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9. ABSTRACT

The fifth section of the collection of papers from the Airlie House conference of 1975 examines the role of economic and social factors in allocating resources for agricultural research. The first paper (by Martin E. Abel and Delane E. Welsch) outlines a theoretical model for exploring the relative effects of environmental constraints and commodity mix on research resource allocation. The second paper (by John W. Mellor) is devoted to an empirical evaluation of the effects of efforts to relate research resource allocation to alternative goals such as labor absorption. In a third paper (by J.P. Ramalho de Castro and G. Edward Schuh) the use of an economic model to establish research priorities, based on data from Brazil, is illustrated. The role of research endowments and relative prices in inducing the choice of alternative paths of technical change—that is, labor saving versus land saving—is documented (by Hans P. Binswanger). The final paper (by Alain de Janvry) presents a theoretical model of dialectical interaction between technical and institutional change in agriculture which suggests important directions for future research.

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Resource Allocation and Productivity in National and International Agricultural Research

Thomas M. Arndt
Dana G. Dalrymple
and
Vernon W. Ruttan
Editors

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Preface

Within the last decade significant steps have been taken to narrow the agricultural technology gap among countries. New international agricultural research centers have been established, and a number of developing countries have made substantial progress in strengthening their national agricultural research capacities. It is estimated that world expenditures on agricultural research (in constant 1971 U.S. dollars) have risen from approximately $1.3 billion in 1959 to $3.8 billion in 1974. In the less developed countries of Latin America, Africa, and Asia, the estimated increase in research expenditures for the same period was from $141 million to $957 million.

The creation of two international agricultural research institutes in the early 1960s was an important factor in this surge of research investment. The establishment of the International Rice Research Institute (IRRI) in the Philippines in 1960 and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in 1966 signaled a wider contemporary refocusing on research as an essential instrument of agricultural productivity change in the less developed countries (LDC's).

The ensuing story is well known. CIMMYT and IRRI developed short-strawed, fertilizer-responsive, high-yielding wheat and rice varieties which were rapidly adapted and adopted in parts of Asia, Africa, and Latin America and which produced an upsurge in grain production popularly known as the "green revolution." By 1975, nine international research institutes and two other international programs were either in operation or in the process of being established in the LDC's (see Table 11-1).

The view that effective research capacity in developing countries is a primary means to raising agricultural productivity is now widely shared. The World Bank, the United States Agency for International Development (USAID), and other donors have begun to give agricultural research a higher priority for assistance. Investment in agricultural research in developing countries has grown rapidly in recent years. As the agricultural research system has continued to expand, research productivity and research resource allocation have become important issues for development planners and science managers.

In order to examine these issues, an international conference was held at Airlie House, Virginia, in January 1975. The conference had two main objectives: to examine recent evidence on the returns to investment in national and international agricultural research systems; and to explore the relevance of social and economic factors for the organization and management of national and international research systems. Technical issues related to the measurement of research productivity, the planning of research programs, and the management of research systems were also discussed.

The conference drew together over fifty natural scientists, social scientists, and administrators from national and international research agencies, some of whom wore more than one hat. The format of the conference was somewhat unusual. Individual papers were not read but rather circulated before the meeting and orally summarized at the conference by preselected discussants, several of whose commentaries proved so stimulating and original that they are included in this volume (chapters 26 and 27). Most of the conference, therefore, was devoted to what turned out to be a rich and vigorous discussion.

Following the conference, contributors were asked to review and revise their papers in the light of the discussions. The revised papers were then edited and returned to the authors for their further review, a painstaking process which was completed in November 1975. As they appear in this book, the twenty-eight papers have been organized into six sections. They are preceded by an introduction (by Thomas M. Arndt and Vernon W. Ruttan) which highlights the main issues discussed at the conference.

The first section of this book is devoted to a series of studies of the *productivity of national research systems* in both developed and less developed countries. There are two papers on the organization and productivity of research systems in developed countries: the first (by Yujiro Hayami and Masakatsu Akino) describes the national-prefectural system in Japan; the second (by Willis L. Peterson and Joseph C. Fitzharris) discusses the federal-state system in the United States. There are also two papers on returns to investment in agricultural research in developing countries, one drawing upon Colombian experience (by Reed Hertford, Jorge Ardila, Andrés Rocha, and Carlos Trujillo) and one focusing upon India (by A. S. Kahlon, P. N. Saxena, H. K. Bal, and Dayanath Jha). The final paper in this section (by Reed Hertford and

Andrew Schmitz), prepared after the conference, reviews some of the theoretical foundations of, and empirical considerations involved in, the evaluation of returns to research.

The second section includes three papers on the *productivity of international research systems*. The first paper (by Dana G. Dalrymple) documents the impact of the CIMMYT and IRRI varietal development programs on wheat and rice production in Asia. A second paper (by Robert E. Evenson) reviews the history of cycles in research productivity and in international diffusion patterns for three commodities: sugarcane, wheat, and rice. A third paper (also by Evenson) presents measures of the rates of return to the resources invested in research at IRRI and CIMMYT. In a fourth paper (by Yoav Kislev) an attempt is made to develop a theoretical model of applied research consistent with the historical experience reviewed in the earlier papers in the first two sections.

The third section is devoted to the *organization and development of the international agricultural research institute system*. The first chapter (by J. G. Crawford) traces the development of a system for organizing, funding, and managing the new institutes, spearheaded by the Ford and Rockefeller foundations and now guided by the Consultative Group on International Agricultural Research. The programs that have been developed to achieve closer articulation of the research programs of the international and national systems are outlined by the director of IRRI (Nyle C. Brady) and the director of CIMMYT (Haldore Hanson). The problem of establishing effective working relationships between the international and national agricultural research systems is then reviewed (by Sterling Wortman). The final paper in this section (by Burton E. Swanson) presents a comparison of the impact of the IRRI and CIMMYT training programs on the career patterns and effectiveness of young scientists who have studied at these two institutes.

The fourth section is devoted to issues bearing directly on the *organization and management of agricultural research systems*. The first paper (by Albert H. Moseman) outlines the evolution of coordinated national research projects for improving food crop production. Two papers focus on the problem of reorganizing and reforming national research systems: in the United Kingdom (by Tilo L. V. Ulbricht) and in Brazil (by José Pastore and Eliseu R. A. Alves). Next, the contribution of private sector international agricultural research is described (by S. M. Sehgal), based on the experience of Pioneer Hi-Bred International. A systems approach to research resource allocation is then outlined and evaluated (by Per Pinstrup-Andersen and David Franklin). The final chapter in this section (by C. Richard Shumway) presents a review and evaluation of the literature on formal models and methods for allocating resources in research.

The fifth section examines the role of *economic and social factors in re-*

search resource allocations. The first paper (by Martin E. Abel and Delane E. Welsch) outlines a theoretical model for exploring the relative effects of environmental constraints and commodity mix on research resource allocation. The second paper (by John W. Mellor) is devoted to an empirical evaluation of the effects of efforts to relate research resource allocation to alternative goals such as labor absorption. In a third paper (by J. P. Ramalho de Castro and G. Edward Schuh) the use of an economic model to establish research priorities, based on Brazilian data, is illustrated. The role of resource endowments and relative prices in inducing the choice of alternative paths of technical change — that is, labor saving versus land saving — is documented (by Hans P. Binswanger). The final paper in this section (by Alain de Janvry) presents a theoretical model of dialectical interaction between technical and institutional change in agriculture which suggests important directions for future research.

The final section is devoted to discussion of the research strategy and management issues that will affect *the future of the international research system* and the productivity of national research systems. The first paper (by A. T. Mosher) is devoted to a discussion of unresolved issues in the evaluation of the international system. A second essay (by Theodore W. Schultz) focuses on the role of economic policy in influencing the prospects for gains from agricultural research. In the final paper (by J. G. Crawford) the policies and problems facing the Consultative Group on International Agricultural Research and its Technical Advisory Committee in their efforts to strengthen national and international research are reviewed.

The papers included in this volume cannot, of course, reflect fully the excitement and challenge of the Airlie House conference. Particularly significant contributions to the discussions were made also by Richard Baldwin of Cargill Inc.; Joel Bernstein of the U.S. Agency for International Development; John K. Coulter of the Consultative Group on International Agricultural Research; George Darnell, James M. Francen, Raj Krishna, and Montague Yudelman of the World Bank; M. McDonald Dey of the National Academy of Sciences, Walter L. Fishel of the U.S. Department of Agriculture; Lowell S. Hardin of the Ford Foundation; W. David Hopper of the International Development Research Centre, Richard Nelson of Yale University; Peter Oram of the Food and Agriculture Organization of the United Nations; S. J. Webster of the Ministry of Overseas Development of the United Kingdom; A. M. Weisblat of the Agricultural Development Council, Inc.; and F. R. Wittnebert of the Parker Pen Co.

The Airlie House conference was given considerable impetus and background by the materials presented and discussed at an earlier symposium on Resource Allocation in Agricultural Research held at the University of Minne-

sota in February 1969. The results of the Minnesota conference, which focused on many of the same issues considered at Airlie House but from a domestic (United States) viewpoint, were published in a book edited by Walter L. Fishel and entitled *Resource Allocation in Agricultural Research* (Minneapolis: University of Minnesota Press, 1971).

Both the Minnesota and Airlie House conferences were oriented to formal research carried out at nonprofit institutions and supported primarily with public or philanthropic funds and, to a lesser extent, to research conducted by private firms. It is recognized, however, that significant technical improvements may also result from informal research by farmers themselves or by small, local firms. Simple selection of improved varieties of seeds has traditionally been an important source of varietal development and yield increase. In the field of mechanical technology, simple but effective mechanical devices invented by farmers or mechanics, such as small irrigation and cultivation equipment, continue to provide many of the models for equipment engineered, manufactured, and marketed by larger firms. The work of both national and international research programs in many cases builds on this indigenous technology. Thus while little is said about informal research in this volume, its potential importance should not go unrecognized.

The structure of public agricultural research differs somewhat between the developed and the less developed nations. In the developed countries, research is conducted both by ministries (or departments) of agriculture and by colleges and universities. In the developing nations, research has traditionally been much more strongly concentrated in specialized arms of the ministries of agriculture or in autonomous, commodity-oriented research institutes. Colleges of agriculture in developing countries have usually concentrated on teaching, although in some cases they have done significant research (the popular rice variety C4-63, for instance, was developed by the College of Agriculture at the University of the Philippines) and may well play a larger role in the future. A paper on "Articulation of the International System with Other Regional Organizations: Ministry and University," by Jose Drilon was originally scheduled for the conference, but unfortunately Dr. Drilon, for reasons beyond his control, was unable to prepare the paper or to participate in the discussions.

We would also like to emphasize that, while this volume focuses on the importance of improved technology in the process of agricultural development, we are quite aware that it is not the only factor. A host of other forces – social, institutional, economic, and technical – both influence the adoption of technology and set the stage for the complex of other changes which must take place in the process of agricultural and economic development. Although improved technology may be the key factor in some societies, in others it may

not. Improved technology alone is clearly not tantamount to agricultural development. But if the proper forms of technology can be efficiently generated through research, the development process can often be facilitated. It is our hope that this volume will contribute to a better understanding of the role of research in the process of technical change and of the role of technical change in agricultural development.

The conduct of the Airlie House conference and the preparation of this volume have been possible only through the help of many individuals and several institutions. The conference planning committee consisted of Robert E. Evenson, Walter L. Fishel, and Vernon W. Ruttan. The conference was sponsored by the Agricultural Development Council under its Research and Training Network Program, a program which, in turn, is funded under a contract with the United States Agency for International Development. Additional support for international participation in the conference was provided by the World Bank.

Turning a set of conference papers by an international cast into a book is, as we learned, far from a quick or simple job. Our task was facilitated by the cooperation and forbearance of the individual authors, most of whom found their carefully revised papers further edited and trimmed. Virginia O. Locke played a key role in the copy editing; her professional skills and contributions were of great assistance. We would also like to express our appreciation to Willis L. Peterson for his review of technical portions of the final page proofs and to Raymond D. Vlasin for his very helpful review and evaluation of a preliminary draft of the conference proceedings manuscript.

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Environmental Constraints, Commodity Mix, and Research Resource Allocation[1]

Martin E. Abel and Delane E. Welsch

The purpose of this chapter is to show how the allocation of research resources among commodities and the effects of such allocations on the output mix depend upon (a) the initial production conditions, (b) the nature of the research production functions, (c) the nature of the demand relations for the commodity outputs, (d) relative factor endowments, and (e) the existence of different types of environmental constraints. The basic model used is a two-factor, two-product model in which certain kinds of technical change are introduced. This model is presented and discussed in the next section. The third section deals with the effects of technical change and of demands for the outputs on the product mix. The role of factor endowments is the topic of the fourth section, which is followed by a discussion of the effect of certain types of environmental constraints on the allocation of research resources and the output mix. The policy implications of the analysis are discussed in the fifth part of the chapter.

The Basic Model

To analyze certain questions concerning the benefits to be derived from the diversification of agricultural production, we need a theoretical model which will enable us to trace through changes in production functions, factor endowments, and relative product prices on output, income, and factor rewards.

A simple, but useful model for looking at the influence of technical change on the output mix is the standard two-factor, two-product model of production.

Let us start by assuming that a region (either an area within a country or a country trading in a larger, world market) produces two goods, q_1 and q_2, with two homogeneous factors of production, L and K, where L is the labor input and K is the land (capital) input. Total factor supplies are assumed to be fixed.

Production of our two goods is given by the Cobb-Douglas production functions

$$q_1 = \tau_1 L_1^{\alpha} K_1^{1-\alpha} = \tau_1 L_1 \left[\frac{K_1}{L_1}\right]^{1-\alpha} \tag{1a}$$

$$q_2 = \tau_2 L_2^{\beta} K_2^{1-\beta} = \tau_2 L_2 \left[\frac{K_2}{L_2}\right]^{1-\beta} \tag{1b}$$

which reflect constant returns to scale. τ_1 and τ_2 are indices of technology. In addition, the fixed supplies of labor and land (capital) are represented by

$$L_1 + L_2 = \bar{L} \tag{2a}$$

$$L_1 \left[\frac{K_1}{L_1}\right] + L_2 \left[\frac{K_2}{L_2}\right] = \bar{K}. \tag{2b}$$

Furthermore, we assume that the factors of production are fully employed.

We can derive the expression for the slope of the production possibility curve, which is

$$-\frac{d\left[\frac{q_1}{\bar{L}}\right]}{d\left[\frac{q_2}{\bar{L}}\right]} = \frac{\tau_1}{\tau_2}(bR)^{1-\alpha}(aR)^{\beta-1}[a+(b-a)\varrho]^{\alpha-\beta}\left[\frac{a+\alpha\varrho(b-a)}{a+(b-a)(1-\beta+\beta\varrho)}\right] \tag{3}$$

where,

$$R = \left[\varrho\left[\frac{K_1}{L_1}\right] + (1-\varrho)\left[\frac{K_2}{L_2}\right]\right] = \frac{\bar{K}}{\bar{L}}$$

$$\varrho = \frac{L_1}{\bar{L}}$$

$$a = \frac{\alpha}{1-\alpha}$$

$$b = \frac{\beta}{1-\beta}.$$

The reader is referred to Johnson and to Abel, Welsch, and Jolly for detailed derivations of the production possibility curve and methods for solving for the outputs q_1 and q_2, given the product prices.[2]

We can consider two possibilities with respect to the influence on product prices of changes in the output levels of our producing region. One is a competitive environment in which both product prices, p_1 and p_2, are given to the region and do not vary with changes in q_1 and q_2. The other is where changes in either q_1 or q_2 influence the levels of market prices. In the first case, the region will face straight line iso-revenue curves. In the second case the iso-revenue curves will be convex to the origin over the relevant range of output. A fuller discussion of the price (revenue) side of the model is contained in Abel, Welsch, and Jolly.[3]

Our model assumes Cobb-Douglas production functions to be relevant throughout the full range of production – from complete specialization in q_1 to complete specialization in q_2. We would like to make two points about this assumption. First, there is no need to suppose that the agricultural production world is fully represented by Cobb-Douglas functions. Other forms of production functions, such as quadratic or CES production functions, may be more appropriate in some circumstances. Second, there is no reason to expect a particular form of production function to hold over the full range of possible factor substitution. At best, any given form may be a good approximation over a given (and sometimes small) range of resource substitution between the two production functions. At the extreme ranges of substitution between q_1 and q_2 the production possibility curve might exhibit either a complementary or a supplementary relationship in the production of q_1 and q_2.

The model presented above has some interesting properties. Most important is that the production possibility curve will have little curvature for a wide range in values of the production elasticities α and β. (This result will hold over the range in output variation for which the Cobb-Douglas production functions are good approximations of the real world.) This has been clearly demonstrated by Johnson and can be easily verified by evaluating equation (3) for alternative values of α, β, and ℓ.[4] From this result, it follows that the sensitivity of the output mix of q_1 and q_2 depends very much on whether the producing region operates as a price-taker or whether changes in the outputs of the region influence product prices. This is illustrated in Figure 22-1. One can easily see how slight variations in the product price ratio, P, would cause large changes in the output mix along the production possibility curve $f(q_1^0, q_2^0) = 0$.

