius Margolis (Eds.) The Analysis and Evolution of Public Expenditures: The PPB-System, Chicao, Markham Pub. Co., 1970.

Equity considerations arise when investments in research and development are made, since they are believed to have a great deal to do with the distribution of future economic growth by geographic region, as well as the functional distribution of income within the society.[1/] Historically, market economies have tended to allow market forces to determine the answers to the question of who will benefit from a new idea or technology.[2/] However, rising levels of conflict suggest that the distributional consequences of this approach are less and less acceptable to society. And as Mrs. Robinson[3/] has pointed out, some political element will ultimately be added to the distribution of bargaining power.

The impact of factor reallocation due to technical change on the distribution of income may be analyzed by means of theory which explains the functional distribution of income and the distribution of economic surplus among consumers and producers. The theory which explains the function distribution of income explains the distribution of income among the factors of production and provides inferences about changes to be expected in factor employment.

[1/] DeJanvry has argued that the higher the rate of technical change and the less developed the protective institutions of a country the greater the socially undesirable external effects of change and, in particular, the greater the potential regressive income effects. See DeJanvry, Alain, "Welfare Implication of Alternative Technological Paths in Agriculture," Ford Foundation Seminar of Program Advisors in Agriculture, Mexico City, November 1972.

[2/] An important exception arises when the government grants patents and permits the licensing of franchises in order to exploit particular technological innovations.

[3/] Robinson, Joan, "The Second Crisis of Economic Theory," AER 62(2): 1-10, May 1972.

However, the final question that must be answered if we are to have any hypothesis about how technology affects the individual is how the functional distribution of income is related to the size distribution of income. The size distribution is mainly a function of the distribution of productive assets (human and non-human capital) among the population. Thus, with the evidence that the distribution of ownership of land and capital is more unequal than that of labor incomes, we can surmise that any change which is detrimental to the share and employment of labor will make the size distribution more unequal.

This suggests that the government of any low income country which is devising a development model and the specific economic policies to implement that model should be aware that at the same time that it is investing in research and development it should also be strengthening protective institutions in order to avoid the undesirable external effects of technological change. To devise such policies requires some knowledge of the expected consequences of technical change. This in turn requires knowledge of the particular direction which technical change is taking or is expected to take as development proceeds.

The Problem

The potential contribution of technical change to agricultural development has been recognized for some time now.[1/] However, it has only recently been fully appreciated that technical change can take alternative routes in its resource-saving effects, and that the particular route that it takes is conditioned by relative factor scarcities.[2/] This immediately implies the concept of an efficient path for technical change, and suggests the importance of allocating scarce research resources in such a way as to direct

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1/ Important contributions to the literature include Schultz, Theodore W., The Economic Organization of Agriculture (New York: McGraw-Hill, 1953), especially Chapter 7; Ruttan, Vernon W., "The Contribution of Technological Progress to Farm Output: 1950-75," Review of Economics and Statistics 38(1):61-69, February 1956; Griliches, Zvi, "The Sources of Measured Productivity Growth: United States Agriculture, 1940-60," Journal of Political Economy, 71(4):331-346, August 1963; Griliches, Zvi, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," American Economic Review 54(6): 961-974, December 1964; Schultz, Theodore W., Transforming Traditional Agriculture (New Haven: Yale University Press, 1964); and Hayami, Yujiro and Veron W. Ruttan; Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971).

2/ Hicks, J.R., of course, was one of the first economists to examine this issue in some detail. (See The Theory of Wages (London: Macmillan and Co., Ltd., 1964)(originally published in 1932). Hicks cast his analysis at the firm level. However, Hayami and Ruttan have recently reactivated the Hicksian notion and applied it at the macro level to the agricultural sector. See Hayami, Yujiro and Veron W. Ruttan, op. cit.. Other important contributions to the theory of induced technical change include Ahmad, S., "On the Theory of Induced Invention," Economic Journal, 76(302): 344-357, June 1966; Kennedy, C., "Induced Bias in Innovation and the Theory of Distribution," Economic Journal, 74(295):541-547,

technical change along such an economically efficient path.[1/]

Although the notion of an efficient path for technical change (in the resource dimension) can serve as an important basis for allocating research resources, it alone is not sufficient. As noted above, technical change has important income distribution consequences. For one thing, the extent to which its benefits redound to the consumer or to the producer depends importantly on the conditions of demand and supply for the product.[2/] In addition, the extent to

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[2/] (continued) September 1964; Samuelson, Paul A., "A Theory of Induced Innovation Along Kennedy-Weisacker Lines," Review of Economics and Statistics, 47(4):343-356, November 1965; Fellner, William, "Two Propositions in the Theory of Induced Innovation," Economic Journal, 71(282);305-308, June 1961; and deJanvry, Alain, "A Socioeconomic Model of Induced Innovation," The Quarterly Journal of Economics, 87(30:410-435, August 1973.

[1/] Hayami and Ruttan put it quite succinctly in the following statements: "We identify the capacity to develop technology consistent with environmental and economic conditions as the single most important variable which explains the growth of agricultural productivity of nations." (pxiii) "Successful achievement of continued productivity growth over time involves a dynamic process of adjustment to original resource endowments and to resource accumulation during the process of historical development." (p 4) "A continuous sequence of technical and institutional innovations to create and evolve a pattern of agricultural production consistent with changes in product demand and factor supply conditions can sharply reduce the cost of increased income streams generated by the agricultural sector." (p. 302). See Hayami and Ruttan, op. cit.

[2/] For a recent attempt to understand who the beneficiaries of a successful agricultural research effort were, see Ayer, Harry W. and G. Edward 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, November 1972.

which the benefits that do redound to the producer are distributed among particular factors of production will depend on both the "direction" which the technical change is taking (in the resource-resource dimension) and the conditions of demand and supply in the individual factor markets.[1/]

The problem to which the present study is addressed is the development and testing of a model which would provide a basis for establishing priorities for agricultural research. If such a model can be developed and successfully implemented, it will provide a basis for making more efficient use of scarce research resources, and in turn enable the resulting technical change to make a larger contribution to agricultural and economic development.

Importance of the Problem

Increasing attention is being given to the problem of management of research resources, and to the importance of allocating such resources according to specified criteria or to some sense of priority.[2/] This increasing concern is

[1/] See Ayer and Schuh, op. cit., for example.

[2/] For an important recent contribution, see Fishel, Walter L. (ed.), Resource Allocation in Agricultural Research (Minneapolis: University of Minnesota Press, 1971). (This source contains references to much of the relevant literature.) Hayami and Ruttan note that "The body of knowledge relating to the organization and management of agricultural research is, if anything, even weaker than the body of research results available to agricultural producers in the less developed countries." Hayami and Ruttan, op. cit., p. 289.) In addition to the Fishel reference, cited above, other useful sources include Blase, M.G.(ed.) Institutions in Agricultural Development (Ames: Iowa State Univ. Press, 1971); Moseman, A.H.(ed.) Agricultural Services for the Developing Nations (Washington: American Association for the Advancement of Science, Publication No. 76, 1964); and Moseman, A.H., Building Agricultural Research Systems in the Developing Nations (New York: Agricultural Development Council, Inc., 1970).

probably in part a result of the growing recognition that the research activity is indeed an economic activity to be organized. But in addition, it probably reflects as well the growing consensus that technical change is a key element or input in the development process and that resources for this purpose are scarce.

The problem takes on particular importance in Brazil, the country to which the proposed model is immediately directed, and from which data will be drawn to test and implement it. Brazil is a country that -- like many other low-income countries -- has probably under-invested in agricultural research. As a result the growth of its agricultural sector has largely been based on the incorporation of additional conventional inputs such as land and labor into the production process.[1/]

One consequence of following the particular development model that Brazil has pursued is that resource productivity in the agricultural sector is low by international standards. This causes factor returns to be low, with the result that the bulk of poverty in the Brazilian economy is concentrated in the agricultural sectors.[2/]

[1/] For an anlysis of the post-World War II development of the Brazilian agricultural sector, see Schuh, G. Edward, The Agricultural Development of Brazil (New York: Praeger Publishers, 1970).

[2/] See Fishlow, Albert, "Brazilian Size Distribution of Income," American Economic Review 62(2):391-402 May 1972, and Langoni, Carlos G., Distribuicao da Renda e Desenvolvimento Economico do Brasil (Rio de Janeiro: Editora Expressao e Cultura, 1973).

However, Brazil appears to be changing the development model for its agricultural sector.[1/] The rapid economic development of the general economy in the last six years, combined with a sizable step-wise devaluation which brought the exchange rate closer to equilibrium, has caused the demand for agricultural output to increase faster than supply has been able to increase by conventional means.[2/] The result is a shift in the intersectoral terms of trade in favor of agriculture (Table 1), and a growing fear that agriculture might become a "brake" on continued rapid economic development.

The recognition of this problem has caused policy makers to give increased attention to agricultural research. One aspect of this policy shift was to negotiate a loan from the United States government in the amount of approximately $12

[1/] It should be noted that development policy has not been univariant in any case. The state of Sao Paulo in Brazil has historically invested rather heavily in agricultural research and extension, with the result that it has developed a reasonably modern agricultural sector. For data on this important agricultural state, see Institute of Agricultural Economics, The Development of Paulista Agriculture (Sao Paulo: Secretariat of Agriculture, 1973). For an attempt to understand why it was that the state of Sao Paulo invested relatively heavily in agricultural research and extension, while these investments were neglected in the rest of Brazil, see Schuh, G. Edward, "The Modernization of Brazilian Agriculture," Department of Agricultural Economics, Purdue University, 1973 (mimeographed).

[2/] For an analysis which suggests that continued rapid economic growth in Brazil is likely to impose unusual demands on the agricultural sector, see Schuh, G. Edward, O Potential Para Crescimento da Agricultura Brasileria: Algumas Alternatives e Suas Consequencias (Brasilia: EAPA/SUPLAN,

Table 1. Indices of Real Wholesale Agricultural Prices and the Ratio of Agricultural to Industrial Prices, Brazil, 1960/1972 (1965/1967 = 100).

Year	Index of Real Wholsale Agricultural Prices	Ratio of Agricultural to Industrial Prices
1960	107	106
1961	105	100
1962	111	110
1963	105	100
1964	110	108
1965	99	96
1966	102	103
1967	99	102
1968	94	91
1969	98	92
1970	101	102
1971	105	109
1972	110	114

Source: Fundacao Getulio Vargos, Conjuntura Economica, 27(12): 2-3, December, 1973.

million to strengthen its Federal agricultural research system.[1/] A second aspect was the complete reorganization of the Federal research service, with the creation of a public company, EMBRAPA,[2/] which has considerable administrative autonomy and flexibility, and an edict from policymakers to get on with the job at hand. And finally, increased resources have been allocated to agricultural research from domestic sources, and an attempt is being made to recruit additional resources for research support from international funding agencies such as the International Bank for Reconstruction and Development.

Of special importance in the context of the present study is the sense of priority and the search for criteria by means of which the scarce research resources might be allocated. EMBRAPA has had a strong planning emphasis from its very beginning, and one of its first activities in "staffing up" was to bring in a small group of economists to

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[2/](continued) Ministerio de Agricultura, 1973). (Also available in English as "The Growth Potential of Brazilian Agriculture: Some Alternatives and Their Consequences," Department of Agricultural Economics, Purdue University, 1973).

[1/]In using these loan funds the first serious attempt to establish research priorities for agriculture was made. However, the criteria were based for the most part on a consideration of product market considerations.

[2/]Empresa Brasileira de Pesquisa Agropecuaria (Brazilian Company of Agricultural Research).

do the analysis which might lead to a more efficient use of resources. This suggests that research which might throw light on research priorities and indicate the resource-saving direction which technical change should take might have a ready acceptance.

Objectives and Procedures

The general objective of the study is to develop and apply empirically a model that can serve as a basis for establishing priorities for agricultural research. This general objective will be attained by means of the following specific objectives:

1. To develop an analytical framework which provides a basis for establishing agricultural research priorities.
2. To develop empirical models which contain the relevant parameters and which can be estimated from available data, or for which parameters can be taken from other sources.
3. To estimate the appropriate parameters, determine changing resource scarcities, and determine the nature of recent technical change in Brazil.
4. To draw implications and make recommendations for the allocation of agricultural research resources in Brazil, with the goal of contributing to the derivation of an appropriate technology policy for the agricultural sector.

The analytical framework is derived for the most part from neoclassical economic theory. However, it draws heavily on recent models of induced technical change, especially as evolved by Ahmad[1/] and deJanvry[2/], on concepts of producer and consumer surplus, and on income distribution theory. The analysis of the income distribution problem is also cast in a general equilibrium framework.

The bulk of the estimation work reported here has to do with a two-stage, separable production function. This particular specification permits the elasticity of substitution to vary among input categories -- a characteristic which is important for the particular model of induced technical change that is used as a basis for the analysis.

The underlying production function is estimated with both cross-sectional and time-series data. The cross-sectional data are taken from the 7-state survey that was made by the Fundacao Getulio Vargas in 1962-63.[3/] The time series data are drawn from regular official sources in Brazil. Data sources for purposes other than the estimation

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[1/] See Ahmad, op. cit.

[2/] See deJanvry, Alain, op. cit.

[3/] The data tape containing this survey data has been graciously provided to the Department of Agricultural Economics, Purdue University by the Fundacao.

of the production function are also drawn from regular government organizations.

Review of Literature

Attempts to come to grips in a systematic way with the problem of establishing research priorities have been fairly limited, and for the most part are of fairly recent vintage. An important point of departure in the recent literature was the Minnesota Symposium, which brought together specialists with rather widely different perspectives and experiences to discuss problems of resource allocation in research and the various kinds of "planning" models that might be used to establish research priorities.[1/] Tweeten, who was a participant in that conference, noted that "It is ironic and a little perplexing that while we continue to search for the science of economics, we now are called to search for the economics of science. Our analytical tools are primarily intended for problems of allocation and growth where a pricing system operates."[2/] This statement implies that an analytical framework for the evaluation of research priorities

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[1/] The papers from the Minnesota Symposium are reported in Fishel, Walter L. (ed.), Resource Allocation in Agricultural Research (Minneapolis: University of Minnesota Press, 1971). This collection is highly recommended as a starting point for the interested reader. It contains empirical and analytical papers which examine the economic aspects of research, methodological papers which examine how the priority question might be analyzed, and descriptions of decision-making in practice as well as various decision-making experiments.

[2/] Tweeten, Luther G., "The Search for a Theory and Methodology of Research Resource Allocation," in Walter L. Fishel

must be so devised that price signals are not the only basis for guidance.

Schuh[1/] wrote with the benefit of the Minnesota Symposoum as a background, and attempted to make a comprehensive analysis of the research priority question. He took the broad social goals of growth, equity, and security as starting points and attempted to arrive at operational sets of goals in terms of which individual research projects could be evaluated. The growth goal was analyzed through a consideration of the product market, the factor markets, and factor-product interactions. An analysis of the equity goal was made by discussing four important issues: (1) the distribution of the benefits of technical change between the producer and consumer; (2) the functional distribution of income among the factors of production; (3) the distribution of the benefits among various size groups of farms; and (4) the impact on the regional distribution of income within the country. Finally, security was discussed in terms of the reduction in risk and uncertainty.

The benefits to society from research have generally been assumed implicitly. However, many observers argue that the nature of these benefits has not been made sufficiently

[2/] (continued) (ed.), Resource Allocation in Agricultural Research (Minneapolis: University of Minnesota Press, 1971), p. 25.

[1/] Schuh, G. Edward, "Some Economic Considerations for Establishing Priorities in Agricultural Research," Ford Foundation Seminar of Program Advisors in Agriculture, Mexico City, November 1972.

explicit. Tichenor and Ruttan[1/], for example, argue that popular support for agricultural research cannot be expected to continue on the basis of the old "theology of science." They point out two reasons for the need to rationalize what they call the science of tomorrow. First, public and private decision-makers need relevant, meaningful cost indicators for research that promises to help attain certain specifiable ends. Second, not all research leads to socially desirable outcomes.

Ayer[2/] reviewed the literature on the cost, returns, and rate of return to investment in agricultural research and found that there were three basic frameworks of analysis. One approach was to utilize an aggregate production function in which expenditures on research, or on research plus education and extension, are included explicitly in the input set. The second approach was to assume that the aggregate supply function for the product in question is shifted downward in proportion to the change in productivity arising from agricultural research on that product. And finally,

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[1/] Tichenor, Phillip Y. and Vernon W. Ruttan, "Problems and Issues in Resource Allocation for Agricultural Research," in Walter L. Fishel (ed,), Resource Allocation in Agricultural Research, op. cit., pp. 3-22.

[2/] Ayer, Harry W., "The Cost, Returns, and Effects of Agricultural Research in a Developing Country: The Case of Cotton Seed Research in Sao Paulo, Brazil," Unpublished Ph.D. thesis, Purdue University, 1970.

regression analysis has been used to determine the relationship between research and education in the agricultural sector and the "residual" or unexplained agricultural output. Ayer used the second approach in his research, but then went on to evaluate who the beneficiaries of technical change were.[1/]

The fact that the return to research has been found to be high in previous studies does not preclude consideration of the allocation of research resources among alternatives. Schultz[2/] analyzed the problem of the non-profit allocation of research resources by casting the problem in a framework of the supply and demand of technology. He stressed the importance of consumers' surplus, which was omitted in his analysis by virtue of the lack of information, and stated: "Economic theory is not lacking, but empirical analysis is wanted."

Shumway[3/] has recently made a selective survey of methodological developments for the selection of research

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[1/] For a report of these findings see Ayer, Harry W. and G. Edward Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," AJAE, 54(4): 557-569, November 1972.

[2/] Schultz, T.W., "The Allocation of Resources to Research," in Walter L. Fishel (ed.), Resource Allocation in Agricultural Research, op. cit., pp. 90-120.

[3/] Shumway, C. Richard, "Allocation of Scarce Resources to Agricultural Research: Review of Methodology," AJAE, 55(4): 557-566, November 1973.

projects and resource allocation. What he describes for the most part are ranking and optimization methods. However, he stated that no optimization models have yet been developed for the allocation of agricultural research resources.

Finally, two additional references are important, not so much because of their relation to the present study, but because they illustrate other classes of approaches to handling the decisions associated with agricultural research. Havlicek and Seagraves[1/] elaborated a model by means of which they could evaluate the cost of not having greater precision in fertilizer research. The basis of their analysis was a response equation, and their goal was to provide decision-makers with guides as to the value of certain types of knowledge. They extended the model in order to compute the value of more precise estimates of single factors that affect production such as prices, weather, and the production function. However, they recognized that to estimate gains from research to farmers and society the elasticity of demand should be taken into account.

Anderson and Dillon[2/] worked along somewhat similar lines, and also at the micro level. They developed a model

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[1/] Havlicek, Jr., Joseph and James A. Seagraves, "The 'Cost of the Wrong Decision' as a Guide in Production Research," JFE 44(1): 157-168, February 1962.

[2/] Anderson, J.R. and John L. Dillon, "Economic Considerations in Response Research," AJAE 50(1): 130-142, February 1968.

to evaluate investments in response research by using essentially a Bayesian decision model. The analysis was conducted in a framework in which the knowledge of a process is viewed in terms of the expected value and the variance of profits.

The above review of literature is by no means exhaustive. However, it does draw out some of the major premises on which the present study is predicated, and thereby shows how the research reported herein is related to the ideas of previous author's in the field. The conceptual model of the present study is an attempt to delineate the economic factors that might be considered in establishing research priorities, given that with the existing state of knowledge it is not likely that a formal decision model could be effectively implemented, especially at the macro level. This model streses the gross flow of benefits from technical change, while at the same time recognizing the importance of knowing more about the role of factor endowments and other economic considerations in determining the kind of technical change that a society should foment, and the importance of considering income distribution consequences when establishing research priorities. The empirical results which are reported attempt to respond to earlier appeals for more empirical work, and are evaluated in such a way as to recognize the importance of particular goals or sets of goals that policy-makers may have.

Organization of the Remainder of the Thesis

Chapter II contains an analytical framework that will serve as the basis for the empirical work and the economic analysis which is to follow. In Chapter III empirical models are specified which provide the means by which data can be brought to bear on the problem. The empirical results are reported in Chapter IV, and the economic and policy implications of these results are discussed in Chapter V. Chapter VI contains a summary, a review of principal conclusions, and suggestions for future research. Supplemental material and the basic data used for the empirical work are presented in Appendices..

CHAPTER II

ANALYTICAL FRAMEWORK

The primary goal of this chapter is to specify an analytical framework for the present study. It is divided into five parts. The first part contains the basic definitions that will be used throughout the study. These include the concepts of mechanical and biological and chemical innovations, Hick's concept of neutral technical change, and the concept of factor biases. The second, third, and fourth parts, which are cast in a partial equilibrium framework, contain most of the basic theory. The second part presents a model of induced technical change, defines the basic variables, and analyzes the way they interact to define the socially optimum technological path. The third section presents an analysis of factors determining how the benefits of technical change will be divided among consumers and producers, given the product market conditions, and is based on the concepts of consumers' and producers' surplus. In the fourth section the focus is on the benefits accruing to agriculture, and the functional distribution of income as well as the expected changes in employment will be analyzed by use of the neoclassical theory of technical change and distribution. In the fifth and final section a two-sector

general equilibrium model is specified to provide an analytical framework for considering the linkages between the farm and nonfarm sectors.

In the interest of brevity only the basic elements of the theory will be presented here. Derivations and supporting material are presented in the Appendices.

Some Definitions

Definitions of Technologies

Heady[1/] has distinguished between "mechanical" and "biological" technical advancements. The former is considered to be primarily labor-saving (cost-reducing), with a negligible output-increasing effect, while the latter is basically yield-increasing and land-saving. Hayami and Ruttan[2/] have also distinguished between "mechanical" and "biological and chemical" technologies. The former includes such innovations as tractors, harvesters, and water pumps, while the latter includes hybrid seeds and other improved plant materials, new breeds of cattle, and fertilizers, insecticides, and pesticides. Although they stress that not all "mechanical" innovations are motivated by incentives to save labor, nor all "biological and chemical" innovations

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[1/] Heady, Earl O., "Basic Economic and Welfare Aspects of Farm Technological Advance," J.F.E. 31(2): 293-316, May 1949.

[2/] Hayami and Ruttan, op. cit., pp. 43-53.

are necessarily motivated by incentives to save land, they note that, whatever the motivations, the historical experience is that mechanization has displaced labor without significant impact on yields and that biological innovations have had a land-saving impact.

Recently, De Janvry[1/] classified technologies into four categories: mechanical, biological, chemical, and agronomic. These technologies can be characterized in terms of their impacts on the marginal rates of technical substitution between capital, labor, and management, and on yield levels. The first three are consistent with earlier definitions, while an agronomic technology refers to cultural practices such as plant spacing and systems of tillage.

De Janvry (following Seckler)[2/] made a distinction between "on line" management and "staff" management. The former consists of the actual direction of farm activities, while the latter deals with decision-making as a choice of activities and of techniques such as investment decisions, financial and fiscal administration, and commercial activities.

[1/] De Janvry, Alain, "A Socioeconomic Model of Induced Innovations for Argentine Agricultural Development," Quarterly Journal of Economics, 87(3): 410-435, August 1973.

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

Mechanical innovations raise the productivity of labor mainly through permitting increases in land per worker. By reducing labor costs, they also will reduce on-line management requirements. Staff management requirements may increase somewhat as the firm becomes more capital intensive.

Biological innovations, according to De Janvry, are fairly neutral with respect to 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 the substitution of capital and labor for land. But they are capital- and labor-deepening, however, since they require both more on-line and staff management per unit of land.

Finally, agronomic innovations are labor and 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- and on-line management-using and very strongly yield-increasing. On the other hand, mechanical innovations are labor- and on-line management-saving and staff management-using.

Definition of Hicks' Neutrality and Biases[1/]

Assuming only two factors of production, the neoclassical theory of production says that the marginal rate of technical substitution is equal to the ratio of the marginal physical products of the two factors which, in equilibrium, is equal in turn to their price ratio. Let us assume a production function which is continuous and twice differentiable:

$$Y = F(K, L)$$

where Y is output, K is capital, and L represents labor.

The marginal rate of technical substitution is defined as:

$$MRTS_{KL} = -\frac{dK}{dL} = \frac{F_L}{F_K} = \frac{P_L}{P_K}$$

where F_L and F_K represent the first order partial derivatives with respect to labor and capital, respectively. P_L and P_K are the prices of labor and capital.

The technical progress is neutral if the ratio of marginal physical products remain unchanged as the technology is introduced. If the marginal physical product of labor increases relative to the marginal physical product of capital (i.e., the MRTS increases), it is a capital-saving

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[1/] The Hicksian definition of technological change will be used in this study. For a review of this approach see Ferguson, C.E., The Neoclassical Theory of Production and Distribution. Cambridge, The University Press, 1971.

(labor-using) technical change. It is labor-saving (capital-using) if the marginal physical product of capital increases relative to the marginal physical product of labor. (See Figures 1 through 3, where I represents the unit isoquant.)

The above definition can be transformed into a definition in terms of factor shares at constant factor prices. New production technology will be capital-using, neutral, or lavor-using according as the relative share of capital increases, remains unchanged, or declines as the technology is introduced. This definition generalizes easily to the many-factor case, and will lead to a unique measure of the biases for each factor. If a definition in terms of factor ratios were used, on the other hand, it would be necessary to consider n-1 factor ratios for each factor in order to determine biases.

The rate of factor-i bias is measured as[1/]:

$$V_i = \frac{\dot{P}_i}{P_i} \lesseqgtr 0 \rightarrow \quad \text{Hicks} \quad \begin{cases} \text{i-Saving} \\ \text{i-Neutral} \\ \text{i-Using} \end{cases}$$

where $i=1,2,\ldots,n$, V measures the bias given the relative factor prices, P_i is the share of factor i, and $\dot{P}_i = dP_i/dt$, where t refers to time.

[1/] A dot over a variable denotes a rate of change in that variable.

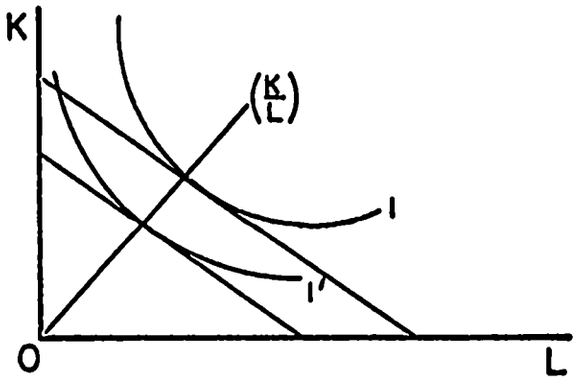

Figure 1. Representation of a Neutral Technological Change.

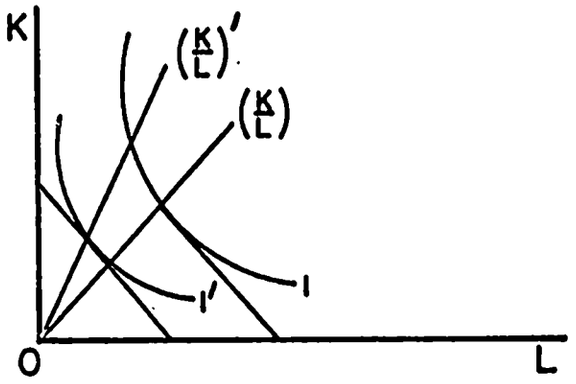

Figure 2. Representation of a Capital-Using (Labor-Saving) Technological Change.

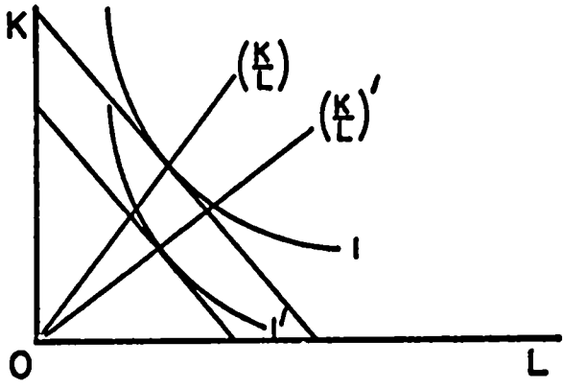

Figure 3. Representation of a Labor-Using (Capital-Saving) Technological Change.

One disadvantage of this approach, however, is that it assumes the relative factor prices to be fixed. Therefore, to estimate biases it is generally not possible to simply look at historic changes in factor shares. The observed changes in shares may have come about through biased technical change and/or through ordinary factor substitution arising from changes in the prices of the factor. The basic problem, therefore, is to sort out to what extent the changes in factor shares have been due to biased technical change and to what extent to price changes. To do this the substitution parameters of the production process have to be estimated before any biases can be measured.

Another point to be noted is that if the elasticity of substitution among factors is unity the factor share will be constant over time.

A Model of Induced Technical Change

The basic idea of the induced innovation theory is that innovations and their resource-saving directions are not determined outside of the economic system, but depend on the conditions prevailing within each economy. In the Hicks-Ahmad[1/] versions the innovation and its resource-saving direction depend on relative factor prices and/or their

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[1/] Ahmad, Syed, "The Theory of Induced Invention," Economic Journal, 76(302): 344-357, June 1966.

change over time, given the stock of knowledge. In the Kennedy-Samuelson[1/] version the emphasis is placed on factor shares.

Ahmad uses the concept of an historic Innovation Possibility curve (IPC). It is assumed that at a given time there exists a set of potential production process which could be developed. This set might be thought of as determined by the state of the basic sciences. Each process in the set is characterized by an isoquant. The IPC is the envelope of all alternative isoquants representing a given output on various production functions.

An important assumption of the Ahmad model is that the cost and time required for moving from one isoquant to another belonging to the IPC of the same period is equal to that required for moving to the IPC of the next period, which is assumed to be nearer to the origin than the IPC of the current period. Another important assumption is that the IPC is not the result of any economic choice. Rather, it is a purely technological or laboratory question.

Figure 4, taken from Ahmad's paper, illustrates the model. For time t the process I_t has been developed. The IPC corresponding to it is IPC_t. Given the relative factor prices of the line P_tP_t, the process I_t is the cost minimizing one.

[1/] Samuelson, P.A., " Theory of Induced Innovation Along Kennedy-Weisacker Lines," Review of Ec. Stat., 47(4): 343-356, November 1965; and Rejoinder, Review of Ec. Stat., 48(4): 444-448, November 1966.

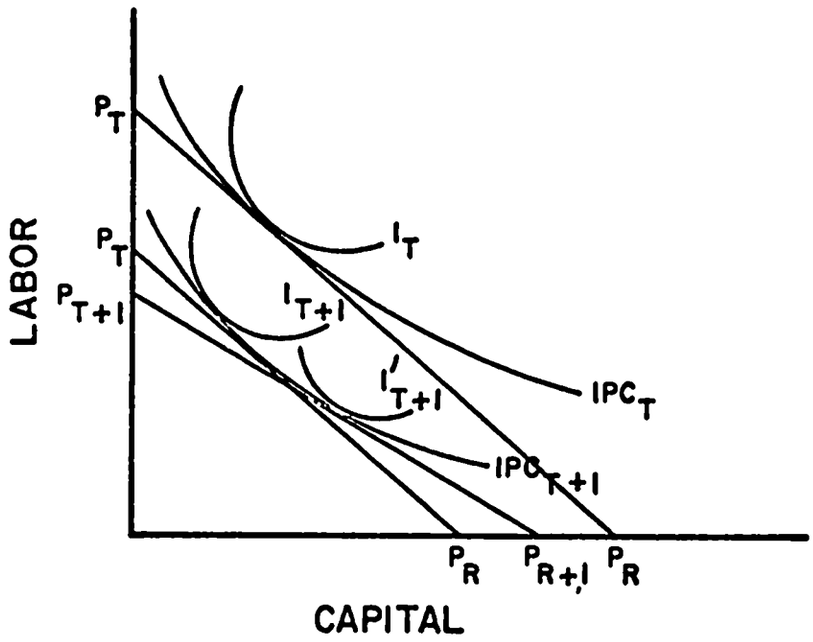

Figure 4. Ahmad's Induced Innovation Hypothesis.

Once I_t is developed the remainder of its IPC becomes irrelevant because, for period t + 1, the IPC is assumed to have shifted inwards to IPC_{t+1}. If factor prices remain the same, entrepeneurs will develop the process I_{t+1} for the next period.

If the IPC has shifted neutrally, the technical change will be neutral. However, Ahmad recognizes that it is possible that the IPC might shift non-neutrally, which would result in biases even at constant factor prices.

If, on the other hand, factor prices change to $P_{t+1}P_{t+1}$, then it is no longer optimal to develop I_{t+1}, but rather the process corresponding to I'_{t+1} becomes optimal. In the figure, $P_{t+1}P_{t+1}$ corresponds to a rise in the relative price of labor. It should be noted that even if the IPC has shifted neutrally, I'_{t+1} will be relatively labor-saving in comparison to I_t under these circumstances.