On the other hand, when our region faces downward-sloping demand curves for one or both products, a high degree of stability in output mix is as-

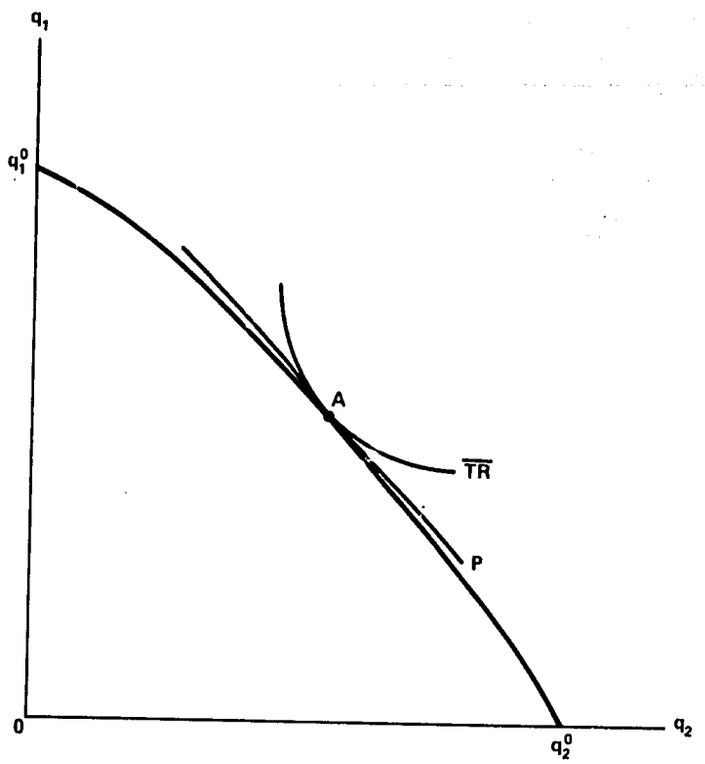

Figure 22-1. Equilibrium in production with either fixed relative prices or downward sloping demand curves.

sured. Exogenous shifts in the demand curves for the two products of our region will result in a rotation of the conic section represented by the iso-revenue line $\overline{TR}$ in Figure 22-1. The less the curvature of the iso-revenue lines, the greater will be the effect of exogenous shifts in the demand curves on changes in the output mix. In other words, as the price elasticities of demand approach infinity, the situation we assume to prevail under a competitive framework, the curvature of our iso-revenue line approaches a straight line, and the effect of a given rotation of the iso-revenue line on changes in the output mix increases.

Technological Change

We now wish to examine the consequences of certain types of technological change in the context of our two-commodity, two-factor world. National re-

search leaders are faced with the question of the allocation of research resources among commodities. Even if research administrators follow the Hayami-Ruttan prescription of generating technological change of a type which is consistent with relative factor endowments and (undistorted) relative factor prices, they are still faced with the question of how best to allocate research resources among commodities.[5] As we shall see, the decision on how research resources are allocated depends not only on characteristics of the research production functions, but also on the nature of the demands for the final products. Three alternative situations are analyzed.

Situation I

This situation is presented graphically in Figure 22-2. The following assumptions are employed.

1. The initial production possibility curve, $f(q_1^0, q_2^0) = 0$, is a straight line which implies $\alpha = \beta$.

2. If q_1 and q_2 are measured in terms of the same physical units, complete specialization in q_1 results in greater output than does complete specialization in q_2.

3. Our producing region can face either fixed prices or downward-sloping demand curves for its outputs.

4. There is a fixed research budget which can be allocated between generating changes in τ_1 or τ_2. Thus, we are concerned with determining the optimum allocation of research resources subject to a research budget constraint.

5. The research production functions for τ_1 and τ_2 exhibit constant returns to scale. For simplicity, we assume the research production functions are of such a nature as to make $q_1^0 q_1^1 = q_2^0 q_2^1$. The latter assumption implies that the two research production functions yield identical absolute increases in production for equal research expenditures on τ_1 and τ_2. The analysis can be modified in appropriate ways for alternative assumptions about $q_1^0 q_1^1$ and $q_2^0 q_2^1$; e.g., a given budget increases efficiency in equal proportions for q_1 and q_2.

The implications of our assumptions are:

1. Allocation of all research resources to increasing τ_1 results in a new production possibility curve $f(q_1^1, q_2^0) = 0$. Similarly, allocation of all research resources to increasing τ_2 results in a new production possibility curve $f(q_1^0, q_2^1) = 0$. Under the assumption of constant returns to scale in the research production function, linear combinations of research expenditures trace out an innovation possibility frontier which is convex to the origin. The innovation possibility frontier represents the highest output combinations attainable from alternative allocations of a fixed research budget. We can illustrate this result in the following way. Assume that research resources are equally divid-

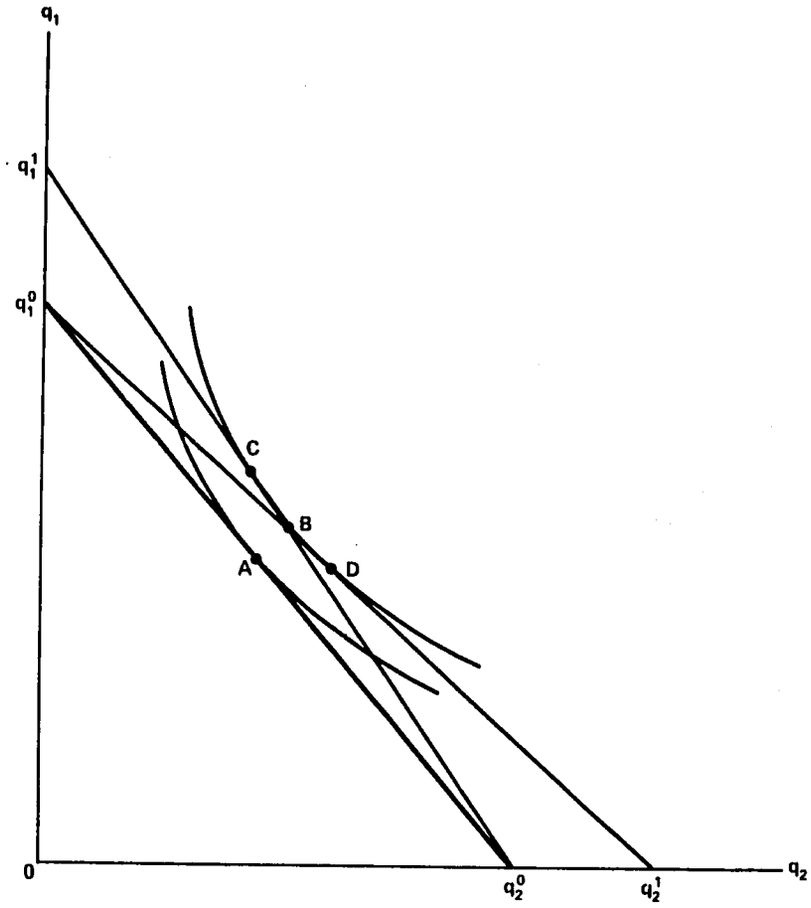

Figure 22-2. Technological change and the output mix with constant returns in research – linear production possibility curves.

ed between increasing τ_1 and τ_2. We get a new production possibility curve such as $f(q_1{}^2, q_2{}^2) = 0$. The line segment CD represents higher levels of output than are attainable from either $f(q_1{}^1, q_2{}^0) = 0$ or $f(q_1{}^0, q_2{}^1) = 0$. If one rotates line $f(q_1{}^2, q_2{}^2) = 0$ to reflect alternative combinations of research resources one can see that this traces out an innovation possibility frontier which is slightly convex to the origin.

2. If the producing region faces fixed prices, it pays to specialize completely in research, and there will be complete specialization in production of either q_1 or q_2. If product prices are such that their initial result is complete special-

ization in q_1 at level $0q_1^0$, our producing region would benefit most from investing all research resources in increasing output of q_1; i.e., generating the new production possibility curve $f(q_1^1, q_2^0) = 0$. The reader can verify that even with a range in relative prices which would result in production of either $0q_1^1$ or $0q_2^1$, total output would be greater at $0q_1^1$ and, therefore, increasing τ_1 is superior to increasing τ_2. If prices are given but result initially in specialized production of $0q_2^0$, then the converse of the situation above holds with respect to technical change. (This would not necessarily hold if $f(q_1^0, q_1^1) = 0$ were sufficiently different from $f(q_2^0, q_2^1) = 0$.)

3. If the region faces downward-sloping demand curves, not only will the region produce a combination of q_1 and q_2, but also the highest level of production is obtainable from allocating research resources to increasing both τ_1 and τ_2. In Figure 22-2 we show that, given the iso-revenue line, the highest level of output is achieved at B, which is on the new production possibility curve $f(q_1^2, q_2^2) = 0$. Furthermore, the more price inelastic the demand curves, the more convex to the origin will be the iso-revenue curves and the smaller will be the effect of technical change on the changes in the output mix.

Situation II

In this case we modify situation I by assuming that decreasing returns to scale prevail in the research production functions. This is probably the most realistic assumption about returns to scale in research. Decreasing returns could arise in two possible ways. First, the static research production functions could exhibit decreasing returns to scale because the stock of "basic" knowledge from which the research activities draw is fixed at any point in time. We assume that our research activities are not directed toward expanding the supply of "basic" knowledge. Second, if one views research as a probabilistic search process, decreasing returns in the research production functions are likely to prevail.[6]

All the remaining assumptions in situation I hold in situation II. The results are illustrated in Figure 22-3.

The implications of our assumptions are:

1. Allocating all research resources to increasing τ_1 results in the new production possibility curve $f(q_1^1, q_2^0) = 0$. Similarly, allocating all research resources to increasing τ_2 gives us $f(q_1^0, q_2^1) = 0$. Linear combinations of research resources on τ_1 and τ_2 will trace out an innovation possibility frontier which is convex to the origin, but less convex than in the case of situation I. We can illustrate this in the following way. Because of decreasing returns in both our research production functions, $q_1^0 q_1^2 > 1/2\, q_1^0 q_1^1$ and $q_2^0 q_2^2 > 1/2 q_2^0 q_2^1$. The line segment BC in Figure 22-3 is relatively longer than CD in

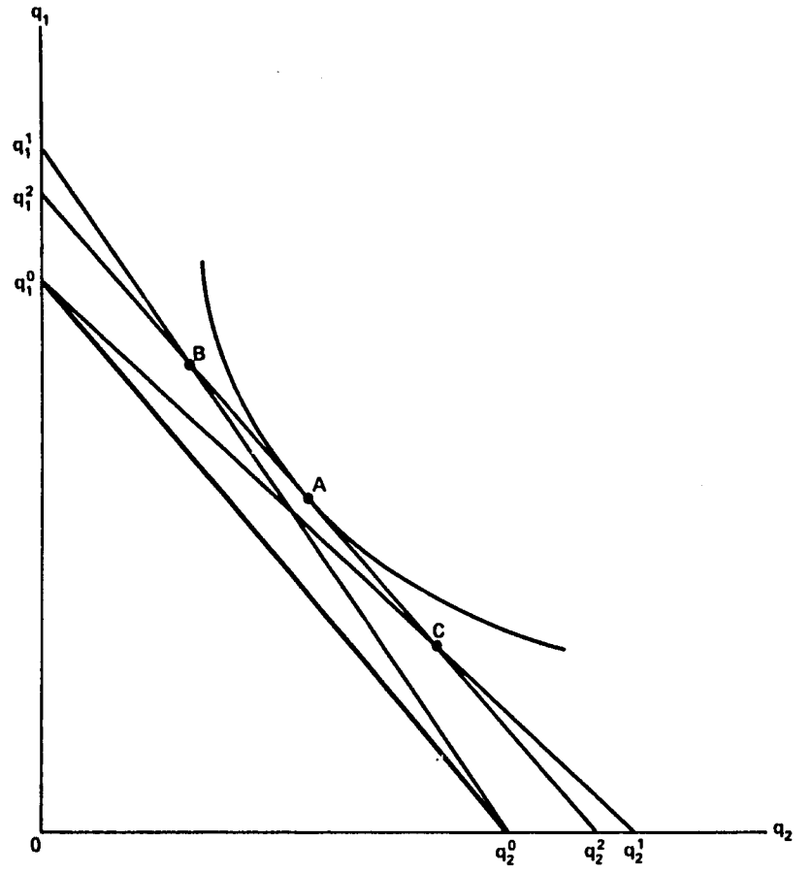

Figure 22-3. Technological change and the output mix with decreasing returns in research – linear production possibility curves.

Figure 22-2. If one rotates line $f(q_1{}^2, q_2{}^2) = 0$ to reflect alternative combinations of research resources, keeping in mind that decreasing returns to scale in the research production functions result in successively smaller increments in τ_1 or τ_2 for successive absolute increases in research resources of a given size, one can see that this traces out an innovation possibility frontier which is convex, but less so than in Figure 22-2.

2. If the producing region faces fixed prices, it pays to specialize completely in research, and there will be complete specialization in production of either q_1 or q_2. This result is the same as that obtained in situation I.

3. If the region faces downward-sloping demand curves for its products,

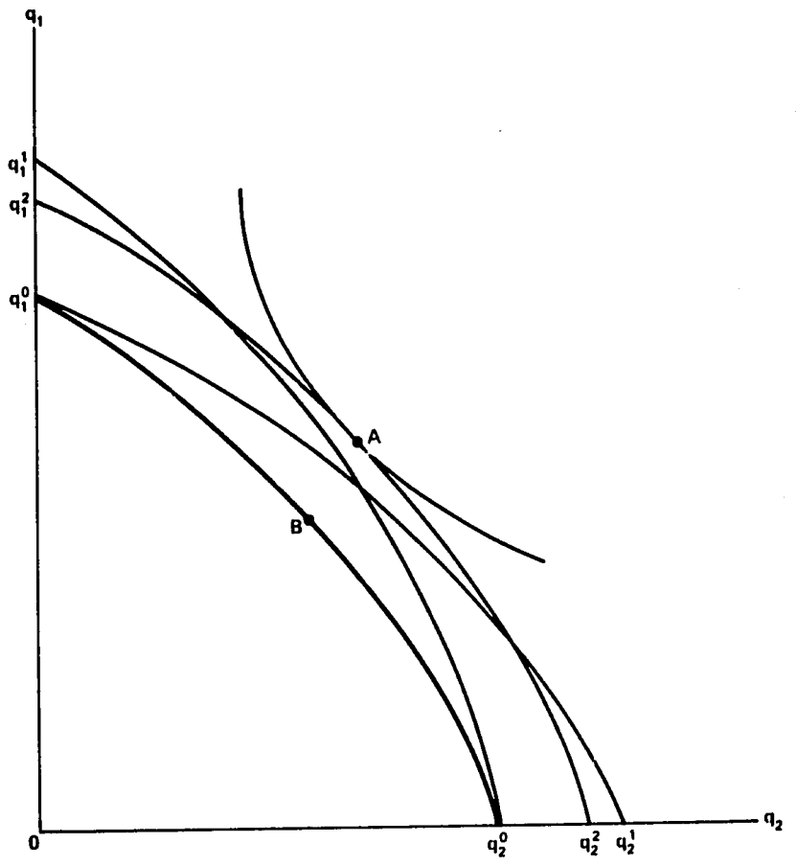

Figure 22-4. Technological change and the output mix with decreasing returns in research – concave production possibility curves.

not only will the region produce a combination of q_1 and q_2, but also the highest level of production is obtainable from allocating research resources to increasing both τ_1 and τ_2. In Figure 22-3 we show that, given the iso-revenue line, the highest level of output is achieved at A, which is on the new production possibility curve $f(q_1{}^2, q_2{}^2) = 0$.

Situation III

In this case we make the same assumptions as in situation II except that we now assume the initial production possibility curve, $f(q_1{}^0, q_2{}^0) = 0$, is concave to the origin. The results of these assumptions are shown in Figure 22-4.

The implications of our assumptions in this situation are as follows:

1. With given prices, the region would completely specialize in the production of q_1 or q_2 only if the terms of trade were sufficiently in favor of one output or the other. Otherwise the region would produce some combination of q_1 and q_2. The more concave the production possibility curve, the more likely it is that there would not be complete specialization in production.

2. Alternative combinations of research resources for increasing τ_1 and τ_2 will trace out an innovation possibility frontier which is concave to the origin. This can be shown by the same procedure suggested in situation II. As in the previous case, the production possibility curve $f(q_1{}^2, q_2{}^2) = 0$ is the one which results from allocating one-half of available research resources to each commodity.

3. In this situation, it might pay to allocate research resources to increasing both τ_1 and τ_2, regardless of whether the region faced fixed product prices or downward-sloping demand curves. This can be seen in Figure 22-4. Assume that relative prices are such that the price line for fixed prices would be tangent to $f(q_1{}^2, q_2{}^2) = 0$ at A. Also assume that the iso-revenue line resulting from downward-sloping demand curves is also tangent to $f(q_1{}^2, q_2{}^2) = 0$ at A. In either case, the highest attainable level of production results from an allocation of research resources to both τ_1 and τ_2 which generates the new production possibility curve $f(q_1{}^2, q_2{}^2) = 0$.

Situation IV

One might also wish to consider the case where the research production functions exhibit increasing returns to scale.[7] Increasing returns may prevail if the research production functions are S-shaped and the fixed research budget is small enough to restrict research activities to the increasing returns portion of the research production function. If the initial production possibility curve is a straight line, as in Figures 22-2 and 22-3, the new innovation possibility frontier representing alternative combinations of research expenditures on q_1 and q_2 will be convex to the origin. If, on the other hand, the initial production possibility curve is concave, the new innovation possibility frontier could be less concave, a straight line, or convex, depending on the degree of increasing returns in the research production function. Increasing returns to research will result in complete specialization in research activity so long as the new innovation possibility frontier is convex. This will be so whether or not the region faces given prices or downward-sloping demand curves for its products.

Resource Endowments and Environmental Constraints

We can also use our model to illustrate how different resource endowments affect both the output mix and the allocation of research resources. Let us

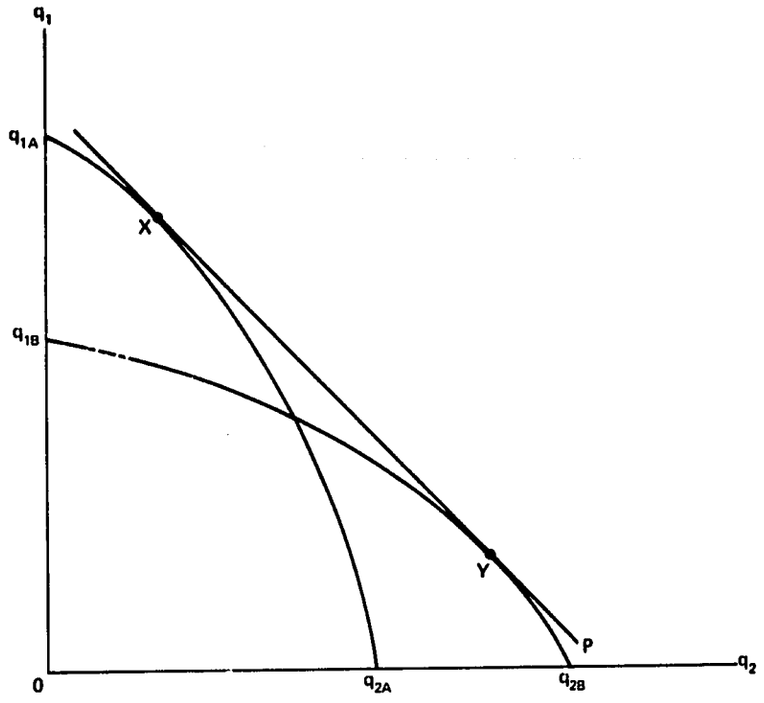

Figure 22-5. Relative factor endowments and the allocation of research among products.

assume that (a) there are two regions, A and B, producing the same two outputs q_1 and q_2; (b) the production function for each output is the same in both regions; (c) the production of q_1 is more intensive in the use of land (capital) relative to labor than the production of q_2; and (d) one region, A, has relatively more land than labor compared with the other region, B.

The initial situation is illustrated in Figure 22-5. The production possibility curve for region A is $f(q_{1A}, q_{2A}) = 0$ and that for region B is $f(q_{1B}, q_{2B}) = 0$. Since the production of q_1 is relatively more land (capital) intensive than the production of q_2 we would expect region A to favor the production of q_1. With both regions facing the same fixed relative prices, P, the output mix of region A would be at point X and the output mix of region B at point Y in Figure 22-5. The results are as one would expect. Region A, which has an abundance of land (capital) relative to labor, produces more of q_1 than q_2, and region B, which has an abundance of labor relative to land (capital), produces more of q_2 than q_1.

Employing the same type of analysis concerning technological change as was used in the previous section and assuming the same fixed relative prices, P, in both regions as shown in Figure 22-5, one can verify that (a) in region A it would pay to invest a higher proportion of the research budget in increasing τ_1 than in increasing τ_2, and (b) in region B it would pay to invest a higher proportion of the research budget in increasing τ_2 than in increasing τ_1. However, the results may change as relative product prices change. If the price of q_2 is significantly higher relative to the price of q_1 then in the situation illustrated in Figure 22-5 region A would allocate more resources to increasing τ_2 than τ_1. With sufficiently strong product price incentives in favor of q_2 both regions A and B would allocate proportionately more of their fixed research budgets to τ_2 than to τ_1. The reverse would be true with sufficiently strong price incentives in favor of q_1.

In addition to the role of demand conditions for the final products and the nature of the research production functions, variations in relative factor endowments and in relative factor intensities with respect to the outputs also play important roles in determining the allocation of research resources. For example, under the product price assumptions illustrated in Figure 22-5 the labor "rich" region will allocate relatively more research resources to the labor intensive commodity, and the labor "poor" region will allocate relatively more research resources to the land (capital) intensive commodity. (See chapter 24 for empirical support for this proposition.)

In the paper on which this chapter is based we used the model to examine how several environmental constraints affect the allocation of research resources and the output mix. We examined the effects of four types of physical or institutional (economic) situations: (1) heterogeneity in the quality of at least one factor of production; (2) restrictions on the use of certain technologies; (3) restrictions on the output of one commodity; and (4) improvement in the quality (productivity) of one or more inputs. The results can be summarized as follows:

1. Heterogeneity in the quality of factors increases the likelihood that it is profitable to allocate research resources to increasing factor productivity for both commodities.

2. Where restrictions are placed on the use of certain technologies, the optimum allocation of research resources depends heavily on final demand conditions. If relative prices more *strongly* favor the production of one product, say, q_2, then research resources should be allocated more to increasing τ_2 than τ_1. As relative prices move more in favor of the other product, say, q_1, the relative mix of research resources will move in favor of increasing τ_1.

3. When an output restraint for one commodity is binding, it may still pay to devote some research resources to increasing factor productivity for that

commodity. However, the general effect of the restraint is to cause a reallocation of research resources to increasing factor productivity for the unrestrained commodity.

4. Investments may be made to improve the productivity of one of the inputs, say, land. As an example, consider a situation in which irrigation is feasible but there is little control over the application of water in individual fields. The effect of improvements in the irrigation system which result in full water control in individual fields will, under given product prices, result in a switch from complete specialization in the initial crop to complete specialization in an alternative crop.

Some Implications

Our analysis shows that the optimum allocation of research resources among commodities and its effect on the output mix of a region depend upon the initial production conditions (concavity of the production possibility curve and the relative size of q_1 and q_2 with complete specialization in the production of each), the extent to which there are either increasing or decreasing returns to scale in research, whether the producing region faces given prices or downward-sloping demand curves for its outputs, and changes in relative factor endowments. To decide on the optimum allocation of research resources among commodities, research administrators need information on all four aspects of the problem.

If the production possibility curve is relatively flat and the region is a price-taker, we would expect significant shifts in the output mix as a result of changes in relative output prices. Furthermore, the allocation of research resources depends heavily on relative product prices and return to scale in research. Research resources would be devoted entirely to increasing the production of q_1 if (a) prices initially favor complete specialization in the production of q_1, (b) there are constant or increasing returns to scale in research, and (c) there are identical production functions for τ_1 and τ_2. Research would strengthen the tendency toward complete specialization in production. On the other hand, if the production possibility curve is concave, both q_1 and q_2 would tend to be produced, except in the case where the region faced fixed prices which were of such an extreme nature as to dictate complete specialization in production. Except for the extreme case, research resources would be allocated to increasing both τ_1 and τ_2.

Even if the production possibility curve is relatively flat over a wide range of variation in q_1 and q_2, we may still observe a high degree of stability in the output mix even with technological change, because the region faces downward-sloping demand curves for its outputs. The more price inelastic the de-

mand curves, the more convex the iso-revenue lines and the less sensitive is the output mix to technological change. Furthermore, even with downward-sloping demand curves, it would still pay to devote all research resources to one commodity if the combination of (a) the slope of the initial production possibility curve and (b) returns to scale in research resulted in an innovation possibility frontier which was either a straight line or convex.

A region might face downward-sloping demand curves for its products either because of short-run rigidities in parts of the marketing system or because changes in output levels of a region were sufficient to change prices throughout the marketing system. There is evidence that significant changes in the production of one crop can cause temporary distortions in the relative price structure of a region compared with prices in a larger marketing area. Lele, in her study of sorghum grain marketing in western India, found that distortions in intermarket price differentials arose when the volume of grain production and marketings pressed against the supply of transport services.[8] Jolly, in a study of corn and soybean price behavior in southwestern Minnesota, found that the margin between central market prices and local prices was a function of the level of output and the output mix in the local region.[9]

Yamaguchi, and Yamaguchi and Binswanger, in a study of the effect of technical change and population growth on the economic development of Japan, observed patterns of production and price behavior consistent with our model.[10] In looking at the agricultural and nonagricultural sectors (equivalent to our two commodities), they found (a) a very flat production possibility curve and (b) a high degree of stability in the output and consumption mixes, because the demand curves for the outputs of both sectors were downward-sloping and especially price inelastic in the case of demand for agricultural products.

In a situation with downward-sloping market demand curves, intervention in the markets for q_1 and q_2 by government (or other groups) in the form of price support measures or trade restrictions can yield results similar to the competitive model, i.e., intervention can result in a higher degree of specialization than would result from a market solution. (This does not automatically follow, because governments can also set the relative support prices in ways which will shift the terms of trade against the commodity experiencing the technological change.) Furthermore, price support programs or trade restrictions can also affect the allocation of research resources to the extent that product price behavior is important in determining such allocations.

The question of which commodity should receive research resources depends very much on society's developmental objectives and policies. For example, suppose it is the primary concern of policy makers to increase the incomes of producers, and relative prices are unimportant. Then one rule which could be followed is to increase the production of the commodity with the

highest price and income elasticities. In this way one would tend to minimize the extent to which a shift in the terms of trade tends to counteract the effect of technological change. On the other hand, suppose one of the commodities is a wage good, it has lower price and income elasticities than the non-wage good, and it is the policy makers' desire to keep the price of the wage good as low as possible. In this case, it would make sense to invest research resources in bringing about technological change in the wage good, i.e., we want to maximize the shift in terms of trade against the wage good. These are but two of many possible situations.

We should be cognizant of the fact that the price elasticity of demand which a region or country faces depends on both domestic and export demand parameters. It is possible for the domestic demand curve to be quite price inelastic while the export demand curve facing the country or region is quite price elastic, e.g., the case of corn in Thailand. In such a situation it would be important for the country or region to follow price policies which did not exclude domestic production from entering export markets, if the policy objective were to minimize the adverse effect on terms of trade for corn of a change in output. On the other hand, if the name of the game were to keep domestic prices as low as possible, then export barriers might be erected, e.g., the case of the rice premium in Thailand.

Finally, we explored in our earlier paper the implications of four environmental situations for the allocation of research resources and for the resulting output mix. In each situation our model gives us useful insights. Demand conditions for the products play an important role in allocating research resources in each environmental situation considered.

Heterogeneity in the quality of factors of production imparts convexity to the production possibility curve. Regardless of demand conditions, heterogeneity in factors will tend to cause research resources to be allocated to both commodities. In the case of restrictions on the use of certain technologies in the production of one of the commodities, the optimum allocation of research resources depends heavily on final demand conditions. Restrictions on the level of output of one commodity should cause a reallocation of research resources to increasing factor productivity in the other commodity. However, it may still be profitable to allocate research resources to both commodities even when the output restraint is binding. Improving the quality of one factor can also have a significant effect on the output mix, with the nature of final demand conditions again playing an important role.

Conclusions

We have constructed a relatively simple theoretical model which shows that the allocation of a fixed research budget between research on two commodi-

ties and the effects of such allocations on the output mix of a region depend on the initial production conditions, the presence of economies or diseconomies of scale in research, the nature of the demands for the outputs of the region, changes in relative factor endowments, and the existence of certain types of environmental constraints. Research administrators require information on all these aspects of the problem in order to determine the optimum allocation of research resources.

Our analysis indicates that there is nothing inherently good or bad about diversification of production. Changes in output mix must be evaluated in terms of a country's resource endowments and developmental objectives. Environmental considerations clearly play an important role in effecting an optimal allocation of research resources. Price policies also have a significant effect, not only on the allocation of traditional resources among commodities in a region but on the allocation of research resources.[11] Falcon has argued cogently that agricultural price policies should be consistent with national development objectives.[12] Unfortunately, price and market policies designed in response to short-run food procurement needs or political pressures from producers often are not consistent with the price policies that would facilitate achievement of longer term development goals.

NOTES

1. This chapter draws heavily on Martin E. Abel and Delane E. Welsch, "Microeconomics of Technology and the Agricultural Output Mix," Staff Paper P74-16, Department of Agricultural and Applied Economics, Minneapolis, University of Minnesota, August 1974.

2. Harry G. Johnson, "Factor Market Distortions and the Shape of the Transformation Curve," *Econometrica*, 34 (July 1966), 686-698; Martin E. Abel, Delane E. Welsch, and Robert W. Jolly, "Technological Change and Agricultural Diversification," Staff Paper P73-10, Department of Agricultural and Applied Economics (St. Paul: University of Minnesota, January 1973).

3. Abel, Welsch, and Jolly, "Technological Change."

4. Johnson, "Factor Market Distortions."

5. Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore and London: Johns Hopkins Press, 1971).

6. Robert E. Evenson and Yoav Kislev, "A Model of Technological Research," processed, August 1971.

7. Robert E. Evenson, "Economic Aspects of the Organization of Agricultural Research," *Resource Allocation in Agricultural Research*, ed. Walter L. Fishel (Minneapolis: University of Minnesota Press, 1971).

8. Uma J. Lele, "Market Integration: A Study of Sorghum Prices in Western India," *Journal of Farm Economics*, 49 (February 1967), 147-159.

9. Robert W. Jolly, "The Derived Demand for Specialized Inputs by a Multi-Product Firm: An Examination of Corn and Soybean Buying by Minnesota Country Elevators," processed, 1973.

10. Mitoshi Yamaguchi, "Technical Change and Population Growth in the Economic Development of Japan," Ph.D. dissertation (Minneapolis: University of Minnesota, 1973); Mitoshi Yamaguchi and Hans P. Binswanger, "The Role of Sectoral Technical Change in Development: Japan 1880-1965," Department of Agricultural and Applied Economics Staff Paper P74-7 (St. Paul: University of Minnesota, April 1974).

11. The role of price in the allocation of resources among crops in developing countries was highlighted by Raj Krishna, "Farm Supply Response in India-Pakistan: A Case Study of the Punjab Region," *Economic Journal*, 73 (September 1963), 477-487, and subsequently by many other analysts. See also Raj Krishna, "Agricultural Price Policy and Economic Development," *Agricultural Development and Economic Growth*, ed. Herman M. Southworth and Bruce F. Johnston (Ithaca: Cornell University Press, 1967).

12. Walter P. Falcon, "The Green Revolution: Generations of Problems," *American Journal of Agricultural Economics*, 52 (December 1970), 698-710.

23

Relating Research Resource Allocation to Multiple Goals

John W. Mellor

In most countries, technical change is necessary for agriculture to play a positive role in economic development. With limited land area and classic diminishing returns to the use of other inputs, it becomes more and more costly to meet the increasing demand for food unless research provides new, higher yielding crop and livestock technologies. The need for effective agricultural research is strongly reinforced in those many low-income countries in which productivity of agricultural labor and even capital have already been driven to very low levels by past population growth. Such research is further necessitated as social objectives accelerate the demand for food by fostering increased employment of low-income people who wish to spent the bulk of their added income on food.

This latter "distributional" pressure on food production capacity will become even greater if international and national demands for more jobs and broader participation in growth are to be met. The dramatic effect on the demand for food of change in income distribution is illustrated by Indian data which show that while the top 5 percent in the expenditure distribution spend only 2 percent of increments to income on food grain, the bottom 20 percent spend 59 percent.[1]

The increasing societal need and demand for agricultural research results lends urgency to achieving efficient allocation of scarce research personnel and institutional resources. This scarcity also requires that attention be given

to organizing and conducting research to expand research capacity. This need for expansion results in part from past failures to recognize the importance of agricultural research and past and present deficiencies in agricultural education. Thus a current objective of research programs must be to make their own growth self-sustaining, through developing their own personnel and institutional resources.

The crucial task of determining public policy for optimal allocation of agricultural research resources cannot rely on the market price mechanism alone. Three particular problems arise in addition to the usual one of the extent to which prices reflect the underlying supply and demand for the commodities from which research derives its returns. First, the relationship between quantity of research resources and productive output is poorly understood. That is, once a problem is defined – even a straightforward one such as increasing yield per acre of a particular crop in a particular area – there is little knowledge of how much research investment of what type will give how much return. Second, agricultural research has a unique capacity to affect variables, such as health and nutritional status, which because of factors such as consumer ignorance may not be given their true societal value in market prices. Third, in a world of unequal distribution of productive assets and income, new technology affects the distribution of income by changing both the relative returns to owners of various productive resources and the prices of goods consumed in unequal proportion by various income classes. Even though society may accept the initial inequality in income and assets, it may not find increased inequality agreeable. We may view determination of public research policy as a process of explicitly creating the demand for research of certain types rather than simply responding to existing demand through estimates of market forces and their effects. In this alternative view, policy may call for an allocation of research resources quite contrary to that suggested by the market relationships.