Ahmad's hypothesis was developed within the context of a market-oriented production or research structure and at a high level of aggregation, since the IPC includes the total stock of scientific knowledge within the economy. Within this context it should be noted that his model does not consider the possibility of spending resources to influence the shift of the IPC. Another point to be noted in Ahmad's model is that it does not account for the determinants of the neutrality and/or non-neutrality of the shift of the IPC.

De Janvry[1] has extended Ahmad's model for purposes of analyzing technological stagnation in the agricultural sector of Argentina. He explicitly introduces the product market by defining the unit cost line as $PtT + PxX = 1$, where Pt and Px are factor prices relative to product prices and T and X are input levels. By this means he can define a range where a socially optimum equilibrium can be reached according to the ratios between product and factor prices, given conditions of perfect competition. The equilibrium point gives what De Janvry calls the latent demand for innovation. He then points out that market imperfections, government interventions such as tariffs, and risk can shift the latent demand for innovation away from the socially optimum path.

An important assumption of De Janvry's model is the costless generation of technological innovations. He notes, however, that this assumption can be relaxed and it assumed instead that research costs are internalized in product prices. In this case the optimum latent demand will shift toward traditional technologies.

The Hayami and Ruttan[2] model of induced technical change is also developed at a lower level of aggregation

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[1] De Janvry, op. cit., Section I.

[2] Ruttan, op. cit., p. 57.

than that used by Ahmad. Moreover, they hypothesize that the generation and adoption of technology in agriculture comes about through dialetic interactions between entrepreneurs and the public research institutions. This hypothesis is an extension of Ahmad's model, since the latter defines the induced innovation in a pure market-oriented production economy, while Hayami and Ruttan bring the public sector into the model.

The concept of a metaproduction function, which is a central element in the Hayami and Ruttan model[1/], is similar to the Innovation Possibility Curve of Ahmad. Hayami and Ruttan characterize the metaproduction function as follows:

> ...we do not claim that the metproduction function is inherent in nature or that it remains completely stable over time. The metaproduction function may shift with the accumulation of general scientific knowledge. We do consider, however, that it is operationally feasible to assume a reasonable degree of stability for a technical "epoch," the time range relevant for many empirical analyses. Shifts in the metaproduction function are much slower than adjustments along the surface, or to the surface from below, of the metaproduction function.

The differentiating characteristic of the metaproduction function, therefore, is its stability, which means that changes within a technical "epoch" will be along its surface. In contrast to this, Ahmad assumes that the IPC is shifting constantly, and that the new equilibrium will occur on a new surface. However, both models agree in assuming that the shift is exogenously determined.

[1/] Hayami and Ruttan, op. cit., pp. 83-84.

To summarize, Ahmad's model does not consider the possibility of spending resources to influence the shift of the IPC, nor does it define the determinants of the neutrality or non-neutrality of the shift in this curve, nor does it recognize that there may be an economic choice in the definition of the IPC. With the analysis limited to a consideration of the agricultural industry only, we, on the other hand, will hypothesize that the neutrality of the shift of the IPC occurs only by chance, that there exists a process of resource expenditure to influence its shift, and that there exists an economic choice in determining it.

Let's begin by redefining the IPC. We will call it a "technical epoch innovation possibility curve"[1/] (TEPC for short). At a given technical epoch (time), assume in the same way as above that there exists a set of potential processes to be developed. This set might be thought of as determined by the state of agricultural sciences plus the state of other sciences relevant to the agricultural sector at that time, given the economic conditions prevailing in the agricultural sector during the "epoch."[2/] Following

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[1/] The "technical epoch" is being used here as defined by Brown, Murray, On the Theory and Measurement of Technological Change, London, Cambridge University Press, 1966, Chapter 5.

[2/] The Hayami and Ruttan findings are consistent with this definition, since the knowledge about chemical and mechanical innovations were known before they were adopted, but were not relevant to the respective TEPC's of the U.S. and Japan during certain technical epochs. See Hayami and Ruttan, op. cit., 132-135.

the classification of technologies given in an earlier part of this chapter, and dividing capital according to whether it is land-saving or labor-saving, an aggregate production function can be specified for the agricultural sector in separable form, where the degree of substitutability among inputs is high within, but quite low between, subfunctions:[1/]

$$Y = F[f(L,K_L),\ g(T,K_T)]$$

where Y is the aggregate agricultural output, T and L are land and labor inputs, respectively, K_L is laboresque capital (mechanical), and K_T is landesque capital (biological, chemical and agronomic).

Consider, now, Figure 5, where the axes measure the composite factors of each subfunction; i.e., W represents the factors L and K_L and Z represents the inputs T and K_T.[2/] Assume that the unit cost line[3/] is AB. Furthermore, since the substitutability between subfunction production functions is postulated to be low, we can assume that once the process is defined on the TEPC it is in fixed proportion, i.e., the elasticity of substitution is zero. Moreover, let

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[1/] See De Janvry, op. cit., and Sato, K., "A Two-Level Constant-Elasticity-of Substitution Production Function," Rev. Econ. Stud. 34(2): 201-218, April 1967 for the derivation of a two stage production function.

[2/] More specifically, $W = L + K_L$ and $Z = T + K_T$.

[3/] The unit cost line is $P_W W + P_Z Z = P_p$, where P_p is the product price, and P_W and P_Z are the composite factor prices of each sub-function.

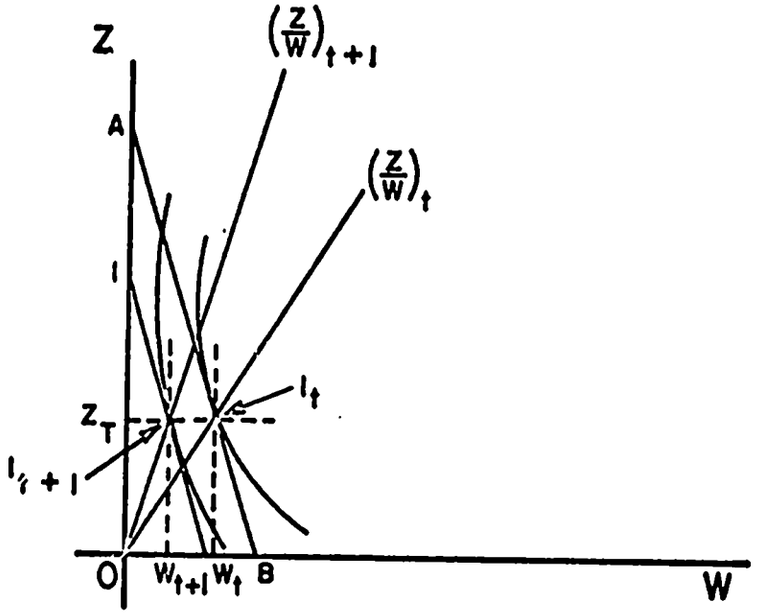

Figure 5. Shift in the TEPC when $AZ_T/OZ_T > 1$.

us assume that the relative factor price is constant over time. If we measure W in terms of Z, i.e., $AZ_T = OW_T \frac{P_W}{P_Z}$, then three cases are possible

$$\frac{AZ_T}{OZ_T} > 1 , \qquad \frac{AZ_T}{OZ_T} < 1 \quad \text{and} \quad \frac{AZ_T}{OZ_T} = 1$$

For time period t the process I_t is assumed to have been developed, given the relative factor prices of the line AB. The question now is, "What would be the direction of technological innovation given that the relative prices of the factor are not expected to change?" If $AZ_T/OZ_T > 1$, this means a relative scarcity of the composite factors, W. Therefore, it can be expected that resources will be allocated to research and development in order to economize on the composite factors, W, given the level of Z, and that as a result there will be a biased shift in the factor ratios from $(Z/W)_t$ to $(Z/W)_{t+1}$.

Contrary results would obtain if $AZ_T/OZ_T < 1$. If, however, $AZ_T/OZ_T = 1$, there will be no incentive to change the direction of technical change, and resources will be allocated to increase the aggregate efficiency of the economy. Therefore, it is expected that some scientists will be working in both directions, and the group which is able to produce the first results will determine the bias. As a result, only by chance will we have neutral change. This will occur if both groups are able to produce results at

the same time and with proportional changes in the combination which gives the same factor proportions used in time t.

The assumption of an elasticity of substitution equal to zero can be relaxed. But by the definition of the separable production function it will have to be less than 1. Therefore, the direction of bias will be the same as postulated above. We can conclude, then, that resources will be allocated to research in order to increase technical efficiency, and the change expected will be neutral only by chance.

The analyses for the subfunctions can be carried out in the same way. The changes within a sub-function will depend on the elasticity of substitution, which is assumed to be greater than one, and the relative factor prices.

The above hypothesis suggests that in a less-developed country or region the TEPC will be based mostly on knowledge from agricultural sciences in other countries and/or from other regions, plus the "outside" knowledge from other sciences relevant to the technical epoch. This would be the case for Brazil in the aggregate, and especially for a region such as the Northeast of Brazil, where only limited new production technology has been developed for the majority of products, and the availability of new technology for some products represents either imported technology, or has been strongly based on imported technology.[1/]

[1/] Patrick, in referring to the Northeast, has observed that "some new varieties and practices have been developed, but often they do not consider the production economic conditions commonly prevailing in the region." This statement

Given that the investment in research planned by the government tends to be exogenously determined, it can be directed to shift the TEPC in such a way as to be consistent with the factor endowment of the country and/or region and the product market conditions. The question then becomes "What should be the planned bias in the shift of the TEPC from the planned investment in research in order that the technological path followed be an efficient one?"

Distribution of Benefits from Technical Change Between Producers and Consumers

The previous section was concerned with the variables that are expected to induce the technical change and determine its resource-saving direction. Given that technical change has occurred, another question arises: "Who, among producers and consumers, will get the benefit of it?" The concept of economic surplus is a useful tool to answer this question.

Originally defined by DuPuit and brought into the current economic literature by Marshall, Hicks, Patinkin and Mishan[1/], the concepts of consumers' and producers' surplus

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1/(continued) suggests that the dialectic interaction hypothesized by Haymi and Ruttan was not occurring. It also suggests that the agricultural scientists were working outside of the relevant TEPC, or within an irrelevant range of the curve. See Patrick, George F, Desenvolvimento Agricola do Nordeste, Rio de Janeiro, IPEA Research Report No. 11, 1972, p. 258.

1/Currie, J.M., John A. Murphy and Andrew Schmitz, "The Concept of Economic Surplus and Its Use in Economic Analysis," The Economic Journal, 81(324): 741-799, December 1971.

have been dealt with extensively in the literature. Consumers' surplus has been defined as the area above the price line and below the demand curve. Producers' surplus, in a somewhat symmetric manner, has been defined as the area below the price line and above the supply curve. As either the supply and/or demand curves shift(s) there will be a change in producers' and/or consumers' surplus, with a possible resulting gain or loss to specific groups in the society.

These concepts have been used to evaluate the welfare effects of public and private investments in agricultural research. The basic analytical model for a closed economy is given in Figure 6.

Suppose that prior to some technological innovation the equilibrium price and quantity is P_0 and Q_0. In addition suppose that the supply curve were perfectly elastic. The gain to society from a technological change which lowered the supply curve to S_1' would be the gain in consumers' surplus, A + B + C. If the initial supply curve were perfectly inelastic, on the other hand, a shift in the supply curve from Q_0S_2 to Q_1S_2' would result in both a change in producers' surplus (F + G - (A + B)), and a change in consumers' surplus (A + B + C). However, if the supply curve is positively sloped, the net gain will be B + C + E + F, since the change in producers' surplus is (E + F) - A, while the gain in consumers' surplus is A + B + C.

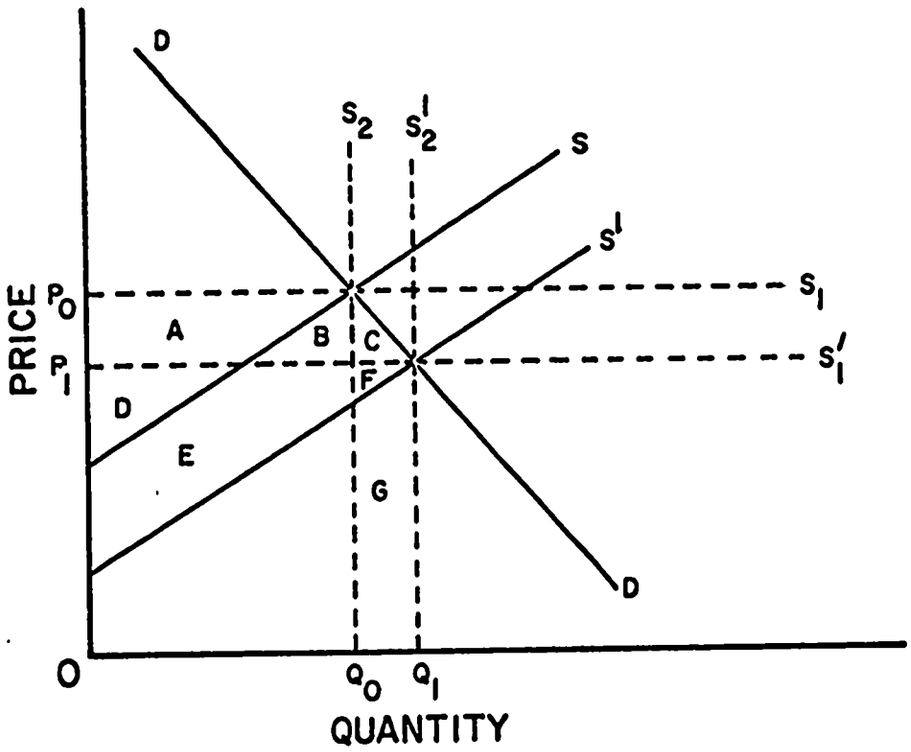

Figure 6. Effects of a Shift in the Supply Curve as a Result of Technological Change in a Closed Economy.

The two extreme cases of a perfectly elastic and perfectly inelastic supply curve were used by Griliches[1/] to estimate the social rate of return on investments in hybrid corn research in the U.S. Peterson[2/] and Ayer and Schuh[3/], on the other hand, have assumed a positively sloped supply curve in estimating the social rate of return to investments in poultry research in the U.S. and cotton research in Brazil, respectively.

If the assumptions are changed to that of an open economy, the distribution of benefits can be understood by means of Figure 7. In the open economy case the export multiplier becomes an additional mechanism through which social gains are realized. These gains are derived from the increased exportable surpluses made available by the new technology. With a shift in the supply curve the elastic demand curve implied by an open economy[4/] will not allow for gains in consumers' surplus if the product has traditionally

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[1/] Griliches, Zvi, "Research Cost and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, 66(5): 419-431, October 1958.

[2/] Peterson, W.L., "Return to Poultry Research in the United States," Journal of Farm Economics, 49(3): 656-669, August 1967.

[3/] Ayer, H.W. 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, November 1972.

[4/] The "small" country assumption is implied, or that the country is relatively unimportant in world markets so that its exports will not affect world prices.

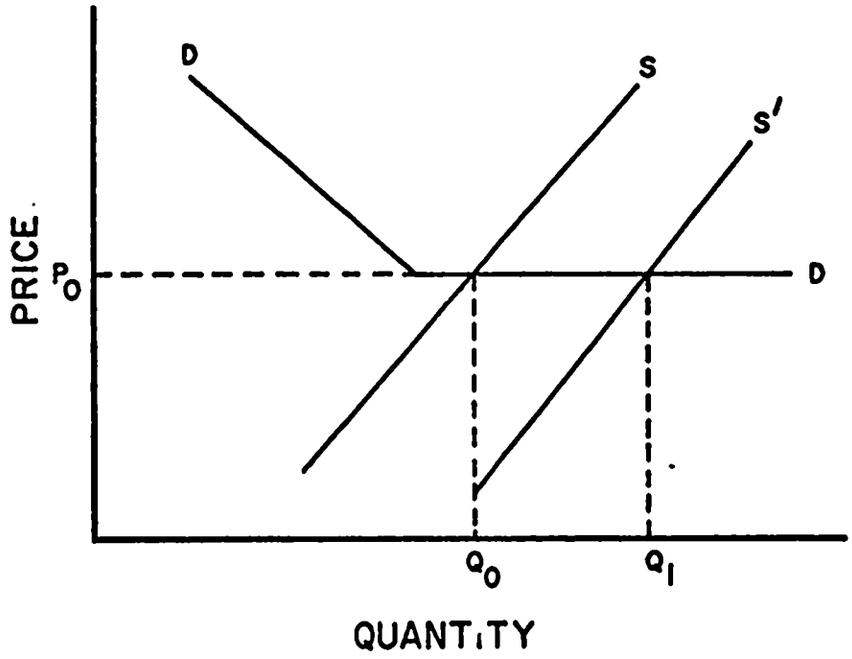

Figure 7. Effects of a Shift in The Supply Curve as a Result of Technological Change in an Open Economy.

been exported. If the product was not exported prior to the technical change, there may be some gain in consumers' surplus as a result of the initial shift of the supply curve. This would occur, for example, if prior to the technical innovation the domestic price were above the world price and "protected" either by transportation costs or trade policy.

It can be seen from Figure 7 that all economic surpluses will accrue to the producers if the product has been traditionally exported. If not (i.e., if it is the first time the product is exported and the internal price was previously above the world market), the producers will share some economic surplus with the consumers for the initial shift in the supply curve. Both the closed and open economy models described above suggest that the proportion of the gain accruing in the form of producers' and consumers' surplus will depend on the elasticities of demand and supply.

These concepts are useful tools for analyzing the return to investments in research, as illustrated by Griliches, Peterson, and Ayer and Schuh. Hence, the basic framework provides a means of selecting the products to which researchers should give priority in their research efforts. In addition, it provides a means of establishing priorities in terms of more specific goals established by policy-makers. Knowledge of the demand and supply elasticities will provide a basis for determining whether the flow of benefits from a given technical change will be realized as a producer surplus

or as a consumer surplus. Then, depending on whether the policy-makers prefer to favor the producer or consumer, research resources can be allocated accordingly.[1]

Technological Change and the Neoclassical Theory of Distribution

In the previous section a model was discussed which showed how the benefits from agricultural research are distributed among consumers and producers. Since an important aspect of the present study is also to determine how the benefits of technical change are distributed among the factors of production, we now turn to an analytical framework that provides the basis for such an analysis and which also provides a means of hypothesizing what the expected effects on the levels of employment will be.

The neoclassical theory of distribution, which is derived from the theory of production, provides the analytical tools for analyzing the problem at hand. However, it is important to be aware of the limitations imposed by the assumptions usually made in using this theory. Friedman's[2] comments clarify in some respects one misleading conception of the problem:

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[1] For an analytical discussion of the problem of defining priorities in agricultural research programs see Schuh, G.E., "Some Economic Considerations for Establishing Priorities in Agricultural Research," Ford Foundation Seminar of Program Advisors in Agriculture, Mexico City, November 1972 (mimeographed).

[2] Friedman, Milton, Price Theory, A Provisional Text, Aldine Publishing Company, 1962, p. 172.

> The 'theory of marginal productivity' is sometimes described as a 'theory of distribution.' This is a misleading statement. The theory of marginal productivity at most analyzes the factors affecting the demand for a factor of production. The price of the factor depends also on conditions of supply. The tendency to speak of a 'marginal productivity theory of distribution' arises because in many problems and contexts it is useful to think of the supply of factors of production as given quantities, as perfectly inelastic. This is particularly relevant if the problem concerns both market and non-market uses of factors of production. In such cases there is a sense in which supply conditions determine only the quantity of the factors, while demand conditions (summarized in the phrase 'marginal productivity') determine price. But note that even in this case a change in supply -- in the fixed amount of a factor -- will change the price of the factor, unless demand is perfectly elastic. So it will be better in all cases to regard the theory of marginal productivity as a theory solely of the demand for factors of production. A complete theory requires a theory of both the demand for and supply of factors of production.

The implications of technical change with respect to the functional distribution of income when marginalist allocation rules apply are determined in a partial equilibrium framework. Technical change will affect the distribution of income through the incentive it provides for the reallocation of factors over production alternatives. The theory of the functional distribution of income gives us an explanation of the distribution of income among factors of production, and information about changes in factor employment in response to changing price relations. At the macroeconomic level, the distributional question of perhaps greatest interest concerns the behavior of aggregate relative shares. Hence, the analysis will focus on this issue.

Let us assume that the production function is given by $Y = F(K, L)$ where F is homogeneous of degree one in K and L (capital and labor, respectively), and the function is twice differentiable in all arguments. Assume further that the first-order derivatives, F_K, $F_L > 0$ and the second order derivatives, F_{KK}, $F_{LL} < 0$, and that $r = F_K$ and $W = F_L$, where r and w denote the real rate of interest and the wage rate, respectively.

By doing the necessary derivation it can be shown that[1/]

$$\frac{\dot{S}}{S} = -(1 - S)\left[B + \left(1 - \frac{1}{\sigma}\right)\frac{\dot{k}}{k}\right]$$

where

S = LF_L/F, the labor share,

$(1-S)$ = KF_K/F, the capital share,

$\dot{S}/S$ = the rate of change in the labor share,

B = the technological bias according to Hicks' definition,

k = K/L, the capital-labor ratio,

$\dot{k}/k$ = the rate of change in the capital-labor ratio, and

F = total product.

1/ The derivation can be found in Ferguson, C.E., The Neo-classical Theory of Production and Distribution (London: Cambridge University Press, 1971) Chapters 11 and 12.

If $B = 0$, the technological progress is neutral and the magnitude of the elasticity of substitution and the direction of change in relative input supplies are the only factors governing the behavior of relative shares. The labor share will be augmented or diminished according as $B \lessgtr 0$; that is, according as technological change is labor-using or capital-using. This offers one customary way of defining technological bias; namely, to say that technological change is labor-using, neutral or capital-using according as the relative share of labor increases, remains unchanged, or declines. However, this is strictly correct only if the elasticity of substitution is unity, or if the rate of change in the capital-labor ratio is zero.

The problem in using the pure neoclassical theory is that the analysis is restricted to two factors. Bajuk[1/], however, has extended the analysis to the n-input case, although he discusses an explicit solution only for the two factor case.

One possible way to proceed is to define an aggregate production function for the agricultural sector in separable form (as was done earlier in this chapter), where the degree of substitutability among inputs is assumed to be greater

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[1/] Bajuk, A., "A Model of the Distribution of Gains from Agriculture Development," Ph.D. research essay, Department of Agricultural Economics, University of California, Berkeley, 1971 (mimeographed).

than one within the postulated subfunctions, but is less than one between subfunctions. In other words, assume that

$$Y = F[(f(L^*,K_L^*),\ g(T^*,K_T^*)] \qquad (2.1)$$

where (*) indicates that the factor in question is measured in "effective" units, e.g., $L^* = t_L L$, where t_L is an index of non-neutral technological change which increases the quality, or "effective units," of the nominal input L (labor). The further assumptions of fixed input prices, homogeneity, and weak separability[1/] allow us to define subfunction price indexes for the subfunctions on the basis of which the optimization process can be performed in two separable stages.

By doing the necessary derivation it is possible to arrive at elasticities which give the effect of non-neutral technological change on the income to individual factors, the functional distribution of income, and the employment of factors of production.[2/] This can be done on the basis of

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[1/] Weak separability implies that change (infinitesimal) in the quantity of an input employed in one group of inputs (or subfunction) does not affect the marginal rate of substitution between inputs in any other group. See Leontief, "A Note on the Interrelation of Subsets of Independent Variables of a Continuous Function with Continuous First Derivatives," Bulletin of the American Mathematical Society, 53(4): 343-350.

[2/] The elasticities are derived basically from Equations (20), (33), (36), (37), and (39) through (54) of Appendix A.

the aggregate inputs, which represent an aggregation of the inputs in an individual subfunction, or on the basis of the elementary inputs which enter a particular subfunction. In order to keep the exposition from becoming burdensome, for the most part only the equations which describe the effects of changes in the labor subfunction[1/] and at the elementary input level will be presented here. Equations describing the effects at the aggregate input level as well as factor share analysis at the elementary input level are presented in Appendix B.

In order to proceed let us define the following terms:

$Z_L = f(L^*, K_L^*)$,

$Z_T = g(T^*, K_T^*)$,

α_L = the price index of Z_L,

α_T = the price index of Z_T,

S_L and S_T = the factor share of the aggregate inputs Z_L and Z_T, respectively,

C_L and C_{K_L} = the factor shares of L and K_L in the labor subfunction,

C_T and C_{K_T} = the factor shares of T and K_T in the land subfunction, and

σ is the elasticity of substitution between the two subfunctions.

The analysis will focus on the income to individual factors of production and factor employment. Consider first

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1/ The effects of changes in the land subfunction are the same, the only difference being in the definition of the input variables.

the effect of a technical change on the total income to an individual factor. Within the labor subfunction the two cases of labor-augmenting and capital-augmenting technical change can be considered. For labor-augmenting technical change,

$$\frac{(\dot{L}\,\dot{P}_L)}{\dot{t}_L}^{1/} = (\sigma_L - 1) + C_L(S_L\eta + S_T\sigma - \sigma_L),$$

$$\frac{(\dot{K}_L\,\dot{P}_{K_L})}{\dot{t}_L} = C_L(S_L\eta + S_T\sigma - \sigma_L), \text{ and}$$

$$\frac{(\dot{T}\,\dot{P}_T)}{\dot{t}_L} = \frac{(\dot{K}_T\,\dot{P}_{K_T})}{\dot{t}_L} = -\,S_L C_L(\sigma - \eta).$$

σ_L is the elasticity of substitution in the labor subfunction, and is assumed to be greater than one, and P_L, P_T, P_{K_L}, P_{K_T} are the prices of L, T, K_L and K_T, respectively.

It should be noted that the price elasticity of demand, η, is an important parameter in determining the direction of change in the return to the elementary input. In order to guarantee an increase in the returns to all factors, η should be large enough to make $S_L\eta + S_T\sigma > \sigma_L$, given the assumption of $\sigma < 1$ and $\sigma_L > 1$. However, if η is not large enough, the elasticities indicate that the return to the "laboresque" capital will decrease. On the other hand, the return to

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1/ The dot notation will henceforth be utilized to represent the relative change in a given variable. For example, $\dot{Y} \equiv dY/Y$. When both the numerator and denominator are expressed in dot notation, the ratio is interpreted as an elasticity. for example, $\dot{Y}/\dot{X} = dY/dX \cdot X/Y$

labor can increase, decrease, or remain constant. (It should be noted in passing that the returns to elementary inputs of the other subfunction (i.e., land) will increase as long as $\eta > \sigma$.)

For laboresque capital-augmenting technological change

$$\frac{L^{\bullet} P_L}{\dot{t}_{K_L}} = C_{K_L}(S_L \eta + S_T \sigma - \sigma_L),$$

$$\frac{K_L^{\bullet} P_{K_L}}{\dot{t}_{K_L}} = (\sigma_L - 1) + C_{K_L}(S_L \eta + S_T \sigma - \sigma_L), \text{ and}$$

$$\frac{T^{\bullet} P_T}{\dot{t}_{K_L}} = \frac{T^{\bullet} P_T}{\dot{t}_{K_L}} = - S_L C_{K_L}(\sigma - \eta).$$

The role of the price elasticity of demand in the case of laboresque capital technological change is symmetric to that for labor-augmenting technological change discussed above. Moreover, the effects on factor returns to elementary inputs of the land subfunction are similar to those described for the labor-augmenting technical change.

The effect of technological change on the employment of factors will depend on the assumption made about factor prices. If the factor prices are assumed to be fixed, the effect of technological change on factor employment will be

the same as those for factor returns, since changes in the income to a factor can only occur through a change in the quantity of an input used. However, another set of equations can be derived from the model which indicate the affect of exogenous changes in factor prices.

Focusing at the elementary input level again, the effects of an exogenous change in the price of labor (P_L) on the income to the factors are given by:

$$\frac{L^{\bullet}P_L}{\dot{P}_L} = \frac{\dot{L}}{\dot{P}_L} + 1 = (1 - \sigma_L) + C_L(\sigma_L - S_L\eta - S_T\sigma), \text{ for labor,}$$

$$\frac{K_L{}^{\bullet}P_{K_L}}{\dot{P}_L} = C_L(\sigma_L - S_L\eta - S_T\sigma), \text{ for laboresque capital, and}$$

$$\frac{T^{\bullet}P_T}{\dot{P}_L} = \frac{K_T{}^{\bullet}P_{K_T}}{\dot{P}_L} = C_L S_L(\sigma - \eta) \text{ for land and landesque capital.}$$

The effects of an exogenous change in the price of landesque capital on the income to factors is given by:

$$\frac{L^{\bullet}P_L}{\dot{P}_{K_T}} = \frac{K_L{}^{\bullet}P_{K_L}}{\dot{P}_{K_T}} = C_{K_T}S_T(\sigma - \eta), \text{ for labor and laboresque capital,}$$

$$\frac{T^{\bullet}P_T}{\dot{P}_{K_T}} = C_{K_T}(\sigma_T - S_T\eta - S_L\sigma), \text{ for land, and}$$

$$\frac{\dot{K}_T P_{K_T}}{\dot{P}_{K_T}} = (1 - \sigma_T) + C_{K_T}(\sigma_T - S_T\eta - S_L\sigma), \text{ for laboresque capital.}$$

The price elasticity of product demand, η, is again an important parameter in determining the direction which the income to factors takes. If η is sufficiently large such that $S_L\eta + S_T\sigma > \sigma_L$, then the result is that the income to each of the factors will decrease as a result of an increase in the price of labor. Different values of η would give different results, of course.

The effect of an exogenous change in the price of labor (P_L) on the employment of factors is given by:

$$\frac{\dot{L}}{\dot{P}_L} = - C_{K_L}\ \sigma_L - (S_L\eta + S_T\sigma)\ C_L, \text{ for labor,}$$

$$\frac{\dot{K}_L}{\dot{P}_L} = C_L(\sigma_L - S_L\eta - S_T\sigma), \text{ for laboresque capital, and}$$

$$\frac{\dot{T}}{\dot{P}_L} = \frac{\dot{K}_T}{\dot{P}_L} = S_L C_L(\sigma - \eta), \text{ for land and landesque capital.}$$

The response to changes in other factor prices will be symmetrical, hence they are not reproduced here. The own price elasticity always will be negative since the negative substitution effect within the corresponding subfunction is reinforced by the negative output effect and the substitution effect between subfunctions.

The cross price-elasticity within a subfunction can be either positive or negative, however. This is due to the fact that in this case the substitution effect within the subfunction is positive. It should be noted, however, that there are two negative effects, the output effect and the substitution effect, between subfunctions. The sum of these two may or may not offset the positive substitution effect.

The cross price-elasticities between inputs in different subfunctions will depend on the relative magnitude of the negative output effect and the positive substitution effect between subfunctions.

A Two-Sector General Equilibrium Model

In order to provide a general view of the effects of technological change in one sector of the economy on employment and the returns to factors, a two-sector general equilibrium model will be specified.[1/] Assume the economy to be divided into two sectors, A and B. The former is assumed to be labor-intensive, while the latter is captial-intensive. Furthermore, it is assumed that the elasticity of demand for sector A's product is less than unity.

The first step in the analysis is to introduce a neutral technical change into the A sector, holding the factor

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[1/] All basic assumptions of the neo-classic theory are assumed here. For a detailed view of the model see Johnson, Harry G., The Two Sector Model of General Equilibrium, Aldine Atherton, Inc., 1971.

prices constant and letting the product prices change. As shown in Figure 8, the introduction of a neutral technical change causes an increase in the output of the A sector. Since the technology is neutral, the (K/L) ratio is not affected in the A sector. Thus, there is no change in the allocation of factors between the two sectors, and therefore there is no change in the output of the B sector. On the other hand, the production of A industry has been increased proportional to the technical progress measured in terms of the decrease in the per unit cost of production.

In order for the factor shares to remain in the same proportion as prevailed prior to the technical change, the elasticity of demand in the A sector would have to be equal to unity. Since it was assumed that the elasticity of demand for the A industry is less than unity, however, a fall in that industry's profits is expected. Therefore, since the industry is labor-intensive, the share of income going to labor has to fall vis-a-vis the capital share of income.

If a labor-using technology is introduced, as shown in Figure 9, the outcome is different. The decrease in the capital-labor ratio associated with the innovation requires a redeployment of both capital and labor out of the A sector into the B sector in order to maintain the full employment of the factors.[1] This is shown in Figure 9 by the movement

[1] The reason for this is that capital is released from the A sector with the decrease in the capital-labor ratio, and by assumption the capital-labor ratio in the B sector does not change. Then some labor has to be released from the A sector in order to maintain full employment.