Research resource allocation is a problem in multivariate analysis: it is a problem of multiple goals and multiple instruments complicated by a lack of information about the relationships between dependent and independent variables. Perhaps it is the bewildering complexity of the task which accounts for the tendency of decision-makers in research resource allocation to follow a simple sequential procedure, emphasizing only one or a few objectives at a time but gradually pyramiding to a meeting of multiple goals. In this approach to decision-making in a context of multiple goals, it is important to set priorities for an appropriate sequence of actions to meet those goals. Even this approach is complicated because societal objectives may be reached through diverse instruments, of which allocation of various types of research resources is only one. The trade-offs in efficiency among the various policy

instruments must be carefully considered in allocating research resouces, and they will certainly affect the sequence of efforts to achieve specific objectives.

The problem of multiple goals presents two major tasks: first, to categorize the goals with sufficient detail and specificity to give them operational meaning; and, second, to set priorities among objectives, reflecting the probabilities of success and the comparative costs of alternative research lines for reaching the various objectives and, perhaps, outlining a schedule for time phasing and ordering.

This chapter attempts to shed light on research decision-making first by a discussion of some specific aspects of societal objectives, then by a brief statement about the nature of the research resources to be allocated, and finally by an analysis of specific instruments of research policy in terms of implications for their choice and manipulation. The analysis concludes with a hypothetical research policy sequence and a statement of research needs for improving research policy. (For a theoretical treatment of some of the issues discussed in this chapter, see chapter 22.)

Societal Objectives of Agricultural Research

Society's objective in research is presumably to increase its own welfare. That objective is advanced by research allocations which maximize the per capita stream of welfare over some time span from the initial stock of resources. This concept allows for augmenting the per capita stock of resources and using research resources specifically to generate more research resources, perhaps in the short run conflicting with research output. Since welfare is likely to be defined in per capita terms, we can say that the further objective of research is to raise the productivity of the stock of labor, subject to the constraint of that labor's working conditions and of fixed resources such as land. Given existing concern about questions of mechanization, employment, and income distribution – to which this chapter will return – it is worth emphasizing this basic concern with labor productivity. At the same time, it must be noted that in densely populated countries research policy may still focus on the intermediate objective of increasing the productivity of land.

Under pressure to simplify choice by concentrating on a simple objective function, the agricultural science research worker often focuses first on yield per acre or on a crop output index. In doing so he is apt to have in mind a set of market weights. Once yield is markedly increased, various subobjectives are pursued, usually sequentially, including reducing the use of inputs such as chemicals and hence costs and reducing variance of yields. Apparently substantial gains in research efficiency are achieved through such simple state-

ment and pursuit of objectives in sequential order. And the resulting loss in economic efficiency may be slight, if price relationships correctly reflect society's costs and values. The demand for simple objectives undoubtedly traces from the very large number of variables with which the agricultural scientist deals – from a wide range of soil and climate variables on the input side to physical output, variance in output, and consumption quality on the output side. Without even considering social factors the agricultural scientist works in a multiple-goal environment.

Beyond the well-known, general market imperfections, two specific problems arise in the use of price-weighted output as an objective function. First is the possibility that consumers may be ignorant of the relationship between a product and aspects of its welfare function such as health and nutrition. Second is the fact that relative prices result from a distribution of income and assets that itself may be inconsistent with societal values. This in turn reflects a broader concern with what society perceives to be a maldistribution of income, often intensified by technical change. Needless to say, the use of "international" rather than domestic prices substitutes a different set of societal structures which may be equally arbitrary and equally inconsistent with current national objectives.

With respect to the effect of consumer ignorance of price relationships, an important caveat is in order. The perception of utility may differ between rich and poor, and it may well be the former, not the latter, who are in error. For example, the poor in low-income countries are unlikely to pay more for increased protein content in food because, contrary to widespread belief, their diet is far more deficient in calories than in protein.

Distribution of income is of increasing concern to society. The fact that technical change has the potential profoundly to influence income distribution enhances the importance of enlightened research policy. However, research policy is only one of many instruments for altering income distribution. The emphasis on the distribution question arises from the divergence between societal objectives with respect to income distribution, the actuality of productive-asset distribution, and the apparent inability of society to redistribute either assets or income directly. On the one hand, inequality of distribution of assets and income may be reinforced by technological change which biases returns toward one production factor. On the other hand, those very biases offer an opportunity to change income distribution in a desired direction. Society may wish to allocate research resources so as to influence factor shares in the desired direction or at least to know how innovation will affect income distribution so that appropriate complementary policies may be instituted. Choice of crops, regions, and disciplines of emphasis all will affect the distribution of gains among regions, be-

tween landowners and laborers, between men and women, and among other class groupings.

It must be recognized that, although there is necessarily a loss in efficiency in attempting to meet distributional objectives through research allocation rather than through other means, all societies appear to face this problem. To attempt to equalize income distribution by breeding labor-intensive crop varieties rather than redistributing the land is analogous to moving the piano to the piano stool. Indeed one wonders why, when the social scientist complains about the skewing of income distribution by the green revolution, the biological scientist hasn't pointed out that better income distribution could be rather simply effected through land redistribution.

In more sophisticated terms, new technology changes the distribution of income because it increases the relative productivity and demand for various factors of production. If all factors were equally owned or if all income were equally divided, no skewing of income would result from change in technology. It is the imposition of change in factor shares on an existing inequality which creates the problem. Clearly, to divert research attention from increasing output per unit of input to additional concern with the bias in factor shares interferes with the accomplishment of primary objectives.

The distributional problem is particularly acute with respect to labor shares. Since their income is directly related to the amount of work needed to be done, laborers are particularly vulnerable to new technologies which increase labor productivity and thus reduce needed man-hours, as do almost all yield-increasing innovations. Such innovation may decrease the demand for labor and result in both a lower wage and less employment. The return to land rises of course since it is the residual claimant after payment to labor. If land were distributed in proportion to labor, then what an individual lost on return to labor would be gained in return to land. A system of taxes on land or on technology-associated inputs could be devised to have the same effect. It should also be noted, as above, that society's welfare objective almost certainly includes raising the productivity and reducing the onerousness of labor — creating a conflict if the very act removes work opportunity for a segment of the population, because of differences in asset distribution and power.

The points made above apply also to the distribution of income among regions. Even if income and assets are equally divided within a region they may occur unequally among regions. In such a case, new technology may intensify interregional disparities. In this context, mainland China's rising rate of regional disparity is especially instructive. Within the commune, mechanization apparently has little effect on income distribution, but since each commune reaps benefits of its own land and labor, those communes where technological input is concentrated will experience greater increase in incomes. In this sys-

tem, as in others, it is difficult to redistribute assets, labor force, or income. In China, too, then, the second best solution – effecting income redistribution through allocation of research resources – may need to be considered.

To summarize, the widely accepted societal objective of increasing total human welfare is subject to the constraint of the distribution of benefits among and within regions. Moreover, welfare is inadequately measured by the price mechanism and nutritional concerns may often be understated. Finally, because of our imperfect knowledge of the effect of research inputs, only very general policies on research resource allocation can be considered.

Before proceeding to a discussion of the resources to be allocated and the instruments of research policy, we may note that actual decisions on research policy are made in a bureaucratic framework in which the primary objective may be one of maintaining power, with consequent potential for departure from general welfare objectives with respect to effects of decisions on the growth of income and its interpersonal and interregional distribution. Indeed, depending on the sources of the political and bureaucratic power, there may be little or no actual concern for the substance of objectives as stated in the preceding paragraphs. An analysis of decision-making in that context would give much more weight to the specific nature of administrative structure and power relationships than does this discussion.

The Nature of Agricultural Research Resources

The agricultural research resources to be allocated are the physical plant and trained personnel and, most important, the institutional structure into which plant and personnel are organized for a productive purpose. Because of the potentials for transfer of research results between indigenous and foreign research units, the nature and quantity of research resources available for indigenous purposes are a complex composite of what now exists plus what will be coming into existence. So little is known of how to train competent personnel and how to build institutions that the most effective way to promote growth in the research resource base is almost certainly through developing the research structure itself.

What this means, in practice, is that the research resources to be allocated should not be viewed in a static sense. In a world of less than infinite discount rates, the very mode of allocation of research resources will strongly influence the quantity of such resources to be allocated in the future. In this context, we need to consider several specific questions.

To what extent can time be saved in the short run by use of foreign technicians, and will such input reduce or increase institutional capabilities in the long run?[2] Will regional diversification of research slow the growth of the sys-

tem by fractionization, or will it speed growth by forcing decentralization and encouraging diffusion of responsibility and consequent growth in capacity? How far will a close relationship with an international system expand results and personnel resources? Will such a relationship effect institutional development, or will it have deleterious consequences through setting up conflicts between national and international perceptions and objectives, by providing less encouragement for important indigenous capabilities? The problem of finding answers to these questions – the dynamics of which may be much more important than the status of allocating current resources – underscores the difficulty of decision-making in this area. We can see how these questions may be decided on the basis of political rather than technical considerations, how the sequential method may be chosen in preference to a multidirectional approach.

The Instruments of Research Policy

The three prime instruments of research policy are (1) allocation among crop and livestock systems; (2) choice of emphasis, within a farming system and among geographic regions, on the productivity of the various factors of production; and (3) selection of research disciplines. The latter, of course, interacts with the others.

From the preceding sections of this chapter it can be seen that, beyond market-price based criteria, analysis for each of these areas of allocation choice should be made with respect to effect on (1) the degree to which the supply of those food commodities most heavily weighted in the consumption patterns of the poor will support increased employment and rising real incomes of low-income people; (2) the demand for labor and the distribution of actual employment among various social classes; (3) the level of total output and producers' net income; (4) variation in producers' net income; and (5) the nutritional composition of the food supply. Through these instruments, research and resultant technological change may have a profound effect on the structure of the society. Understanding of the relationships is important in pointing the way to optimal allocation of research resources. Such knowledge can be even more important in assisting societies to adjust to the stresses which typically accompany technological changes no matter how beneficial such change may ultimately be.

Choice of Crop and Livestock Systems

Research results affect the choice of farming systems by increasing the efficiency and reducing the cost of production of one system compared with another. Technological change is likely to increase production both directly,

with a given set of resources, and indirectly, by increasing relative profitability and thereby transferring resources from other enterprises. Farming systems vary in the extent to which they contribute to various objectives. Four specific characteristics are discussed below to illustrate the nature of such variation and its relationship to research resource allocation.

Food grains as basic wage goods. Allocation of research resources to food grains facilitates employment growth through expansion of the supply of basic wage goods. In India, as noted earlier, the two lowest deciles in expenditure class spend 59 percent of increments to income on food grains (Table 23-1). Without a large increase in imports and an effective system of rationing, an employment program which increases incomes of low-income laborers must be matched by rapid increase in domestic food grain production. If it is not, sharp inflationary pressures will bring about a demand, on the part of the politically powerful urban middle class for cessation of the program.[3] Such an effort to improve employment justifies an initial major emphasis on basic food grains in research resource allocation. Now if rapid technological change in food grain production is not matched by an increase in the incomes of low-income consumers, deficiency of demand will result in reduced relative food grain prices which on the one hand directly raise real incomes of the poor but on the other hand may remove the price incentive needed to stimulate continued application of high input technological methods. Clearly, there is a high degree of interdependence between technological progress in food grain production and high employment policies. Policy in respect to one must be meshed with policy on the other.

Employment content and factor shares. While research emphasis on food grains helps to release the most basic wage goods constraint to employment, it tends in itself to provide only a small portion of employment at the new equilibrium level. Although geographically concentrated breakthroughs in food grain production may provide substantial aggregate increase in employment in those areas, they augment the capacity to support increased employment by a vastly greater amount.

For example, in a typical case of the new wheat technology in India, only 10 percent of the added gross income produced by the high-yielding variety is expended for labor, while 67 percent is allocated to family-owned capital and land, and 23 percent is paid out for other inputs, of which fertilizer represents a major component (Table 23-2).

Table 23-3 illustrates two important aspects of employment in food grain production. First, there is considerable variability in the labor share of increased output. Second, typically only a small share – roughly 5 percent to 15 percent – is paid as wages. It follows then that food grain production, al-

Table 23-1. Division of Incremental Expenditure among Expenditure Categories, by Rural Expenditure Class, India, 1964-65

Expenditure Category	Rural Expenditure Class by Decile[a]						
	Bottom Two (landless)	Third (under 1 acre)	Fourth and Fifth (1-5 acres)	Sixth, Seventh, and Eighth (5-10 acres)	Ninth (10-15 acres)	Lower One-Half of Tenth (15-30 acres)	Upper One-Half of Tenth (30 + acres)
Mean per capita monthly expenditure (Rs.)	8.93	13.14	17.80	24.13	30.71	41.89	85.84
Allocation of additional rupee of expenditure							
Agricultural commodities	0.79	0.69	0.59	0.52	0.46	0.40	0.33
Food grains	0.59	0.38	0.25	0.16	0.11	0.06	0.02
Nonfood grains	0.20	0.31	0.34	0.36	0.35	0.34	0.31
Milk and milk products	0.07	0.11	0.12	0.13	0.13	0.12	0.09
Meat, eggs, and fish	0.02	0.03	0.03	0.03	0.03	0.03	0.02
Other foods	0.01	0.05	0.07	0.09	0.10	0.12	0.16
Tobacco	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Vanaspati		0.01	0.02	0.02	0.02	0.02	0.01
Other oils	0.05	0.05	0.04	0.04	0.03	0.02	0.01
Sweeteners	0.04	0.05	0.05	0.04	0.03	0.02	0.01
Nonagricultural commodities	0.21	0.31	0.41	0.48	0.54	0.60	0.67
Textiles	0.09	0.08	0.07	0.08	0.07	0.06	0.07
Cotton textiles	0.09	0.08	0.07	0.06	0.06	0.05	0.03
Woolen textiles				0.01	0.01	0.01	0.02
Other textiles				0.01			0.02
Nontextiles	0.12	0.23	0.34	0.40	0.47	0.54	0.60
Footwear		0.01	0.01	0.01	0.01	0.01	0.01
Durables and semidurables	0.01	0.01	0.01	0.02	0.02	0.03	0.05
Conveyance	0.01	0.01	0.02	0.02	0.03	0.05	0.10
Consumer services	0.02	0.02	0.02	0.03	0.03	0.04	0.06
Education	0.01	0.01	0.02	0.03	0.03	0.05	0.11
Fuel and light	0.07	0.07	0.06	0.05	0.05	0.04	0.03
House rent		0.01	0.01	0.02	0.03	0.04	0.08
Miscellaneous		0.09	0.16	0.22	0.27	0.28	0.16
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: John W. Mellor and Uma J. Lele, "Growth Linkages of the New Foodgrain Technologies," *Indian Journal of Agricultural Economics*, 28:1 (January-March 1973), 35-55. The data are reported in B. M. Desai, "Analysis of Consumption Expenditure Patterns in India," Cornell University-USAID Employment and Income Distribution Project, Department of Agricultural Economics, Occasional Paper no. 54, Ithaca, Cornell University, August 1972. The source for the data is National Council on Applied Economic Research, *All-India Consumer Expenditure Survey, 1964-65*, vol. 2 (New Delhi, 1967).

[a] Roughly corresponding agricultural holdings are in parentheses.

Table 23-2. Allocation among Inputs of the Increased "Payments" from a High-Yielding Wheat Variety, Aligarh District, Uttar Pradesh, India, 1967-68[a]

Inputs	Allocation of Payments[b]		Allocation of Incremental Payments[c]		Percent of Increment in Gross Value of Production of Incremental Payments
	Traditional Variety	High-Yielding Variety			
Gross value of production	653	1,115	462	(71)	100
Payments to:					
All inputs except labor	573	989	416	(73)	90
Family land and capital	380	690	310	(82)	67
Inputs other than family land and capital	193	299	106	(55)	23
Fertilizer	37	76	39	(110)	8
Labor	80	126	46	(59)	10
Family labor	54	91	37	(68)	8
Hired labor	26	35	9	(35)	2

Source: Adapted from R. S. Dixit and P. P. Singh, "Impact of High Yielding Varieties on Human Labor Inputs," *Agricultural Situation in India*, 24:12 (March 1970).

[a] The traditional variety of wheat in Aligarh District yielded 7.5 quintals per acre, while the high-yielding variety yielded 14.8 quintals per acre, an increase of 96 percent. "Payment" is defined here as either the amount of income paid out for inputs such as fertilizer or the value of income assigned to inputs such as family labor.

[b] In rupees per acre.

[c] In rupees per acre, with percent of increment in parentheses.

though necessary to relax a wage goods constraint, has not normally provided a full solution to the employment problem. And consequently, not only is there insufficient effect on the social welfare objective, but the production objective is brought into question as well, since the increase in demand for food grains will not be commensurate with the increased supply. For that balance, one requires the indirect or linkage effects of the food grain production increase.[4] It is here that one must recognize the options in dealing with problems of policy. Emphasis on increasing the secondary employment effects of new production technology may be more effective than attempts to direct research so as to increase the primary employment effects.

A major potential for increasing employment within agriculture lies with increasing emphasis on and shifts among various nonfood grain crops. Schluter shows, for Surat District, India, that sugar can return 50 percent more income to labor per acre than rice and nearly four times as much as improved varieties of wheat (Table 23-4). Similarly, among unirrigated crops, both groundnut and cotton return more to labor than sorghum (but less than rice), while

Table 23-3. Division of Increased "Payments" between Labor and Other Inputs, Various High-Yielding Varieties and Areas, India

Area	Increase in Gross Value of Output		Increase in Labor "Payments"		Percentage of Increased Output to Labor[a]	Percentage of Increased Output to Other Inputs[b]	Percentage Increase in Labor "Payments" for a 1 Percent Increase in Gross Value of Output
	Rupees per Acre	Percentage Increase	Rupees per Acre	Percentage Increase			
					Wheat		
Aligarh, U.P.	462	71	46	58	10	90	0.8
Varanasi, U.P.	620	65	11	15	2	98	0.2
Udaipur, Rajasthan	343	43	18	13	5	95	0.3
Punjab	450	100	56	42	12	88	0.4
					Kharif Paddy		
West Godavari, Andhra Pradesh	269	38	32	17	12	88	0.4
East Godavari, Andhra Pradesh	216	33	20	13	10	90	0.4
Uttar Pradesh	1,100	200	67	92	6	94	0.5
Tamil Nadu	550	100	33	20	6	94	0.2
Laguna, Philippines	374	72	3	3	1	99	0.0
Sambalpur, Orissa	404	95	36	28	11	89	0.3
					Rabi Paddy		
West Godavari, Andhra Pradesh	562	86	39	16	7	93	0.2
East Godavari, Andhra Pradesh	761	153	39	30	5	95	0.2
Tamil Nadu	625	100	46	21	7	93	0.2
Gumai Bil, Bangladesh	948	208	302	125	32	68	0.6
					Bajra		
Kaira, Gujarat	300	85	39	27	13	87	0.3
Average	532	97	52	35	9	91	0.3

Source: John W. Mellor and Uma J. Lele, "Growth Linkages of the New Foodgrain Technologies," *Indian Journal of Agricultural Economics*, 28:1 (January-March 1973), 35-55, Table II.

[a] Labor "payment" is defined as physical labor input (family and hired) in man-days at a constant wage.

[b] Other inputs "payments" defined as gross value of output minus share to labor.

Table 23-4. Returns to Labor and Land per Acre for Unirrigated and Irrigated Crops over a Six-Year Period in Surat District, India

Crop	Returns to Labor[a]	Returns to Land[b]
Unirrigated, 1966/67-1971/72		
Rice (with fertilizer)[c]	129	202
Groundnuts	108	207
Cotton (without fertilizer)[c]	65	230
Sorghum	50	163
Irrigated, 1971-72[d]		
Improved rice	242	507
HYV rice	265	608
Improved wheat	82	237
HYV wheat	68	473
Sugarcane	383[e]	2219

Source: Michael G. G. Schluter, "Interaction of Credit and Uncertainty in Determining Resource Allocation and Incomes on Small Farms, Surat District, India," Cornell University-USAID Employment and Income Distribution Project, Department of Agricultural Economics, Occasional Paper no. 68, Ithaca, Cornell University, February 1974, chapter III, Table 7, p. 14.

[a] Estimated at the market rate. The number of man-days used for each operation is multiplied by the appropriate wage rate, with no distinction between the hired and family labor inputs. For unirrigated crops, we assume a general wage of 2.00 rupees per man-day; for weeding, we assume 1.50 rupees. For rice, we use 3.00 rupees per day; for rice weeding, irrigation, and fertilizer application, 2.50 rupees. For wheat and sugarcane, we use 2.00 rupees per day but 3.00 rupees for planting, as this occurs during a peak period.

[b] Estimated as a residual. From gross returns, subtract average total variable costs in 1971-72, including the imputed value of family labor. The only cost not subtracted is interest charges. Gross returns include the value of the by-product.

[c] Most farmers in the unirrigated zone use fertilizer on rice, but no farmer uses it on cotton.

[d] For irrigated crops we use data for 1971-72 rather than for the six-year period, owing to the difficulties of obtaining time-series yield data for the new varieties.

[e] Over 50 percent of this goes to migrant workers from Maharashtra who are employed by the factory for harvesting.

groundnut returns to labor two-thirds more than cotton. Data on vegetables or on livestock such as dairy would be even more striking.

Donovan shows, through a linear programming analysis, the substantial effect of cropping pattern changes on labor requirements in Mysore State, India, and he stresses the role of seasonal labor bottlenecks and the possibilities of

clearing those bottlenecks offered by migration and mechanization.[5] Similarly, Desai and Schluter show dramatically how changes in cropping patterns, specifically between groundnut and cotton, alter the total demand for labor in Surat District, India.[6] The same point could be made in respect to change between jute and rice in Bangladesh.

It is of course crucial to recognize that production patterns must be in balance with demand and hence that efforts to increase employment by changing the structure of production must be matched by shifts in demand. Such demand shifts may occur as indirect effects from expenditure of rising incomes, or they may be the prod· ɛ of specific public policy. Some of the most labor-intensive agricultural enterprises such as sugar, vegetables, milk, and certain other livestock commodities have highly elastic demand. On the one hand, demand will grow rapidly for such commodities as incomes rise, creating a favorable environment for increasing production and employment. On the other hand, if supply is inelastic, rising production costs and hence prices will readily shift consumption to other commodities which may or may not provide as many jobs. Consequently it is important to provide the institutional changes needed to facilitate ready increases in production and marketing, while research which increases production efficiency and the supply elasticity can greatly facilitate growth in employment in this sector.

In a context of rapid growth in incomes, a favorable environment is provided for increasing production of demand elastic, potentially labor-intensive commodities such as sugar, vegetables, and livestock products. Since relaxing the wage goods constraint through increased food grain production may be effective in creating such an environment, a simple research allocation strategy follows: first, stress food grain production; then set in motion a high employment program, which creates a favorable demand environment; finally, accentuate labor-intensive crops and livestock in research programs.

After taking advantage of the increased income from new food grain technology as a means of increasing demand for labor-intensive production, one may pursue additional steps. First, export demand may be stimulated for labor-intensive agricultural commodities. This could be further facilitated by the introduction of technological change which decreases cost of production. Second, internal demand structure may be influenced by subsidy and educational programs. The key point is that, while agricultural research may appropriately emphasize labor-intensive commodities, it must be backed up by policies which increase or shift demand accordingly. Research policy must be seen in complementary play with other policies.

Risk and uncertainty. Allocating research resources in such a way as to decrease the variation in yields in a context of varying weather and management prac-

tices will reduce risk and uncertainty. Lessening the probability of particularly poor results not only raises average returns but reduces variance as well, and this may be seen as part of the general effort to increase production efficiency.

However, variation in results has implications beyond the effect on average production. In general, society prefers present income to future income and so risk involves a loss through unexpected deferral of income. Perhaps more important, low-income farmers tend to avoid risk, and hence the amount of variation in results affects the distribution of benefits and the adoption of innovation.

Schluter's analysis of Surat District, India, shows clearly that lower income farmers choose the lower profit and less labor-intensive but more certain enterprises. Thus the farmers with lower income tend to choose cropping patterns with a lesser deviation in income. More specifically, on the basis of a MOTAD model Schluter shows that for each 100 rupees of increased income from change in cropping pattern there is a sacrifice of 100 rupees in increased variance.[7] It follows that it would be useful to small farmers to reduce variance of income in the more labor-intensive and profitable crops. Indeed, because the more profitable crops are more labor-intensive, it follows that, except for risk aversion, small farmers should have a comparative advantage in those crops.

Although variation in income arises from fluctuations in both price and yield, fluctuation in yield is the more important factor. For example, Schluter shows for Surat District that the coefficient for variation for yield is greater than that for price by a factor of 4 for rice, 3 for sorghum, 1½ to 2 for cotton, and 1½ for groundnuts (Table 23-5). Further, price variation tends to be inverse to yield variation and therefore tends to reduce overall variation, given the fluctuation in yield induced by weather.[8] Thus, as Schluter's data confirm, in the complex real world of many conflicting forces, price stabilization schemes may increase income instability, at least for lower income producers.

It follows then that the burden of reducing variation in income must fall more on production than on price policy factors. Within production policy there are many variables: expenditure on extension effort may improve management and reduce crop failure; expenditure on irrigation may reduce dependence on favorable weather; expenditure on credit programs or insurance schemes may provide greater staying power. However, a research program designed to reduce variation in results may be an efficient means of dealing with the problems. The greater the concern with reducing income disparities and increasing the participation of small farmers, the more emphasis will be given to research on reducing variation in results. Such emphasis may contribute initially to the most widely grown high-yielding varieties of crops and

Table 23-5. Coefficients of Variation for Yield, Price, and Revenue under Alternative Price Stabilization Policies for Major Unirrigated Crops, Surat District, India, 1966/67-1971/72

Crop	Yield	Price	Revenue		
			No Stabilization	Partial Stabilization[a]	Complete Stabilization[b]
Rice					
Low fertilizer	0.40	0.09	0.36	0.39	0.40
High fertilizer	0.42	0.09	0.36	0.39	0.42
Cotton					
Low fertilizer	0.42	0.24	0.30	0.36	0.42
High fertilizer	0.51	0.24	0.43	0.47	0.51
Sorghum	0.39	0.13	0.43	0.40	0.39
Groundnuts	0.37	0.26	0.42	0.34	0.37

Source: Michael G. G. Schluter, "Interaction of Credit and Uncertainty in Determining Resource Allocation and Incomes on Small Farms, Surat District, India," Cornell University-USAID Employment and Income Distribution Project, Department of Agricultural Economics, Occasional Paper no. 68, Ithaca, Cornell University, February 1974, chapter VII, Table 30, p. 44.

[a] Gross returns with price deviations from the mean reduced by 50 percent in each year.

[b] Gross returns with prices fixed at the mean levels.

then spread to the high profit, demand elastic, labor-intensive enterprises which have such a substantial potential to increase employment.

Nutrition aspects of the production pattern. Finally, a word on nutrition. Nutrition may deserve special emphasis in research allocation because consumer ignorance may result in too little expenditure for nutritious foods, while research may be able to increase nutritive content of foods at low cost and high convenience.

Unfortunately it is all too often forgotten that the key trade-off in research allocation vis-à-vis nutrition is likely to be between yield and nutrients other than calories. Thus the critical question may be what is most detrimental to the health of a particular population – insufficient calories or lack of other nutrients, such as protein or vitamins.

For most of the world's low-income people, food grains are usually the basic source of calories. It is only after expenditure is sufficient to meet basic calorie needs that consumption may properly stress protein and other nutrients in the cropping pattern. Just as the objective of increasing employment calls for first increasing food grain production and then more labor-intensive crops, so improving nutrition calls for food grains first and then other crops. As noted earlier, it is a common error to minimize calorie deficiency relative to protein deficiency.[9] As long as calories are deficient, research should not emphasize other nutrients at the expense of yield.

In this context, however, one should note the interaction of improved nutrient content with labor intensity. Although nutritious foods like livestock products may be inefficient means of providing nutrients such as protein and may in any case be sold to higher income persons, they may also provide the demand for labor which, in turn, provides the purchasing power for the poor to meet their more basic food needs. Thus, research that accentuates income generation for the poor may do much for their state of nutrition through market processes.

Again it should be noted that if low-income persons are to be encouraged to devote scarce land and other productive resources to production of vegetables to improve home nutrition, then it is important to reduce the risks involved in their production. Moreover, there is a clear trade-off between allocating resources to research to reduce yield variance and allocating resources to such activities as extension for teaching cultivation methods that reduce variation in results.

Choice of Emphasis within an Enterprise Category

Once decisions are made on the relative research emphasis among various enterprises, there remain allocational questions on the relative weight of objectives for the individual enterprises. In the broader sense the research objective is to increase physical efficiency – output per unit of input. But since various factors of production are distributed unevenly, raising the productivity of such factors unevenly will affect the distribution of income. And the extent to which the reduction of variation in results is highlighted will affect rates of adoption among income classes and hence the distribution of benefits. Similarly, relative accent on approaches that raise or lower the use of purchased inputs will affect income distribution.

Choice of Discipline

Relative emphasis on various academic disciplines in staffing a research institution is an important policy instrument and is likely to have substantial effect on the distribution of benefits. The most interesting set of considerations in this regard is probably that which arises with respect to engineering, since that is particularly related to mechanical innovations which have been most associated with displacement of labor. The allocation among disciplines is, however, very complex, even from an employment point of view. For example, a general production problem is that of seasonal labor bottlenecks. This is particularly a problem of intensive multiple-cropping programs, but even societies with large numbers of very low-income people suffer clear labor constraints to production at seasonal periods.[10] Now, increasing total employment may require mechanization to break seasonal bottlenecks. It is by

no means certain, however, that such effort will not overshoot the mark, reducing total earnings of the poor. Ideally, research resource allocation would stress increase in efficiency, including labor efficiency, using redistribution of assets and income to deal with income distribution problems. Unfortunately, that is not necessarily how policy priorities get set. The conflict calls for detailed economic analysis of seasonal labor supply/demand balances to facilitate research on how to break seasonal labor bottlenecks without displacing labor and thereby reducing incomes of the poor. This is an area where cooperation between social scientists and production scientists can be particularly effective.

Presumably reduction of the arduousness of work is a widespread human objective. Technical innovation which accomplishes this is desirable on egalitarian grounds only if the benefits are distributed to those formerly performing the arduous task. In a communal society machine hulling of rice relieves the low-income women of a very difficult task and releases their time for better child care and other welfare-increasing activities. However, if income and assets are unequally distributed, displacing hand pounding of rice may simply eliminate the primary source of income of a low-income group with an increase in net income of a higher income entrepreneurial class and a higher income consuming group. A similar point could be made for many other rural activities. Again, conflict between stated societal objectives and societal realities greatly complicates research resource allocation.

As in the case of allocation among crops, a decision regarding one crop must be made on the extent to which various nutritional elements will be emphasized. Again, the main trade-off appears to lie in the choice between increasing protein content or increasing yield, or calorie production. As we have seen, the Western approach has tended to accent protein. Clearly, more research is needed, both on the effects of diet and health among the poor and on the extent to which foods naturally contain a sufficient balance of nutrients as long as the total quantity is adequate.

The Regional Problem

The choice of enterprise to emphasize and the approach to research on any one enterprise profoundly affect the distribution of income among geographic regions. This is the result of not only regional deficiencies in soils, topography, and climate, but also economic and social differences – including income differences – which affect the acceptability of various types of innovations. In the long run, the regional allocation of research resources may be one of the most powerful influences on regional power and equity.

In countries with generally adequate food supplies, such as Thailand, it

may be regional disparities of food which are most constraining to increased equity. Even mainland China has had great difficulty in meeting the problems of regional inequity. Trade-offs in research may be substantial, with emphasis on regions with poor production resources resulting in high costs of research and low increases in productivity. And again, the trade-offs in achieving objectives with unequal investment in education or with direct income transfers should be considered in allocating research resources.

An Example of a Research Policy Sequence

The criteria for research policy are, of course, dependent on the objectives stated for research policy, the research resource availabilities, and the political acceptability of alternative means of reaching objectives. The latter, of course, reflects a broader set of objectives, both explicit and implicit, and the weights on these objectives dictated by the power structure within the society. Pursuing objectives in a sequential manner recognizes that priorities can be established and that effective research requires clearly understood guidelines, which are possible only if objectives are separated and sequenced. Then research policy must set the priorities which order the sequence of effort – that is, not only the order of objectives but the ease of meeting particular objectives given the realities of the tasks and the resources. In particular it should be recognized that adding criteria to research both reduces productivity and reinforces the need for pursuing objectives sequentially rather than simultaneously.

The process may be exemplified by assuming that we are faced with a society attempting to increase participation of the poor in growth, but without major redistribution of income or assets. Such a society might first emphasize increasing yields per acre of the basic food grains in the most responsive areas of the country. This would release the wage goods constraint to employment and increase the supply of basic calories. As success is met on the basic food grain front, geographic area coverage of the effort would be expanded to less productive regions. Soon, coverage would be extended to additional crops, with priority given those which are particularly labor-intensive in production. The latter effort would be coordinated with expansion of demand either through exports, rising domestic incomes, or subsidies. In each case, however, the conditions of success require expansion of basic food grain production. The reason for this is obvious in the case of domestic markets, but even raising income from exports requires a large supporting increase of domestic food production.[11] Throughout each of these thrusts research would stress reduction in year-to-year yield variation because of the special risk aversion of lower income farmers.

Research Needs for Improved Research Direction

Because of our minimal background of knowledge and experience, the allocation of research resources offers in its own right an area ripe for research. Research in the social sciences to support optimal decision-making in allocation of production research resources needs to emphasize definition of societal objectives; sources and means of income by income class; the consumption pattern of various income classes; and the factor share bias of innovations.