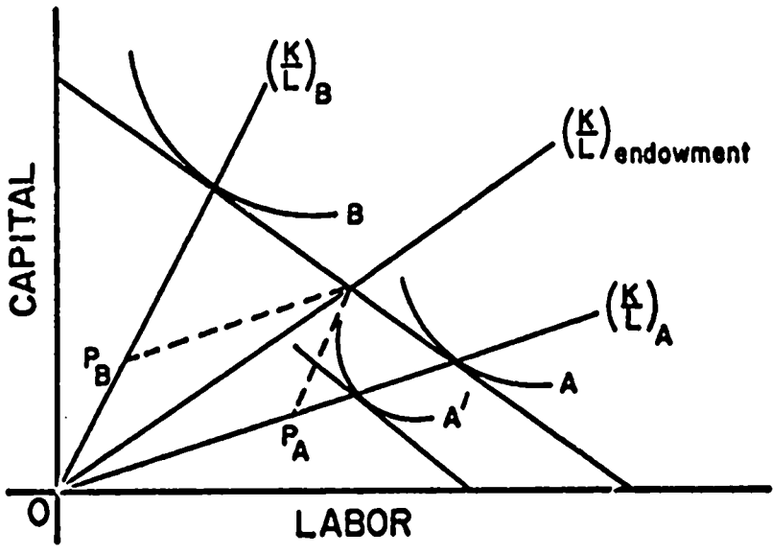

Figure 8. A Neutral Technological Change with Factor Prices Constant.

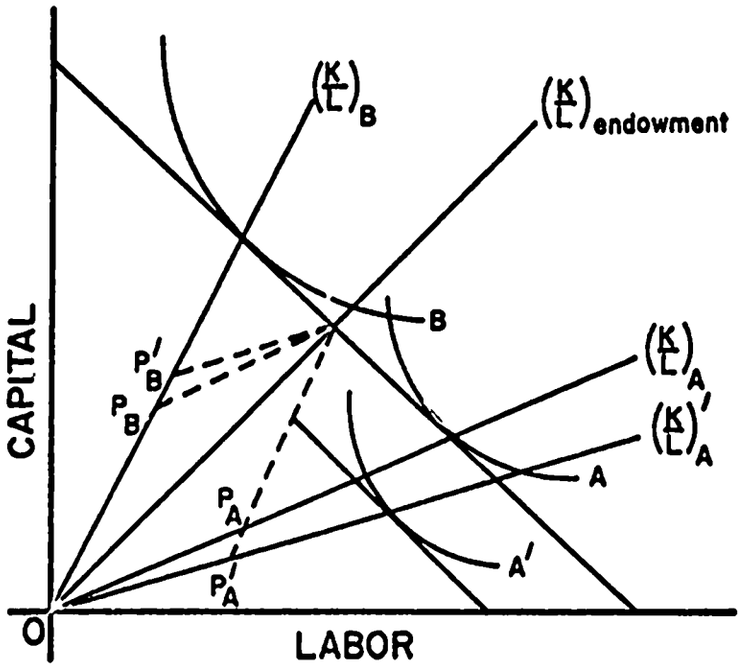

Figure 9. A Labor-Using Technological Change with Factor Prices Constant.

from P_B to P_B' and from P_A to P_A'.

The output of the B sector must rise, while that of the A industry may fall or rise, depending on whether the resource exodus is or is not great enough to offset the improvement in productivity due to the innovation. In any case, the critical value of the Hicksian elasticity of demand for A, which determines the movement of relative shares and of absolute shares, is something less than unity.

It is also possible to examine the introduction of a labor-intensive technology in the A sector with an alternative model which holds product prices constant but allows factor prices to change. The labor-intensive technological change in the already labor-intensive sector lowers the K/L ratio as shown in Figure 10. In order for the product price to remain constant the factor price must change. The tangency points between the old A-sector isoquant and the new A-sector isoquant and the (W/r) line indicates that the K/L ratio rises in the B sector and the (W/r) rises also. The rationale of this is that as the marginal productivity of labor increases in the A sector, with the product prices constant, the price of labor is bid up. At the same time capital is released from this sector. These two features induce the B sector to substitute capital for labor, thereby increasing the (K/L) ratio and bringing the (W/r) ratio into equilibrium.

Holding product prices constant and assuming full employment of both factors of production, the share going to

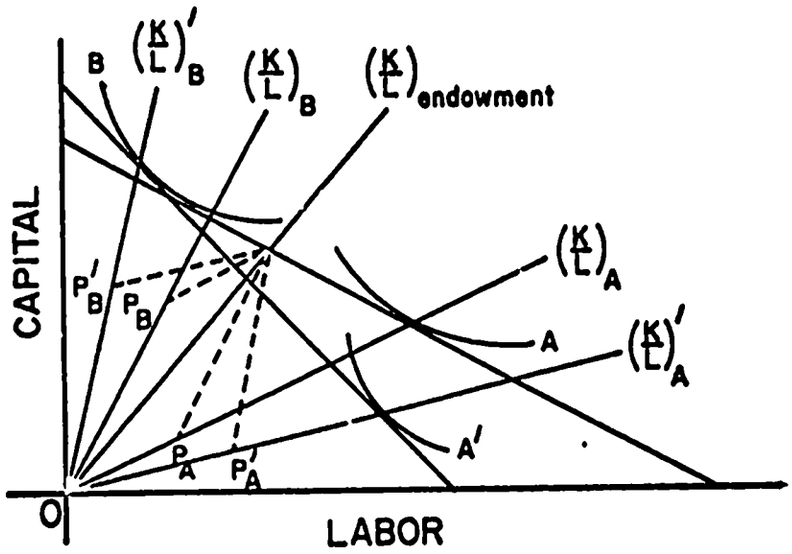

Figure 10. A Labor-Using Technological Change with Product Prices Constant.

labor increases. However, to keep the A prices constant will depend on the adjustment in the factor market between the two sectors, as well as the increase or decrease of output in both sectors, and the elasticity of demand for their output. Two outcomes are possible. First, there may be an increase in the output of the B sector and a decrease in the A sector. In this case, with elasticity of demand greater than one for the B sector and less than one for the A sector, it is expected that the labor share will increase vis-a-vis capital.

The second outcome is to decrease the output in the B sector and increase it in the A industry. With the elasticities of demand described above it is expected that the capital share will increase vis-a-vis labor.

So far, perfect competition in both markets and full employment of the factors has been assumed. If the assumption of full employment of labor in the A sector is relaxed, with a labor-using technological change no redeployment of factors is needed and the expected outcome is to increase output in the A sector. Since it is assumed that the elasticity of demand is less than one, it is expected that the share of labor will decrease vis-a-vis capital.

If at the same time we assume that some subsidy is given to capital in the A sector, some substitution of capital for labor is expected. To the extent that the subsidy

is enough to bring the (K/L) to the initial point despite the labor-using technology, the expected outcome will be similar to the case in which the technological innovations were of a neutral type. As a consequence, the share of income going to labor has to fall vis-a-vis capital.

CHAPTER III

THE EMPIRICAL MODEL

In this chapter an empirical model is developed from which it is possible to obtain the relevant parameters for the present study. The chapter is concerned with expressing the theoretical models of the previous chapter in more specific empirical form, and with describing estimation and other empirical procedures.

Basically two sets of problems are involved. The first is to develop a means of estimating the consumer, producer and total surpluses in order that inferences can be made about choices among products to which agricultural research should be directed. The second problem is to estimate the underlying production function in such a way that induced innovation can be analyzed and priorities for research in the resource-saving dimension can be established.

Consumers', Producers' and Total Surpluses

Griliches[1/] has derived equations which describe the upper and lower limits of the total gain from a technological change that is expressed as a shift in the supply function.

[1/] Griliches, Z., op. cit.

He made two extreme assumptions about the nature of the supply curve: (1) that it was perfectly elastic, which provides an estimate of the lower limit of the gains, and (2) that it was perfectly inelastic, which provides an estimate of the upper limit of the gains. The functional forms for these upper and lower limits are:[1/]

$$\text{upper limit} = k_s P_0 Q_0 (1 + \tfrac{1}{2} k_s \eta)$$

$$\text{lower limit} = k_s P_0 Q_0 (1 - \frac{k_s}{2\eta})$$

where k_s is a shift parameter which represents the magnitude of technical change, P_0 and Q_0 refer to the price and quantity at the initial equilibrium, and η is the price elasticity of demand for the product.

Peterson[2/] developed an equation to measure the total surplus (consumers' plus producers' surpluses) on the assumption that the supply function generally has some (positive) slope. From that equation he demonstrated that Griliches' equations are in fact the upper and lower limit. Then, in order to have a conservative estimate of the rate of return, he used Griliches' lower limit to calculate the return to poultry research in the United States.

[1/] The functional forms differ from those presented by Griliches since he was interested in an ex-post problem and we are interested in an ex-ante problem.

[2/] Peterson, W.L., op. cit.

Ayer and Schuh[1/], on the other hand, derived the consumers' and producers' surpluses and the total gain through integration of the relevant parts of the curves. They did this because they had point estimates of the parameters in both the demand and supply equations.

For purposes of the present study it would be useful to have simple equations which could be used to calculate separately the consumers' and producers' surpluses and the total gain, given only the shift parameter of the supply equation, observations on price and quantity at the initial equilibrium, and estimates of the demand and supply elasticities. Such equations were derived[2/], with the following results:

$$\text{Consumer Surplus} = \frac{k_q}{\eta} P_0 Q_0 (1 + \tfrac{1}{2} k_q),$$

$$\text{Producer Surplus} = P_0 Q_0 (1 + \tfrac{1}{2} k_q)(k_s - \frac{k_q}{\eta}), \text{ and the}$$

$$\text{Total gain} = k_s P_0 Q_0 (1 + \tfrac{1}{2} k_q),$$

where $k_q = \eta k_s (\frac{E_s}{E_s + \eta})$, E_s is the elasticity of supply, and the other parameters are defined as above.

[1/] Ayer, H.W. and G.E. Schuh, op. cit.

[2/] The formal derivation is presented in Appendix C.

A comparison of the expression for the consumers' surplus with that for the producers' surplus indicates that consumers will gain more than producers if $\frac{k_q}{\eta} > (k_s - \frac{k_q}{\eta})$, and vice-versa. Substituting k_q by its expression we have:

$$k_s(\frac{1}{1 + \eta}) > (k_s - k_s \frac{1}{1 + \eta}).$$

Simplifying this express we obtain:

$$\frac{1}{1 + \eta/E} > (1 - \frac{1}{1 + \eta/E}).$$

Therefore, given the supply elasticity, consumers will gain more than producers the smaller is the demand elasticity. On the other hand, given the demand elasticity, consumers will gain more than producers the larger is the supply elasticity. Both propositions are consistent with generally accepted economic theory.

To compute the producers' and consumers' surplus as well as total gains, the Griliches upper and lower bounds will be used, since they permit the full range in variation of the total gain. To proportion the gain between producers and consumers, however, the above formulas will be used.

The shift parameter, k_s, will be set arbitrarily at 10 percent[1/], which is considered to be a conservative, viable

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[1/] The shift parameter is assumed to be the result of a combination of the potential capacity to shift the supply curve from a hypothetical technical change and the extent of adoption of the new technology. For a discussion of this problem, see Griliches, Z., op. cit., and Ayer and Schuh, op. cit.

shift in the supply curve from a concerted research effort. Estimates of the elasticities of demand, η_i, will be taken from previous studies when available, and in those cases where estimates are not available, some realistic range will be assumed. Similarly, estimates of the supply elasticities will be taken from previous studies when available, with a realistic range assumed for the elasticities when such estimates are not available.

The Production Function

As a basis for determining in what direction the research should be focused in the factor-factor dimension and how the producers' surplus will be distributed among the factors of production, some knowledge is needed of the elasticities of substitution among resource categories and the price indices for the subfunctions of the aggregate production function. These in turn require estimates of the underlying production function, with the production function specified in a particular form. It is to the specifications of this production function and the derivation of the appropriate parameters that we now turn.

Even though some attention has been given to extending the classical model of distribution to the n-factor case[1/],

[1/] For useful references, see Bajuk, A., op. cit.; Ferguson, C.E., "Production, Prices, and the Theory of Jointly Derived Input Demand Functions," Economica, 33(132):454-461, November 1966; and Hertford, R., "Determinants of the Distribution of Agricultural Incomes: A Structural Approach," Research Workshop on Problems of Agricultural Development in Latin America, Caracas, Venezuela, June 1971 (mimeographed).

an informative analytical solution is still lacking for the case of more than two factors, since problems of aggregation arise. One possible way of by-passing some of these problems is the introduction of separability into the aggregate production function. However, restrictive assumptions such as perfect competition and fixed input prices are still required in order to derive the relevant parameters.

Assume that the aggregate production function is strongly separable[1/] into two subfunctions that are homogeneous of degree one and which belong to the CES class of production functions.[2/] Their functional forms are:[3/]

$$Y = [\gamma_L Z_L^{-\rho} + \gamma_T Z_T^{-\rho}]^{-1/\rho} \qquad \gamma_L, \gamma_T > 0, \ -1>\rho = \frac{1-\sigma}{\sigma}, \tag{3.1}$$

where Y is output and Z_L and Z_T are the subfunctions which have the following functional forms:

1/ Strong separability means that the marginal rate of technical substitution between two inputs in a set is not affected by the quantity of other inputs not in that set, i.e.,

$$\partial\left(\frac{\partial Y/\partial L}{\partial Y/\partial K_L}\right)/\partial T = 0 \qquad L, K_L \varepsilon Z_L \text{ and } T \notin Z_L$$

2/ Sato, K., "A Two-Level Constant Elasticity of Substitution Production Function, Review of Economic Studies, 34(2): 201-218, April 1967.

3/ By asserting that gross output is a function of only Z_L and Z_T, we are assuming that the other factors are fixed. For other ways to define output as function of only Z_L and Z_T, see Sato, K., op. cit., pp. 204-205.

$$Z_L = f(L,K_L) = [\beta_1 L^{-\rho_L} + \beta_2 K_L^{-\rho_L}]^{-1/\rho_L} \quad \beta_1,\beta_2>0, -1<\rho_L = \frac{1-\sigma_L}{\sigma_L} \tag{3.2}$$

$$Z_T = f(T,K_T) = [\beta_3 T^{-\rho_T} + \beta_4 K_T^{-\rho_T}]^{-1/\rho_T} \quad \beta_3,\beta_4>0, -1<\rho_T = \frac{1-\sigma_T}{\sigma_T} \tag{3.3}$$

Equation (3.1) is a two-factor CES production function, provided that the factors of production can be partitioned into separate bundles, Z_L and Z_T. We justify the aggregation by the fact that aggregated factors are similar in techno-economic characteristics. One such similarity is obviously the ease of substitution. Therefore, we assume that $\sigma<1$, where σ is the elasticity of substitution between the subfunctions, and $\sigma_L,\sigma_T>1$, where σ_L and σ_T are the elasticities of substitution between factors within each subfunction. L and T are labor and land, respectively, and K_L and K_T are the so called "laboresque" and "landesque" capital, respectively.

What is needed now is to derive a form which facilitates empirical estimation. From the assumption of strong separability, which implies that allocation of factors within each class is determined exclusively by relative factor prices of that class only, the choice of the cost-minimizing factor combination is effectively separated into two stages.

Therefore, statistical estimation may also be carried out in two stages. In the first stage, the functions Z_L and Z_T are estimated, and in the second stage the interfunction elasticity of substitution is estimated.

In the first stage, on the assumptions of perfect competition, instantaneous adjustment, and differentiability of the functions, we have:

$$\frac{\partial Z_L}{\partial K_L} = [\beta_1 L^{-\rho_L} + \beta_2 K_L^{-\rho_L}]^{-(1/\rho_L+1)} \beta_2 K_L^{-(\rho_L+1)} \tag{3.4}$$

$$\frac{\partial Z_L}{\partial L} = [\beta_1 L^{-\rho_L} + \beta_2 K_L^{-\rho_L}]^{-(1/\rho_L+1)} \beta_1 L^{-(\rho_L+1)} \tag{3.5}$$

From the first-order condition of cost minimization, the following relationship holds

$$\frac{(3.4)}{(3.5)} = \frac{\beta_2}{\beta_1} \left(\frac{K_L}{L}\right)^{-(\rho_L+1)} = \frac{P_{K_L}}{P_L}$$

Since $\rho_L = 1 - \sigma_L/\sigma_L$, then $-(\rho_L+1) = -1/\sigma_L$

Therefore,

$$\frac{\beta_2}{\beta_1} \left(\frac{K_L}{L}\right)^{-1/\sigma_L} = \frac{P_{K_L}}{P_L}$$

Taking the value of K_L/P_L, we have

$$\frac{K_L}{L} = \left(\frac{\beta_2}{\beta_1}\right)^{\sigma_L} \left(\frac{P_{K_L}}{P_L}\right)^{-\sigma_L} \tag{3.6}$$

Adding a random term, e^{u_L}, to Equation (3.6) in view of the stochastic nature of observations, and transforming the equation into logarithmic form, we obtain the convenient estimational form:

$$\log \frac{K_L}{L} = \sigma_L \log(\frac{\beta_2}{\beta_1}) - \sigma_L \log(\frac{P_{K_L}}{P_L}) + u_L \qquad (3.7)$$

By the same procedures,

$$\log(\frac{K_L}{T}) = \sigma_T \log(\frac{\beta_4}{\beta_3}) - \sigma_T \log(\frac{P_{K_T}}{P_T}) + u_T \ . \qquad (3.8)$$

So far we have the means of estimating the "intra-class" elasticities of substitution. The next step is to estimate the "inter-class" elasticity of substitution, the convenient form of which can be derived from the first-order condition of profit maximization. Define

$$\pi = PY - \alpha_L Z_L - \alpha_T Z_T \quad .$$

Therefore,

$$\pi = P[\gamma_L Z_L^{-\rho} + \gamma_T Z_T^{-\rho}]^{-1/\rho} - \alpha_L Z_L - \alpha_T Z_T$$

where α_L and α_T are the price indices which correspond to the quantity indices Z_L and Z_T, respectively, and P is the product price.

Taking the derivative of π with respect to Z_L, we have

$$\frac{\partial\pi}{\partial Z_L} = P[\gamma_L Z_L^{-\rho} + \gamma_T Z_T^{-\rho}]^{-(1/\rho+1)} \quad \gamma_L (Z_L)^{-(\rho+1)} \quad -\alpha_L$$

From the first-order condition we have

$$P[\gamma_L Z_L^{-\rho} + \gamma_T Z_T^{-\rho}]^{-(1/\rho+1)} \quad \gamma_L (Z_L)^{-(\rho+1)} = \alpha_L$$

Multiplying both sides by Z_L/Py,

$$\gamma_L [\gamma_L Z_L^{-\rho} + \gamma_T Z_T^{-\rho}]^{-1} \quad Z_L^{-\rho} = \frac{\alpha_L Z_L}{PY}$$

Since the term between brackets on the left-hand side is equal to Y^{ρ}, then:

$$\frac{\alpha_L Z_L}{PY} = \gamma_L [\frac{Z_L}{Y}]^{-\rho}.$$

Adding a random term, e^u, in view of the stochastic nature of the observations, and substituting $-\rho = \frac{1-\sigma}{\sigma}$, we have the relation

$$\frac{\alpha_L Z_L}{PY} = \gamma_L [\frac{Z_L}{Y}]^{-(1-\sigma/\sigma)} \quad e^u \qquad (3.9)$$

The left-hand side is the relative expenditure share of the labor subfunction. Transforming Equation (3.9) into logarithmic form, we obtain

$$\log \frac{\alpha_L Z_L}{PY} = \log\gamma_L - \frac{1-\sigma}{\sigma} \log \frac{Z_L}{Y} + U_L \tag{3.10}$$

By the same procedures,

$$\log \frac{\alpha_T Z_T}{PY} = \log\gamma_T - \frac{1-\sigma}{\sigma} \log \frac{Z_T}{Y} + U_T \tag{3.11}$$

To estimate Equations (3.10) and (3.11), estimates of Z_L, Z_T, α_L and α_T are needed. Assuming that α_L is the imputed minimum cost of "producing" a unit of Z_L, we have:[1/]

$$\alpha_L = [\beta_1^{\sigma_L} P_L^{1-\sigma_L} + \beta_2^{\sigma_L} \cdot P_{K_L}^{1-\sigma_L}]^{\frac{1}{1-\sigma_L}} \tag{3.12}$$

Assuming $\alpha_L = 1$, then from Equation (3.12) we obtain

$$1 = [\beta_1^{\sigma_L} + \beta_2^{\sigma_L}]^{1/1-\sigma_L}$$

Since $1/1-\sigma_L$ is different from zero, then

$$\beta_1^{\sigma_L} + \beta_2^{\sigma_L} = 1 \tag{3.13}$$

Dividing both sides of Equation (3.13) by $\beta_1^{\sigma_L}$ we obtain

$$1 + \left(\frac{\beta_2}{\beta_1}\right)^{\sigma_L} = \frac{1}{\beta_1^{\sigma_L}} \tag{3.14}$$

[1/] For the derivation of this expression, see Sato, K., op. cit., pp. 216-217 and Uzawa, H., "Production Function with

Since we have estimates of β_2/β_1 and σ_L from the estimation of Equation (3.7), we can estimate $_1$ and $_2$. Therefore we can compute Z_L from Equation (3.2).

Following the same procedure we have

$$1 + \left(\frac{\beta_4}{\beta_3}\right)^{\sigma_T} = \frac{1}{\beta_3^{\sigma_T}} \tag{3.15}$$

To estimate the labor subfunction's price index, α_L, we make use of the following relation:

$$\alpha_L Z_L = P_L L + P_{K_L} K_L$$

Therefore:

$$\alpha_L = \frac{P_L L + P_{K_L} K_L}{Z_L}. \tag{3.16}$$

which, of course, should coincide with the value computed from Equation (3.12), except for a random element.

Following the same procedures we can obtain Z_T from Equation (3.3) and α_T from (3.17) below.

$$\alpha_T = \frac{P_T + P_{K_T} K_T}{Z_T} \tag{3.17}$$

α_L and α_T are the basis for making inferences about the direction research should take in the factor-factor dimension. In other words, if $\frac{\alpha_L}{\alpha_T} > 1$, this suggests that agricultural research should be directed to the labor subfunction. In the Hicksian framework the relation between α_L and α_T

1/ (continued) Constant Elasticities of Substitution," Review of Economic Studies, 29(4): 291-299, October 1962.

indicates the relative scarcity of the composite factors Z_L and Z_T.

In summary, the estimating Equations are (3.7), (3.8), (3.15), (3.16), (3.2), (3.3), (3.16), (3.17), (3.10) and/or (3.11). They will be estimated in that order.

The parameters of the equations that are estimated directly (Equations (3.7), (3.8), (3.10) and/or (3.11)) will be estimated with two sets of data. One set is derived from a survey carried out in 7 Brazilian states by the Fundacao Getulio Vargas.[1/] Two of the states (Ceara and Pernambuco) are located in the Northeast, two (Minas Gerais and Espirito Santo) in the East region, one is Sao Paulo, and the final two (Rio Grande do Sul and Santa Catarina) are located in the South region. These states represent a wide range of economic conditions and permit the estimation of both regional and national models.

The models will also be estimated with time series data for a recent period. These data refer only to national aggregates, and hence do not lend themselves to a regional analysis.

Given the independence between Equations (3.7) and (3.8), which follows from the basic assumption of separability,

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[1/] For a description of the survey and its revision, see Appendix A, of Alves, E.R., "An Econometric Study of Agricultural Labor Market in Brazil: A Test of Subsistence and Commercial Family Farm Models," Unpublished Ph.D. Thesis, Purdue University, 1972.

the parameters can be estimated by ordinary least squares. The fact that the estimated equations are reduced forms of a general structural model implies that the parameters are fully identified.

The variables are defined in the following way:

K_L = the service of some proxy of mechanical devices considered as a substitute of labor;

L = the amount of labor used by a unit of observation, which is a year for the time series data and a farm for the cross-section data;

P_{K_L} = the price of the proxy, K_L, used;

P_L = the prevailing wage rate for each unit of observation;

K_T = the quantity of fertilizer used by each unit of observation;

T = the amount of land devoted to production by each unit of observation;

P_{K_T} = the price of fertilizer;

P_T = the price of land for each unit of observation;

Y = the output observed;

P = the price of the output; and

U_L, U_T and U = stochastic terms with the usual properties.

CHAPTER IV

EMPIRICAL RESULTS

This chapter is divided into three parts. In the first part the potential gains from a specified technologically-induced shift in the supply curve for selected crops is estimated, together with estimates of the distribution of these gains between producers and consumers. In the second part the estimates of the elasticities of substitution for the production function are presented. And in the third part the price indices for the subfunctions are presented, together with supplemental information on prices and factor shares.

Total Gains from Assumed Technological Changes and their Distribution between Consumers and Producers

This part is divided into three sections. In the first section the selection of the crops which serve as the basis for the estimation of potential gains from assumed technological changes is discussed. The second section contains a discussion of the selection of the elasticities of demand and supply for those crops. And finally, the empirical results are presented.

Selection of the Crops

Allocation decisions with respect to agriucltural research are generally made on a crop basis, with the decision concerned about whether and in what proportions resources should be allocated to specific crops. The following analysis is designed to provide information which will help in making that decision, on the assumption that the total flow of benefits expected from a given technological change is important, and that policy makers or research managers have some notion with respect to what extent they desire to benefit producers and consumers.

Two criteria were considered in selecting crops for further analysis.[1/] The first was their relative economic importance, as measured by value of total output, total area planted to the crop, and the geographic spread of the crop over the country.

The second criteria was the magnitude of the price elasticity of demand. This parameter was considered because it was shown in the conceptual chapter that the relative share of benefits going to consumers and producers depends on the size of this elasticity. An important determinant of the magnitude of this elasticity is whether the product has export potential. If it does, then the demand elasticity

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[1/] The livestock sector was not considered in the analysis because of data limitations and the fact that so little is known about demand and supply parameters for this sector.

will be relatively high[1] and a major share of the benefits from technical change will go to the producers.[2] Therefore, it was decided to choose some products that have only a domestic market, and others which have either been exported in the past, or which have the potential to be exported. By this means it was possible to conduct the analysis under a rather wide range of values for the structural parameters.

The crops that met these criteria, and yet which kept the problem manageable, were: cotton, sugar-cane, corn, rice, edible beans and manioc (cassava).[3] During the period 1966/1970 these crops accounted for 46 percent of the total output from crops and 74 percent of the total acreage (Tables 2 and 3). Moreover, each of them was grown rather extensively in Brazil.

Cotton and sugar-cane are two of the traditional export products from Brazil. Rice and corn have been exported

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[1] This statement implies that the small-county hypothesis applies, or that the country is so unimportant in world trade for the given crop that it is unable to influence price.

[2] Indirect effects through the export multiplier, which could benefit the consumer, are ignored in the present study.

[3] Coffee would have been a candidate for inclusion on the basis of its relative economic importance. However, the prevalence of sizable government interventions in this sector and the relative importance of Brazil in world markets complicate the analysis and caused us to drop it from consideration.

Table 2. Output from Six Selected Crops, Output of All Crops, and Proportion Selected Crops Represent All Crops, Brazil, 1966/1970.[a]

	1966	1967	1968	1969	1970	Average 66/70
Cotton	512,287	601,128	915,360	1,048,688	1,343,567	884,206
Sugar-cane	656,886	812,898	1,041,565	1,241,678	1,578,945	1,066,394
Rice	865,365	1,402,133	1,666,473	1,690,889	2,254,806	1,575,933
Corn	810,608	1,186,430	1,352,310	1,730,110	2,198,940	1,455,680
Edible beans	577,659	660,436	725,833	1,060,196	1,412,026	887,230
Manioc	473,033	706,339	936,757	1,136,210	1,397,138	929,895
Total	3,895,838	5,369,364	6,638,298	7,907,771	10,185,422	6,799,339
All Crops	8,890,113	11,038,676	14,534,842	17,480,047	22,719,766	14,932,689
Percent	43.82	48.64	45.67	45.24	44.83	45.53

[a] Output measured in Cr$1,000.

Source: Fundacao IBGE. Anuario Estatistico do Brasil (various issues).

Table 3. Acreage Harvested of Six Selected Crops, of All Crops, and Proportion Selected Crops Represent of All Crops, Brazil 1966/1970.[a]

	1966	1967	1968	1969	1970	Average 66/70
Cotton	3,897,709	3,719,805	3,902,238	4,194,676	4,298,573	4,002,600
Sugar-cane	1,635,503	1,680,763	1,686,727	1,672,101	1,725,121	1,680,043
Rice	4,004,850	4,291,147	4,458,952	4,620,699	4,479,165	4,370,963
Corn	8,703,169	9,256,321	9,584,754	9,653,757	9,858,108	9,411,222
Edible beans	3,324,592	3,650,568	3,663,301	3,633,264	3,484,778	3,551,301
Manioc	1,779,806	1,914,439	1,998,197	2,029,373	2,024,557	1,949,274
Total	23,345,629	24,513,043	25,294,169	25,803,870	25,870,302	24,965,403
All Crops	31,449,754	32,752,963	33,564,057	34,579,533	35,891,677	33,647,597
Percent	74.23	74.84	75.36	74.62	72.08	74.20

[a] Area measured in hectares.

Source: Fundacao IBGE - Anuario Estatistico do Brasil (various issues).

occasionally, but not on nearly as large a scale as cotton and sugar-cane. They are produced primarily for the domestic market. Edible beans and manioc are traditional staple foods, and for the most part have not been exported. Hence, the analysis focuses on two crops that have been traditionally exported, two that have export potential, and two that are produced primarily for domestic consumption.

Definition of the Elasticities

The first step in defining the elasticities was to survey previous research on individual commodities that had been conducted either at the national level or for individual states. The results are presented in Tables 4 and 5. It turned out that there has been more work on the supply side than on the demand side, and that on the supply side there were more estimates available for the state of Sao Paulo than for either Brazil as a whole or for other states.[1/]

Given the range in the estimates of the parameters, it was decided to select three alternative estimates for the supply side -- a low, medium, and high -- so that some notion could be obtained of the sensitivity of the results to the value of the elasticity. On the demand side only two alternative estimates of the elasticities were selected --

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[1/] The parameter estimates for the national economy tend to be more consistent than those for the State of Sao Paulo, which vary substantially from one study to another.

Table 4. Selected Supply Elasticities for Brazil, State of Sao Paulo, and State of Goias from Various Authors.

Products	Brazil						Sao Paulo								
	Pastore		Paniago		Thompson		Pastore		Toyama & Pescarin		Brandt		Ayer & Schuh	Goias Villas	
	SR[a]	LR[b]	SR	LR	SR	LR	?	LR	SR	LR	SR	LR	LR	SR	LR
Cotton	.19	.63	----	----	----	----	1.22	2.03	.37	----	.69	1.57	.944	----	----
Sugar-cane	.16	.16	----	----	----	----	.12	.12	.27	.39	---	----	----	----	----
Rice	.31	1.17	.31	1.74	----	----	.61	1.96	.42	.69	.62	4.10	----	.30	2.34
Corn	.15	.57	----	----	.15	.58	----	----	.83	3.32	.45	2.55	----	----	----
Edible beans	.14	.15	----	----	----	----	.37	.37	.31	.43	.10	.31	----	----	----
Manioc	.11	.96	----	----	----	----	.26	.47	----	----	---	----	----	----	----

[a] Short-run elasticity as implied by a Nerlove-type distributed lag model.

[b] Long-run elasticity as implied by a Nerlove-type distributed lag model.

Source: Pastore, A.C., "A Oferta de Produtos Agricolas no Brazil," Pesquisa e Planejamento 1(2):171-234, December 1971. Paniago, E., "An Evaluation of Agricultural Prices for Selected Food Products: Brazil," Unpublished Ph.D. Thesis, Purdue University, 1969. Thompson, R.L., "The Impact of Exchange Rate Policy and Other Restricted Policies on Corn Exports in Brazil," Unpublished M.S. Thesis, Purdue University, 1969. Toyama, N.K., and R.M.C. Pescarin, "Projecoes da Oferta Agricola do Estado de Sao Paulo," Agricultura em Sao Paulo, 17(9/10):1-97, September/October, 1970. Brandt, S. and M. Barros and O.D. Neto, "Relacoes Area-Preco de Algodao no Estado de Sao Paulo," Agricultura em Sao Paulo, 12(1/2):31-38, January/February 1965. Ayer, H.W. and G.E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," AJAE, 54(4):557-569, November, 1972. Vilas A.T., "Estimativas de Funcoes de Oferta de Arroz para o Estado de Goias e, suas Implicacoes Economicas, Periodo 1948-1969," Unpublished M.S. Thesis, Federal University of Vicosa, Brazil, 1972.

Table 5. Selected Elasticities of Demand for Brazil and the State of São Paulo, Various Authors.

Products	Ayer & Schuh[a]	Martini[b]	Paniago	Mandell	Thompson
Cotton	-5.3	----	----	----	----
Sugar-cane	----	-.56	----	----	----
Rice	----	----	-.10	-.16	----
Corn	----	----	----	----	-.66
Edible beans	----	----	-.32	----	----
Manioc	----	----	----	----	----

[a] Elasticity for the State of Sao Paulo.

[b] Demand elasticity for sugar.

Source: Ayer and Schuh, op. cit. Paniago, E., op. cit. Thompson, R.L., op. cit. Martini, E., "Acucar no Brazil: Producao, Procura e Preco," Unpublished M.S. Thesis, Federal University of Vicosa, Brazil, 1964. Mandell, P.I., "A Expansao da Moderna Rizicultura: Crescimento da Oferta Numa Economia Dinamica," Revista Brasileira de Economia, 26(3):169-236, July/September, 1972.

an upper and a lower. In both cases arbitrary values were chosen in some cases in order to have a desired range in the parameters. For sugar-cane and rice a relatively elastic response to price on the demand side was assumed since both have considerable potential in world markets.[1/] In the case of manioc, for which there were no demand elasticities available, it was assumed from a priori knowledge that it is an inferior good and that it therefore would be expected to have a low elasticity of demand.

The elasticities chosen are presented in Table 6.

The Gains from Technical Change and their Distribution between Consumers and Producers

The results are presented and discussed on a crop by crop basis. In order to facilitate the comparison and analysis, the gains are expressed as a percent of the total value of output in the base period. An estimate of the absolute value of the benefits will be presented in the text however.

Cotton. The results for cotton are presented in Table 7. Since the demand for cotton is relatively elastic with respect to price, the producers receive the largest share of the gains. However, as the supply elasticity increases for a given demand elasticity, the producers' share

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[1/] The available estimate for sugar-cane is based solely on the domestic market.

Table 6. Elasticies of Supply and Demand Chosen for Analysis, Brazil.

Product	Supply			Demand	
	Lower	Medium	Higher	Lower	Higher
Cotton	.19[a]	.94[a]	1.57[a]	-2.00[b]	-5.30[c]
Sugar-cane	.10[b]	.60[b]	--	- .56[c]	-2.50[b]
Rice	.31[a]	1.17[a]	2.34[a]	- .16[1]	-1.50[b]
Corn	.15[a]	.58[a]	3.32[a]	- .30[b]	- .66[c]
Edible beans	.15[a]	.31[a]	.43[a]	- .32[c]	- .50[b]
Manioc	.11[a]	.47[a]	.96[a]	- .10[b]	- .30[b]

[a] Selected from Table 4.

[b] Arbitrarily chosen on the basis of available estimates.

[c] Selected from Table 5.

Table 7. Consumers', Producers' and Total Gain from Postulated Technological Change, Expressed as a Percent of Total Output, Cotton, Brazil (1966/70 base).

Demand Elasticities	Beneficiary	Supply Elasticities .19 Consumer	.19 Producer	.19 Total	.94 Consumer	.94 Producer	.94 Total	1.57 Consumer	1.57 Producer	1.57 Total	Griliches' Limits Upper	Griliches' Limits Lower
2.00	Consumer	.88			3.30			4.29				
	Producer		9.21			7.02			5.85			
	Total			10.09			10.32			10.44	11.00	9.75
5.30	Consumer	.35			1.57			2.43				
	Producer		9.74			8.83			8.18			
	Total			10.09			10.40			10.61	12.65	9.91

decreases and the consumers' share increases. Similarly, for a given supply elasticity the producers' share increases as the demand elasticity increases. The estimates of the total gains always lie between the upper and lower Griliches' limits, and approach the upper limit as the elasticity of supply increases.[1/]

In summary, if the demand for cotton is in fact relatively price elastic, the results suggest that producers will tend to gain more than the domestic consumers from technical changes. More specifically, they will gain more than 90 percent of the total gain if the demand elasticity is no less than 2.00. The total gain to both producers and consumers is estimated to be more than 10 percent of the total annual output when the supply shifts, or an expected flow of over Cr$88 million per year if the supply shift is maintained and the value of output corresponds to that obtained in the 1966/70 period.[2/]

Sugar-Cane. The results for sugar-cane are similar to those for cotton (Table 8). However, they do present a

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[1/] Estimates of these limits are presented in order to indicate what the conservative and "optimistic" magnitudes would be, as contrast to the basic estimates presented in the Tables, which are based on positively sloped supply curves.

[2/] It should be noted throughout this analysis that the flow of benefits is calculated in gross terms, since neither the cost of obtaining the technical change nor the value of complementary inputs such as fertilizer is considered.

Table 8. Consumers', Producers' and Total Gain from Postulated Technological Change, Expressed as a Percent of Total Output, Sugar-cane, Brazil (1966/70 base).

Demand Elasticities	Beneficiary	Supply Elasticities .10 Consumer	.10 Producer	.10 Total	.60 Consumer	.60 Producer	.60 Total	Griliches' Limits Upper	Griliches' Limits Lower
.56	Consumer	1.65			5.24				
	Producer		8.40			4.90			
	Total			10.05			10.15	10.28	9.11
2.5	Consumer	.38			1.99				
	Producer		9.66			8.26			
	Total			10.05			10.24	11.25	9.80

new aspect. When the supply elasticity is very small, .10 in this case, the producers' share is larger than the consumers' share, even though the demand is inelastic. The situation is reversed, however, when the supply elasticity is larger. Therefore, if the supply elasticity for sugarcane is greater than .5 and there are restrictions on the exports of sugar, any shift of the supply curve to the right tends to benefit relatively more the consumers. If, on the other hand, the supply response is relatively low and free trade prevails, the producers will tend to receive the larger share of the benefits.

The total gain is equal to slightly more than 10 percent of the total value of output if supply shifts as hypothesized. This corresponds to an annual flow of (gross) benefits of over Cr$106 million at the 1966/70 base level of output.

Rice. As expected the results for rice (Table 9) are similar to those for the crops described above. The total gain to society is equal to more than 10 percent of the value of output if the supply curve shifts as hypothesized, which corresponds to a flow of (gross) benefits of over Cr$157 million at the 1966/70 level for value of output.

The results for rice show in a marked way, however, the role of the supply elasticity in determining how the benefits are distributed. When the supply elasticity was small, the producer received the major share of the benefits,

Table 9. Consumers', Producers' and Total Gain from Postulated Technological Change, Expressed as a Percent of Total Output, Rice, Brazil (1966/70 base).

Demand Elasticities	Beneficiary	Supply Elasticities .31 Consumer	.31 Producer	.31 Total	1.17 Consumer	1.17 Producer	1.17 Total	2.34 Consumer	2.34 Producer	2.34 Total	Griliches' Limits Upper	Griliches' Limits Lower
.16	Consumer	1.99			8.86			9.43				
	Producer		8.06			1.21			.64			
	Total			10.05			10.07			10.07	10.25	9.00
1.50	Consumer	1.73			4.52			6.37				
	Producer		8.39			5.80			4.08			
	Total			10.13			10.33			10.46	10.75	9.67

independently of whether the upper or lower estimate of the demand elasticity was used. When the supply elasticity was large, however (greater than one), the consumer tended to receive the larger share of the benefits, the exception being when the demand elasticity was larger than the supply elasticity.

Corn. (Table 10) The results for corn also present a pattern similar to that for the other crops. The gain to society is slightly greater than 10 percent of total value of output in the base period, which amounts to a total annual flow of (gross) benefits of over Cr$145 million.

The results for corn again show the importance of the relative magnitude of the elasticities. When the supply elasticity is small relative to the demand elasticity,the producer tends to receive relatively more of the benefits, even though the absolute value of the elasticities is less than one in both cases. When the supply elasticity is larger than the demand elasticity, the consumer receives the larger share of the benefits.

Given that corn is produced primarily for domestic consumption (with a relatively low demand elasticity implied), the producers would tend to gain a larger share of the benefits of technological change only as long as the supply elasticity were relatively low. Therefore, it is expected that the consumers will be the main beneficiary from the development of new technology for corn production, unless

Table 10. Consumers', Producers' and Total Gain from Postulated Technological Change, Expressed as a Percent of Total Output, Corn, Brazil (1966/70 base).

Demand Elasticities	Beneficiary	Supply Elasticities .15 Consumer	.15 Producer	.15 Total	.58 Consumer	.58 Producer	.58 Total	3.32 Consumer	3.32 Producer	3.32 Total	Griliches' Limits Upper	Griliches' Limits Lower
.30	Consumer	3.35			6.66			9.30				
	Producer		6.70			3.44			.84			
	Total			10.05			10.10			10.14	10.15	8.33
.66	Consumer	1.86			4.73			8.56				
	Producer		8.20			5.42			1.71			
	Total			10.06			10.15			10.28	10.33	9.25

Brazil should become strongly competitive in world markets and export a relatively large share of its output.

Edible Beans. Edible beans are produced exclusively for the domestic market and, with an income elasticity of demand close to zero or negative[1/], it is expected that the elasticity of demand would also be quite low. It is expected, therefore, that consumers would be the major beneficiaries of technical change in this crop. The results in Table 11, however, indicate that the size of the supply elasticity is important. For low values of the supply elasticities the producers tend to receive the larger share. In fact, within the range of parameters examined, only when the demand elasticity is .32 and the supply elasticity .43 do the consumers receive the larger share of the benefits.

The total gain to society is again approximately 10 percent of the value of output in the base period, with the estimated lower limit being about 8 percent of the value of output. This annual flow of (gross) benefits would amount to about Cr$88 million per year, if the shift of the supply curve was as postulated. It should be noted that even though the production of edible beans is primarily for domestic consumption, the total gain is not greatly different from the other products described above.

[1/] For estimates of income or expenditure elasticities for the principal Brasilian food items, the reader is referred to Projections of Supply and Demand for Agricultural Products of Brazil Through 1975, The Getulio Vargas Foundation, USDA, 1968.

Table 11. Consumers', Producers' and Total Gain from Postulated Technological Change, Expressed as a Percent of Total Output, Edible Beans, Brazil (1966/70 base).

Demand Elasticities	Beneficiary	Supply Elasticities .15 Consumer	.15 Producer	.15 Total	.31 Consumer	.31 Producer	.31 Total	.43 Consumer	.43 Producer	.43 Total	Griliches' Limits Upper	Griliches' Limits Lower
.32	Consumer	3.21			4.96			5.78				
	Producer		6.84			5.12			4.31			
	Total			10.05			10.08			10.09	10.16	8.44
.50	Consumer	2.32			3.87			4.67				
	Producer		7.74			6.23			5.44			
	Total			10.06			10.10			10.12	10.25	9.00

Manioc. Manioc is basically a food for the lower income groups in Brazil. Estimates of its income elasticity tend to indicate a negative relationship[1/], and its price elasticity is expected to be the lowest among the six products considered in this study. Therefore, the presumption is that the consumer will tend to benefit more from a technologically-induced shift in the supply curve for this crop.

The results presented in Table 12 tend to support this presumption. It is only when the supply elasticity is quite low, and lower than the demand elasticity, that the producer receives a larger share of the benefits.

Two points should be noted about the case of manioc, however. First, it has potential as a livestock feed, especially for swine. Development of this potential in Brazil could raise the demand elasticity. In addition, there may be considerable export potential, especially in light of what appears to be a growing world short-fall in feed grains.

The total gain from the postulated shift in the supply curve is estimated to be about 10 percent of the value of output. However, the Griliches' lower limit, 5 percent, is the lowest among the six products considered. A gain of 10 percent represents an annual flow of benefits of approximately Cr$92 million per year at the 1966/70 level of value of output.

[1/] See Projections of Supply and Demand for Agricultural Products of Brazil through 1975, the Getulio Vargas Foundation, USDA, 1968.

Table 12. Consumers', Producers' and Total Gain from Postulated Technological Change, Expressed as a Percent of Total Output, Manioc, Brazil (1966/70).

Demand Elasticities	Beneficiary	Supply Elasticities .11 Consumer	.11 Producer	.11 Total	.47 Consumer	.47 Producer	.47 Total	.96 Consumer	.96 Producer	.96 Total	Griliches' Limits Upper	Griliches' Limits Lower
.10	Consumer	5.25			8.28			9.10				
	Producer		4.77			1.76			.95			
	Total			10.03			10.04			10.05	10.05	5.00
.30	Consumer	2.69			6.16			7.71				
	Producer		7.35			3.93			2.41			
	Total			10.04			10.09			10.11	10.05	9.06

To the extent that the supply response is technologically determined, the research effort might be directed at least in part to this end. In this way both consumers and producers might benefit from a technological thrust.

Estimates of the Elasticities of Substitution

This part is divided into three sections. The first section presents the results for the labor subfunction, the second the results for the land subfunction, and the third section the results for the total function.

The Labor Subfunction

The model was first tested with the cross-sectional data. Estimates of the parameters were made for each of the selected states[1/], plus a "national" model in which the state data were pooled.

A limitation of the statistical analysis from the very beginning was that the estimating equation could not be used in the form specified in Chapter III. Rather, an alternative formulation had to be used in which only the price of labor could be treated as an independent variable:[2/]

[1/] The states are: Sao Paulo (S.P.), Minas Gerais (M.G.), Pernambuco (P.E.), Rio Grande do Sul (R.G.S.) and Ceara (C.E.).

[2/] The original specification of the model was

$$\log \frac{K_L}{L} = \sigma_L \log \frac{\beta_2}{\beta_1} - \sigma_L \log \frac{P_{K_L}}{P_L}$$

$$\log \frac{K_L}{L} = \sigma_L(\log \frac{\beta_2}{\beta_1} - \log P_{K_L}) + \sigma_L \log P_L$$

The reason for this was the need to aggregate capital, and a lack of confidence in the degree to which reported prices for such capital items as tractors might in fact represent true pieces of the services rendered by these goods.

The results of estimating this equation were disappointing. The coefficients were not significantly different from zero at usually accepted levels for any of the states, or the pool, and the coefficients of determination were close to zero.

Various experiments were made with the model in order to test alternative specifications of the variables. In one experiment capital was defined as motorized and motor-related equipment plus animal-drawn implements.[1/] In a second experiment hand tools were added to the capital stock as defined above. And finally, tractors alone were used as a proxy for the laboresque capital.[2/] This latter experiment could be carried out only for the state of Sao Paulo, since the

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[1/] The form in which the data were published does not permit a separation of motorized and non-motorized equipment.

[2/] Tractors were basically the only choice available for a single measure of laboresque capital, since other kinds of motorized equipment such as combines and threshing machines were fairly limited on the farms covered by the sample.

number of tractors in the other states was fairly limited.

For all experiments labor was aggregated by standardizing to that of the daily worker paid in cash. The price of labor was specified as the daily wage for the cash, daily-paid worker.

The only model which resulted in a significant coefficient for the price variable was when tractors were used as the proxy for the laboresque capital, with the analysis restricted to Sao Paulo. The results for this equation were:

$$\log \frac{K_L}{L} = -.367 - .837 \log P_L$$

The t-value on the coefficient of price was 2.12, which indicates that the coefficient is significantly different from zero at the 5 percent level. However, the coefficient of determination was only .05, and the coefficient of the price variable was contrary to a priori expectations.

The results with time series data were more encouraging, and in the end provided important insights about the stage and character of modernization in Brazilian agriculture. Two time series of data for Brazil as a whole were available to further test the model. One data series referred to tractors on farms and covered the period from 1950 to 1971. This was used as a proxy for laboresque capital, with the price of a "typical" tractor unit used as its

price.[1] The flow of tractor services was estimated as the combination of an opportunity-cost rate of interest and depreciation.[2]

Estimates of the labor input were made from data on the total agricultural labor force and an assumption that on the average each laborer worked 150 days a year. The daily wage rate for the cash, daily-paid worker of Sao Paulo was used as the price of labor.

The second time series provides estimates of the stock of horsepower on farms and is available for the period from 1962 to 1971. This data series provides an alternative measure of laboresque capital. It was also possible to estimate an average price per unit of horsepower. In this case the "stock" of horsepower also represents the flow, and hence the problem of estimating the flow of services is reduced. The price of the "flow" of horsepower was again estimated assuming a 20-year life for the tractor. The labor input and price of labor were defined in the same way when this data series was used.

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[1] The basis for the price series was the Fordson 42 horsepower tractor for the 1950 decade, spliced to the Massey-Ferguson 50X, which has a 44.5 horsepower motor. A description of the data is presented in Appendix E, and the data series are presented in Appendix F. The price of the flow of services from the tractor was estimated as 5 percent of the tractor price, which assumes a 20-year life for the tractor. This is essentially a "rental" price.

[2] The opportunity cost on capital was assumed to be 10 percent, and the depreciation charge was 5 percent. This latter assumes straight-line depreciation and an expected

The basic model as described in Chapter III was used for estimating purposes and the results are presented in Table 13. The statistical results for both periods (and both specifications of the capital variable) are reasonably good. The coefficients of determination are relatively high, and the coefficients for the price variable are statistically different from zero at the 1 percent level. However, the sign of the price coefficients had opposite signs in the two equations.[1/] The sign for the 1950/1971 period was consistent with the limited findings obtained with the cross-sectional data, and contrary to a priori expectations. The sign for the 1962/1971 period, on the other hand, was consistent with that hypothesized a priori.

These results suggest that there was what might be called a technological turning point sometime around or shortly after 1960. Alternatively, however, the difference in results may be due to the difference in definition of the laboresque capital and its price, since the horsepower definition involves an implicit qualitative adjustment for the capital variable.[2/]

[2/] (continued) life of 20 years. Sensitivity analysis indicated that the results were quite stable under alternative measures of the flow of services.

[1/] It should be noted that the R^2 in the horsepower specification is substantially higher than in the "tractor" specification.

[2/] If tractors are used primarily for the power they use, estimating the "stock" of tractor services by the number of horsepower they represent may be a more accurate measure of

Table 13. Regression Results for the Labor Subfunction with Time Series Data, National Model, Brazil.

Coefficients	Proxies	
	Tractor (1950/71)	Horsepower (1962/71)
Constant term	-12.588***	-2.174***
Price Variable	3.740 (4.231)[a]	-.605 (-10.681)
R^2	.46	.92
D.F.	20	8

[a] The numbers in parentheses are t-values.
***Significant at the 1 percent level

To test this hypothesis the 1950/1971 series was disaggregated into two periods, one extending from 1950 to 1961 and the other from 1962 to 1971. The statistical results for the two periods are presented in Table 14. They support the hypothesis of the existence of a turning point. The coefficients of determination are again reasonably large and the coefficients for the price variables are significantly different from zero at the 1 percent level, and again have opposing signs for the two periods.

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[2] (continued) tractor services than the flow of services estimated from the value of the stock of tractors. Estimating the services of tractors by their monetary value may introduce factors which could lead to measurement error.

Table 14. Regression Results for the Labor Subfunction with 1950/1971 Time Series Disaggregated into Two Components, National Model, Brazil.

	1950/1961	1962/1971
Constant term	-10.500 ***	5.570 ***
Price Variable	2.754 (12.510)[a]	-2.311 (-2.902)
R^2	.93	.48
D.F.	10	8

[a] The numbers in parentheses are t-values.
***Significant at the 1 percent level.

The evidence for a technological turning point is thus rather strong. The negative coefficient for the latter period is obtained with both concepts of the laboresque capital.

However, a problem still remains. When the capital variable is measured as the value of tractor services, the coefficient of the price variable is larger than one, and hence consistent with a priori expectations. When the flow of horsepower services is used, the coefficient is less than one (although negative), and hence not entirely consistent with expectations.

It was decided to use the horsepower measure in further analyses for basically two reasons. In the first place,

it would seem to represent a conceptually "cleaner" measure of the services provided by laboresque capital. In addition (and perhaps because it is a better measure), it results in a larger coefficient of determination for the estimation equation (.92 as contrast to .48).

Both the notion of a turning point and the relatively small coefficient on the price variable are reasonably plausible results. The point is that up until 1960 the level of mechanization was indeed low in Brazil.[1/] Moreover, the most important use of tractors was for the power-demanding land preparation operation, which is believed by most authorities on the subject to increase the demand for labor rather than to be labor displacing. The increased demand for labor comes about by increasing the crop area and by increasing yields.[2/]

During the decade of the 1960's there was considerable mechanization in Brazil. Moreover, a start was made towards mechanizing the harvesting operation, especially for crops like wheat, soybeans, and cotton, and to a lesser extent

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[1/] The 1960 Agricultural Census indicates that 76 percent of the Brazilian farms were using only human power, while less than one percent were using some mechanical power. See Schuh, G. Edward, The Agricultural Development of Brazil. (New York: Praeger Publishers, 1970), p. 154.

[2/] These points were suggested by Sanders, J.H. in "Mechanization and Employment in Brazilian Agriculture, 1950-1971," Unpublished Ph.D. Thesis, University of Minnesota, 1973, p. 14 and Appendix F.

sugar-cane. The mechanization of the harvesting operation is generally believed to be strongly labor displacing.

This difference in both the extent and kind of mechanization would appear to be a plausible explanation of the turning point. The fact that even as late as 1971 the level of mechanization was fairly limited, and not yet generalized in the harvesting operation, is the probable explanation for the coefficient not being greater than one. It should be noted, however, that as mechanization becomes more extensive, and as it is extended to the harvesting operation through greater use of combines and harvesters, it may be that the substitutability of capital for labor will increase. This has important implications in terms of establishing research priorities.

Land Subfunction

From the states originally selected, equations were estimated only for Sao Paulo (S.P.), Minas Gerais (M.G.), Pernambuco (P.E.), Rio Grande do Sul (R.G.S.), and a pool among these four states. Ceara was eliminated because in that state only a limited number of the farms included in the survey used fertilizer. Various experiments were again made with the model in order to test alternative specifications of the variables as well as alternative formulations of the model.

Experiments 1, 2, 3 and 5 involved the original formulation as specified in Chapter III, with the factor proportion

between land and fertilizer regressed on the price ratio of these two inputs. In Experiment 1 land was defined to include the total area in the farm (the sampling unit), with the different "qualities"[1/] of land standardized to the base of flat land for crops. Chemical fertilizer was used as a proxy for landesque capital. Observations from all farms were included in the regression, with a value close to zero used for the observation on fertilizer when the farm did not use any of this input.[2/] The prices of land and fertilizer were as reported by the individual farms. When a farm did not use fertilizer it was assumed that it was available to him at the average price of the sample.

In Experiment 2 only observations from farms that had used fertilizer entered the regression. The variables were measured in the same way as in Experiment 1.

Experiments 3 and 5 also utilized only data from farms that had used fertilizer. In Experiment 3 it was assumed that the farms fertilized only crop land, and the land variable was therefore defined accordingly. In Experiment 5 the definition was even more restrictive, and land was defined as only the flat land used for crops. This assumption is

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[1/] Land quality was assumed to be characterized by the topography and the use of the land.

[2/] The regression equations were estimated in logarithmic form. Values which are very close to zero do not affect the slope.

not as heroic as it might seem, since fertilizer use in Brazil at the time of the survey was still at a very low level.[1/]

In Experiments 4 and 6 the following variant of the model was used:

$$\log \frac{K_T}{T} = \sigma_T(\log \frac{\beta_4}{\beta_3} + \log P_T) - \sigma_T \log P_{K_T} \qquad (4.1)$$

When using this specification it is assumed that the price of land does not vary systematically with the price of fertilizer.[2/] Therefore, the fertilizer-land ratio was regressed only on the price of fertilizer.

The statistical results are presented in Table 15. The results from Experiment 1 provide strong support for the model. The coefficients of determination are relatively high, given that cross-sectional data are being used to test the model. The coefficients of the price variables for the four states and the pool had the expected sign, and the size of the coefficient was relatively large, as hypothesized. In

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[1/] To test the underlying theory one would ideally like to have observations on the land that was in fact fertilized and the corresponding quantity of fertilizer that was used, with their respective factor prices. Unfortunately, the basic data did not permit this degree of refinement. It was for this reason that various specifications of the variables were tried.

[2/] This variant was tried because the price of land obtained in the survey may not represent a true market price, or it may be poorly measured.

Table 15. Regression Results for the Land Subfunction, Selected States, Brazil (1962/64).

Experiments	Sao Paulo				Minas Gerais			
	Constant Term	Price Variable	R^2	Degrees of Freedom	Constant Term	Price Variable	R^2	Degrees of Freedom
1	-14.889	-3.213*** (-34.608)[a]	.73	452	-13.735	-3.372*** (-15.533)	.56	191
2	.343	.018 (.146)	.00	151	- 1.450	- .705*** (-2.500)	.14	38
3	- .595	-.537*** (-4.657)	.12	161	-1.055	- .749***	.20	38
4	.677	-.480*** (-3.088)	.06	161	.666	-1.071*** (-2.671)	.16	38
5	.316	-.456** (-2.268)	.04	129	-1.062	-1.467*** (-3.861)	.36	26
6	1.437	-.614*** (-2.344)	.04	129	2.197	-2.001*** (-3.809)	.36	26

Table 15. Continued.

Experiments	Pernambuco				Rio Grande do Sul			
	Constant Term	Price Variable	R^2	Degrees of Freedom	Constant Term	Price Variable	R^2	Degrees of Freedom
1	-13.036	-2.840*** (-40.381)	.87	240	-14.660	-4.041*** (-14.454)	.47	234
2	.613	.263 (.633)	.01	28	.668	.666*** (2.881)	.15	46
3	.653	.075 (.272)	.00	28	-.320	-.399*** (-2.107)	.09	46
4	.634	-.475 (-1.166)	.05	28	.368	-1.917*** (-3.915)	.25	46
5	2.831	.224 (.119)	.00	23	1.029	- .415 (-.845)	.02	32
6	3.394	-4.344* (-1.673)	.11	23	2.005	-5.488*** (-3.836)	.31	32

Table 15. Continued.

Experiments	Pool			
	Constant Term	Price Variable	R^2	Degrees of Freedom
1	-13.462	-2.954*** (-46.101)	.65	1123
2	- .393	- .272*** (-3.518)	.04	273
3	- .43	- .468*** (6.992)	.15	279
4	.593	- .592*** (-4.561)	.07	279
5	1.391	- .059 (- .428)	.00	216
6	1.698	- .958*** (-3.834)	.06	216

a/ Numbers in parentheses refer to t-values.

*** --Significant at 1 percent level.

** --Significant at 5 percent level.

* --Significant at 10 percent level.

addition, all coefficients were significantly different from zero at the 1 percent level.

The results with Experiment 2 were rather weak, however. The coefficients of determination were quite low, and the coefficients for the price variable were significantly different from zero at usually accepted levels only for Minas Gerais, Rio Grande do Sul, and the pool. The coefficient for Rio Grande do Sul had the wrong sign[1/], however, and in all cases the size of the coefficient was smaller than what was hypothesized.

The statistical results from Experiment 3 were slightly improved over Experiment 2. The coefficients of determination were still low, however, although in three of the five cases they were larger than in Experiment 2. Four of the coefficients of the price variable -- for Sao Paulo, Minas Gerais, Rio Grande do Sul and the pool -- were significantly different from zero and had the expected sign. (Only in the case of Pernambuco did the coefficient have the wrong sign.) The size of the coefficients were still relatively small, however.

The results from Experiment 4 were similar to those from Experiment 3, with some further improvement noted. The

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[1/] The coefficients for Sao Paulo and Pernambuco also have signs that are contrary to expectations, but they are not significantly different from zero at usually accepted levels.

coefficients of the price variable for Minas Gerais and Rio Grande do Sul had the expected size, and the coefficient for Pernambuco had the expected sign, even though it was not significantly different from zero. The coefficients of determination were still relatively small, however.

The results from Experiment 5 were rather weak. In overall terms this experiment showed the lowest coefficients of determination, with a reasonable fraction of the variance being explained only in the case of Minas Gerais. In addition, the coefficients of the price variable were significantly different from zero at usually accepted levels only in the cases of Sao Paulo and Minas Gerais. All states but Pernambuco and the pool had the expected sign on the coefficient. However, only Minas Gerais had a coefficient whose size was consistent with the a priori hypothesis.

The statistical results from Experiment 6 were improved in relation to Experiment 5. The coefficient of determination were still relatively low, but in the cases of Minas Gerais and Rio Grande do Sul a reasonable portion of the variance was explained. The coefficients on the price variables all had the expected sign and were significantly different from zero at usually accepted levels. Three of them -- for Minas Gerais, Pernambuco and Rio Grande do Sul -- had a size of coefficient that was consistent with the a priori hypothesis, and the size of the coefficient from the pool was close to being of the expected magnitude.

The overall statistical results from the cross-sectional data provide limited support for the underlying model. When all the farms in the sample are included (Experiment 1), the statistical results were reasonably good and the size and sign of the coefficients were consistent with the a priori hypotheses. However, when only farms that use fertilizer were considered, the statistical results were somewhat disappointing. Even though the coefficient of the price variable was significantly different from zero at usually acceptable levels a fairly large portion of the time, the coefficient of determination tended to be low, the size of the coefficient was not always as large as hypothesized from a priori considerations, and there were occasional wrong signs.

For this reason it was decided to turn to time series data.[1/] Data were available which provide estimates of the aggregate quantity consumed and the respective prices for each nutrient (nitrogen, phosphorus, and potassium), plus the area in crops in Brazil.[2/] Unfortunately, it was not

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[1/] The data which were readily available cover the period 1950 to 1970.

[2/] In fitting the models it was assumed that all fertilizers were used for crop production. This is a plausible assumption, given that fertilizer is seldom used on pastures in Brazil. Knight has noted that even in Rio Grande do Sul, which has a fairly advanced agriculture and one in which modern beef production is important, fertilizer is used on pasture only for experimental purposes. See Knight, Peter, Brazilian Agricultural Technology and Trade: A Study of Five Commodities, New York, Praeger Publishers, 1971.

possible to obtain a long data series on either the price or rental value of land, since this data is available only from 1966 to the present. Therefore, we were restricted to the use of the alternative model referred to at the beginning of this section.

Given that the results for the labor subfunction suggest a turning point in the production technology at some point in the early 1960's, the equations were estimated for three different time periods: (1) the whole period, 1950/1970, (2) the period 1950/1960, and the period 1961/1970. In addition, separate models were estimated for each nutrient and for the aggregate of the three.

The statistical results (Table 16) were consistent with those for the labor subfunction in the sense that they also indicate the existence of a technological turning point in the early 1960's. When the equations were fitted with data from the 1950/60 period, in no case were the coefficients of the price variable significantly different from zero, and the coefficients of determination were close to zero. These results are consistent with the hypothesis that the elasticity of substitution between fertilizer and land is zero, or that they are complements in production.

When data were used from the period 1961-70, however, the coefficients of the price variable were all significantly different from zero at usually accepted levels, and the coefficients of determination were relatively high. The

Table 16. Regression Results for the Land Subfunction, Time Series Data, 1950/1970-Brazil.

	N			P_2O5		
	1950/70	1950/60	1961/70	1950/70	1950/60	1961/70
Constant Term	2.957	2.004	2.994	1.722	1.060	2.395
Price of Fertilizer	-1.089*** (-2.862)[a]	-.778 (-.860)	-1.025*** (-7.328)	-.461** (-1.739)	-.202 (-.437)	-.717** (-2.729)
R^2	.29	.07	.85	.13	.02	.45
Degrees of Freedom	19	9	8	19	9	8

	K_2O			Total		
	1950/70	1950/60	1961/70	1950/70	1950/60	1961/70
Constant Term	2.703	.462	3.587	2.389	.869	3.341
Price of Fertilizer	-.939** (-2.516)	-.079 (-.105)	-1.237*** (-3.424)	-.596** (-1.859)	-.010 (-.015)	-.933*** (-5.751)
R^2	.24	.00	.56	.15	.00	.79
Degrees of Freedom	19	9	8	19	9	8

[a] Numbers in parentheses are t-ratios.

***Significant at 1 percent level.
**Significant at 5 percent level.
*Significant at 10 percent level.

coefficients all have the expected signs, and for nitrogen and potash the coefficients (elasticities of substitution) are greater than one.

In conclusion, the time series data provide evidence for a technological turning point in both components of the production function. The explanation for these turning points seems to be that during the decade of the 1950's the modern inputs of fertilizer and machinery were still used at relatively low levels. In the case of machinery, both the level and kind of mechanization were such that it was highly complementary with labor, and in effect increased the demand for the latter. In the case of fertilizer, the complementarity with land was not quite so high. In fact, fertilizer application may have been doing little more than replacing nutrients removed by crops.

During the decade of the 1960's, however, the use of both fertilizer and mechanization appear to have reached the point where they were land- and labor-substituting, respectively. This change in structure has very important implications for research policy and the establishment of research priorities.

The Inter-Subfunction Elasticity of Substitution

In the previous section the results obtained for the land and labor subfunctions were presented. The present section reports the results of estimating the elasticity of substitution between the two subfunctions. For this purpose

the results using the time series data for the period 1962/71 will be used (Table 13).

It will be recalled that the estimating equations for this purpose are:[1/]

$$(1) \quad \log \frac{\alpha_L Z_L}{P \cdot Y} = \log \gamma_L - \frac{1 - \sigma}{\sigma} \log \frac{Z_L}{Y} + U_L$$

and/or

$$(2) \quad \log \frac{\alpha_T Z_T}{P \cdot Y} = \log \gamma_T - \frac{1 - \sigma}{\sigma} \log \frac{Z_T}{Y} + U_T$$

The estimates of σ can be obtained from either equation. However, in principle the parameters of both equations should be estimated in order to have a check on the parameter estimates. It was not possible to follow this procedure, however, since the parameters of the land subfunction[2/] were estimated with the alternative model which considered only variations in the price of fertilizer. Because of this, a key parameter, the β's, cannot be estimated from the constant term.[3/] Therefore, the estimate of σ will be made only from Equation (1).