Societal objectives have been defined in this chapter in terms primarily of level and distribution of income with added attention to uncertainty of income and nutritional status. However, little is known about the importance of absolute income as compared with relative income in determining well-being, yet that distinction may be crucial to determining optimal policy. Similarly, if research is to be keyed explicitly to societal objectives, is is important to know whether the same forces which prevent land reform, presumably because redistribution of income is not a prime objective of society, will prevent effective impact of research results which would effect redistribution of income. Or could it be a stated objective to effect income redistribution through research only as long as such effort is not effective? It may be inconvenient to make societal objectives explicit, but that may be essential to effective public sector decision-making.

Only when it is known how much income each income class generates through what production means can research policy be designed to improve income distribution. Innovation affects income distribution through its effect on demand for factors of production and supply of consumer goods. Generally the poor provide labor, and relative increase in demand for labor increases their income in relation to that of others. Effective policy demands knowledge of the precise nature of labor supply and demand, including elasticity of labor supply. Such knowledge provides a basis for estimating returns to increased demand for labor and probable wage behavior. Similarly, consumption patterns of the low- and high-income classes differ greatly. Research concentrated on goods the poor consume will benefit them relative to the more well-to-do. Despite this obvious fact little detail is available on the precise nature of consumption patterns of the poor.

Finally, knowledge is needed of the effect of various innovations on the demand for payment to various factors of production. What is needed is knowledge not only of the average amount of labor used and yield increase but of the variation in functional relationships between input and output and the variance in those relationships. Then optimal choice of technology can be made in the context of varying risk and uncertainty and levels of input.

We close on a research-oriented note in this chapter on research alloca-

tions. Social scientists could contribute substantially to increased efficiency in this most crucial area of development. To do so, they must verse themselves in the technology of agriculture to grasp somewhat more fully the constraints that delineate the art of the possible. They must recognize the impracticality of a general equilibrium approach in this extraordinarily complex area and settle for numerous partial approaches and consequent doubt of whether or not they have even an approximation of a correct answer. Finally, they must immerse themselves in the operational context of the real world so that they may choose economically among the many possible "partial" problems in allocating their own potentially valuable resources.

NOTES

1. John W. Mellor and Uma J. Lele, "Growth Linkages of the New Foodgrains Technologies," *Indian Journal of Agricultural Economics*, 28:1 (January-March 1973), 35-55.

2. For a full discussion of this point see Uma Lele, *The Design of Rural Development: Analysis of Programs and Projects in Africa* (Baltimore: Johns Hopkins University Press, 1975).

3. Uma J. Lele and John W. Mellor, "Jobs, Poverty and the Green Revolution," *International Affairs*, 48:1 (January 1972), 20-31.

4. For a full treatment, see Mellor and Lele, "Growth Linkages," pp. 35-55.

5. Graeme W. Donovan, "Employment Generation in Agriculture: A Study in Mandya District, S. India," Cornell University-USAID Employment and Income Distribution Project, Department of Agricultural Economics, Occasional Paper no. 71, Ithaca, Cornell University, June 1974.

6. Gunvant M. Desai and Michael G. G. Schluter, "Generating Employment in Rural Areas," *Seminar on Rural Development for the Weaker Sections* (Bombay: Indian Society of Agricultural Economics, 1973).

7. See Michael G. G. Schluter, "Interaction of Credit and Uncertainty in Determining Resource Allocation and Incomes on Small Farms, Surat District, India," Cornell University-USAID Employment and Income Distribution Project, Department of Agricultural Economics, Occasional Paper no. 68, Ithaca, Cornell University, February 1974.

8. *Ibid.*

9. See the discussion of this controversy in Uma J. Lele, "The Green Revolution, Income Distribution and Nutrition," *Proceedings – Western Hemisphere Nutrition Congress III*, ed. Philip L. White (Mount Kisco, N.Y.: Futura, 1972).

10. M. Habibullah shows this clearly for Bangladesh in *The Pattern of Agricultural Unemployment: A Case Study of an East Pakistan Village* (Dacca: Dacca University, Bureau of Economic Research, 1962).

11. For a detailed analysis of this point, see Lele, *The Design of Rural Development*. For a somewhat different set of points, emphasizing the dependence of labor-intensive exports on relaxing the food grains constraint to employment, see John W. Mellor and Uma Lele, "The Interaction of Growth Strategy, Agriculture and Foreign Trade – The Case of India," *Trade, Agriculture and Development*, ed. G. S. Tolley (Cambridge: Ballinger, 1976).

24

An Empirical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study

J. P. Ramalho de Castro and G. Edward Schuh

Increased attention has been given in recent years to the management and allocation of research resources according to specified criteria or to some sense of priority.[1] This increased concern is in part a result of the growing recognition that research is indeed an economic activity involving the organization of scarce resources. But, in addition, it reflects the growing consensus that technical change is a key element in the development process.

This chapter reports a modest attempt to formalize the economic concepts available for establishing research priorities, to utilize data to test the model, and to bring to bear as much empirical information as possible on the problem of establishing research priorities for a particular economy. The basic model draws on the concepts of consumer and producer surplus, the neoclassical theory of production, recent work on models of induced technical change, and a two-sector general equilibrium model. Important themes in the analysis are (1) that the specification of goals is a critical element in the establishment of research priorities; (2) that an understanding of the distribution of benefits from technical change is a key to understanding the extent to which these goals are met; and (3) that in a country the size of Brazil regional differences are important.

The Model

The starting point of the model is to view new production technology as having an instrumental role in attaining a larger set of goals and objectives. Tech-

nical change in agriculture can be understood in the context of the contributions agriculture can make to general economic development. These contributions include (1) supplying food for the total population; (2) supplying capital to the economy, especially for expansion of the nonfarm sector; (3) supplying labor for the expansion of nonfarm activities; (4) supplying exchange earnings in order that imports critical to the development process can be purchased from abroad; and (5) providing a market for the products of the nonfarm sector. The development and distribution of new production technology can be a powerful means of strengthening agriculture in regard to each of these factors. Hence, the demand for new production technology can be derived from this framework.

There are rather obvious conflicts between some of these contributions. For example, if all of agriculture's surplus earnings are siphoned off as capital for the nonfarm sector, agriculture's potential as a market for goods and services produced by the nonfarm sector is greatly reduced. In addition, the relative importance of each contribution will depend on the stage of development of the economy, the particular development model the government uses as a basis for economic policy, and the specific policy measures the government uses to implement its policy.[2]

For analytical purposes we specified four alternative sets of goals for the research program: (1) to increase the total net income of the agricultural sector; (2) to increase employment and income of workers 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. These goals are somewhat broader than the contributions that agriculture can make to economic development, although in most cases a direct linkage can be made to the latter. The advantages of these particular specifications are that they are operational in terms of the more formal model that will be presented below and that they are commonly held goals for agricultural research.

It should be obvious that to attain each of these goals may require different "kinds" of technical change. Hence, the choice of technology becomes an important issue. In addition, the kind of technology chosen will have different income distribution consequences, as will the choice of product on which to focus the research program. Therefore, we next turn to a discussion of the theory that will help to answer these questions.

Induced Technical Change

The basic idea of the induced innovation theory is that innovations and their resource-saving directions depend on economic conditions prevailing within a given economy rather than being determined exogenously to it, as

is frequently assumed. Hayami and Ruttan have extended the theory of induced innovation from its micro-formulation to an understanding of technical change at the sectoral level.[3]

Two elements of the model developed by Hayami and Ruttan are of interest from our standpoint. First, they recognize that technical change can take alternative routes in its resource-saving effects and that the particular route it takes is conditioned by relative factor scarcities. This idea gives rise to the concept of an efficient path for technical change and suggests the importance of allocating scarce research resources so that technical change is directed along such an economically efficient path. Hayami and Ruttan argue that for agricultural technology to be an efficient source of growth, it must be directed toward easing the barriers to output expansion posed by inelastic factor supplies.

The second element of the Hayami-Ruttan model is the instrumental role it assigns to individual "technologies" in facilitating the substitution of one input for another. Hayami and Ruttan view biological improvements, such as the development of varieties that are more responsive to fertilizer, as a means of facilitating the substitution of fertilizer for land. Mechanization, on the other hand, is a means of facilitating the substitution of land for labor in the sense that it permits a substantial change in the man/land ratio. In both cases there is an infusion of capital into the production process, but the contribution in facilitating substitution among the primary inputs of land and labor may be as important as the contribution of the additional input qua input.

We use the Hayami-Ruttan framework in an *ex-ante* sense as a normative model of what direction technical change *ought* to take if it is to be an efficient source of growth. Our analytical-empirical task is to identify the resource constraint that is inhibiting output expansion so that production technology can be directed toward easing such constraint. This information will enable us to determine whether the research program should concentrate on biological or mechanical innovations.

Distribution of Benefits between Consumers and Producers

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. Technical change has important income distribution consequences, and these in turn are important in determining the extent to which a given research program will attain specified goals. One issue is the extent to which the benefits of technical change redound to the consumer or to the producer. A second issue is the extent to which the producer

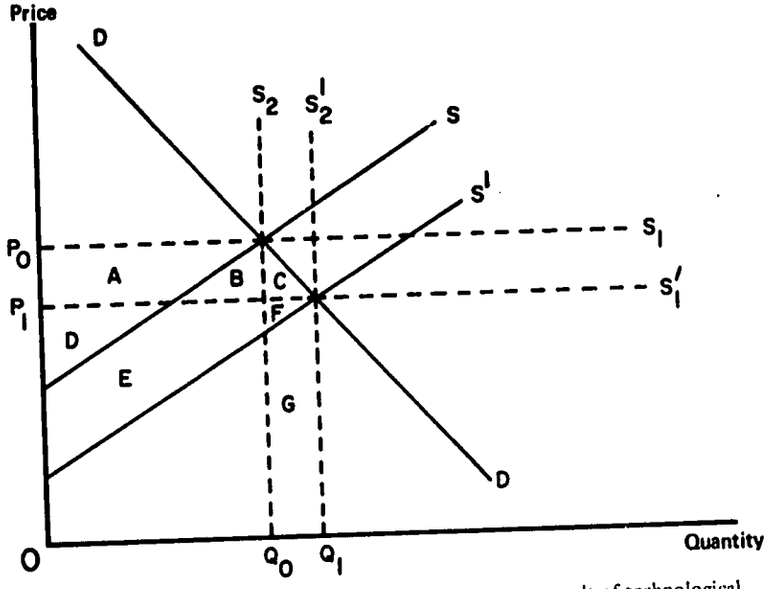

Figure 24-1. Effects of a shift in the supply curve as a result of technological change in a closed economy.

surplus redounds to particular factors of production. In this and the following sections we turn to a consideration of these issues.

The concept of economic surplus is a useful tool for analyzing the distribution of benefits between consumers and producers.[4] The basic analytical model for a closed economy is given in Figure 24-1. Suppose that before some technological innovation the equilibrium price and quantity are 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.

For our purposes we want to extend this model to that of an open economy with traded products. The distribution of benefits in this case can be un-

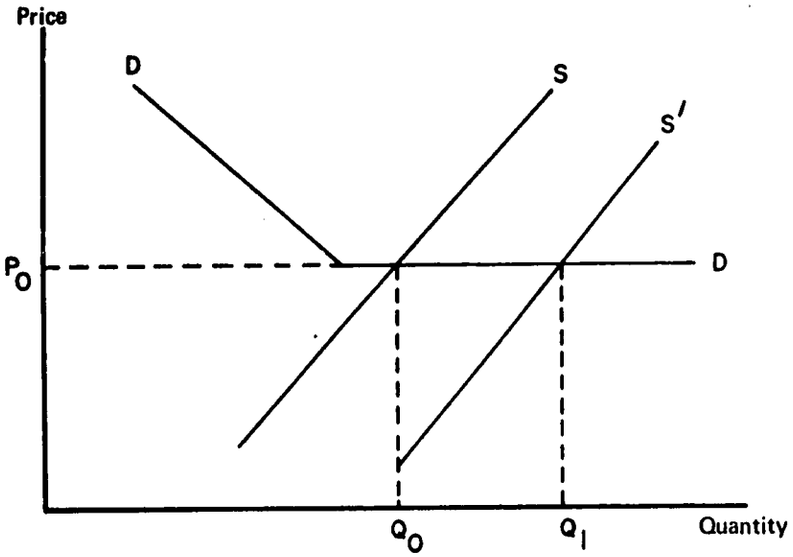

Figure 24-2. Effects of a shift in the supply curve as a result of technological change in an open economy.

derstood by means of Figure 24-2. The figure is drawn on the assumption that the country is relatively unimportant in world markets so that its exports will not affect world prices. This assumption can be relaxed, although it was not necessary to do so in our research.

With a shift in the supply curve, the elastic demand curve implied by an open economy will not allow for gains in consumers' surplus if the product has traditionally been exported. If the product was not exported before 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 before the technical innovation the domestic price were above the world price and "protected" either by transportation costs or by trade policy.

It can be seen from Figure 24-2 that all economic surpluses will accrue to the producers if the product has been traditionally exported. If this is the first time the product has been exported, however, and if 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.

These concepts are useful tools for analyzing the return to investments in research, as illustrated among others by Griliches, Peterson, Ayer and Schuh, and papers presented at the Airlie House conference.[5] And if rate of return

criteria were to be used for establishing research priorities, the basic framework would provide a means of selecting the products to which researchers should give priority in their research efforts.

For our purposes, however, these concepts provide a means of setting 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 the consumer, research resources can be allocated accordingly.

It should be noted that 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. Although recognized where relevant, the gains realized through the export multiplier are not explicitly accounted for in the empirical work reported below.

Technological Change and the Neoclassical Theory of Distribution

Another important aspect of the present study is to determine how the benefits of technical change are distributed among the factors of production. The neoclassical theory of distribution provides the means for analyzing this problem. At the macroeconomic level one distributional question of interest concerns the behavior of aggregate relative shares in response to technical change. In fact, one customary way of defining technological bias is by whether the relative share of labor increases, remains unchanged, or declines as technological change takes place.

The problem in using the pure neoclassical theory is that the analysis is restricted to two factors. One possible way to proceed is to specify the aggregate production function in separable form, where the degree of substitutability among inputs is assumed to be greater than one within the postulated subfunctions, but less than one between subfunctions. More specifically, assume

$$Y = F(f(L^*, K_L^*), g(T^*, K_T^*))$$

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).[6] The asterisk indicates that the factor in question is measured in "effective" units, e.g., $L^* = t_L L$, where t_L is an index of nonneutral 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 permit the definition

of price indices for the subfunctions on the basis of which the optimization process can be performed ir two separable stages.

Elasticities can be derived which indicate the effect of nonneutral technological change on the income to individual factors, on the functional distribution of income, and on the employment of individual factors of production. Since the magnitudes of the estimated elasticities of substitution were not consistent with the a priori restrictions, this part of the analysis was prejudiced.[7] However, the parameters of the production function are of interest in their own right and will be presented below.

General Equilibrium Considerations

The analysis above assumes a partial equilibrium framework. However, to provide a complete view of the effects of technological change in one sector of the economy on employment and the returns to factors, general equilibrium considerations must be taken into account. The problem that arises in the general equilibrium framework is that technical change affects the level of output, which in turn can affect the relative prices among products. The change in price of the product can lead to a redeployment of resources which in some instances can more than offset the direct effect of the production technology on factor productivity.

Empirical Results

The empirical results are presented in three sections: (1) estimates of the total potential gains from an assumed technologically induced shift in the supply curve for selected crops, together with estimates of the distribution of these gains between producers and consumers; (2) estimates of the parameters of the underlying production function; and (3) data on recent trends in factor prices as a basis for determining relative factor scarcity.

Total Gains from Assumed Shifts in the Supply Curve and Their Distribution between Consumers and Producers

At some point in the decision process allocation decisions on research money are made on a crop basis. (The livestock sector was excluded from the present study). Policy makers decide that X amount of money will be allocated to crop Y and that some crops will receive attention while others will not. Our assumption is that decision variables involved in this process include some judgment about the expected flow of total benefits from a given research effort and some notion of who will receive the benefits of the research.

Two criteria were considered in selecting crops for this part of the analysis. 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 criterion was the size of the price elasticity of demand, since this parameter is important in determining the relative distribution of benefits between consumers and producers.

An important determinant of the size of the demand elasticity is whether the product is exported or not. Therefore, it was decided to choose some products that have only a domestic market and others that either have been exported in the past or have the potential to be exported. By this means the analysis would consider a rather wide range of values for the structural parameters.

The crops chosen according to these criteria were cotton, sugarcane, corn, rice, edible beans, and manioc.[8] Cotton and sugarcane are traditional exports from Brazil. Rice and corn have been exported occasionally but for the most part on a much smaller scale than cotton and sugarcane. Edible beans and manioc are traditional staple foods which for the most part have not been exported. During the period 1966-70 these six crops accounted for 46 percent of the total value of output from crops and 74 percent of the total area in crops. Moreover, each of them was grown over a rather wide area in Brazil.

Available estimates of the demand and supply elasticities for these crops are summarized in Tables 24-1 and 24-2. As the tables indicate, there has been more work on the supply side than on the demand side, and on the supply side there were more estimates available for the state of São Paulo than for Brazil as a whole or for other states.