[1/] The variables are defined in Chapter III.

[2/] It was desired to use the land subfunction that was estimated with the time series data in order to provide consistency with the labor subfunction.

[3/] The reader is referred to Chapter III and below for the procedures used in estimating the β's.

To estimate the inter-function elasticity of substitution and the subfunction quantity index, Z_L, as well as the subfunction expenses, $\alpha_L Z_L$, must first be calculated. The equations for this purpose are:

$$(3) \quad \alpha_L Z_L = LP_L + K_L P_{K_L}$$

and

$$(4) \quad Z_L = [\beta_1 L^{-\rho_L} + \beta_2 K_L^{-\rho_L}]^{-1/\rho_L}$$

where

$$\beta_1 = \frac{1}{(1 + (\frac{\beta_2}{\beta_1})^{\sigma_L})^{1/\sigma_L}}$$

$$\beta_2 = (\frac{\beta_2}{\beta_1}) \beta_1$$

and

$$\rho_L = \frac{1 - \sigma_L}{\sigma_L}$$

The ratio β_2/β_1 and the estimate of σ_L are derived from the estimated parameters in Table 13. (Log β_2/β_1 = -3.593 and ρ_L = .653.) The magnitude of these parameters indicates that β_1 approaches one and β_2 approaches zero, since log β_2/β_1 is negative and its characteristic is three.

Given that the estimated value of β_1 approaches one and β_2 approaches zero, and that ρ_L is greater than zero, the term $\beta_2 K_L^{-\rho_L}$ in Equation 4 approaches zero.[1/] Therefore, Z_L was taken to be equal to the total labor used, with capital ignored.

Two alternative means of estimating $\alpha_L Z_L$ were tried, with the result that two alternative estimates of the inter-subfunction elasticity of substitution were obtained. In one formulation only the value of the labor services was considered (Experiment 1). In the second case the value of the flow of tractor services (measured in horsepower) was added to the value of the labor services. For this purpose the "rental" value of the horsepower unit (5 percent of the price of a horsepower) was multiplied by the number of horsepower.

The statistical results (Table 17) can be considered reasonably good. The coefficients of determination are relatively high, and the coefficients of the input/output ratio (Z_L/Y) have the expected sign and are significant at the 1 percent level.

The size of the elasticity of substitution as estimated from the input/output ratio was consistent with a priori expectations (less than 1), and was almost invariant

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[1/] This is consistent with the argument made earlier that mechanization is fairly limited in Brazilian agriculture in the aggregate.

Table 17. Regression Results for the Inter-Subfunction Elasticity of Substitution, National Model, Time Series Data, 1962/71, Brazil.

Experiments	Constant Term	Input/ Output Variable	R^2	D.F.	Elasticity[b/] of Substitution
1	3.144	-.110*** (-4.927)[a/]	.73	8	.901
2	3.154	-.111*** (-5.127)	.74	8	.900

[a/] The number in parentheses are t-values.
[b/] Estimated from the coefficient on the input/output variable.
***significant at the 1 percent level.

to the alternative assumptions. However, the elasticity was larger than the elasticity of substitution in the labor subfunction (.605). The elasticity of substitution in the land subfunction was .933.[1/] This is larger than the inter-subfunction elasticity, but in neither case were the elasticity, but in neither case were the elasticities of substitution in the subfunctions greater than one, as postulated.

The Price Indices for the Subfunctions

Price indices for the aggregate input represented by a subfunction can be calculated from knowledge of the

[1/] The elasticity for the aggregate fertilizer variable is used.

parameters of the production function. In the context of the basic analytical model which was postulated in Chapter II, these indices are important parameters in their own right, since their ratio should give an indication of the direction that research should take. That is, the ratio should indicate whether emphasis should be given to the labor or the land subfunction in the research program, since it should indicate the relative factor scarcity in the Hicksian sense.

Unfortunately, it was not possible to estimate the ratio of the price indices, since the price ratio for the land subfunction cannot be calculated. The reason for this is that the alternative model in which only the price of fertilizer was used was the basic estimation equation. This precludes the estimation of the β's.

Given the inability to estimate the aggregate price indices, the alternative is to examine the trends in prices for the individual inputs. The recent trends in the prices of land and labor, the two principal inputs in Brazilian agriculture, are graphed in Figure 11. The Figure indicates that between 1966 and 1973 the price of land services has been increasing faster than the price of labor.[1/] These data suggest that in recent years land has become increasingly scarce in relation to labor. Therefore, a tentative

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[1/] The input prices are measured in real terms, with the original data deflated by the cost of living index.

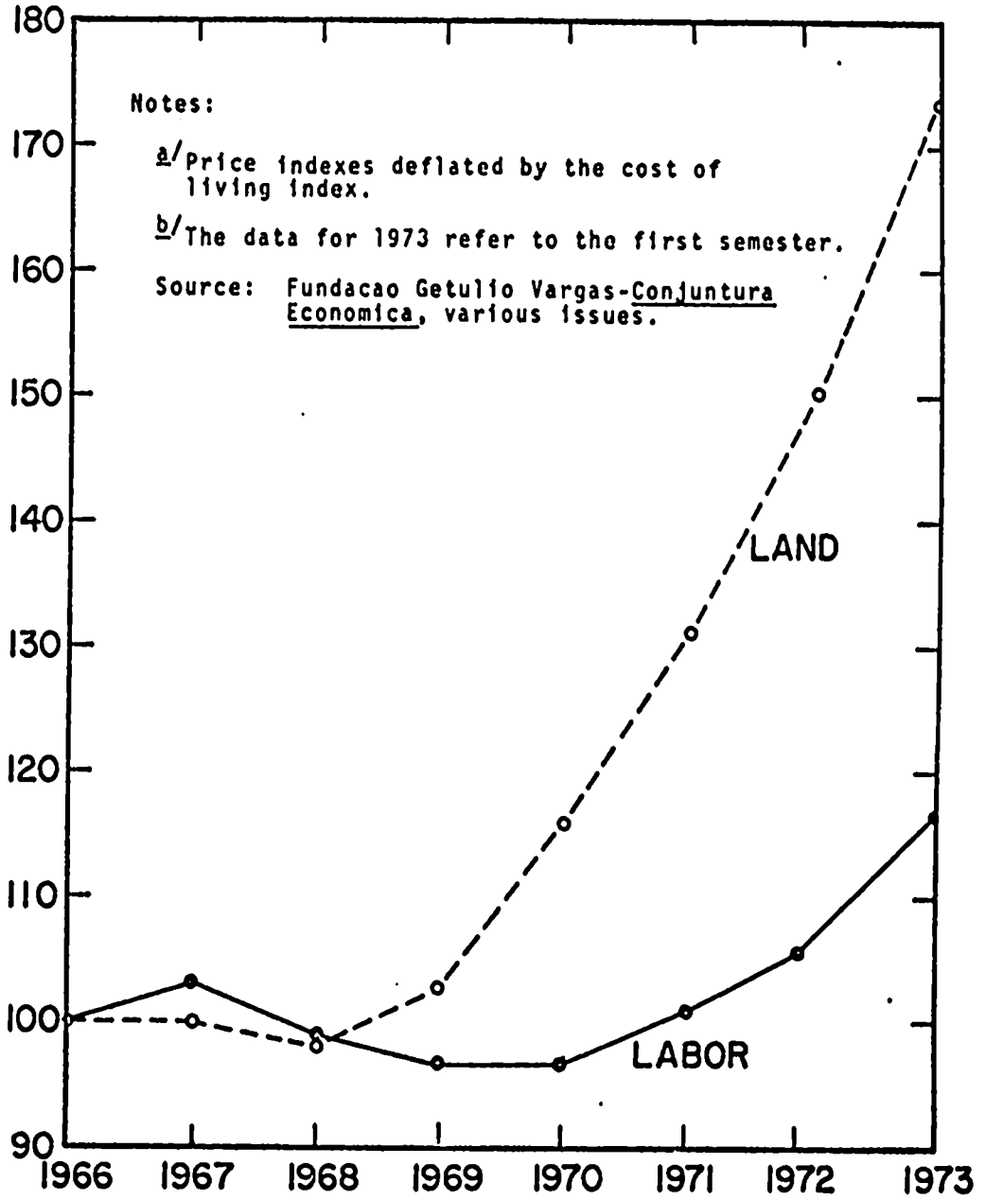


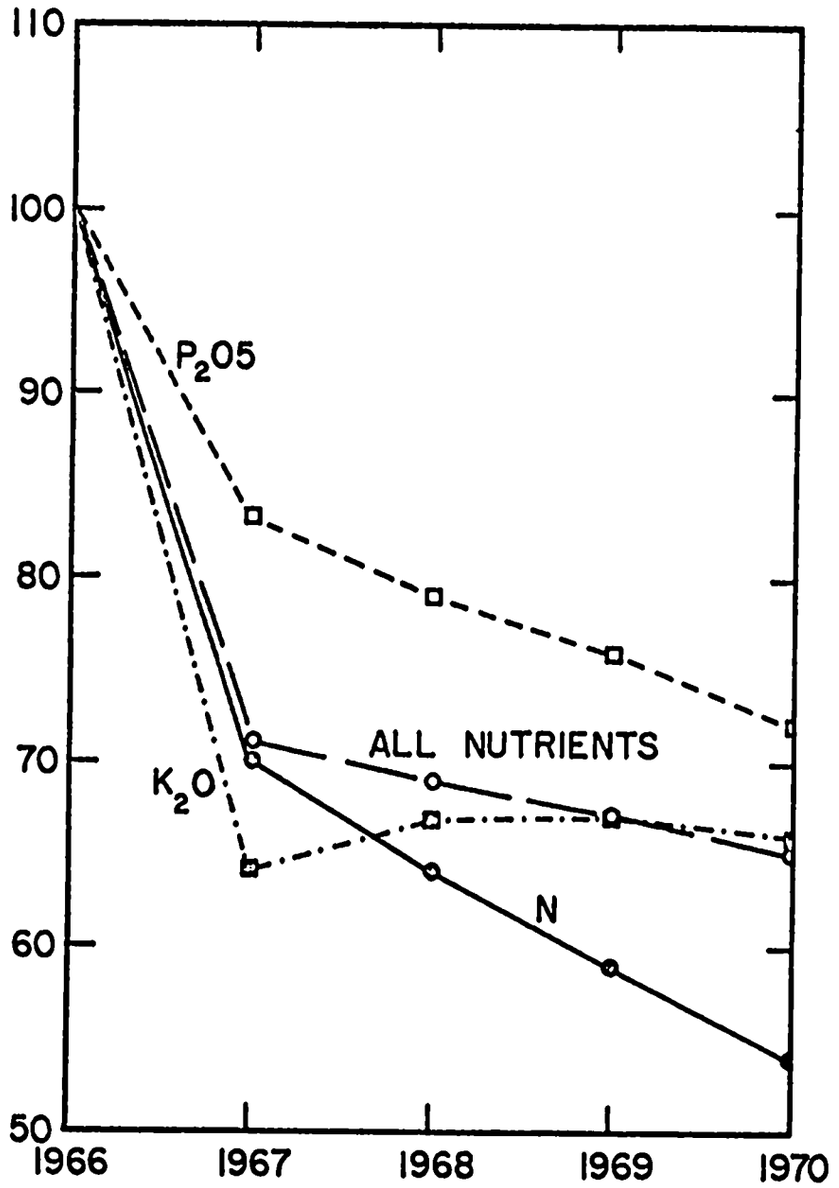
Figure 11. Recent Trends in Factor Prices in Real Terms[a/]. Brazilian Agriculture, 1966-1973.[b/]

conclusion is that the agricultural research program should give special attention to the development and adoption of land substitutes.

However, this conclusion should be drawn with a certain degree of caution, because Brazil is not basically a land-scarce country. It still has large areas of unsettled land, and the government is making sizable investments to open up new areas, especially in the vast Amazon region. Hence, it is possible that the relative scarcity of land and labor can change, especially if the recent rapid rates of industrialization continue into the future.

The trends in the prices of the close substitutes of labor and land -- tractors and fertilizers, respectively -- provide additional insights with respect to what direction research should take. Figures 12 and 13 indicate that in general the weighted price of fertilizer has been declining relatively more than the price of tractors. The real price of fertilizers in the aggregate declined some 35 percent from 1966 to 1970, while the price of tractors declined on the order of 25 percent. Among the plant nutrients, nitrogen has declined the most, followed by potassium, with the price of phosphorus (an important nutrient under Brazilian conditions) declining the least.

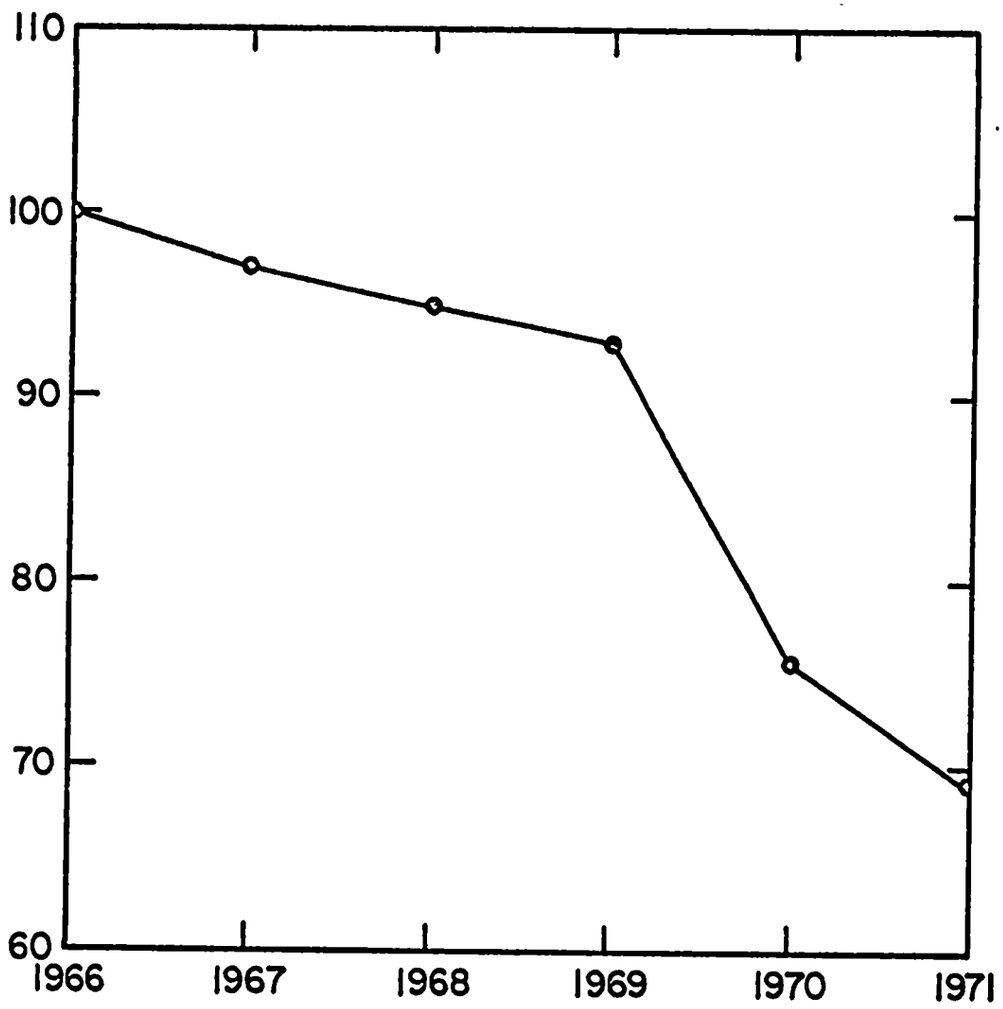
A consideration of the recent trends in factor prices alone, therefore, suggests that research on the land sub-function -- the development of improved varieties, increased



a/ Price index deflated by the cost of living index.

Source: Fundacao Getulio Vargas, Conjuntura Economica, (various issues).

Figure 12. Recent Trends in Fertilizer Prices, in Real Terms a/, Brazil 1966/1970.



[a] Price index deflated by the cost of living index.

Source: Fundacao Getulio Vargas, Conjuntura Economica, (various issues).

Figure 13. Recent Trends in Tractor Prices, in Real Terms,[a] Brazil 1966/1971.

knowledge about pesticides and fertilizers, etc. -- should receive high priority. It should be noted that recent efforts of the Brazilian government to strengthen its agricultural research arm are therefore in the right direction. Moreover, the large road-building programs designed to open up new areas are also consistent with the need to ease what appears to be a growing land constraint.

Another way to consider the factor-saving direction which research should take is through the trends in the shares of the factors. Attention will be focused only on the shares of the factors accounted for in the subfunctions -- labor and tractors in the labor subfunction, and land and fertilizer in the land subfunction -- since those are the primary factors and their respective substitutes that have been of principal concern in this study.

The trends in the shares of the above factors in output (Table 18) between 1966/1970 suggest that the factor share of labor has been decreasing. In 1966 it accounted for 75 percent of the share going to the four factors, and by 1970 it accounted for only 69 percent. Tractors, the proxy for the close substitute of labor, showed virtually no trend during the full period considered, although it also declined from 1968 to 1970.

Land also showed no trend during the first four years. However, it increased substantially in the last year. On

Table 18. Factor Shares for Selected Inputs, Brazil, 1966/1970.

Year	Labor[a/] (1)	Tractor[b/] (2)	Land[c/] (3)	Fertilizer[d/] (4)	(1)+(2) (5)	(3)+(4) (6)	(5)+(6) (7)
1966	.480	.007	.146	.007	.487	.153	.640
1967	.460	.007	.141	.007	.467	.148	.615
1968	.450	.009	.141	.010	.459	.151	.610
1969	.407	.007	.141	.008	.414	.149	.563
1970	.411	.006	.163	.014	.417	.177	.594

a/ It was assumed that each worker was employed 150 days a year. The price was for hired labor, taken from: Conjuntura Economica, Julho, 1971.

b/ The tractor service was defined as 5 percent of the total stock value.

c/ The price is the rental price taken from Conjuntura Economica, Julho, 1971.

d/ Total expenditure in nutrients.

the other hand, fertilizer showed a tendency to increase as a proportion of total output.

The aggregate share for these four input groups (column 7, Table 18) showed a tendency to decrease. This indicates that the decrease in labor's share has tended to be of such a magnitude as to override the increase in fertilizer's share. The rather large increase in the share to both fertilizer and land in 1970 caused a rise in the share going to all four inputs.

One disadvantage of simply looking at historic changes in factor shares is that the relative factor prices are assumed fixed. Therefore, a consideration of the movements in both product and factor prices will help to understand the observed changes in factor shares (Table 19).

The index of crop prices has recently increased quite substantially, and has been increasing more than the prices of fertilizers, tractors and labor. On the other hand, the price of land has been increasing more than the price of crops and the other factors of production here considered. This finding suggests that changes in the relative prices account for some part of the decrease in the aggregate share going to the farm inputs.

In the particular case of fertilizer the data indicate that the use of fertilizer has been growing at a rate sufficient to compensate for the shift in price relative, and for the share of fertilizer in the total to increase. On

Table 19. Price Indices for Crops, Labor, Tractors, Fertilizer and Land, in Real Term, Brazil, 1966/1973.[a]

Year	Crops	Labor	Tractor	Fertilizer	Land
1966	100	100	100	100	100
1967	95	103	97	71	100
1968	94	99	95	69	98
1969	101	97	93	67	103
1970	92	97	76	65	116
1971	116	101	69	c/	131
1972	119	106	c/	c/	150
1973	c/	117[b]	c/	c/	174[b]

a/ Deflated by the cost of living index.

b/ Refers only to the first semester of 1973.

c/ Not available.

Source: Conjuntura Economica, various issues and Appendix III.

the other hand, the decline in the share of labor was due at least in part to a decline in the real wage.

The same behavior as was indicated for the share in output is observed when we consider the share that each of the four factors makes up of their combined total cost (Table 20). When we consider the share of the cost of each subfunction in the total cost, we observe that the labor subfunction's share had a tendency to decline, while the land subfunction's share increased. This finding again suggests that land has become a relatively more scarce factor.[1/]

Finally, the factor proportions within each subfunction indicate a tendency for the use of the modern inputs, tractors and fertilizers, to increase (Table 21). Furthermore, their use has increased sufficiently to compensate for the decline in their respective prices as related to their counterpart in each subfunction, since their relative increase in price has been less.

To conclude, at least three points should be emphasized from this analysis of factor prices and factor shares. First, the evidence is rather strong that Brazil is moving against a land constraint to further output expansion in its agricultural sector. The decrease in fertilizer prices which

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[1/] The land scarcity, of course, is in a relative sense in the case of Brazil, given the huge amount of land not in production. Moreover, the increase in land values may reflect location values associated with the recent, rather sustained economic boom. It should be noted, however, that the source of the increase in the price of land services is rather beside the point in the present context.

Table 20. Factors' Share on Total Cost of Labor, Land, Tractor and Fertilizer, Brazil, 1966/1970.[a]

Year	Labor (1)	Tractor (2)	Land (3)	Fertilizer (4)	(1)+(2) (5)	(3)+(4) (6)
1966	.750	.011	.228	.011	.761	.239
1967	.748	.011	.230	.012	.759	.242
1968	.738	.014	.232	.016	.752	.248
1969	.723	.012	.251	.014	.735	.265
1970	.692	.011	.275	.023	.703	.298

[a] Same definitions as Table 18.

Table 21. Factor Proportions, Brazil, 1966/1970.[a]

Year	Labor/Tractor	Land/Fertilizer
1966	68.93	21.02
1967	67.91	19.41
1968	52.52	14.75
1969	61.80	18.21
1970	64.75	12.05

[a] Same definitions as in Table 18.

has occurred in recent years, if maintained, makes the development of fertilizer-responsive varieties an attractive means of easing that constraint.

Second, there is also a growing scarcity of labor, although not to the extent implied for land. If the current economic boom continues into the future, however, the mechanization of agriculture may become an increasingly important aspect of the development process.

Finally, the use of modern inputs has increased fairly rapidly in recent years. This increased use appears to be the result of changing factor prices, which provides support for the model of induced technical change that is the basis of the analytical model developed for the present study.

CHAPTER V

ECONOMIC AND POLICY IMPLICATIONS

The primary objective of this chapter is to discuss the economic and policy implications suggested by the analytical framework and the empirical results. The results are not such as to provide conclusive recommendations on research priorities, since considerations such as the expected costs of making a given technological advance are not considered. However, they are suggestive of emphases that might be considered in defining priorities for the allocation of a given research budget among alternatives in such a way that goals established by the policy makers can be met.

Primary guidance for the analysis is provided by two basic assumptions. The first is that, as pointed out by Kaldor[1/], the demand for new knowledge is derived from the contribution it is expected to make to the achievement of individual and collective goals, or to the solution of private and public problems. The second assumption is that the rate of return to investment in agricultural research is expected

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[1/] Kaldor, op. cit., p. 64.

to be high.[1/]

Therefore, new production technology is treated as if it were an input in the development process, and not as an end in itself. This implies that the relative emphasis on products as well as the direction that research should take in the factor-saving direction should change with the set of goals specified for both the agricultural and non-agricultural sectors. An important problem with this criterion is the instability that these goals tend to have, since research in general, and agricultural research in particular, takes time in order to obtain results.

Four alternative sets of goals may be specified for the agricultural sector according to the stage of development of the economy, the particular development model the government is implementing, and the specific economic policies it uses

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[1/] Even though the number of empirical studies dealing with this subject is still fairly limited, to the best of our knowledge all have found a relatively high rate of return. Ayer and Schuh report approximately an 80 percent social rate of return in real terms to investments in cotton research in Sao Paulo, Brasil, op. cit. For rates of return on investments in research in other countries see Griliches, op. cit., Griliches, Zvi, "Research Expenditures, Education and the Aggregate Production Function," AER, 54(6): 961-974, December, 1964; Evenson, Robert, "The Contribution of Agricultural Research to Production," JFE, 401(5): 1415-1425, December 1967; Barletta, Nicholas Ardito, "Cost and Social Returns of Agricultural Research in Mexico." Ph.D. Thesis, University of Chicago, 1970 (University Microfilms, Ann Arbor, Michigan; and Tang, Anthony M., "Research and Education in Japanese Agricultural Development," Economic Studies Quarterly, 13, February-May 1963, 27-41 and 91-99.

to implement this model.[1] These sets of goals include: (1) to increase aggregate income to the agricultural sector, (2) to increase income and employment of agricultural labor, (3) to enlarge agriculture's contribution to general economic development, and (4) to increase consumers' welfare.

These goals are not mutually exclusive, nor are they exhaustive. However, they do represent relatively distinct policy emphases that a government might have, and represent distinctive shifts which policy makers might make over time as they respond to changing economic conditions.

With the above guidelines as a basis the following analysis will be carried out in four parts. First the direction of research in the factor-factor dimension and its income distribution implications will be analyzed. Then the direction of research in the product-product direction will be evaluated. This will be followed by a consideration of the potential for technological change in the crops considered. And finally, some considerations from the two-sector general equilibrium framework will be discussed.

The Direction of Research in the Factor-Factor Dimension and Its Distributive Implications

Hayami and Ruttan[2] have argued that if a country fails to follow the correct technological path in its pursuit of

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[1] For a discussion of these points in the context of establishing priorities for agricultural research, see Schuh, G. Edward, "Some Economic Considerations for Establishing Priorities in Agricultural Research," Ford Foundation Seminar of Program Advisors in Agriculture," Mexico City, November 1972.

[2] Hayami and Ruttan, op. cit., p. 54.

output growth its society will bear a high cost and its development will be retarded. In the context of their induced innovation model the correct technological path is that which eases the particular factor scarcity that is constraining output expansion. In their framework the factor scarcities which may be limiting are primarily land and labor, which they define as the primary inputs. They provide no role for a capital limitation in their model.[1/,2/]

If we assume that the adoption of new production technology at the farm level involves basically the investment of capital in land and/or labor substitutes, the movement along the correct path involves the substitution of such inputs for the primary factors, and the goal of the research effort should be to facilitate this substitution. The criteria for this substitution would be the trends in relative

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1/ The explanation for this particular emphasis may be the (implicit) assumption that over time capital has been generated through the combination of the traditional factors. This implicitly involves in addition a more basic assumption that the supply curve for capital is relatively elastic.

2/ In the case of the Brazilian economy at least superficially labor and land would appear to be relatively abundant, with capital appearing to be the scarce or limiting factor to further output expansion. The relative scarcity of factors has to be understood in the context of the supply price at which additional quantities of the individual factors can be supplied to the economy, however.

factor prices and resource endowments.[1] Data on these were presented in the previous chapter and provide strong clues with respect to the direction that research should take.

These data show that in the aggregate there tended to be an increase in the price of land relative to the price of labor in the period 1966/1973. Furthermore, land was the factor which had the largest absolute increase in price of the farm inputs considered (Table 20). This suggests that relatively more emphasis should be given in research efforts to the land subfunction and, more specifically, to research which helps bring more land into production (soil research, for example) or which facilitates the substitution of land substitutes for land. This latter could be soil research, including more work on such problem soils as the cerrados[2], or the development of varieties that are highly responsive to fertilizer.

Other factors are of course important, however. For example, the ultimate beneficiary of the development process

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[1] Within the Hayami-Ruttan framework the correct choice of production technology would be that which eases the constraint imposed by the resource that is most inelastic in supply. It should be noted in passing that an alternative framework could be postulated in which an ex ante rate of return was the decision variable. Hayami and Ruttan implicitly assume that technology which eases the relatively more elastic factor supply would be the high pay-off investment.

[2] The cerrado soils are for the most part highly leached out latosols with a high degree of acidity, low nutrient levels, and apparently some problems of toxicity. They cover large areas of Brazil and very little is known about them.

is without doubt man or the human agent. Therefore, the output per man should be an important consideration in devising an appropriate research strategy.[1]

Consider the following relationship:

$$Y/L = (Y/T)(T/L)$$

where Y is gross output, L is labor, and T is land. Increases in labor productivity (Y/L) can be achieved either by raising land productivity (Y/T), by increasing the land-worker ratio (T/L), or by some combination of the two. The tentative conclusion reached above, which was to focus research efforts on the land subfunction, will concentrate primarily on increasing the productivity of land. However, it should be noted that by virtue of the above equation, increasing the productivity of land is one way of increasing the productivity of labor. This may have special relevance in the case of the Brasilian Northeast, where the land frontier is almost closed and where, according to the 1970 Census, 63 percent of the population economically active was in the agricultural sector.[2] (For Brazil as a whole this percentage was 44 percent, and in the Southeast it was about 27 percent.)

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[1] In other words, since labor is a major input in the Brazilian agricultural sector, and since increased labor productivity leads to a higher per capita income and standard of living, policy makers may want to give it major consideration.

[2] The Northeast also has approximately one-third of the Brazilian population.

These large regional disparities also suggest that in a country as large as Brazil it would be difficult to arrive at a single policy recommendation that fits the needs of the country as a whole. The case of the Central-West frontier in Brazil further stresses this point. In that region labor is in relatively short supply, which in turn provides incentives for the use of tractors and mechanical equipment. Sanders[1/] argued that there were two principal reasons for mechanization on the Mato Grosso and Goias frontiers. One was the cost of obtaining and controlling seasonal labor, and the other was the difficulty (due to hardness) of working the soil.

In addition to factors such as these, the effect on the demand for land in the old regions due to the government's highway construction program in the Central-West and Amazon regions should also be considered. These investments facilitate labor mobility and the colonization of those regions. Hence, the single conclusion to work on the land subfunction may not be as obvious as it at first appears, at least for Brazil as a whole.

Figures 14 and 15 show recent trends in the prices of land and labor in selected regions. The data presented in these figures indicate that in the old regions (Northeast, East and South) the land prices have been increasing at a faster rate than in the more recently opened region, the

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[1/] Sanders, op. cit., pp. 98-102.

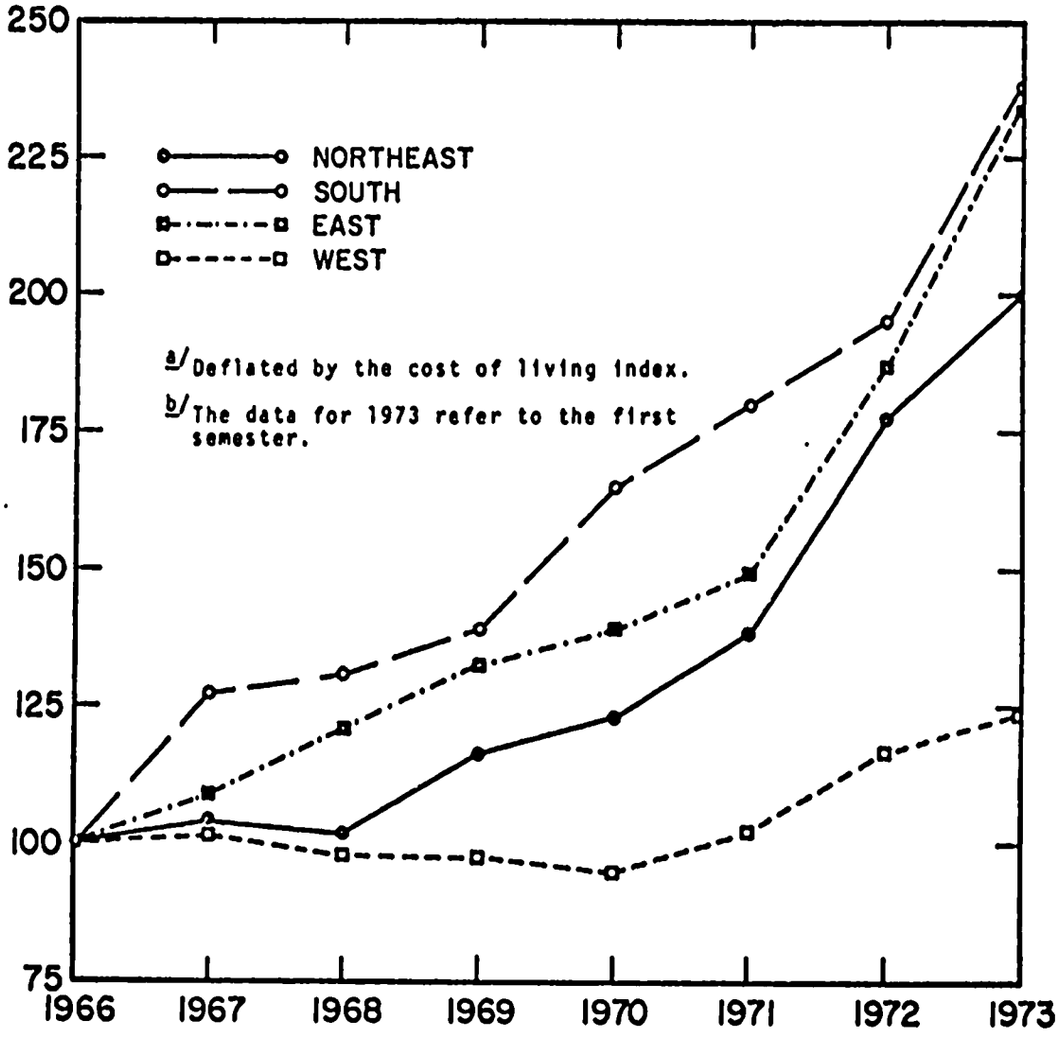
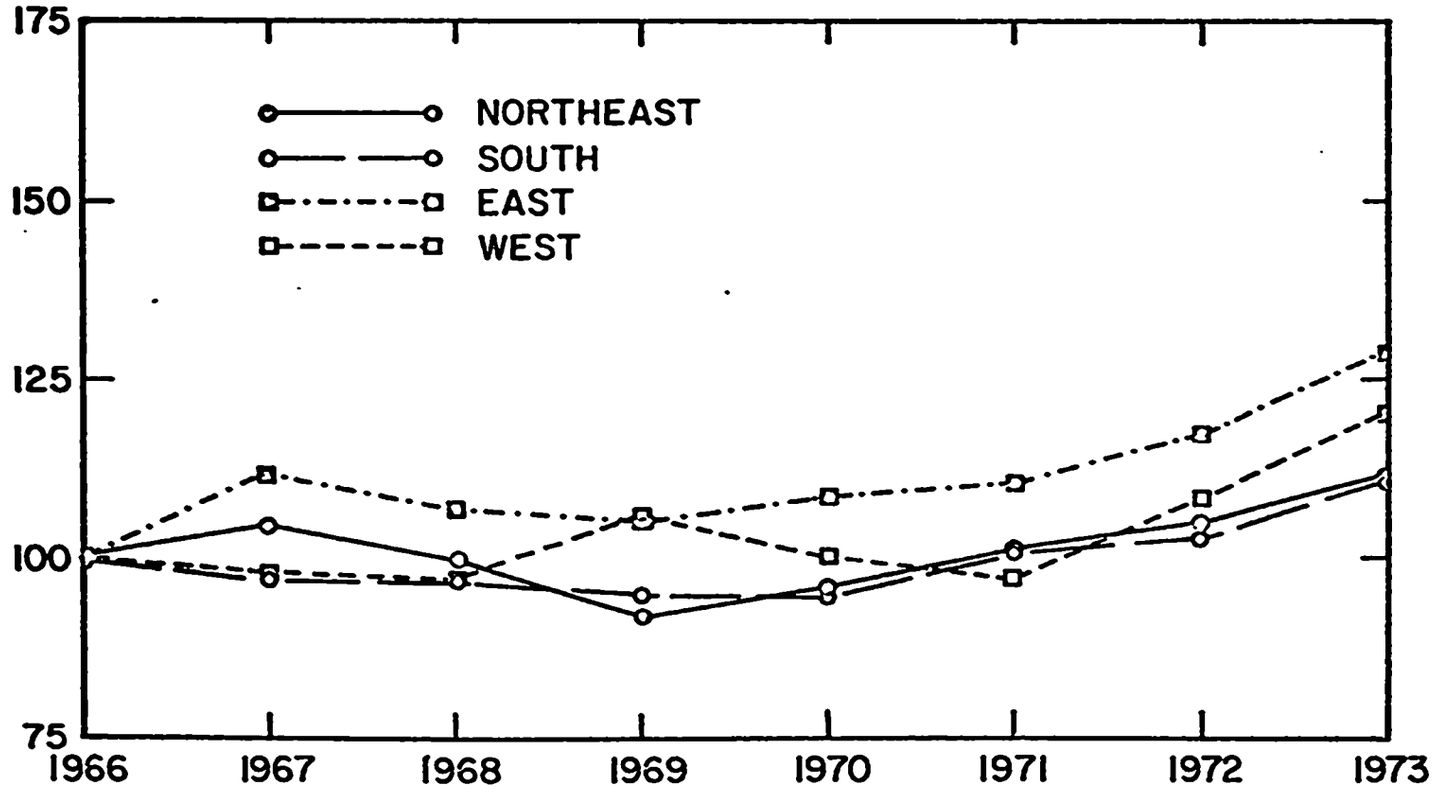


Figure 14. Recent Trends in Land Prices in Selected Regions, Real Terms,[a] Brazil, 1966/1973.[b]



[a] Reflected by the cost of living index.

[b] The data for 1973 refer to the first semester.

Figure 15. Recent Trends in Labor Prices for Selected Regions, Real Terms,[a] Brazil 1966/1973.[b]

Central West. Trends in the price of labor tend to be more uniform due to its greater mobility. But even despite this tendency, wages in the Central West have been increasing more sharply in the last couple of years than in the other regions, which supports the hypothesis of a growing shortage of labor in the new regions.

Another interesting finding is that the price of labor in the East region has been above the price of labor in the other regions during most of the period since 1966. The explanation for this tendency is that the states which comprise this region (Minas Gerais, Espirito Santo and Rio de Janeiro) are all located close to the industrial complexes of Guanabara and Belo Horizonte. Both of these are important, rapidly growing urban-industrial complexes, and migration out of agriculture in the surrounding regions has been fairly extensive in recent years.

To summarize, the above discussion suggests two basic conclusions if output growth is the primary goal of technology policy. First, in the aggregate primary attention should be directed to the land subfunction in order to ease what appears to be a growing land constraint to output expansion. However, given the rather wide regional disparities in resource endowments within Brazil, a case can be made for differential regional emphases in research policy. More specifically, less emphasis should be given to raising land

productivity in the Central West[1/], and more attention should be given to raising labor productivity in that region by means of mechanization. In the other three regions major attention should be given to raising land productivity, although if the economy continues to expand as rapidly as it has in the past, mechanization may become increasingly important, especially in the East.

Finally, the estimated elasticities of substitution for the subfunctions suggest additional factors that might be considered in establishing research priorities. In both cases the estimated elasticities of substitution are less than one. This implies in the case of the land subfunction that particular attention might be given to developing varieties that are more responsive to fertilizer in order to facilitate the substitution of fertilizer for land. In the labor subfunction it suggests that more research might be directed to developing mechanization under Brazilian conditions.

So far the factor-saving direction of research has been discussed only in a growth or development context, without considering its effects on the functional distribution of income. However, the analytical framework of Chapter II

[1/] This conclusion is also consistent with the notion that new lands tend to have relatively high natural fertility, at least for a period of time.

provides a means of analyzing the distributional effects of a technical change under the assumption that the elasticities of substitution within the subfunctions are greater than one, and that the elasticity of substitution for the inter-subfunction is less than one. The empirical results for the Brazilian agricultural sector in the aggregate suggest that the latter assumption was valid (σ = .9), while the former was not (σ_T = .933 and σ_L = .605) (Tables 13-16). Furthermore, they suggest the existence of a change in the technical epoch (in Brown's[1/] sense). This change in the technical epoch leads us to believe that there may be a further change in the intra-function elasticities of substitution over time as the TEPC shifts in response to changing economic conditions and/or the relative prices change.

Even though part of the a priori hypothesis did not prove to be valid, the analytical framework is still appropriate since the price elasticity of demand is the key parameter. In addition, at the aggregate input level[2/] it is the elasticity of substitution of the inter-subfunction which enters the equations in addition to the demand elasticity, and the

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[1/] Brown, op. cit., Chapter V.

[2/] The aggregate input level refers to the combination of inputs within a subfunction.

estimate of this parameter was consistent with a priori expectations.

When interest focuses on the elementary input level, however, the third parameter, the intra-subfunction elasticities of substitution enters the equations. In this case the demand elasticity has to be of such a magnitude as to compensate the low elasticities of substitution within the subfunctions. Therefore, the selection of products, which will be considered in the next section, is crucial in determining the distributional effects of technical change. For example, if the policy-maker's goal is to increase the return to labor, even though the technological path chosen in terms of the growth objective is to ease the scarcity of land, the products chosen to receive expanded research efforts should be those with a price elasticity of demand greater than .9. Among the six products considered in this study, two crops that are likely to have such high demand elasticities are cotton and sugar-cane.

The finding that the elasticity of substitution in the labor subfunction is less than one (.605), plus the conclusion that one way to increase output per unit of labor is to increase the land/labor ratio, suggest that there is a place for research on the labor subfunction, if the goal is to raise labor productivity and income. In this case, however, particular attention should be given to research on mechanization for land preparation, which is not expected to

greatly affect the displacement of agricultural labor. This consideration is important, since with the exception of the Central West (and possibly the East), labor is not the constraint to output expansion.

A word with respect to the movements in factor prices is also in order. The earlier analytical framework shows that changes in factor prices affect the distribution of income and the level of employment. If, for example, the government establishes a policy to increase the consumption of fertilizer through reductions in its price, the effect on labor returns when the fertilizer is applied to crops like corn, rice, edible beans and manioc is likely to be regressive, due to the low price elasticity of demand for these crops. On the other hand, given the low substitutability between labor and tractors, and given the relatively large elasticity of substitution between the subfunctions (.9), a decrease in theprice of tractors may have a positive effect on labor income, even though the price elasticity of demand for individual crops is low. This analysis makes clear the importance of knowledge about both the parameters which characterize the underlying production function and the price elasticity of demand.

The Product-Product Dimension[1/]

The price elasticity of demand is an important parameter in determining the gains to society at large from technological change, as well as in determining its effects on the functional distribution of income. Therefore, the relative priority in research that is given to the individual products plays an important role in the attainment of the goals established by the policy makers with respect to the agricultural sector. The four alternative sets of goals referred to at the beginning of this chapter will serve as the basis for the present discussion.

If policy makers choose to increase the income to the agricultural sector as the primary goal, the analytical model and the empirical results suggest that the products that should be considered are those with a large price elasticity of demand. Among the six products considered in this study, cotton and sugar-cane would be the first candidates, since they have been traditionally produced for the world market. The second candidates would be corn and rice, especially if the research results would be of such a nature and magnitude as to make Brazil more competitive in the world markets for these crops.

[1/] The analysis will be carried out for the country as a whole. However, the reader should keep in mind that regional considerations could change the conclusions.

The annual flow of gross benefits to be expected from the first two crops would be approximately Cr$195 million on the 1966/1970 base of value of output, while the second two crops would give a gross flow of benefits of approximately Cr$300 millions. The differential in the expected flow of gross benefits is large. If in addition to this finding it is also recognized that corn and rice are produced more widely over the country, which implies a more ample distribution of benefits from such research, the decision to increase the investment in cotton and sugar-cane research is not so obvious. Apparently, a key factor that should be considered in making the decision is how close the present Brazilian technology is to making corn and rice competitive in world markets.

A third product that might be considered is manioc. It presently is for the most part a staple food, and is consumed largely by low income groups. However, it has the potential to become an export product, given the growing feed grain shortage in world markets. And again, manioc is produced rather widely in the country, which suggests that it also should be considered as a potential candidate for expanded research efforts if the goal is to distribute the benefits of the production technology over as wide a geographic area as possible.

The same set of conclusions would apply if the goal were <u>to increase the income and employment of agricultural</u>

labor. If the technological change is in the land subfunction (e.g., a technological package that involves varieties that are more responsive to fertilizer), then it is sufficient that the price elasticity of demand (η) be greater than .9 in order for the specified goal to be attained. However, it should be noted that η must be large for any kind of technological change to attain this goal.

To attain the goal of increasing consumers' welfare, the policy to be implemented has a quite different perspective. The products to be selected are those with a low price elasticity of demand and those that are consumed by low income groups. Corn and rice, given their large flow of gross benefits, would be candidates for high priority, under the condition that the technological change does not alter their current competitive position in the world market. If the latter were the case, then producers might benefit relatively more than consumers. However, the consumers still might benefit indirectly as a result of the higher rate of economic growth which the increase in exports would help finance.

Edible beans and manioc, the second in line of priority, given this goal, present a different picture, since both are staple foods with an income elasticity of demand close to zero or negative. However, manioc has the potential to eventually become an export product. Therefore, edible beans is the crop for which technical change will tend to benefit

more the consumers, while manioc may or may not, according to the realization or not of its export potential. The gross flow of benefits from these two crops is the smallest (Cr$186 millions) among the three groups here considered.

The attainment of the goal of enlarging agriculture's contribution to general economic development is a bit more complicated, since it depends on easing the constraints which prevent the economy from realizing its potential. Five subsets of this goal can be considered: (1) to keep the price of food relatively low so that nominal wages can be kept low without depressing real wages, or possibly while permitting an increase in the real wage[1/], (2) to increase the supply of exchange earnings, (3) to supply capital to the economy, especially for expansion of the non-farm sector, (4) to provide a market for the products of the non-farm sector, and (5) to supply labor for the expansion of the non-farm sector.

The recommendations for attaining the first subset that are suggested by the results of this study are the same as those for the goal to benefit the consumers, which was specified above. Emphasis would be given to corn, rice, edible beans, and manioc. Even though corn is not a direct food except on a limited scale, its contribution would come indirectly through the livestock sector.

[1/] This should provide added incentive to the expansion of the industrial sector.

The recommendations suggested for attaining the goals of increasing agricultural income and/or to increase the income and employment of agricultural labor can be applied to meet the subsets of goals (2), (3) and (4). However, different emphases should be given according to the respective weights that are given to each of these subset of goals.[1/]

Finally, the last subset of goals -- to supply labor for the expansion of the non-farm sector -- has to be analyzed in both the short- and long-run. In the short-run the empirical results suggest that labor has not been a scarce factor in the agricultural sector. Therefore, these results implicitly imply that the demand for labor from other sectors is not increasing rapidly.[2/]

In the long-run, as the non-agricultural sector expands and requires the release of labor from the agricultural

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[1/] It should be noted in passing that economic policies in Latin America in general, and in Brazil in particular, have discriminated against the agricultural sector, which in turn has kept it from making its maximum contribution to general economic development. See Schuh, G. Edward, "Patterns of Equity under Agricultural Development in Latin America," Chapter 12 of Heady, E.O., and Ball, A.G. (eds.), Externalities in the Transformation of Agriculture: The Distribution of Benefits and Costs from Development, Ames: Iowa State University Press, forthcoming.

[2/] Whitaker, Morris D., in "Labor Absorption in Brazil: An Analysis of the Industrial Sector," Unpublished Ph.D. Thesis, Purdue University, 1970, has argued that the non-agricultural sector of the Brazilian economy has not been able to absorb the labor released from the agricultural sector.

sector, two quite different strategies might be pursued. First, research could be focused on the labor subfunction, and second, the research could be directed to those crops with a low price elasticity of demand. These two actions together would release labor from agriculture rather rapidly. However, the second strategy would tend to depress the income of those individuals employed in the agricultural sector, which in turn would bring negative effects to the development process. Therefore, the specific set of goals in terms of what is expected from agriculture for the economy as a whole are crucial in defining research priorities in the product dimension.

The Potential for Technical Change

So far the analysis has for the most part been made under the implicit assumption that comparable investments in research directed to each of the crops would produce comparable results. However, to obtain the same yield increase for each crop would likely require different amounts of expenditure. Therefore, ex ante knowledge of the rate of return to such investments would be useful information in deciding how many resources should be allocated among the various crops.

In the absence of such knowledge other kinds of information may be considered. One such type of information is the potential for improvements in yield, which can be evaluated at least in part by means of a comparison of

Brazil's yields with international standards. Another criterion would be the availability of, or the ease with which, international technology can be adapted to Brazilian conditions. And finally, an evaluation could be made of the research under way in Brazil in order to determine how close researchers currently are to obtaining a breakthrough.

A comparison of average yields in Brazil with those from selected other countries for each of the six crops here considered (Tables 22 through 27) bring out some interesting points. In general, yields in Brazil are low for crops such as rice when compared with the other countries, and have not been increasing over time, while yields in other countries have experienced sizable increases. These data suggest that the potential of a 10 percent shift in the supply curve hypothesized in this study is probably conservative.

Considering only the proximity of Brazilian yields to international standards, the priority for research should probably be, in order, corn, rice, cotton, sugar-cane, edible beans and manioc. By proceeding in this sequence resources would be allocated where the greatest technological gap exists, and where presumably the yield increases would be the easiest to obtain.

With respect to the transfer of technology, the most promising potential would appear to be with those crops that have received attention from the so-called International Centers. For example, the International Rice Research Institute in the Philippines has generated an improved germ

Table 22. Yields of Corn in Selected Countries, 1948/1952, 1961/1965, 1970/1971, Kg/Hectare.

Country	1948/1952	1961/1965	1970/1971
Italy	1840	3280	4705
France	1360	3020	5170
U.S.A.	2490	4160	4975
Argentina	1630	1760	2385
Brazil	1260	1290	1450
Japan	1430	2550	2875
New Zealand	3610	4930	7070

Source: F.A.O., Production Year Book, 1971.

Table 23. Yields of Rice in Selected Countries, 1948/1952, 1961/1965, 1970/1971, Kg/Hectare.

Country	1948/1952	1961/1965	1970/1971
Italy	4850	5080	4915
France	3610	3920	4235
U.S.A.	2560	4370	5160
Argentina	2990	3540	3935
Brazil	1580	1610	1960
Japan	4250	5020	5445

Source: F.A.O., Production Year Book, 1971.

Table 24. Yields of Sugar-cane in Selected Countries, 1948/1952, 1961/1965, 1970/1971, Kg/Hectare.

Country	1948/1952	1961/1965	1970/1971
Costa Rica	39,100	46,100	49,750
El Salvador	58,700	61,100	69,550
U.S.A.	78,100	89,700	93,400
Argentina	33,900	49,600	52,650
Brazil	38,700	43,300	45,600
Japan	25,400	59,500	60,550
Philippines	46,400	53,500	52,450

Source: F.A.O., Production Year Book, 1971.

Table 25. Yields of Cotton in Selected Countries, 1948/1952, 1961/1965, 1970/1971, Kg of Lint/Hectare.

Country	1948/1952	1961/1965	1970/1971
Italy	160	270	230
U.S.A.	360	550	490
Argentina	240	230	280
Brazil	150	170	150[a]

[a] Refers to 1970.

Source: F.A.O., Production Year Book, 1971

Table 26. Yields of Edible Beans in Selected Countries 1948/1952, 1961/1965, 1970/1971, Kg/Hectare.

Country	1948/1952	1961/1965	1970/1971
Italy	290	570	965
France	750	1050	1345
U.S.A.	1180	1430	1370
Argentina	960	1050	965
Brazil	680	660	640
Kalam	1030	1140	1225

Source: F.A.O., Production Year Book, 1971.

Table 27. Yields of Manioc (Cassava) in Selected Countries, 1948/1952, 1961/1965, 1970/1971, Kg/Hectare.

Country	1948/1952	1961/1965	1970/1971
Costa Rica	4,500	2,800	2,750
El Salvador	2,800	7,600	7,950
Barbados	10,100	30,100	26,700
Argentina	14,800	11,900	11,600
Brazil	13,000	13,800	14,700
Philippines	5,900	6,200	5,600

Source: F.A.O., Production Year Book, 1971.

plasm for rice which appears to be rather easily adaptable to Brazilian conditions. However, to the best of our knowledge little has been done to adapt this source of improved plant material to Brazilian production areas.

At least one example of such adaption and further development of plant material has occurred in Brazil. The cotton research in the State of Sao Paulo started out basically with imported varieties, and proceeded to adapt and develop them to suit local conditions. The social rate of return to this program was quite high.[1/]

The Expected Returns from Investments in Research

The discussion to this point has concentrated on research priorities, without raising the question of whether expanded research efforts would be a desirable decision. In this section an attempt is made to obtain a crude estimate of the magnitude of the expected return to investments in research.

Since data on the expenditures on agricultural research in Brazil are not available, it was necessary to use an alternative means of estimating research costs. One way of doing this is on the basis of the salary costs of professionals with a B.S. or higher who are working in the

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[1/] Ayer and Schuh, op. cit.

agricultural sector.[1] The 1970 census reports that there were 11,507 such workers. If a salary of Cr$6,000.00 per month[2] is imputed to each worker, and it is assumed that all professionals were to work on the six crops considered in this study, the total annual personnel expense would be on the order of Cr$828 million. In addition if it is assumed that an amount equal to 40 percent of personnel expenses is required to cover other expenses associated with research, then the total annual expenses would be on the order of Cr$1,160 million. This provides an upward-biased estimate of the total current expenditure in agricultural research and development in Brazil.

A crude estimate of the flow of benefits can be obtained in the same way. Since the flow of gross benefits calculated in Chapter IV was never less than 10 percent of the value of total output, this percentage can be used to multiply the average value of output for the six crops in the 1966/1970 period. The result is an annual flow of gross benefits on the order of Cr$680 million. The estimated flow of benefits in this case is a little more than halfe the magnitude of the flow of research costs. Whether this would imply a high rate of social return would depend on other

[1] The implicit assumption is that all technicians with a B.S. or better are engaged in scientific-technological activities. This obviously over-states the case, but in the present context this is desirable since it will provide an upper estimate of costs.

[2] This is a high level for 1970, since the federal university system in Brazil is paying this amount for a Ph.D. at the present time.

considerations. For example, if six years of concentrated effort could produce a 10 percent increase in yields that could be sustained with a relatively small maintenance research effort, so that the flow of benefits would continue into the future with a much smaller annual cost, the rates of returns could be relatively high.

In any case, it should be noted that the estimates are relatively conservative in nature. All technicians trained at the B.S. level or better are assumed to work on the six crops, and the flow of benefits is limited to these six crops. Moreover, a relatively modest increase of only 10 percent in yields is assumed. The object of the exercise was to provide some dimensions to the expected flow of benefits compared to the possible costs of the research effort.

General Equilibrium Considerations

A final word is in order. The above analyses have been cast in a partial equilibrium framework. A shift of resources from one crop to the other, as well as between sectors, should be expected when a technological breakthrough is obtained. Therefore, considerations from a two-sector general equilibrium framework may be useful in making any final decision with respect to allocating research resources.

The two sector general equilibrium model described in the analytical chapter not only examined the output and factor reallocation effects of technical change, but by

incorporating the elasticity of product demand, provided the means by which conclusions could be deduced as to the changes in the distribution of income that could be expected between the two factors of production, labor and capital. By combining this model with the analytical framework derived from a separable production function, some effects in the two-sector general equilibrium can be drawn.

The discussion will be conducted in two step. First, the agricultural sector will be analyzed in relation to the non-agricultural sector. And second, groups of crops, defined on the basis of their price elasticity of demand, will be considered in relation to the rest of the economy.

Let us assume, first of all, that the economy is in equilibrium. Then assume a technical change in the agricultural sector as a whole with, for example, a land-saving technology. The empirical results of Chapter IV show a relatively large elasticity of substitution between the subfunctions (.9) and a relatively low elasticity of substitution (.625) and (.933) for the labor and land subfunctions respectively. In a closed economy the price elasticity of demand for the agricultural sector in the aggregate is expected to be low. As a result of these conditions a decrease in labor incomes[1/] is expected from the technical change.

[1/] See the discussion above about the effects of a technological change on factor returns.

Therefore, it is expected that labor will be forced to leave the sector to seek better opportunities elsewhere. Depending on the output effect of the new technology, agricultural output could even decrease.

The above reasoning suggests that even a technical change which apparently is not labor displacing will cause the displacement of labor, given the negative effect of output on the (sectoral) distribution of income to agriculture. This finding has important policy implications. It indicates that investments in research will eventually displace labor no matter what kind of technological path is chosen, if the demand for the product is inelastic.[1/] Therefore, policy measures designed to facilitate this process of adjustment should be considered by policy-makers. These measures should be directed to increase the labor absorptive capacity of the non-farm sector, as well as to increase the mobility of labor.

If the assumption of a closed economy is relaxed, the weight of exports in the total output of the product and in the use of labor could alter these conclusions. However, this would require that the technological change be concentrated on those products for which exports are relatively more important.

Similar conclusions follow if the analysis is conducted at a more disaggregated level. Consider the group of products

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[1/] This will tend to be the case unless exports are important.

which are produced primarily for the domestic sector, such as rice, corn, edible beans, and manioc, and which tend to have relatively small price elasticities of demand. For the same reason described above, a technological change for any one or all of these crops will release labor when the technical change takes place. Therefore, there will be an increase in the supply of labor to the rest of the agricultural sector and to the non-agricultural sector, and adjustments will be required if a new equilibrium is to be obtained.

On the other hand, if the products selected are cotton and sugar-cane, which have high price elasticities of demand, then the expected outcome is to increase the return to labor, which in turn should attract labor from the other activities. A new equilibrium will be established in which the labor share will likely have increased.

To conclude, the analysis of this section stresses an additional point that should be considered when decisions are made with respect to the allocation of resources to agricultural research. This new aspect is the problem of employment and the associated adjustment problems that are associated with technological change. Because of the importance of these problems, specific policies should be implemented to facilitate the adjustment process in order that labor does not have to bear the full burden of the adjustment

process, and so that both the benefits and costs of technical change will be more equitably distributed.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND SUGGESTIONS FOR ADDITIONAL RESEARCH

Summary

On the assumptions that agricultural research is indeed an economic activity to be organized,and that priorities in research have to be defined by extra-market means when the pricing system operates imperfectly, the present study was directed to the development and testing of a model which would provide a basis for establishing priorities for agricultural research. The model was tested with data from the Brazilian economy.

The model developed can be divided into three parts. In the first part, the share of benefits going to consumers and producers as well as the total benefits from a technological change are analyzed in a partial equilibrium framework, using the concepts of consumers' and producers' surpluses. The relevant parameters for this analysis are the price elasticity of demand, the elasticity of supply with respect to product price, and a shift parameter for the supply curve. The price elasticities of supply and demand were selected from previous studies made by various authors, and the shift parameter was set arbitrarily at 10 percent. Six

crops were selected for evaluating the share of benefits that would accrue to consumers and producers from a given technological change. These crops were cotton, sugar-cane, corn, rice, edible beans and manioc. One criterion used to select them was their relative economic importance in terms of total output and area planted. The six crops accounted for 46 percent of total crop output in the period 1966-1970, and for 74 percent of the total crop acreage. A second criterion was that some crops should be considered that have been produced for the world market, and some should be considered that have been produced exclusively or almost exclusively for the domestic market.

Under the assumption of linear supply and demand equations, the consumers' and producers' gain from a shift in the supply curve due to a technological change was evaluated under different assumptions with respect to the demand and supply elasticities. The results showed that consumers tend to gain more than producers if the price elasticity of demand is low and the supply elasticity is high, and vice-versa. The total gain increases as the respective demand and supply elasticities increase, and the size of the flow of gross benefits is equal to more than 10 percent of the value of output during a recent base period.

The second part of the model was concerned with changes in the functional distribution of income that might arise from a technological change. The neoclassic theory of

distribution provided the basis for this analysis. However, to have an analytical system for more than two factors of production, a two-stage, separable, constant elasticity of substitution (CES) production function was assumed where the maximization is performed in two steps. The first step is a profit maximization problem, and the second step is a cost minimization problem.

The factors of production were separated into two groups. One group was composed of labor and that part of capital which is a close substitute for labor (laboresque capital). The second group was composed of land and that capital which can be considered to be a close substitute for land (landesque capital). The relevant parameters for the analysis are the price elasticity of demand, the intra-group elasticities of factor substitution within the production function, which were hypothesized to be greater than one, and the inter-group elasticity of factor substitution, which was hypothesized to be less than one.

The elasticities were estimated with two sets of data. One was a set of cross-sectional data from a survey carried out in seven states of Brazil between 1962 and 1964. The results obtained with this set of data were not particularly good.

The second set of data consisted of time series for the national economy. The statistical results with these data were reasonably good. However, the a priori hypothesis

about the magnitude of the intra-group elasticities of substitution did not prove to be valid. Point estimates of these parameters were found to be .605 for the labor subfunction and .933 for the land subfunction. The point estimates of the inter-group elasticity of substitution was found to be .9. An interesting and significant finding was the apparent existence of a turning point in the technological path in the early 1960's, with apparent complementary relationships between capital and each of the primary inputs in the earlier period turning to substitute relationships at this time.

One decision in the research priority problem is the extent to which research should be directed to easing the constraints implied by the land subfunction or by the labor subfunction. The criterion for this decision in the analytical framework postulated would be the implicit price relation implied by the two-stage production function. However, it was not possible to estimate this price index for the land subfunction, since it was necessary to use an alternative model for estimation due to a lack of data on land prices. Trends in the prices of labor and land as well as in factor shares in the recent period were therefore used as alternative criteria. These data showed that between 1966-1970 the price and share of land was increasing faster than the price and share of labor. This finding suggests that the land subfunction should receive more attention from research

efforts than the labor subfunction. However, the low elasticity of substitution found for the labor subfunction suggests that there is room for research on this subfunction without depressing the employment and income of labor.[1/]

The third part of the analysis was a two-sector general equilibrium model. The aim of this model was to analyze the adjustment problem between sectors, given a technological change in one sector. The relevant parameters are the price elasticity of demand and the bias in the technological change. The results obtained in applying this model suggest that if research were directed to rice, corn, edible beans and manioc, the expected consequence would be the release of labor from the agricultural sector. Therefore, government action might be necessary in order to avoid the full burden of the adjustment problem falling on the labor force.

Principal Conclusions

1. The choice of products which should have priority in the research effort will depend upon the goal or goals of the government:

   a. If the goal is to increase income to the agricultural sector, the products to be selected are

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[1/] Behind this statement is an implicit assumption that labor absorption problems continue to be severe in the Brazilian economy, and that as a result labor should not be released from agriculture in "excessive" amounts for the moment.

those with a high price elasticity of demand. An important class of such products are those with a comparative advantage in world markets, such as cotton and sugar-cane.

b. If the goal is to increase the income and employment of agricultural labor, the choice would be the same products.

c. If the goal is to increase consumer welfare, the products to be considered must be those with a low price elasticity of demand, such as corn, rice, edible beans and manioc.

d. If the goal is to enlarge agriculture's contribution to general economic development, the choice will depend upon the prevailing constraint at the particular point in time. If, for example, the constraint is capital, the products to be selected are those which give the greater flow of gross benefits, which are corn and rice. On the other hand, if the constraint is exchange earnings, cotton and sugar-cane would be higher on the priority list.

2. The results suggest that the bulk of research should go to increase land productivity. However, there is room for research on the labor subfunction if the research is directed to activities which are not strongly labor displacing (for example, research with tractors to improve land preparation).

3. The results obtained in estimating the parameters of the production function with time series data suggest a basic change in the production technology in the early 1960's. Modern inputs such as fertilizer and machinery, which appear to have been complementary to their corresponding primary inputs in an earlier period, became substitutes of the primary inputs in the more recent period.

4. An exogenous change in factor prices will affect the distribution of income and the level of employment differently, according to the crops which use the factors the most. For example:

a. If the price of fertilizer is lowered and it is used for crops with a low price elasticity of demand, such as rice, corn, edible beans and manioc, the effect on labor income will be regressive.

b. A decrease in the price of tractors for land preparation may have a positive effect on labor income, however, even if it is used for those same crops. This is due to the low substitutability among tractors and labor (.605), and the relatively larger elasticity of substitution (.9) between the two subfunctions of land and labor.

5. Finally, the adjustment problem in the labor market between the agricultural and non-agricultural sectors is

expected to be large if research is directed to the crops with a low price elasticity of demand, such as corn, rice, edible beans, and manioc, even though the research is designed basically to improve land productivity. On the other hand, if research were directed more to those crops such as cotton and sugar-cane which are produced for the world market, the demand for labor will be expected to increase if the research is focused on the land subfunction, and/or on the labor subfunction, if the technical change that results is not strongly labor displacing.

Suggestions for Additional Research

One of the more serious problems encountered in this study was the lack of data on the price or rental value of land. This deficiency limited the testing of the model as a whole, and precluded the calculation of the implicit price index of the land subfunction, which could have been an important decision variable for indicating the direction of research between the two subfunctions.

This problem could be solved as more information becomes available, since a data series does exist for the period from 1966 to the present. However, major priority should be given to synthesizing a longer time series from available primary sources.

Another problem is the definition and measurement of the service and rental price of the substitute capital for labor. A more precise measurement should improve the statistical

results. Similarly, improved estimates of the level of employment and better data on wage rates would also improve the results.

It would be useful to test the model with cross-sectional data from more recent years. This might strengthen the finding of a change in the "technical epoch" during the early 1960's.

A limitation of the results as a guide for establishing research priority is the level of aggregation at which the research was conducted. Further research with the data disaggregated by region and by enterprise would improve the precision of the model and increase the specificity with which research recommendations could be made.

The availability of studies on the demand for agricultural products also places some limitations on the scope and range of the analysis. The price elasticity of demand plays an important role in various parts of the model. Therefore, more research in this area should receive high priority, and will determine the extent to which disaggregated analysis can be made.

More studies were available on the supply side, although more work is needed here also. Of special importance is knowledge on regional supply functions and the nature of the supply response as modernization proceeds.

The present study ignored the benefits in terms of a higher growth rate that might result from a technologically

induced increase in exports. Research which considered export multipliers and the benefits from this source could well provide an additional dimension to the problem of establishing research priorities.

Finally, to strengthen the validity of and to search for improvements in the model, it should be tested in more advanced economies and in other less-developed countries. This would provide a wider range of data and, hopefully, provide additional insights into the research priority problem.