Given the range in the estimates of the parameters, three alternative estimates for each crop were selected on the supply side – low, medium, and high – and two were selected on the demand side – low and high. On both the demand and supply side it was necessary to specify arbitrary values in some instances in order to have a desired range in the parameters. For sugarcane and rice a relatively elastic response to price on the demand side was assumed since both have considerable potential in world markets. (The available estimate for sugarcane is based solely on the domestic market.) In the case of manioc, for which no estimates of the demand elasticity were 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 24-3. It would have been desirable to have more precise estimates of these parameters, but econometric work is not yet very far advanced in Brazil. Consequently, the results which are presented below have to be interpreted as illustrative of the effects of demand and supply elasticities in determining who receives the benefits from technologically induced shifts in the supply curves.

Since the analysis is cast in an *ex-ante* rather than an *ex-post* framework,

Table 24-1. Selected Supply Elasticities for Brazil, State of São Paulo, and State of Goias from Various Authors

	Brazil						São Paulo							Goias	
	Pastore		Paniago		Thompson		Pastore		Toyama & Pescarin		Brandt		Ayer & Schuh	Villas	
Products	SR[a]	LR[b]	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	LR	SR	LR
Cotton	.19	.63					1.22	2.03	.37		.69	1.57	.944		
Sugarcane	.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							

Source: A. C. Pastore, "A oferta de produtos agricolas no Brasil," *Pesquisa e planejamento*, 1:2 (December 1971), 171-234. E. Paniago, "An Evaluation of Agricultural Prices for Selected Food Products: Brazil," Ph.D. thesis, Purdue University, 1969. R. L. Thompson, "The Impact of Exchange Rate Policy and Other Restricted Policies on Corn Exports in Brazil," M.S. thesis, Purdue University, 1969. N. K. Toyama and R. M. C. Pescarin, "Projeçoes da oferta agricola do Estado de São Paulo," *Agricultura em São Paulo* 17:9-10 (September-October 1970), 1-97. S. Brandt, M. Barros, and D. D. Neto, "Relaçoes area-preço de algodao no Estado de São Paulo," *Agricultura em São Paulo*, 12:1-2 (January-February 1965), 31-38. H. W. Ayer and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in São Paulo, Brazil," *American Journal of Agricultural Economics*, 54:4 (November 1972), 557-569. A. T. Vilas, "Estimativas de funçoes de oferta de arroz para o Estado de Goias e suas implicaçoes economicas, periodo 1948-1969," M.S. thesis, Federal University of Vicosa, Brazil, 1972.

[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.

Table 24-2. Selected Elasticities of Demand for Brazil and the State of São Paulo from Various Authors

Product	Elasticity	Author
Cotton	− 5.3[a]	Ayer & Schuh
Sugarcane	− .56[b]	Martini
Rice.	− .10	Paniago
	− .16	Mandell
Corn	− .66	Thompson
Edible beans	− .32	Paniago

Source: H. W. Ayer and G. E. Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in São Paulo, Brazil," *American Journal of Agricultural Economics*, 54:4 (November 1972); E. Martini, "Açúcar no Brasil: Produçao, procura e preço," M.S. thesis, Federal University of Vicosa, Brazil, 1964; E. Paniago, "An Evaluation of Agricultural Prices for Selected Food Products: Brazil," Ph.D. thesis, Purdue University, 1969; P. I. Mandell, "A expansão da moderna rizicultura: Crescimento da oferta numa economia dinamica," *Revista Brasileira de economia*, 26:3 (July-September 1972), 169-236; R. L. Thompson, "The Impact of Exchange Rate Policy and Other Restricted Policies on Corn Exports in Brazil," M.S. thesis, Purdue University, 1969.

[a] Elasticity for the State of São Paulo.

[b] Demand elasticity for sugar.

an arbitrary shift of 10 percent was assumed for the supply curve. One of the first results obtained is the flow of total benefits by crop that would result from the specified shift. Based on the average value of output in the 1966-70 period, the annual flow of benefits from a 10 percent shift to the right in the supply curve is estimated to be: rice, $157 million; corn, $145 million; sugarcane, $106 million; manioc, $92 million; edible beans, $88 million; and cotton, $88 million. These data represent gross benefits since neither the cost of obtaining the supply shift, the value of complementary inputs such as fertilizers, nor adjustment costs are considered. The gross benefits give some notion of the relative payoff from investments in research under the assumptions that the cost of obtaining a given supply shift is the same among crops and that complementary inputs and adjustment costs are ignored. It is worth noting, moreover, that the gross flow of benefits is determined largely by the relative economic importance of the crop. The elasticities have less influence.

Data on the relative distribution of these benefits among consumers and producers according to various assumptions about the structural parameters are summarized in Table 24-3. The results support the notion that technological shifts for crops that have a relatively high price elasticity of demand (e.g.,

Table 24-3. Percent of Benefits to Consumers and Producers Resulting from a Specified Shift in the Supply Curve, Based on Two Demand and Three Supply Elasticities for Each of Six Crops, Brazil

Crop	Demand Elasticities	Percent of Benefits[a]					
		Consumer	Producer	Consumer	Producer	Consumer	Producer
		(.19)		(.94)		(1.57)	
Cotton	− 2.00	9	91	32	68	42	58
	− 5.30	4	96	15	85	23	77
		(.10)		(.60)			
Sugarcane	− .56	16	84	52	48		
	− 2.50	4	96	19	81		
		(.31)		(1.17)		(2.34)	
Rice	− .16	20	80	88	12	94	6
	− 1.50	17	83	44	56	61	39
		(.15)		(.58)		(3.32)	
Corn	− .30	33	67	66	34	92	8
	− .66	18	82	47	56	83	17
		(.15)		(.31)		(.43)	
Edible beans	− .32	32	68	49	51	57	43
	− .50	23	77	38	62	46	54
		(.11)		(.47)		(.96)	
Manioc	− .10	52	48	82	18	91	9
	− .30	27	73	61	39	76	24

[a] Supply elasticities are given within parentheses.

crops with export potential) will tend to favor the producer, while for crops with a relatively low price elasticity of demand (e.g., necessities) the shifts tend to favor the consumer. However, the results also illustrate that it is the relative magnitude of the elasticities that is important. If the supply elasticity were larger than the demand elasticity, regardless of the absolute size of the demand elasticity, the consumer would tend to receive a larger share of the benefits. (The extreme cases of perfectly elastic or perfectly inelastic demand and supply curves are ruled out of this comparison.)

The case of rice illustrates this relationship rather well. Even with a relatively low price elasticity of demand, producers receive a major share of the benefits from a shift in the supply curve if the supply elasticity is low. Similarly, if the supply elasticity is high, consumers can receive a (comparatively) large share of the benefits even if the demand curve is relatively price elastic. To benefit consumers, therefore, one would want to induce shifts in the supply curve for crops that have a relatively low price elasticity of demand and a relatively high supply elasticity (manioc may be a case in point). To benefit producers, on the other hand, one would want to shift the supply curve for crops that have a relatively high price elasticity of demand and a relatively low supply elasticity (cotton, for example).

An additional inference that could be drawn is that, if the crop has a high price elasticity of demand, the research effort might be directed to increasing the supply elasticity if it were desired to increase the share of benefits going to the consumer. This might be done by increasing the geographic area of adaptability of a particular crop.

Estimates of the Production Function

The estimates of the parameters of the separable production function provided important insights about the stage and character of modernization in Brazilian agriculture, even though they did not turn out quite as expected.* To estimate the parameters of this function it was assumed that the aggregate production function is strongly separable into two subfunctions that are homogeneous of degree one and which belong to the CES class of production functions. One subfunction contained labor and the "laboresque" capital variable (mechanization) as independent variables, and the other contained land and the "landesque" capital variable (fertilizers). It was expected that the elasticity of substitution between the two variables in each subfunction would be greater than one and that the elasticity of substitution between the two subfunctions would be less than one.

Two time series of data for Brazil as a whole were available to estimate the parameters of the labor subfunction. 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 the price. The flow of tractor services was estimated as the *combination* of an opportunity cost rate of interest and depreciation. (The opportunity cost of capital was assumed to be 10 percent, and the depreciation charge was 5 percent. The latter assumes straight line depreciation and an expected life of twenty years. Sensitivity analysis indicated that the results were quite stable under alternative measures of the flow of services.) Estimates of the labor input were made from data on the total agricultural labor force. The daily wage rate for the cash, daily-paid worker of São Paulo was used as the price of labor.

The second time series provides estimates of the stock of horsepower on farms and is available only 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. Again, the price of the "flow" of horsepower was

* The authors' detailed discussion of the production functions utilized has been omitted to shorten and simplify the presentation. For details, see the work cited in n. 7. – Ed.

Table 24-4. Regression Results for the Labor Subfunction with Time Series Data, National Model, Brazil

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

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

estimated by assuming a twenty-year life for the tractor. The labor input and price of labor were defined in the same way when this data series was used.

The statistical results with the two sets of data are presented in Table 24-4. In both cases they 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 price coefficient has opposite signs in the two equations. (The R^2 in the horsepower specification is also substantially higher than it is in the tractor specification.) The sign when data for the longer period (and the tractor variable) were used was contrary to a priori expectations, while the expected sign was obtained when data for the shorter period (and the horsepower variable) were used.

One interpretation of these results is that about 1960 there was what Brown would call a technological turning point.[9] To test this hypothesis, the 1950-71 series was disaggregated into two periods, one extending from 1950 through 1961 and the other from 1962 through 1971. The statistical results for the two periods are presented in Table 24-5. They support the hypothesis of the existence of a turning point.

The evidence for a technological turning point is rather strong, since the negative coefficient for the more recent 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 and hence not entirely consistent with expectations. Despite this problem, the results with the horsepower measure were used in further analyses, in part because horsepower would seem to represent a conceptually "cleaner" measure of the services provided by laboresque capital, and in part because the use of this measure results in a larger coefficient of determination for the estimation equation (.92 in contrast to .48).

Table 24-5. Regression Results for the Labor Subfunction with 1950-71 Time Series Disaggregated into Two Components, National Model, Brazil

Coefficients	1950-61	1962-71
Constant term	− 10.500*	5.570*
Price variable	2.754	− 2.511
	(12.510)[a]	(− 2.902)
R^2	.93	.48
D.F.	10	8

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

Both the notion of a turning point and the relatively small coefficient for the price variable are plausible results. Up until 1960 the level of mechanization was indeed low in Brazil.[10] 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 yields.[11]

During the 1960s there was considerable mechanization in Brazil. Moreover, a start was made toward mechanizing the harvesting operation, especially for crops like wheat, soybeans, and cotton, and, to a lesser extent, sugarcane. The mechanization of the harvesting operation is generally believed to be strongly labor displacing.

This difference in both the extent and the kind of mechanization seems a plausible explanation of the turning point. The finding of a coefficient no greater than one is probably explained by the fact that as late as 1971 mechanization in general was fairly limited and in particular was not yet widely used in the harvesting operation. As mechanization becomes more widespread, however, and as it is extended to the harvesting operation through greater use of combines and harvesters, the substitutability of capital for labor will probably increase. This has important implications for the establishment of research priorities.

To estimate the parameters of the land subfunction, data were available on the total quantity consumed and the respective prices for each nutrient (N, P, K) plus the area in crops in Brazil.[12] Unfortunately, data were available on land values or land rentals only since 1966. Therefore, only the price of fertilizer was used as an independent variable in estimating the elasticity of substitution. This specification assumes that the price of land does not vary systematically with the price of fertilizer.

Given that the results for the labor subfunction suggested a turning point in the production technology at some time in the early 1960s, the equations

were estimated for two different time periods: 1950-60 and 1961-70. In addition, separate models were estimated for each nutrient and for the aggregate of the three.

The statistical results (Table 24-6) were consistent with those for the labor subfunction in that they also indicated the existence of a technological turning point in the early 1960s. 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 were consistent with the hypothesis that the elasticity of substitution between fertilizer and land is zero, or that they are complements in production.

When data from the 1961-70 period were used, 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 coefficients all have the expected signs, and for nitrogen and potash the coefficients (elasticities of substitution) are greater than one. This suggests that fertilizer was becoming a good substitute for land.

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 1950s the modern inputs of fertilizer and machinery were still used at relatively low levels. The complementarity of fertilizer with land was not quite so high as was the complementarity of mechanization with labor. In fact, fertilizer application may have been doing little more than replacing nutrients removed by crops. During the decade of the 1960s, however, the use of both fertilizer and mechanization appears 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.

Because of data limitations, only one estimate of the elasticity of substitution between the two subfunctions was made. The statistical results were reasonably good. The coefficient of determination was relatively high (.74), and the coefficient of the input/output ratio had the expected sign and was significant at the 1 percent level. The size of the elasticity of substitution (.90) as estimated from the input/output ratio was consistent with a priori expectations (less than 1).

Trends in Factor Prices

Trends in factor prices should give some notion of relative factor scarcity and hence some notion of the direction in which research should be focused in the factor-factor dimension. It was originally hoped to be able to estimate

Table 24-6. Regression Results for the Land Subfunction, Time Series Data, 1950-70, Brazil

Item	N		P_2O_5		K_2O		Total	
	1950-60	1961-70	1950-60	1961-70	1950-60	1961-70	1950-60	1961-70
Constant term	2.004	2.994	1.060	2.395	.462	3.587	.869	3.341
Price of fertilizer	− .778	− 1.025**	− .202	− .717*	− .079	− 1.237**	− .010	− .933**
	(− .860)[a]	(− 7.328)	(0.437)	(− 2.729)	(− .105)	(− 3.424)	(− .015)	(− 5.751)
R^2	.07	.85	.02	.45	.00	.56	.00	.79
Degrees of freedom	9	8	9	8	9	8	9	8

* Significant at 5 percent level.
** Significant at 1 percent level.
[a] Numbers in parentheses are t ratios.

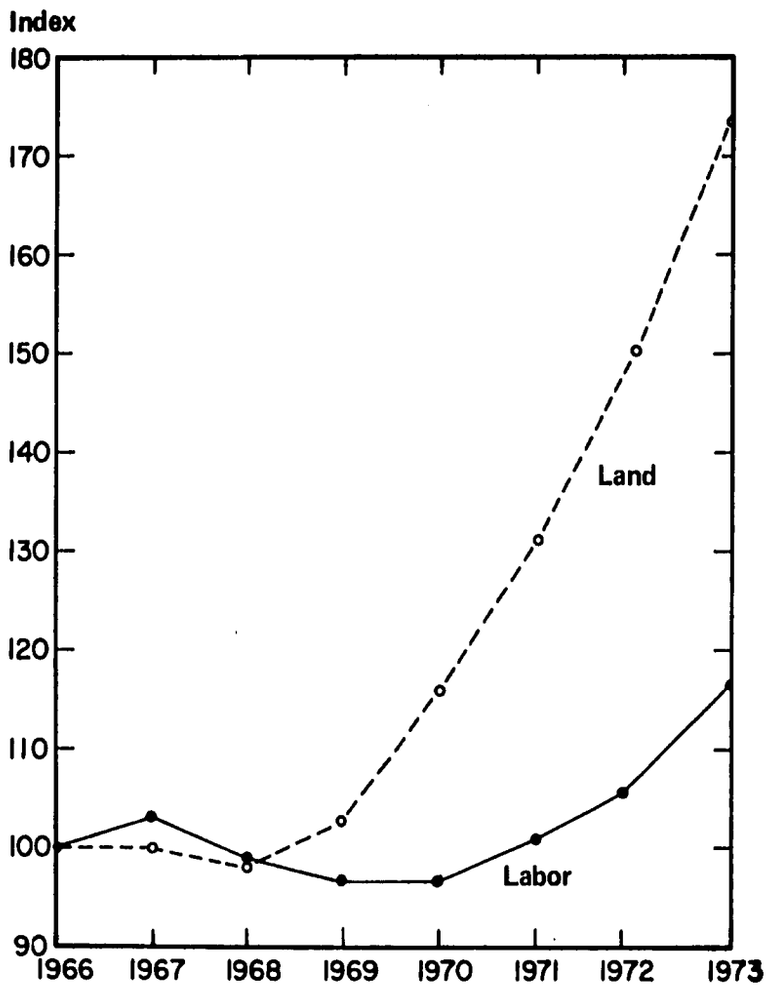

Figure 24-3. Recent trends in factor prices in real terms, Brazilian agriculture, 1966-73 (prices deflated by the cost of living index; data for 1973 refer to the first semester).
Source: Fundaçao Getulio Vargas, *Conjuntura Economica*, various issues.

implict prices through knowledge of the production function, but, because the lack of time series data on land values precluded the identification of a key parameter, this was not possible. Instead, trends in the prices of the individual inputs were considered.

Data on the real price of land and labor, the two primary inputs, are graphed in Figure 24-3. The data indicate that between 1968 and 1973 the price of

land had been increasing faster than the price of labor, although the prices of both have been increasing since 1970. These data suggest that in recent years land has become increasingly scarce in relation to labor. Therefore, a tentative conclusion is that the agricultural research program should give special attention to the development and adoption of land substitutes.