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APPENDICES

Appendix A. Derivation of Analytical Equations from the Separable Production Function

An important part of the empirical work reported in this thesis assumes a two-stage separable production function. The purpose of this appendix is to provide the basic derivations which serve as a basis for the analytical equations used in the research, since this particular specification of the production function is not widely used. The material presented here is based in large part on Bajuk,[1] although some aspects of the derivations are made explicit here that are not available in the original source.

The production function is specified in separable form which means that the output is postulated to be a function of two subfunctions:

$$Y = F[f(L^*, K_L^*),\ g(T^*, K_T^*)] \tag{A.1}$$

where

Y is output;

$L^* = t_L L$, labor measured in "effective" units;

$K_L^* = t_{K_L} K_L$, "laboresque" capital measured in "effective" units;

$T^* = t_T T$, land measured in "effective" units;

$K_T^* = t_{K_T} K_T$, "landesque" capital measured in "effective" units;

t_i = is an index of non-neutral technological change which increases the quality, or "effective" units, of the nominal input.

[1] Bajuk, A., "A Model of the Distribution of Gains from Agricultural Development," Ph.D. Research Essay, Department of Agricultural Economics, University of California, Berkeley, 1971 (mimeo).

The basic characteristic of the production function (1) is that capital is divided into two types, one of which is labor-saving and the other of which is land-saving. The degree of substitutability between inputs within a subfunction is assumed to be high (greater than one), while the degree of substitutability between the aggregate inputs represented by the subfunctions is assumed to be low (less than one).

Let us define

$$Z_L = f(L^*, K_L^*) \tag{A.2}$$

and

$$Z_T = g(T^*, K_T^*) \ . \tag{A.3}$$

Then equation (A.1) becomes

$$Y = F(Z_L, Z_T) \ . \tag{A.4}$$

Fixed input prices and weak separability are assumed. According to Leontief[1/] weak separability means that the marginal rate of substitution between inputs in one subfunction is a function of the quantities of inputs in that subfunction alone, given the input prices, and hence independent of the value of any variable outside the subfunction. In the present context this requires that, say, a capital augmenting technological change in the land subfunction does not affect the marginal rate of substitution between labor

[1/] W. Leontief, "A Note on the Interrelation of Subsets of Independent Variables of a Continuous Function with Con-Continuous First Derivatives," Bulletin of the American Mathematical Society, 53(4): 343 -350, April 1947.

and laboresque capital. Homogeneity within the subfunction is also assumed, which permits the definition of group price indexes on the basis of which the optimization process can be consistently performed in two separable stages. The optimization is as follows:

First Stage

$$\text{Max } P \cdot F(Z_L, Z_T) - \alpha_L Z_L - \alpha_T Z_T \tag{A.5}$$

s.t.

$$Y = h(P) \tag{A.6}$$

where equation (A.6) is the demand function, α_L, α_T are the price indexes for the subfunctions, and P is the product price. In this stage the exogenous variables are α_L and α_T, and the endogenous variables are P, Y, Z_L, Z_T.

Second Stage

$$\text{Min } \frac{L^*}{t_L} P_L + \frac{K_L^*}{t_{K_L}} P_{K_L} + \lambda_L [Z_L - f(L^*, K_L^*)] \tag{A.7}$$

$$\text{min } \frac{T^*}{t_T} P_T + \frac{K_T^*}{t_{K_T}} P_{K_T} + \lambda_T [Z_T - g(T^*, K_T^*)] \tag{A.8}$$

where $P_i (i = L, T, K_L, K_T)$ are nominal input prices. The exogenous variables in the labor subfunction are Z_L, P_L, P_{K_L}, t_L, t_{K_L}, and the endogenous variables are L, K_L, and λ_L. In the land subfunction the exogeneous variables are Z_T, P_T, P_{K_T}, t_T, t_{K_T}, and the endogeneous variables are T, K_T and λ_T.

The first stage is a profit maximization problem, while the second stage is a cost minimization problem. In the first stage the first-order conditions are:

$$\alpha_L = PF_{Z_L}$$

$$\alpha_T = PF_{Z_T} \qquad (A.9)$$

$$h(P) = F(Z_L, Z_T)$$

By taking total differentials in the logarithmic form of the set of equations (A.9) we obtain:[1/]

$$\dot{\alpha}_L = \frac{PF_{Z_L Z_L} dZ_L}{PF_{Z_L}} + \frac{PF_{Z_L Z_T} dZ_T}{PF_{Z_L}} + \frac{F_{Z_L} dP}{PF_{Z_L}}$$

$$\dot{\alpha}_T = \frac{PF_{Z_T Z_T} dZ_T}{PF_{Z_T}} + \frac{PF_{Z_T Z_L} dZ_L}{PF_{Z_T}} + \frac{F_{Z_T} dP}{PF_{Z_T}} \qquad (A.10)$$

$$\frac{h_P dP}{h(P)} = \frac{F_{Z_L} dZ_L}{F(Z_L, Z_T)} + \frac{F_{Z_T} dZ_T}{F(Z_L, Z_T)}$$

By making the appropriate simplification and transformation in equation (A.10) we obtain:

[1/] A dot above a variable denotes a rate of change for that variable, i.e., $d\alpha_L/\alpha_L$, and F_i, F_{ii} are the first- and second-order derivatives, respectively, $i = Z_L, Z_T$.

$$\dot{\alpha}_L = F_{Z_L}^{-1} F_{Z_L Z_L} Z_L \hat{Z}_L + F_{Z_L}^{-1} F_{Z_L Z_T} Z_T \hat{Z}_T + \hat{\rho}$$

$$\dot{\alpha}_T = F_{Z_T}^{-1} F_{Z_T Z_L} Z_L \hat{Z}_L + F_{Z_T}^{-1} F_{Z_T Z_T} Z_T \hat{Z}_T + \hat{\rho} \qquad \text{(A.11)}$$

$$-\eta\hat{\rho} = S_L \hat{Z}_L + S_T \hat{Z}_T$$

where η is the negative of the elasticity of final demand, and

$$S_L = \frac{F_{Z_L} Z_L}{F(Z_L, Z_T)}$$

$$S_T = \frac{F_{Z_T} Z_T}{F(Z_L, Z_T)} \qquad \text{(A.12)}$$

are the subfunction factor shares.

For functions that are linear homogeneous, the following identities hold.[1/]

$$F_{Z_L Z_L} \equiv -\frac{Z_T}{Z_L} F_{Z_L Z_T}$$

$$F_{Z_T Z_T} \equiv -\frac{Z_L}{Z_T} F_{Z_T Z_T} \qquad \text{(A.13)}$$

Substituting identities (A.13) into (A.11) we have:

[1/] See Ferguson, C.E., The Neoclassical Theory of Production and Distribution (London: Cambridge University Press, 1971), p. 226.

$$\dot{\alpha}_L = F_{Z_L}^{-1}(-\frac{Z_T}{Z_L} F_{Z_L Z_T})Z_L\dot{Z}_L + F_{Z_L}^{-1}F_{Z_L Z_T}Z_T\dot{Z}_T + \dot{P}$$

$$\dot{\alpha}_T = F_{Z_T}^{-1}F_{Z_T Z_L}Z_L\dot{Z}_L + F_{Z_T}^{-1}(-\frac{Z_L}{Z_T} F_{Z_T Z_L})Z_T\dot{Z}_T + \dot{P} \qquad (A.14)$$

$$0 = S_L\dot{Z}_L + S_T\dot{Z}_T + \eta\dot{P}$$

By manipulating equations (A.14) we obtain:

$$\dot{\alpha}_L = - F_{Z_L}^{-1}F_{Z_T}^{-1}YF_{Z_L Z_T}Z_T Y^{-1}\dot{Z}_L + F_{Z_L}^{-1}F_{Z_T}^{-1}YF_{Z_T Z_T}Z_T F_{Z_T} Y^{-1}\dot{Z}_T + \dot{P}$$

$$\dot{\alpha}_T = F_{Z_T}^{-1}F_{Z_L}^{-1}YF_{Z_T Z_L}Z_L F_{Z_L} Y^{-1}\dot{Z}_L - F_{Z_T}^{-1}F_{Z_L}^{-1}YF_{Z_T Z_L}Z_L F_{Z_L} Y^{-1}\dot{Z}_T + \dot{P}$$

$$0 = S_L\dot{Z}_L + S_T\dot{Z}_T + \eta\dot{P} \qquad (A.15)$$

Since our function is assumed to be homogeneous of degree one, the elasticity of substitution among factors can be defined as:[1/]

$$\sigma = \frac{F_{Z_L} F_{Z_T}}{YF_{Z_L Z_T}} \qquad (A.16)$$

Therefore, by using (A.12) and (A.16) equation (A.15) becomes:

[1/] Ferguson, C.E., op. cit., p. 96.

$$\dot{\alpha}_L = -\frac{S_T}{\sigma}\hat{Z}_L + \frac{S_T}{\sigma}\hat{Z}_T + \beta$$

$$\dot{\alpha}_T = \frac{S_L}{\sigma}\hat{Z}_L - \frac{S_L}{\sigma}\hat{Z}_T + \beta \qquad (A.17)$$

$$0 = S_L\hat{Z}_L + S_T\hat{Z}_T + \eta\beta$$

The representation of equations (A.17) in matrix form is:

$$\begin{bmatrix} -\frac{S_T}{\sigma} & \frac{S_T}{\sigma} & 1 \\ \frac{S_L}{\sigma} & -\frac{S_L}{\sigma} & 1 \\ S_L & S_T & \eta \end{bmatrix} \begin{bmatrix} \dot{Z}_L \\ \dot{Z}_T \\ \beta \end{bmatrix} = \begin{bmatrix} \dot{\alpha}_L \\ \dot{\alpha}_T \\ 0 \end{bmatrix} \qquad (A.18)$$

Therefore

$$\begin{bmatrix} \hat{Z}_L \\ \hat{Z}_T \\ \beta \end{bmatrix} = \begin{bmatrix} -\frac{S_T}{\sigma} & \frac{S_T}{\sigma} & 1 \\ \frac{S_L}{\sigma} & -\frac{S_L}{\sigma} & 1 \\ S_L & S_T & \eta \end{bmatrix}^{-1} \begin{bmatrix} \dot{\alpha}_L \\ \dot{\alpha}_T \\ 0 \end{bmatrix} \qquad (A.19)$$

By taking the inverse in (A.19) we obtain:

$$\begin{bmatrix} \hat{Z}_L \\ \hat{Z}_T \\ \beta \end{bmatrix} = \begin{bmatrix} -S_L\eta - S_T\sigma & S_T(\sigma-\eta) & 1 \\ S_L(\sigma-\eta) & S_T\eta - S_L\sigma & 1 \\ S_L & S_T & 0 \end{bmatrix} \begin{bmatrix} \dot{\alpha}_L \\ \dot{\alpha}_T \\ 0 \end{bmatrix} \qquad (A.20)$$

The first-order conditions for the second stage for the labor subfunction are:

$$P_L = \lambda_L f_{L*} t_L$$

$$P_{K_L} = \lambda_L f_{K_L^*} t_{K_L} \qquad (A.21$$

$$Z_L = f(L^*, K_L^*)$$

By taking total differentials in the logarithmic form of (A.21) we obtain:

$$\dot{P}_L = \frac{t_L \lambda_L f_{L*L*} dL^*}{\lambda_L f_{L*} t_L} + \frac{t_L \lambda_L f_{L*K*} dK_L^*}{t_L \lambda_L f_{L*}} + \frac{\lambda_L f_{L*} dt_L}{t_L \lambda_L f_{L*}} + \frac{t_L f_{L*} d\lambda_L}{t_L \lambda_L f_{L*}}$$

$$\dot{P}_{K_L} = \frac{t_{K_L} \lambda_L f_{K_{K*L*}} dL^*}{t_{K_L} \lambda_L f_{K_{L*}}} + \frac{t_{K_L} \lambda_L f_{K_L^* K^*_L} dK_L^*}{t_{K_L} \lambda_L f_{K_L^*}} + \frac{\lambda_L f_{K_L^*} dt_{K_L}}{t_{K_L} \lambda_L f_{K_L^*}} + \frac{t_{K_L} f_{K_L^*} d\lambda_L}{t_{K_L} \lambda_L f_{K_L^*}}$$

$$\dot{Z}_L = \frac{f_{L*} dL^*}{f(L^*, K_L^*)} + \frac{f_{K_L^*} dK_L^*}{f(L^*, K_L^*)} \qquad (A.22)$$

Simplifying equations (A.22) we have:

$$\dot{P}_L = f_{L*}^{-1} f_{L*L*} dL^* + f_{L*}^{-1} f_{L*KL*} dK_L^* + \dot{t}_L + \dot{\lambda}_L$$

$$\dot{P}_{K_L} = f_{K_L^*}^{-1} f_{K_L^* L*} dL^* + f_{K_L^*}^{-1} f_{K_L^* K_L^*} dK_L^* + \dot{t}_{K_L} + \dot{\lambda}_L \qquad (A.23)$$

$$\dot{Z}_L = Z_L^{-1} f_{L*} dL^* + Z_L^{-1} f_{K_L^*} dK_L^*$$

From the definition of the variables in equation (A.1) we have:

$$f(L^*,K_L^*) = f(t_L L, t_{K_L} K_L).$$

Therefore,

$$\frac{\partial f(L^*,K_L^*)}{\partial L} = \frac{\partial(t_L L, t_{K_L} K_L)}{\partial L} \equiv f_L$$

$$f_L = \frac{\partial f(L^*,K_L^*)}{\partial L^*} \quad \frac{\partial L^*}{\partial L} \quad ,$$

$$f_L = f_{L^*} t_L, \text{ since } L^* = t_L L$$

ı general,

$$f_i = f_{i^*} t_i \quad \text{where } i = L, K_L. \tag{A.24}$$

And by the same procedure we have

$$f_{ii} = f_{i^*i^*} t_i^2 \tag{A.25}$$

and

$$d_{i^*} = t_i d_i + i dt_i \tag{A.26}$$

By using the relations (A.24), (A.25) and (A.26), equation (A.23) becomes:

$$\dot{P}_L = t_L f_L^{-1} f_{LL} t_i^{-2}(t_L dL + L dt_L) + t_L f_L^{-1} f_{LK_L} t_{K_L}^{-1} t_L^{-1}(t_{K_L} dK_L + K_L dt_{K_L})$$

$$+ \dot{t}_L + \dot{\lambda}_L$$

$$\dot{p}_{K_L} = t_{K_L} f_{K_L}^{-1} t_{K_L}^{-1} t_L^{-1} f_{K_L L}(t_L dL + L dt_L) + t_{K_L} f_{K_L}^{-1} f_{K_L K_L} t_{K_L}^{-2}(t_{K_L} dK_L$$

$$+ K_L dt_{K_L}) + \dot{t}_{K_L} + \dot{\lambda}_L \qquad (A.27)$$

$$\dot{Z}_L = Z_L^{-1} t_L^{-1} f_L (t_L dL + L dt_L) + Z_L^{-1} t_{K_L}^{-1} f_{K_L}(t_{K_L} dK_L + K_L dt_{K_L})$$

By simplifying and manipulating the equations (A.27) we obtain:

$$\dot{p}_L = f_L^{-1} f_{LL} L\dot{L} + f_L^{-1} f_{LK_L} K_L \dot{K}_L + f_L^{-1} f_{LL} L\dot{t}_L + \dot{t}_L + f_L^{-1} f_{LK_L} K_L \dot{t}_{K_L}$$

$$+ \dot{\lambda}_L$$

$$\dot{p}_{K_L} = f_{K_L}^{-1} f_{K_L L} L\dot{L} + f_{K_L}^{-1} f_{K_L K_L} K_L \dot{K}_L + f_{K_L}^{-1} f_{K_L L} L\dot{t}_L + f_{K_L}^{-1} f_{K_L K_L} K_L \dot{t}_{K_L}$$

$$+ \dot{t}_{K_L} + \dot{\lambda}_L \qquad (A.28)$$

$$\dot{Z}_L = Z_L^{-1} f_L L\dot{L} + Z_L f_{K_L} K_L \dot{K}_L + Z_L^{-1} f_L L\dot{t}_L + Z_L^{-1} f_{K_L} K_L \dot{t}_{K_L}$$

By making use of relations like (A.13), we have:

$$\dot{p}_L = f_L^{-1}(-\frac{K_L}{L} f_{LK_L}) L\dot{L} + f_L^{-1} f_{LK_L} K_L \dot{K}_L + f_L^{-1}(-\frac{K_L}{L} f_{LK_L}) L\dot{t}_L$$

$$+ \dot{t}_L + f_L^{-1} f_{LK_L} K_L \dot{t}_{K_L} + \dot{\lambda}_L$$

$$\dot{p}_{K_L} = f_{K_L}^{-1} f_{K_L L} L\dot{L} + f_{K_L}^{-1}(-\frac{L}{K_L} f_{K_L L}) K_L \dot{K}_L + f_{K_L}^{-1} f_{K_L L} L\dot{t}_L$$

$$+ f_{K_L}^{-1}(-\frac{L}{K_L} f_{K_L L}) K_L \dot{t}_{K_L} + \dot{t}_{K_L} + \dot{\lambda}_L \qquad (A.29)$$

$$\dot{Z}_L = Z_L^{-1} f_L L\dot{L} + Z_L^{-1} f_{K_L} K_L \dot{K}_L + Z_L^{-1} f_L L\dot{t}_L + Z_L^{-1} f_{K_L} K_L \dot{t}_{K_L}$$

By using the relations like (A.12) and (A.16), equation (A.29) becomes:

$$\dot{p}_L = -\frac{C_{K_L}}{\sigma_L}\dot{L} + \frac{C_{K_L}}{\sigma_L}\dot{K}_L - \frac{C_{K_L}}{\sigma_L}\dot{t}_L + \dot{t}_L + \frac{C_{K_L}}{\sigma_L}\dot{t}_{K_L} + \dot{\lambda}_L$$

$$\dot{p}_{K_L} = \frac{C_L}{\sigma_L}\dot{L} - \frac{C_L}{\sigma_L}\dot{K}_L + \frac{C_L}{\sigma_L}\dot{t}_L - \frac{C_L}{\sigma_L}\dot{t}_{K_L} + \dot{t}_{K_L} + \dot{\lambda}_L \qquad (A.30)$$

$$\dot{Z}_L = C_L\dot{L} + C_{K_L}\dot{K}_L + C_L\dot{t}_L + C_{K_L}\dot{t}_{K_L}$$

where $C_L = Z_L^{-1} f_L L$, the labor share within the labor subfunction,

$C_{K_L} = Z_L^{-1} f_{K_L} K_L$, the share of laboresque capital within the labor subfunction, and

σ_L = the elasticity of substitution between L and K_L.

By representing equations (A.30) in matrix form we have:

$$\begin{bmatrix} \frac{C_{KL}}{\sigma_L} & \frac{C_{KL}}{\sigma_L} & 1 \\ \frac{C_L}{\sigma_L} & -\frac{C_L}{\sigma_L} & 1 \\ C_L & C_{K_L} & 0 \end{bmatrix} \begin{bmatrix} \dot{L} \\ \dot{K}_L \\ \dot{\lambda}_L \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \frac{C_{K_L}}{\sigma_L}-1 & -\frac{C_{K_L}}{\sigma_L} \\ 0 & 1 & 0 & -\frac{C_L}{\sigma_L} & \frac{C_L}{\sigma_L}-1 \\ 0 & 0 & 1 & -C_L & -C_{K_L} \end{bmatrix} \begin{bmatrix} \dot{p}_L \\ \dot{p}_{K_L} \\ \dot{z}_L \\ \dot{t}_L \\ \dot{t}_{K_L} \end{bmatrix} \tag{A.31}$$

Therefore:

$$\begin{bmatrix} \dot{L} \\ \dot{K}_L \\ \dot{\lambda}_L \end{bmatrix} = \begin{bmatrix} -C_{K_L}\sigma_L & C_{K_L}\sigma_L & 1 & C_{K_L}\sigma_L-1 & -C_{K_L}\sigma_L \\ C_L\sigma_L & -C_L\sigma_L & 1 & -C_L\sigma_L & C_L\sigma_L-1 \\ C_L & C_{K_L} & 0 & -C_L & -C_{K_L} \end{bmatrix} \begin{bmatrix} \dot{p}_L \\ \dot{p}_{K_L} \\ \dot{z}_L \\ \dot{t}_L \\ \dot{t}_{K_L} \end{bmatrix} \tag{A.32}$$

Cost minimization in the land subfunction, following the same steps for the labor subfunction, will yield:

$$\begin{bmatrix} \dot{t} \\ \\ \dot{K}_T \\ \\ \dot{\lambda}_T \end{bmatrix} = \begin{bmatrix} -C_{K_T}\sigma_T & C_{K_T}\sigma_T & 1 & C_{K_T}\sigma_T-1 & -C_{K_T}\sigma_T \\ \\ C_T\sigma_T & -C_T\sigma_T & 1 & -C_T\sigma_T & C_T\sigma_T-1 \\ \\ C_T & C_{K_T} & 0 & -C_T & -C_{K_T} \end{bmatrix} \begin{bmatrix} \dot{P}_T \\ \dot{P}_{K_T} \\ \dot{Z}_T \\ \dot{t}_T \\ \dot{t}_{K_T} \end{bmatrix} \tag{A.33}$$

where C_{K_T} and C_T are factor shares of K_T and T in total land subfunction cost, i.e., $\alpha_T Z_T$, and σ_T is the elasticity of substitution between K_T and T within the land function.

Now, let us define the price indices for the subfunctions, α_L and α_T, referred to in equation (A.5).[1]

$$\alpha_L Z_L = LP_L + K_L P_{K_L}$$

Therefore

$$\alpha_L = \frac{L}{Z_L} P_L + \frac{K_L}{Z_L} P_{K_L} \quad . \tag{A.34}$$

By taking total differentials in the logarithmic form of (A.34) and making the necessary simplification we have:

$$\dot{\alpha}_L = \frac{LP_L}{LP_L + K_L P_{K_L}} [\dot{P}_L + \dot{L}] + \frac{K_L P_{K_L}}{LP_L + K_L P_L} [\dot{P}_{K_L} + \dot{K}_L] - \dot{Z}_L$$

[1] The reader is referred to Gorman, W.M., "Separable Utility on Aggregation," Econometrica 27(3):469-481 and Green, H.A.J.,

or

$$\dot{\alpha}_L = C_L(\dot{P}_L + \dot{L}) + C_{K_L}(\dot{P}_{K_L} + \dot{K}_L) - \dot{Z}_L \quad . \qquad (A.35)$$

Equation (A.35) is homogeneous of degree one in prices since $C_L + C_{K_L} = 1$. Since $L^* = t_L L$ and $K^*_L = t_{K_L} K_L$, then

$$\dot{L}^* = \dot{L} + \dot{t}_L \text{ and } \dot{K}^*_L = \dot{K}_L + \dot{t}_{K_L} \quad .$$

Therefore (A.35) can be written as

$$\dot{\alpha}_L = C_L(\dot{P}_L + \dot{L}^* - \dot{t}_L) + C_{K_L}(\dot{P}_{K_L} + \dot{K}^*_L - \dot{t}_{K_L}) - \dot{Z}_L \qquad (A.36)$$

By the same reasoning, the price index α_T is

$$\dot{\alpha}_T = C_T(\dot{P}_T + \dot{T}^* - \dot{t}_T) + C_{K_T}(\dot{P}_{K_T} + \dot{K}^*_T - \dot{t}_{K_T}) - \dot{Z}_T \qquad (A.37)$$

Given the equations derived above we can now derive the two stage elasticities of the derived demands for elementary inputs:

$$\frac{\dot{L}}{\dot{P}_L} = \left.\frac{\dot{L}}{\dot{P}_L}\right|_{Z_L} + \frac{\dot{L}}{\dot{Z}_L}\,\frac{\dot{Z}_L}{\dot{\alpha}_L}\,\frac{\dot{\alpha}_L}{\dot{P}_L} \qquad (A.38)$$

1/ (continued) Aggregation in Economic Analysis (Princeton, Princeton University Press), Ch. 4, pp. 25-32 for the existence of the prices and input quantity indexes.

The first term on the right hand side denotes the elasticity of the demand for labor with respect to its own price when Z_L is held constant. The second term measures the percentage change in the quantity of L demanded due to a first stage reallocation of aggregate inputs induced by a change in P_L. Therefore, in equation (A.38), the total effect on L of a change in P_L was decomposed into a sum of a within-subfunction and a between-subfunction adjustment. In addition, we have:

$$\left.\frac{\dot{L}}{\dot{P}_L}\right|_{Z_L} = -C_{K_L}\sigma_L$$

$$\frac{\dot{L}}{\dot{Z}} = 1 \quad .$$

From (A.20),

$$\frac{\dot{Z}_L}{\dot{\alpha}_L} = - S_L\eta - S_T\sigma$$

From (A.36),

$$\frac{\dot{\alpha}_L}{\dot{P}_L} = C_L \quad .$$

Therefore, (A.38) can be written as:

$$\frac{\dot{L}}{\dot{P}_L} = - C_{K_L}\sigma_L - (S_L\eta + S_T\sigma)\ C_L \qquad \text{(A.39)}$$

Similarly[1]

$$\frac{\dot{L}}{\dot{p}_{K_L}} = \left.\frac{\dot{L}}{\dot{p}_{K_L}}\right|_{Z_L} + \frac{\dot{L}}{\dot{Z}_L}\frac{\dot{Z}_L}{\alpha_L}\frac{\alpha_L}{\dot{p}_{K_L}} = C_{K_L}\sigma_L - (S_L\eta + S_T\sigma)\, C_{K_L} \qquad (A.40)$$

$$\frac{\dot{L}}{\dot{p}_T} = \frac{\dot{L}}{\dot{Z}_L}\frac{\dot{Z}_L}{\dot{\alpha}_L}\frac{\dot{\alpha}_T}{\dot{p}_T} = S_T(\sigma - \eta)C_T \qquad (A.41)$$

$$\frac{\dot{L}}{\dot{p}_{K_T}} = \frac{\dot{L}}{\dot{Z}_L}\frac{\dot{Z}_L}{\dot{\alpha}_T}\frac{\dot{\alpha}_T}{\dot{p}_{K_T}} = S_T(\sigma - \eta)C_{K_T} \qquad (A.42)$$

Due to the assumption of weak separability into two subfunctions, the subfunction price indexes are functions of the subfunction prices alone. Therefore, $\frac{\dot{L}}{\dot{p}_T}$ and $\frac{\dot{L}}{\dot{p}_{K_T}}$ depends only on the effects that a change in P_T and/or P_{K_T} have on the corresponding group price index, α_T (that is, on the adjustments in elementary inputs due to a reallocation at the first stage level).

The elasticities of the derived demand for elementary inputs related to factor-augmenting changes are:

$$\frac{\dot{L}}{\dot{t}_L} = \left.\frac{\dot{L}}{\dot{t}_L}\right|_{Z_L} + \frac{\dot{L}}{\dot{Z}_L}\frac{\dot{Z}_L}{\dot{\alpha}_L}\frac{\dot{\alpha}_L}{\dot{t}_L} = C_{K_L}\sigma_L - 1 + (S_L\eta + S_T\sigma)C_L \qquad (A.43)$$

$$\frac{\dot{L}}{\dot{t}_{K_L}} = \left.\frac{\dot{L}}{\dot{t}_{K_L}}\right|_{Z_L} + \frac{\dot{L}}{\dot{Z}_L}\frac{\dot{Z}_L}{\dot{\alpha}_L}\frac{\dot{\alpha}_L}{t_{K_L}} = - C_{K_L}\sigma_L + (S_L\eta + S_T\sigma)C_{K_L} \qquad (A.44)$$

[1] The derivations depend on equations (A.32), (A.33), (A.36) and (A.37).

$$\frac{\dot{L}}{\dot{t}_T} = \frac{\dot{L}}{\dot{Z}_L}\frac{\dot{Z}_L}{\dot{\alpha}_T}\frac{\dot{\alpha}_T}{\dot{t}_T} = -S_T(\sigma - \eta)C_T \tag{A.45}$$

$$\frac{\dot{L}}{\dot{t}_{K_T}} = \frac{\dot{L}}{\dot{Z}_L}\frac{\dot{Z}_L}{\dot{\alpha}_T}\frac{\dot{\alpha}_T}{\dot{t}_{K_T}} = -S_T(\sigma - \eta)C_{K_T} \tag{A.46}$$

Similarly, the elasticities of the derived demand for K_L are:

$$\frac{\dot{K}_L}{\dot{p}_L} = C_L\sigma_L - (S_L\eta + S_T\sigma)C_L \tag{A.47}$$

$$\frac{\dot{K}_L}{\dot{p}_{K_L}} = -C_L\sigma_L - (S_L\eta + S_T\sigma)C_{K_L} \tag{A.48}$$

$$\frac{\dot{K}_L}{\dot{p}_T} = S_T(\sigma - \eta)C_T \tag{A.49}$$

$$\frac{\dot{K}_L}{\dot{p}_{K_T}} = S_T(\sigma - \eta)C_{K_T} \tag{A.50}$$

$$\frac{\dot{K}_L}{\dot{t}_L} = -C_L\sigma_L + (S_L\eta + S_T\sigma)C_L \tag{A.51}$$

$$\frac{\dot{K}_L}{\dot{t}_{K_L}} = -C_L\sigma_L - 1 + (S_L\eta + S_T\sigma)C_{K_L} \tag{A.52}$$

$$\frac{\dot{K}_L}{\dot{t}_T} = - S_T(\sigma - \eta)C_T \tag{A.53}$$

$$\frac{\dot{K}_L}{\dot{t}_{K_T}} = - S_T(\sigma - \eta)C_{K_T} \tag{A.54}$$

Since the two subfunctions are similar the demand elasticities for the elementary inputs in the land subfunction are analogous to those corresponding to the labor subfunction.

Appendix B. Additional Effects of Technological Change on the Income to Individual Factors, the Functional Distribution of Income, and the Employment of Factors

In Chapter II of the text some analytical equations were presented which describe the effect of particular kinds of technological change on factor income, factor shares, and factor employment. The purpose of this appendix is to complete that set of equations.[1/] Although the relations presented herein were not used in the research reported in the text, they may be useful to the reader who is interested in other aspects of the analysis, and may be of use in further evaluating the results that are reported.

The Appendix is divided into two parts. The first part presents the equations relevant to understanding changes in the pertinent variables at the aggregate input level. The second part presents some additional material on changes expected in factor shares at the elementary input levels.

The same notation is used as in the text and Appendix A, with the following terms defined:

$Z_L = f(L^*, K_L^*)$,

$Z_T = g(T^*, K_T^*)$,

α_L = the price index of Z_L,

α_T = the price index of Z_T,

[1/] The equations are derived basically from material presented in Appendix A.

S_L and S_T = the factor share of the aggregate inputs Z_L and Z_T, respectively,

C_L and C_{K_L} = the factor shares of L and K_L in the labor subfunction,

C_T and C_{K_T} = the factor shares of T and K_T in the land subfunction, and

σ is the elasticity of substitution between the two subfunctions.

Changes Expected at the Aggregate Input Level

The effects of particular kinds of technological changes on the respective aggregate relative factor shares to the labor subfunction are given by

$$\frac{\frac{\alpha_L^{\bullet} Z_L}{\alpha_T Z_T}}{\dot{t}_L} = C_L(\sigma - 1)$$ for the effect of a labor-augmenting technical change,

$$\frac{\frac{\alpha_L^{\bullet} Z_L}{\alpha_T Z_T}}{\dot{t}_{K_L}} = C_{K_L}(\sigma - 1)$$ for the effect of a laboresque capital-augmenting technical change,

$$\frac{\frac{\alpha_L^{\bullet} Z_L}{\alpha_T Z_T}}{\dot{t}_T} = - C_T(\sigma - 1)$$ for the effect of a land-augmenting technical change, and

$$\frac{\frac{\alpha_L^{\bullet} Z_L}{\alpha_T Z_T}}{\dot{t}_{K_T}} = -C_{K_T}(\sigma - 1)$$ for the effect of a landesque capital-augmenting technical change.

Since σ is assumed to be less than one, a decrease in the relative income position of the aggregate input in which

a factor-augmenting technical change has occurred is to be expected. The effect will be greater, the greater is the share of the augmented factor within the corresponding sub-function.

Similarly, the effects on the income to the aggregate factors from particular kinds of technological changes are given by

$$\frac{\alpha_L^{\bullet} Z_L}{t_L} = C_L(S_L\eta + S_T\sigma - 1)^{1/}; \qquad \frac{\alpha_T^{\bullet} Z_T}{t_L} = - S_L C_L(\sigma - \eta)$$

$$\frac{\alpha_L^{\bullet} Z_L}{t_{K_L}} = C_{K_L}(S_L\eta + S_T\sigma - 1); \qquad \frac{\alpha_T^{\bullet} Z_T}{t_{K_L}} = - S_L C_{K_L}(\sigma - \eta)$$

$$\frac{\alpha_L^{\bullet} Z_L}{t_T} = - S_T C_T(\sigma - \eta); \qquad \frac{\alpha_T^{\bullet} Z_T}{t_T} = C_T(S_T\eta + S_L\sigma - 1)$$

$$\frac{\alpha_L^{\bullet} Z_L}{t_{K_T}} = - S_T C_{K_T}(\sigma - \eta); \qquad \frac{\alpha_T^{\bullet} Z_T}{t_{K_T}} = C_{K_T}(S_T\eta\ S_L\sigma - 1)$$

The size of the elasticity of demand plays an important role in this case. If $1 > \eta > \sigma$, then the aggregate returns will decrease for the aggregate input in which the factor-augmenting technical change took place. On the other hand, if η is sufficiently greater than one, the positive output

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1/ η refers to the absolute value of the price elasticity of demand.

effect, measured by $S_L\eta$ and $S_T\eta$, will offset the negative effect on the quantity demanded due to the increase in the quality of the corresponding input.

Finally, the effects on the <u>employment of the aggregate inputs</u> is given by:

$$\frac{\dot{Z}_L}{\dot{t}_L} = C_L(S_L\eta + S_T\sigma) \quad ; \quad \frac{\dot{Z}_T}{\dot{t}_L} = -S_L(\sigma - \eta)C_L$$

$$\frac{\dot{Z}_L}{\dot{t}_{K_L}} = C_{K_L}(S_L\eta + S_T\sigma); \quad \frac{\dot{Z}_T}{\dot{t}_{K_L}} = -S_L(\sigma - \eta)C_{K_L}$$

$$\frac{\dot{Z}_L}{\dot{t}_T} = -S_T(\sigma - \eta)C_T; \quad \frac{\dot{Z}_T}{\dot{t}_T} = C_L(S_T\eta + S_L\sigma)$$

$$\frac{\dot{Z}_L}{\dot{t}_{K_T}} = -S_T(\sigma - \eta)\,C_{K_T} \; ; \quad \frac{\dot{Z}_T}{\dot{t}_{K_T}} = C_{K_T}(S_T\eta + S_L\sigma)$$

The equations above suggest that employment of the aggregate input in which factor-augmenting technological change occurred will increase. However, the employment of the other aggregate input will increase if $\eta > \sigma$. This implies that the expansion effect through increases in output (e.g., $S_LC_L\eta$) will offset the negative substitution effect ($-S_LC_L\sigma$).

Equations which evaluate the effect of exogenous changes in the prices of the factors of production can also be derived. The effects on relative aggregate input shares for changes in

each of the (four) prices are given by

$$\frac{1}{\dot{P}_L}\left(\frac{\dot{\alpha_L Z_L}}{\alpha_T Z_T}\right) = \frac{1}{\dot{P}_L}(\dot{\alpha}_L + \dot{Z}_L - \dot{\alpha}_T - \dot{Z}_T) = C_L(1 - \sigma)$$

$$\frac{1}{\dot{P}_{K_L}}\left(\frac{\dot{\alpha_L Z_L}}{\alpha_T Z_T}\right) = C_{K_L}(1 - \sigma)$$

$$\frac{1}{\dot{P}_T}\left(\frac{\dot{\alpha_L Z_L}}{\alpha_T Z_T}\right) = -C_T(1 - \sigma)$$

$$\frac{1}{\dot{P}_{K_T}}\left(\frac{\dot{\alpha_L Z_L}}{\alpha_T Z_T}\right) = -C_{K_T}(1 - \sigma)$$

The crucial parameter is the inter-subfunction elasticity of substitution, σ, which is by assumption less than one. Therefore, an increase in the price of an elementary input will increase the relative income position of the aggregate input to which it belongs. On the other hand, if $\sigma > 1$, more substitution will take place and the relative income position will reverse.

The effect of changes in the price of inputs on the income to the aggregate inputs can also be derived. These will be presented only for changes in P_L and P_{K_L}, since changes in P_T and P_{K_T} have similar effects. The effects of changes in P_L are given by

$$\frac{\alpha_L^{\cdot} Z_L}{\hat{P}_L} = C_L(1 - S_L\eta - S_T\sigma), \text{ and } \quad \frac{\alpha_T^{\cdot} Z_T}{\hat{P}_L} = C_L S_L(\sigma - \eta),$$

while the effects of changes in P_{K_T} are given by

$$\frac{\alpha_L^{\cdot} Z_L}{\hat{P}_{K_T}} = C_{K_T} S_T(\sigma - \eta) \quad \text{and} \quad \frac{\alpha_T^{\cdot} Z_T}{\hat{P}_{K_T}} = C_{K_T}(1 - S_T\eta - S_L\sigma) \quad .$$

Once again the critical parameter is η, given the assumption of $\sigma < 1$. Therefore, if the decrease in total output, measured by $S_L\eta$, combined with the low possibility of substitution, $S_T\sigma$, is not enough to offset the decrease in the quantity demanded of the aggregate input due to an increase in its price, then the return to the aggregate input of the labor subfunction will increase.

The effects of the changes in factor prices on the employment of the aggregate inputs can also be analyzed. Again, given the symmetry between the subfunctions, the relations will be specified only for changes in P_L and P_{K_T}. For the change in P_L,

$$\frac{\hat{Z}_L}{\hat{P}_L} = - C_L(S_L\eta + S_T\sigma) \quad \text{and} \quad \frac{\hat{Z}_T}{\hat{P}_L} = C_L S_L(\sigma - \eta) \quad .$$

For the change in P_{K_T},

$$\frac{\hat{Z}_L}{\hat{P}_{K_T}} = C_{K_T} S_T(\sigma - \eta) \quad \text{and} \quad \frac{\hat{Z}_L}{\hat{P}_{K_T}} = - C_{K_T}(S_T\eta + S_L\sigma)$$

The crucial parameter is again η. The only unquestionable result is the decrease in the employment of the aggregate input represented by the subfunction when an increase in price occurs. The effects on employment in the other subfunction depends on η being less or greater than σ.

Changes Expected at the Elementary Input Level

Most of the analysis at this level were presented in Chapter II of the text. What remains are the effects of particular kinds of technical change on relative factor shares within the subfunction, and the effect of exogenous changes in factor prices on relative shares. The equations are presented only for the labor subfunction, since they are symmetrical for the land subfunction.

The effects of a labor-augmenting technological change are given by

$$\frac{1}{t_L}\left(\frac{L^{\bullet}P_L}{K_LP_{K_L} + TP_T + K_TP_{K_T}}\right) = (\sigma_L - 1) + 2S_LC_L(\sigma - \eta),$$

$$\frac{1}{t_L}\left(\frac{K_L^{\bullet}P_{K_L}}{LP_L + TP_T + K_TP_{K_T}}\right) = -(\sigma_L - 1) + 2S_LC_L(\sigma - \eta),$$

and

$$\frac{1}{t_L}\left(\frac{TP_T}{LP_L + K_LP_{K_L} + K_TP_{K_T}}\right) = \frac{1}{t_L}\left(\frac{K_T^{\bullet}P_{K_T}}{LP_L + K_LP_{K_L} + TP_T}\right) =$$

$$-(\sigma_L - 1) - 2C_L(S_L\eta + S_T\sigma - 1)$$

The value of η again plays a crucial role, given the assumption about the elasticities of substitution. If $\eta < \sigma$, there is only one unquestionable result: the relative share of labor will increase. Expected changes in the relative factor shares of the other elementary inputs are indeterminate.

On the other hand, if $\eta > \sigma$, then the unquestionable result is that the relative income of the laboresque capital will decrease, with the other being indeterminate.

The effects of a laboresque capital-augmenting technical change are given by

$$\frac{1}{\dot{t}_{K_L}}\left(\frac{L^{\bullet}P_L}{K_LP_{K_L} + TP_T + K_TP_{K_T}}\right) = -(\sigma_L - 1) + 2S_LC_{K_L}(\sigma - \eta),$$

$$\frac{1}{\dot{t}_{K_L}}\left(\frac{K_L{}^{\bullet}P_{K_L}}{LP_L + TP_T + K_TP_{K_T}}\right) = (\sigma_L - 1) + 2S_LC_{K_L}(\sigma - \eta), \text{ and}$$

$$\frac{1}{\dot{t}_{K_L}}\left(\frac{T^{\bullet}P_T}{LP_L + K_LP_{K_L} + K_TP_{K_T}}\right) = \frac{1}{\dot{t}_{K_L}}\left(\frac{K_T{}^{\bullet}P_{K_T}}{LP_L + K_LP_{K_L} + TP_T}\right)$$

$$= -(\sigma_L - 1) - 2C_{K_L}(S_L\eta + S_T\sigma - 1)$$

The analysis in this case is similar to that for the labor-augmenting technological change. The corresponding effects in the land subfunction, with land-augmenting and landesque-augmenting technological change, are analogous to those discussed above.

To evaluate the effect of changes in the factor prices on relative factor shares, only the change in P_L will be considered since the results for the change in the other prices are symmetric. The expected effects are

$$\frac{1}{\dot{P}_L}\left(\frac{L\dot{P}_L}{LP_L + TP_T + K_TP_{K_T}}\right) = \frac{1}{\dot{P}_L}(\dot{L} + \dot{P}_L - \dot{K}_L - \dot{P}_{K_L} - \dot{T} - \dot{P}_T$$

$$- \dot{K}_T - \dot{P}_{K_T}) = (1 - \sigma_L) - 2C_LS_L(\sigma - \eta) ,$$

$$\frac{1}{\dot{P}_L}\left(\frac{K_L\dot{P}_{K_L}}{LP_L + TP_T + K_TP_{K_T}}\right) = (1 - \sigma_L) - 2C_LS_L(\sigma - \eta), \text{ and}$$

$$\frac{1}{\dot{P}_L}\left(\frac{T\dot{P}_T}{LP_L + K_LP_{K_L} + K_TP_{K_T}}\right) = \frac{1}{\dot{P}_L}\left(\frac{K_T\dot{P}_{K_T}}{LP_L + K_LP_{K_L} + TP_T}\right)$$

$$= - (1 - \sigma_L) - 2C_L(\sigma_L - S_L\eta - S_T\sigma).$$

The size of the demand elasticity again plays an important role in determining the direction of the expected changes. A priori, all shares of the factors are indeterminate. If $\eta > \sigma$, the only unquestionable result is that the share of the associated elementary input in the same subfunction will increase.

It should be noted that changes in factor prices are similar, in their effects, to factor-augmenting technological change. This occurs because an improvement in the quality of an input has the same effect as a decrease in its own price.

Appendix C. Derivation of Alternative Expressions for the Concepts of Economic Surplus

For part of the empirical work reported in this thesis it was desired to have simple equations which could be used to calculate separately the consumers' and producers' surpluses and the total net gain from a technologically-induced shift in the supply curve, given only the shift parameter of the supply equation, observations on price and quantity at an initial equilibrium in the market, and estimates of the demand and supply elasticities. The present appendix is devoted to a derivation of such equations.

As indicated in Chapter II, the consumers' surplus (Figure C.1) that results from a shift of the supply curve (S to S') is measured by the area A + B + C. Producers' surplus is measured by area E + F - A, and the total gain is B + C + E + F.[1/]

Assume that the parameter shift is $k_s = P_0 - P_2/P$.[2/] Given this parameter, what is desired is an estimate of the percentage change in price, $P_0 - P_1/P_0$, and an estimate of the percentage change in quantity, $k_q = Q_1 - Q_0/Q_0$. Since

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[1/] Linear demand and supply curves are assumed throughout the analysis.

[2/] This assumes a shift in the supply curve of the $P_0 - P_2$ magnitude, expressed in percentage terms.

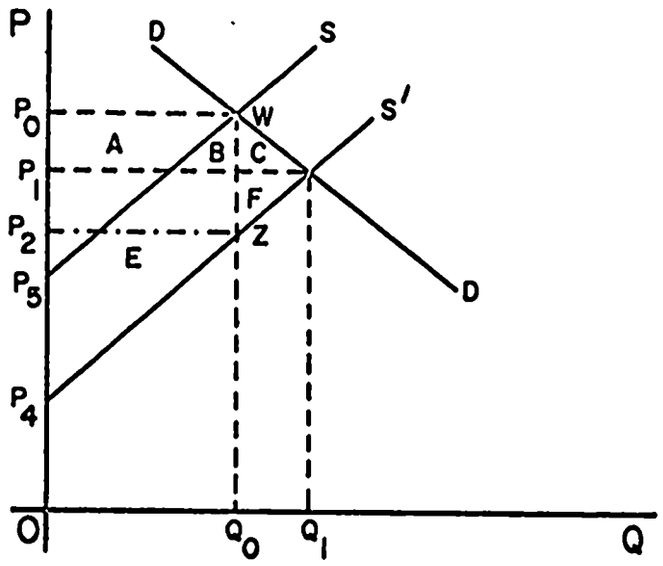

Figure C.1. Consumers' and Producers' Surplus Given a Shift in the Supply Curve.

$P_o - P_1 / P_o - P_2 = E_s / E_s + \eta$,[1] where E_s and η are the supply and demand elasticities, respectively, then

$$\frac{\frac{P_o - P_1}{P_o}}{\frac{P_o - P_2}{P_o}} = \frac{E_s}{E_s + \eta} .$$

Therefore,

$$\frac{P_o - P_1}{P_o} = k_s \frac{E_s}{E_s + \eta} , \qquad (C.1)$$

which is an estimate of the <u>percentage change in price</u>.

By definition the arc elasticity of demand is:

$$\frac{\frac{Q_1 - Q_o}{Q_o}}{\frac{P_o - P_1}{P_o}} = \eta .$$

Therefore, from equation (C.1) we have

$$k_q = \eta \, k_s \left(\frac{E_s}{E_s + \eta}\right) \qquad (C.2)$$

as an estimate of the percentage change in quantity.

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[1] For a derivation of this expression see Appendix D.

Given equations (C.1) and (C.2), the consumers', producers', and total surplus can be derived. The <u>consumers' surplus, (C.S.) is</u>

$$C.S. = A + B + C$$

where $A + B = (P_o - P_1)Q_o$ and $C = \frac{1}{2}(P_o - P_1)\ (Q_1 - Q_o)$.

From equation (C.1) and (C.2) we can state that

$$(P_o - P_1) = P_o \frac{k_q}{\eta}$$

and

$$Q_1 - Q_o = Q_o k_q \quad .$$

Therefore,

$$C.S. = P_o Q_o \frac{k_q}{\eta} + \frac{1}{2} P_o Q_o \frac{k_q^2}{\eta}$$

Factoring the above expression,

$$C.S. = \frac{k_q}{\eta} P_o Q_o (1 + \frac{1}{2} k_q) \ . \qquad (C.3)$$

The <u>total surplus (T.S.)</u>, is given by

$$T.S. = B + E + C + F$$

where

$$B + E = (P_o - P_2)Q_o$$

from the fact that the triangles $P_2\ Z\ P_4$ and $P_o\ W\ P_5$ are equal, and

$$C = \frac{1}{2}(P_o - P_1)(Q_1 - Q_o)$$

and

$$F = \frac{1}{2}(P_1 - P_2)(Q_1 - Q_o) \quad .$$

Therefore,

$$T.S. = (P_o - P_2)Q_o + \frac{1}{2}(P_o - P_1)(Q_1 - Q_o) + \frac{1}{2}(P_1 - P_2)(Q_1 - Q_o).$$

Factoring $(Q_1 - Q_o)$ we have

$$T.S. = (P_o - P_2)Q_o + \frac{1}{2}(Q_1 - Q_o)(P_o - P_1 + P_1 - P_2).$$

Therefore,

$$T.S. = (P_o - P_2)Q_o + \frac{1}{2}(Q_1 - Q_o)(P_o - P_2)$$

By definition of k_s we have that $(P_o - P_2) = P_o k_s$. Then,

$$T.S. = k_s P_o Q_o + \frac{1}{2} k_s P_o Q_o k_q \quad .$$

Factoring, we have

$$T.S. = k_s P_o Q_o (1 + \frac{1}{2} k_q) \quad . \qquad (C.4)$$

The <u>producers' surplus (P.S.)</u> is given by

$$P.S. = E + F - A,$$

which is equation (C.4) minus equation (C.3).

Therfore,

$$P.S. = k_s P_o Q_o (1 + \frac{1}{2} k_q) - \frac{k_q}{\eta} P_o Q_o (1 + \frac{1}{2} k_q).$$

Factoring,

$$P.S. = P_o Q_o (1 + \frac{1}{2} k_q) (k_s - \frac{k_q}{\eta}). \qquad (C.5)$$

Appendix D. The Relative Change in Price from A Shift In the Supply Schedule

Let us assume that $y = f(P)$ is the supply function, SS, in Figure D.1, and $y = h(P)$ is the demand function, DD. At point Z in Figure D.1 the equilibrium condition is $f(P) = h(P)$.

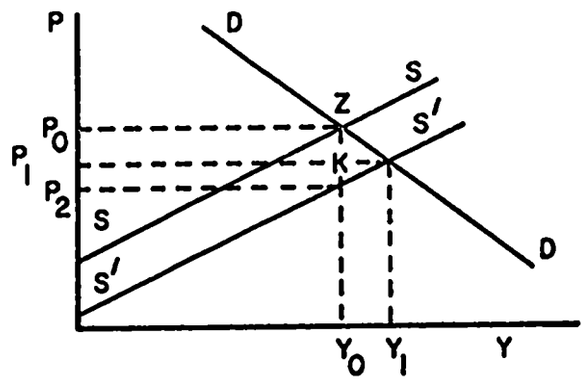

Figure D.1. Relative Change in Price Induced by a Shift in the Supply Function.

Now, assume that the supply schedule shifts down K. units per unit of output. Therefore, the price for each quantity in the new supply function is $P - K = P'$. Thus, the supply function, S'S', is $Y = f(P')$.

Therefore, given the demand function, $y = h(P)$, the new equilibrium price can be determined as a function of K from the following system:

$$f(P') = h(P) \tag{D.1}$$

$$P = P' + K \tag{D.2}$$

Totally differentiating this system we have:

$$f_p' \, dP' = h \, dP \qquad (D.3)$$

$$dP = dP' + dK \qquad (D.4)$$

where a subscript represents the first derivative, e.g.,

$$f_p' = \frac{df(P')}{dP'} \quad .$$

By substituting dP' from equation (D.4) into (D.3) we obtain:

$$f_p'(dP - dK) = h_p dP$$

or

$$(f_p' - hp)dP = f_p' \, dK \quad .$$

Therefore,

$$\frac{dP}{dK} = \frac{f_p'}{f_p' - hp} \qquad (D.5)$$

At the starting point, i.e., before any shift, we had that P' = P. Therefore,

$$f_p' = E_s \frac{Y}{P} \qquad (D.6)$$

and

$$hp = -\eta \frac{Y}{P} \quad . \qquad (D.7)$$

where E_s is the supply elasticity and η is the positive (absolute) value of the demand elasticity. Moreover, at point Z in Figure D.1, the equilibrium condition is $Y_0 = f(P) = h(P)$. Thus, since dP/dK is the change in price

due to the shift K in the supply function, it follows that:

$$\frac{dP}{dK} = \frac{E_s}{E_s + \eta} . \qquad (D.8)$$

Appendix E. Description of the Data

The selection of data series to represent the theoretical constructs of the economic as well as the econometric models frequently involves the compromise of an ideal. Data collection is usually guided by a different concept than that used in the model. Moreover, difficulties in measuring a concept, no matter how defined, often present problems.

When relying on secondary data, the best that can be done is to delineate what an optimum measurement concept would be in terms of the theoretical model, discuss the alternative measures available and contrast them to the optimum, and then indicate which data series is used in the model. This is the principle underlying this appendix.

Employment in Agriculture

Due to the seasonality of agricultural production, a measure of the labor resource that does abstract from numbers of people is more meaningful as a measure of the labor resource, and is the concept used in this thesis. Employment during the slack season is frequently much less than what it is during the peak season.

However, the data available are estimates of the agricultural labor force from the 1950, 1960, and 1970 census, together with estimates of their annual rates of increase. Therefore, to estimate the total labor input into agriculture,

the assumption that each member of the labor force worked an average of 150 days a year was made. It is difficult to say if this assumption over- or under-states the labor input, since data on agricultural employment in the aggregate and on seasonal unemployment are not available.

A final criticism of the data series is that it makes no allowance for differences in the quality of labor services rendered by members of the labor force. Children 10 years of age are treated equally with men 30 years of age, for instance. A more desirable concept of labor would be one in which the labor was standardized for differences in age, sex, training, and education.

Wage Rate

The concept of a weighted average of all types of wage rates would be the ideal to be used in this study. However it is not possible to construct such a wage index, nor was a series of wages by state or by region available. Therefore, the daily agricultural wage paid in the state of Sao Paulo was used. However, this definition is consistent with the definition of the labor resource used that was defined above, except for the limitation in its geographic coverage.

Laboresque Capital

The definition of laboresque capital should include all types of capital which are close substitutes for labor. This would include specialized machines and other forms of capital

for land preparation, planting, weed control and harvesting. However, the only form of capital that has been increasing in use and employed more widely is the tractor. Moreover, this is the only form of capital for which a data series is available.

The measurement of the flow of services, given, for example, in tractor hours used, would be an acceptable definition. However, such data were not available. Therefore, the flow of services was defined as the rate of depreciation of the stock, plus an opportunity cost.

Actual depreciation may vary according to the extent that repairs and maintenance services vary with the level of industrialization of a state. No data were available to make this kind of adjustment, however. Therefore, a flat 20 years life per tractor was assumed.

The opportunity cost under the assumption of a perfectly operating capital market should be the prevailing interest rate. However, since there exist imperfections in the capital market, especially for financing tractors, where there are government interventions, a "true" interest rate was not available. Therefore, a 10 percent rate was arbitrarily assumed.

Data on the stock of horsepower were available. This concept is an improvement over the simple stock of tractor units. It allows for some quality adjustment, while representing a more appropriate estimate of the flow of services

available.

Both concepts were used in estimating the parameters.

Rental Price of Capital

The tractor rental price (P_{K_T}) is equal to the capital cost of a tractor (P), times the interest rate (r), plus the depreciation rate (d), plus the variable costs of tractor use as a percent of capital costs [(v):P_{K_T}=P(r+d+v)]. Another alternative definition of the rental price would be the price charge per unit of time in the market.

Since no data were available on the interest rate, depreciation, variable costs, and rental price in the market, the rental price of a tractor was taken as the capital cost of a tractor[1/] times the "depreciation" rate defined above (5 percent), plus the "interest rate" defined above (10 percent), [P_{K_T}=P(r+d)].

The same criterion was used on the horsepower data, i.e., 15 percent over the horsepower cost.

Land

The variation in land quality is well recognized. Therefore, to define an index of land used should carry some quality adjustment. Classification of the land should be made,

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[1/] The basis for the capital cost was the Fordson 42 horsepower tractor for the 1950 decade, spliced to the Massey-Ferguson 50X, which has a 44.5 horsepower motor.

and class weights should be given in order to have a "true" aggregate of land.

However, when a country is taken as a whole, this is almost an impossible task, especially in Brazil, where a complete soils map for the country is not available. Therefore, the land area harvested was the only available data on land area devoted to crops.

Land Price

A rental price of land series as well as a market price has only been available in Brazil since 1966. This did produce a shortcoming in the test of the model of this thesis. In other words, it forced the use of an alternative specification of the land subfunction models in order to estimate the relative parameters.

Landesque Capital

The definition of the substitutes for land would include capital invested in land and water resource development, in organic and inorganic sources of plant nutrients, in new biologically efficient crop varieties and in chemicals to control insects and diseases. These are the whole package of substitutes for land. However, in Brazil data are not available which account for all these kinds of capital.

The alternative was to take the use of chemical fertilizers as a proxy. The series available is by plant nutrient (nitrogen, phosphorous, and potassium), and their

aggregate. Such aggregation carries the assumption of perfect substitutibility among the nutrients.

Fertilizer Price

The data series available refer to the price for Brazil per unit of nutrient. The price of the aggregate is a weighted average of these prices.

Appendix F. Data Series Used in Estimation of the Labor and Land Subfunction

Table F-1. The Data and Variables for the Regression of the Labor Subfunction, Brazil, 1950/1971.

		TRACTOR						
Year	Labor Demand[a]	Tractor[b] Stock (Cr$)	15 Percent of Tractor Stock (Cr$)	Ratio: 15% of Stock Value of Tractor over Labor Demand K_L/L	Labor[c] Wage (Cr$)	Tractor[d] Price (Cr$)	15 Percent of Tractor Price (Cr$)	Ratio: 15% of Tractor Price over Labor Wage
1950	1,543,894,800	570,843.	85,626.	1×10^{-4}	.024	39	5.85	243.75
1951	1,570,141,050	1,069,496.	160,424.	1×10^{-4}	.027	43	6.45	238.89
1952	1,596,833,400	1,518,608.	227,791.	1×10^{-4}	.034	49	7.35	216.18
1953	1,623,979,650	2,812,044.	421,807	3×10^{-4}	.037	89	13.35	360.81
1954	1,651,587,300	6,552,470.	982,871.	6×10^{-4}	.049	155	23.25	474.49
1955	1,679,664,300	10,011,100.	1,501,665.	9×10^{-4}	.060	220	33.00	550.00
1956	1,708,218,600	11,600,015.	1,740,002.	10×10^{-4}	.063	245	36.75	583.33
1957	1,737,258,300	13,879,720.	2,081,958.	12×10^{-4}	.076	268	40.20	528.95
1958	1,766,791,650	15,379,728.	2,306,959.	13×10^{-4}	.082	273	40.95	499.39
1959	1,796,827,050	36,496,848	5,474,527.	30×10^{-4}	.103	628	94.20	914.56
1960	1,824,450,000	44,494,805.	6,674,221.	37×10^{-4}	.110	655	98.25	893.18
1961	1,837,221,150	55,146,360	8,271,954.	45×10^{-4}	.171	760	114.00	666.67
1962	1,850,081,700	115,258,874.	17,288,831.	9×10^{-3}	.254	1,478	221.70	872.83
1963	1,863,032,250	261,138,903.	39,170,835.	21×10^{-3}	.398	3,080	462.00	1,160.80
1964	1,876,073,550	612,269,021.	91,840,353.	49×10^{-3}	.814	6,519	977.85	1,201.29
1965	1,889,206,050	933,127,529.	139,869,129.	74×10^{-3}	1.547	9,555	1,433.25	926.47
1966	1,902,430,500	1,129,550,360	169,432,554.	89×10^{-3}	2.071	11,061	1,659.15	801.13
1967	1,915,747,500	1,432,838,691.	214,927,304.	112×10^{-3}	2.538	13,735	2,060.25	811.76
1968	1,929,157,650	1,828,819,572	274,322,936.	142×10^{-3}	3.700	16,724	2,508.60	678.00
1969	1,942,661,850	2,255,038,954.	338,255,843.	174×10^{-3}	4.081	19,785	2,967.75	727.21
1970	1,960,707,750	2,384,625,908	357,693,886.	182×10^{-3}	5.511	19,436	2,915.40	529.01
1971	1,974,432,750	2,939,637,656.	440,945,698	223×10^{-3}	7.071	21,223	3,183.45	450.21

Table F-1. Continued.

	HORSEPOWER				
Year	Horsepower[g/] Stock (No.)	Ratio: Horsepower over Labor Demand K_L/L	Horsepower[f/] Price (Cr$)	5 Percent of Horsepower Price (Cr$)	Ratio: 15% of Horsepower Price over Labor Price
1950					
1951					
1952					
1953					
1954					
1955					
1956					
1957					
1958					
1959					
1960					
1961					
1962	3,059,494.	17×10^{-4}	40.60	2.03	7.99
1963	3,457,841.	19×10^{-4}	73.50	3.68	9.25
1964	4,005,622.	21×10^{-9}	118.90	5.95	7.31
1965	4,269,731.	23×10^{-4}	173.20	8.66	5.60
1966	4,602,022.	24×10^{-4}	196.30	9.82	4.74
1967	4,765,206.	25×10^{-4}	252.80	12.64	4.98
1968	5,185,431.	27×10^{-4}	364.80	18.24	4.93
1969	5,570,962.	29×10^{-4}	343.60	17.18	4.21
1970	6,187,680.	32×10^{-4}	358.00	17.90	3.25
1971	7,239,373.	37×10^{-4}	402.50	20.13	2.85

Table F-1. Continued.

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a/ Labor was evaluated in the following way: Given the labor force it was assumed that each worker was employed 150 days a year.

b/ The tractor stock was based upon the estimate of tractors, excluding micro-tractors, with the 1950 census as the base of the estimate. Then a declining balance (a five percent rate) method of treating depreciation and the import and domestic sales data were used to obtain an estimate of the tractor stock excluding micro-tractors. See Sanders (Table A-1) for further detail.

c/ The labor wage was the Sao Paulo daily worker paid in cash.

d/ This is the purchase price of the "Fordson" 42 horsepower tractor in the period 1950/1961. From 1962/1971 it is the purchase price of the "Massey-Ferguson 50X", which has a 44.5 horsepower motor.

e/ The average horsepower of the Sao Paulo tractor stock was used to estimate the average horsepower of the total Brazilian stock (in the 1960 census Sao Paulo had 44.3 percent of the tractors in the country).

f/ The horsepower price was obtained by taking the median purchase price of one representative factory and dividing it by the weighted (by sales) horsepower of their basic model. See Sanders (Tables A-5 and C-9).

Source: Sanders, John H. "Mechanization and Employment in Brasilian Agriculture, 1950-1971. Unpublished Ph.D. Thesis, University of Minnesota, 1973.

Fundacao Getulio Vargas - 1950, 1960 and 1970 Census.

Table F-2. The Data and Variables for the Regression of the Land Subfunction, Brazil, 1950/1970.

Year	Crop Area (1000 ha)	Fertilizer Consumption (metric tons of nutrients)				Fertilizer per Crop Area (Kg/ha) (K_T/T)				Deflated Fertilizer Price[b/] (Cr$/metric ton)($P_T$)			
		Nitrogen	Phosphorus	Potassium	All Nutrients	Nitrogen	Phosphorus	Potassium	All Nutrients	Nitrogen	Phosphorus	Potassium	All Nutrients
1950	19,100	14,200	50,800	23,500	88,500	.743	2.659	1.230	4.632	333.60	233.24	364.44	234.47
1951	19,213[a/]	18,600	73,600	28,700	120,900	.968	3.831	1.494	6.293	350.61	225.39	313.04	288.48
1952	19,382[a/]	10,600	46,900	15,300	72,800	.547	2.420	.789	3.756	291.39	179.62	258.21	212.18
1953	19,665	20,600	64,800	31,200	116,600	1.043	3.235	1.587	5.329	312.54	175.31	293.01	231.48
1954	20,944	17,800	77,400	28,300	123,500	.850	3.696	1.351	5.897	359.57	207.75	335.60	251.30
1955	21,877	22,900	88,600	49,500	161,000	1.047	4.050	2.263	7.359	323.37	191.39	316.77	248.79
1956	22,792	30,200	93,500	41,500	165,300	1.325	4.102	1.825	7.253	259.35	176.58	253.83	211.34
1957	23,303	28,600	118,700	60,200	207,500	1.227	5.094	2.583	8.904	270.77	169.23	232.09	201.63
1958	23,702	41,400	143,300	65,000	249,700	1.747	6.046	2.742	10.535	349.74	187.66	217.52	222.21
1959	24,773	44,800	124,000	57,400	226,200	1.808	5.005	.317	9.131	250.36	142.18	253.45	191.94
1960	26,370	64,700	127,700	106,300	298,700	2.454	4.843	4.031	11,327	328.77	287.97	388.76	332.61
1961	27,329	56,800	118,400	71,900	247,100	2.078	4.332	2.631	9.042	449.04	397.51	531.16	365.69
1962	28,506	50,900	117,500	68,400	236,800	1.786	4.122	2.399	8.307	527.51	369.72	587.90	466.47
1963	29,842	65,200	156,800	92,100	314,000	2.185	5.254	3.086	10.522	351.43	271.86	384.58	321.52
1964	30,773	50,800	135,100	49,600	255,400	1.651	4.390	2.262	8.299	455.17	274.49	472.55	364.52
1965	32,609	70,600	120,100	99,700	290,400	2.165	3.683	3.057	8,906	461.60	258.41	472.64	381.36
1966	31,450	71,100	116,600	93,300	281,100	2.261	3.707	2.967	8.938	301.87	195.46	290.69	254.32
1967	32,753	103,400	204,600	136,900	444,900	3.157	6.247	4.180	13.583	211.19	161.50	186.35	180.69
1968	33,564	144,300	273,100	184,300	601,700	4.299	8.137	5.491	17,927	193.00	155.00	193.00	175.75
1969	34,579	164,400	265,700	200,300	630,400	4.754	4.732	5.793	18.231	180.20	149.54	196.07	172.32
1970	35,892	275,900	415,900	306,700	938,500	7.687	11,588	8.545	27,820	161.65	139.91	184.04	161.01

Source: Appendix E of Nelson, William Charles, "An Economic Analysis of Fertilizer Utilization in Brazil. Unpublished Ph.D. Thesis, The Ohio State University, 1971, and Fundacao Getulio Vargas, Anuario Estatistico, various issues.

VITA

VITA

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