This conclusion should be tempered with a certain degree of caution, however, because Brazil is basically not 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. Thus it is possible that the relative scarcities of land and labor may change, especially if the recent rapid rates of industrialization continue and if new areas of fertile land become available to the economy as a result of improvements and extensions of the transportation system.

The trends in the prices of the close substitutes of labor and land – tractors and fertilizers, respectively – provide additional insights into what direction research should take. 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 experienced the greatest decline in price, followed by potassium, with the price of phosphorus (an important nutrient under Brazilian conditions) declining the least.

These data abstract from the recent upsurge in fertilizer prices. However, if this is of a temporary nature, the data on price trends suggest that research on the land subfunction – the development of improved varieties, increased 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.

The decrease in fertilizer prices which was occurring until recently makes the development of fertilizer-responsive varieties an attractive means of easing the emerging land constraint. If the current economic boom continues, however, the mechanization of agriculture may also become an increasingly important aspect of the development process.

Finally, the use of modern inputs has increased fairly rapidly in recent years. The fact that this increase appears to be the result of changing factor prices provides support for the model of induced technological change from which the present analytical model was developed.

Economic and Policy Implications

The results presented above do not provide conclusive recommendations on research priorities since they do not take account of the expected costs of making a given technological advance. However, they do suggest certain emphases for consideration in allocating a given research budget among the many alternatives faced by the decision-maker. The particular emphasis chosen will depend on the goals held for the research program.

The following discussion is organized in four parts. First, the focus of the research in the factor-factor dimension is dealt with. Then some general equilibrium matters are discussed, followed by a consideration of research priorities in the product-product dimension. Finally, a crude evaluation of the potential for technological change in the six crops studied is presented as a proxy for the cost of making technological advances with them. An implicit assumption throughout the analysis is that the rate of return to investment in agricultural research will be high.

The Factor-Factor Dimension

In the context of the Hayami-Ruttan induced innovation model the correct technological path for a country to choose is that which eases the particular factor scarcity that is constraining output expansion, with the factor scarcities of major interest being those of the primary inputs, land and labor. The trends in relative factor prices are important, since these would indicate which resource was most inelastic in supply.

Data on the trends in relative factor prices were summarized in the previous section and provide strong clues on the direction that research should take in Brazil. There was evidence of a growing relative factor scarcity of both land and labor in recent years, but the price of land was increasing at a much higher rate than the price of labor. This suggests that greater emphasis should be given in the research program to the land subfunction than to the labor subfunction. Of particular interest would be research which helps to bring more land into production (soil research, for example) or which facilitates the replacement of land by land substitutes. Soil research might be focused on problem soils such as the *cerrados*,[13] while biological research might focus on the development of varieties that are more responsive to fertilizer.

A legitimate question might be raised whether so much emphasis on raising land productivity is justified when labor productivity is so low and higher earnings are not likely to be realized until the productivity of labor is increased. These alternatives are not mutually exclusive, however. If one recognizes the well-known relationship between labor productivity and the productivity of land and the land/man ratio,

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

(where Y = gross output, L = labor, and T = land), it becomes clear that increasing the productivity of land may raise the productivity of labor without having a large labor-displacing effect. To focus more directly on raising labor productivity by increasing the land/labor ratio (by increasing mechanization, for example) may have a strong labor displacement effect.

Considerations such as these may have special relevance in the Brazilian Northeast, where the land frontier is almost closed, some 63 percent of the labor force is still in agriculture, and the absorptive capacity of the nonfarm sector is still quite limited. Increasing the productivity of land may be the only way that agricultural research can improve the welfare of the rural population without having strong labor-displacing effects. Ultimately, of course, other measures are needed to solve this problem, including greater investments in schooling and training, the reduction in factor price distortions, and more generalized industrialization within the region. These may be more effective means of solving the problem of low returns to labor than agricultural research per se.

This discussion of the special problems of the Northeast brings to the fore the larger question of regional disparities in a country as large as Brazil. For example, in contrast to the Northeast, the frontier of the Central West is characterized by a relative abundance of land and a relative scarcity of labor. Sanders has argued that one of the reasons for mechanization on the Mato Grosso and Goias frontiers is the cost of obtaining and controlling seasonal labor.[14]

Trends in the prices of land and labor in selected regions are presented in Figures 24-4 and 24-5. Land prices have been increasing at a faster rate in the old regions (Northeast, East, and South) than in the more recently opened region, the Central West. There is less disparity in the trends in real wages, but in the last two years there was a sharp upward movement in both the West and the East. The latter region is close to the industrial heartland of Belo Horizonte, Guanabara, and São Paulo. The rapid industrialization of recent years has drawn a lot of labor away from agriculture in this region, with the result that the real wage has started to rise.

To summarize, the discussion above 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 regional diversity in Brazil, a case can be made for regional differences in research policy. In the Northeast, East, and South, major emphasis should be given to raising land productivity. In the West and East, however, a labor constraint is emerging. Moreover, if the economy continues to expand at the rapid rates of the recent past, more attention may need to be given generally to the problem of labor scarcity.

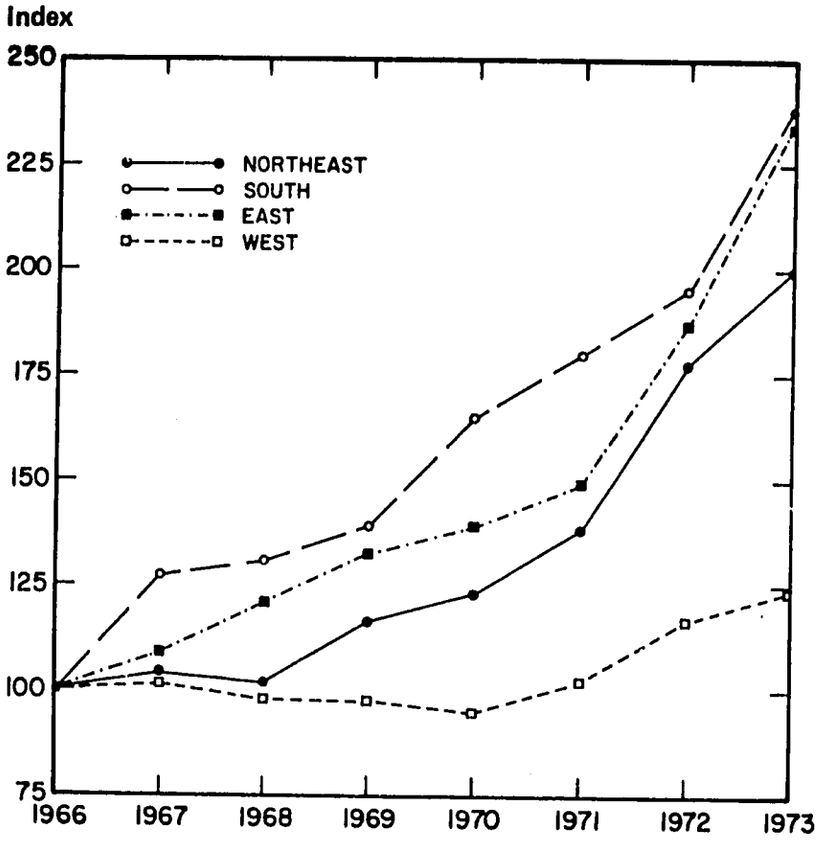

Figure 24-4. Recent trends in land prices in selected regions, real terms, Brazil, 1966-73 (prices deflated by the cost of living index; data for 1973 refer to the first semester).

General Equilibrium Considerations

The analysis above has been cast in a partial equilibrium framework. However, a technological breakthrough is expected to lead to a shift of resources from one crop to another as well as from agriculture to the nonfarm sector. A two-sector general equilibrium framework is useful for analyzing these shifts and for drawing implications regarding the allocation of research resources.[15]

The contribution of the general equilibrium model is to introduce the price elasticity of demand for the product into the analysis so that conclusions can be drawn about changes in the distribution of income between the two fac-

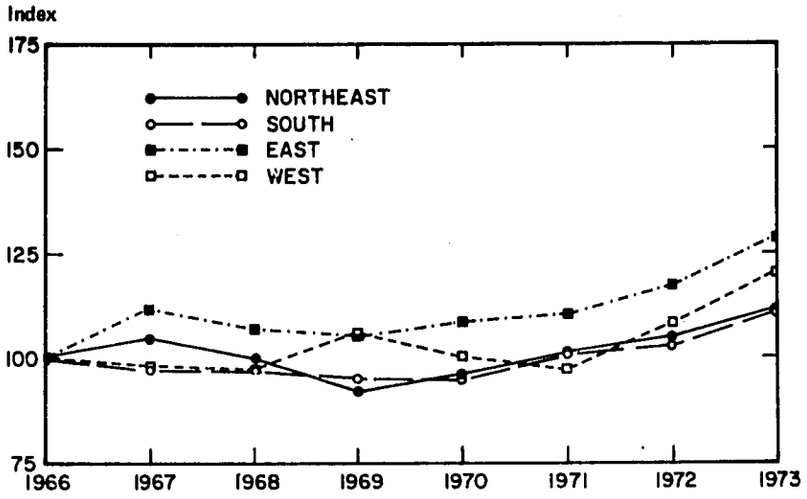

Figure 24-5. Recent trends in labor prices for selected regions, real terms, Brazil, 1966-73 (prices reflected by the cost of living index; data for 1973 refer to the first semester).

tors of production, labor and capital. The discussion will be conducted in two steps. First, the agricultural sector will be analyzed in relation to the nonagricultural sector. Second, groups of crops, classified according to their price elasticity of demand, will be considered in relation to the rest of the economy.

Consider the introduction of a land-saving (or land-augmenting) technical change into agriculture. The estimates of the elasticities of substitution in the production function were .625 between labor and mechanization, .933 between land and fertilizer, and .900 between the land subfunction and the labor subfunction. Since the labor subfunction was made up primarily of labor (the level of mechanization being quite low), we have essentially two estimates of the elasticity of substitution between labor and other inputs: .625 and .900. The latter is probably more appropriate for the present analysis, for it indicates the elasticity of substitution for a broader category of inputs.

In a closed economy the price elasticity of demand for agricultural output in the aggregate tends to be low. Although to the best of our knowledge no estimates are available for Brazil, most analysts would judge this elasticity to be in the range of .4 to .6. Under these conditions a decrease in labor incomes is expected from the technical change, and a redeployment of labor out of the sector will be the result.

If the economy is opened, the demand elasticity will be much larger, with the size depending on the extent to which the small-country assumption applies and on the relative importance of exports. In principle the elasticity of demand in the aggregate could be sufficiently large so that no decline in labor income would result nor would a redeployment of labor out of agriculture be required. However, in the past Brazil has discriminated severely against its agricultural sector by means of restrictive trade policies (export quotas) and a greatly overvalued currency. Consequently, technical change would have been strongly labor displacing, almost independently of what technological path was chosen.

During the late 1960s and early 1970s trade policy shifted to overt export promotion, with an exchange rate that was near equilibrium. But because of the convulsion in commodity markets in recent years, restrictive practices have been imposed again to protect the domestic consumer. This is being done at the very time that the research infrastructure is being strengthened. It should be noted that, although such policies do benefit consumers, they force a major adjustment problem onto the labor force.

The results are similar at the lower level of aggregation. Products such as rice, corn, edible beans, and manioc have relatively low price elasticities of demand. A technological change for any one or all of these crops will release labor to the rest of the agricultural sector and to the nonfarm sector, and adjustments will be required if a new equilibrium is to be reached. If the research program is focused on export products such as cotton and sugarcane, however, the expected outcome will be an increase in the return to labor and an increase in employment, other things remaining equal.

The moral to this story is that even technical changes which are not directly labor displacing can cause the displacement of labor as a result of the output effects and their effect on product price. To the extent that the research program focuses on export products and free trade is promoted, this problem need not arise. But to limit the research program to export crops is to forgo the benefits to consumers from a more generalized technical change. If these benefits are desired, then complementary policies to facilitate the labor adjustment problem are required.

The Product-Product Dimension

As the analysis above suggests, the choice of product for research emphasis is an important determinant of who will receive the benefits from a given expenditure on research. This is because the price elasticity of demand for the product is an important determinant of the distribution of benefits between the producer and the consumer, as well as the functional distribution of in-

come. The present section contains a more systematic analysis of this choice, cast in the framework of four alternative sets of goals. (The role of the supply elasticity is submerged in this discussion.)

If policy makers choose *to increase the income to the agricultural sector* as their primary goal, the products that should be considered are those with a large price elasticity of demand. Among the six products treated in this study, cotton and sugarcane would be the obvious choices, since they are traditional export products. But products such as corn, of which Brazil is a marginal exporter, would also have considerable potential. And more generally, products which are already exported or which would have export potential with technological improvements should receive attention.

The same set of conclusions would apply if the goal were *to increase the income and employment of agricultural labor*. If the technological change is in the land subfunction (i.e., the development of more fertilizer-responsive varieties and the increased use of fertilizer), then it is sufficient that the price elasticity of demand for the product be greater than .9 in order for the specified goal to be attained. Obviously labor-displacing technologies such as mechanization should be avoided, with an important caveat for that mechanization which does increase the demand for labor.

If the goal is *to increase consumers' welfare*, the choice should stress those products which have a low price elasticity of demand. And it may be desirable to emphasize those products that are consumed by low-income groups. Of the six products considered in this study, corn, edible beans, and manioc would receive high priority, as would rice. As development proceeds in Brazil, corn is declining in importance as a human food, but it may eventually become important as a feed input for the production of the livestock products. Rice is consumed by all income groups, but as long as the goal is to benefit the consumer, it should receive attention.

The attainment of the goal of *enlarging agriculture's contribution to general economic development* is a bit more complicated than achieving the other three goals. It depends in part on easing the constraints which prevent the economy from realizing its potential. The choice of product for research emphasis can contribute to this end, as seen by recalling the five contributions that agriculture can make to the general development of the economy: (1) to keep the price of food low so that wage pressures are diminished — a stimulus to industrialization, (2) to increase the supply of exchange earnings, (3) to supply capital for the expansion of the nonfarm sector, (4) to provide a market for the products from the nonfarm sector, and (5) to supply labor for the expansion of the nonfarm sector.

The product choice to facilitate contribution (1) is the same as that for

benefiting the consumer. Certain agricultural products are wage-goods, and these should receive emphasis. Among the six products considered, emphasis should be given to corn, rice, edible beans, and manioc.

Contributions (2), (3), and (4) will be attained by the same product choice that will increase the income to agriculture in the aggregate. To the extent that the choice focuses on export products there will be less competition with the nonfarm sector through the product market and a larger net gain to the economy.

Finally, to release labor from agriculture (5), two approaches can be taken. The first is to concentrate on labor-displacing mechanization. The second, and more important in the present context, is to focus the research effort on those crops with a low price elasticity of demand. Since these products tend to be those that are wage-goods, such an approach would make a double contribution to the labor market. In addition to releasing labor directly from the agricultural sector, it would also keep nominal wages down in the nonfarm sector by helping to lower the price of wage-goods.

The Potential for Technical Change

Our analysis up to this point has completely neglected the cost side of the question. The assumption has been implicit that comparable investments in research directed to each of the crops would produce comparable results. This is not likely to be the case.

In the absence of data on the costs required to obtain a given technological advance or data on the expected rate of return to research on particular crops, other rather crude indicators can be considered. For example, the immediate potential for yield increases might provide a crude proxy for the costs required to obtain yield increases. One measure of this potential would be a comparison of yields in Brazil with those in other countries. Another indicator would be the ease with which international technology can be adapted to Brazilian conditions.

A comparison of yields in Brazil with those from selected other countries for each of the six crops considered shows that, in general, Brazilian yields are quite low by international standards and have shown little tendency to increase. On the basis simply of the differentials between Brazilian and these foreign yields, we may hypothesize that yield increases will be easiest to obtain with corn, followed by rice, cotton, sugarcane, edible beans, and manioc, in decreasing order. This consideration of existing yield differentials, although a crude indicator, may provide a first approximation of the costs involved in increasing yields.

With respect to the transfer of technology, the most promising potential

would appear to be with those crops that have received attention from the international centers. Not only have these centers concentrated on increasing the ecological adaptability of the crops they work with, but they also have the capacity to deal with these crops under ecological and economic conditions that are at least somewhat similar to those in Brazil. By this criterion, rice, wheat, corn, and manioc may offer the lowest cost advances.

Some Concluding Comments

The "model" presented here does not lend itself to formalization in a system of equations. We believe, however, that it points out the directions in which analysis might proceed to develop such a formal model. One of the most serious deficiencies at the present time is the lack of input-output data on the research process itself – data which would indicate how much it would cost to make a given technological advance. In making more precise judgments about research priorities, however, some estimation of these costs could be achieved by working closely with knowledgeable biological scientists and administrators.

The analysis also points up the importance of certain key parameters as the basis for establishing research priorities. The state of knowledge for many of these for countries like Brazil is rather deficient. As the basic econometric work proceeds, however, improved judgments about research priorities can be made.

The question of research priorities is strongly dependent on policy makers' goals for both the agricultural sector and the research program itself. These in turn will depend on the stage of development of the economy, the particular development model used as a basis for policy, and the particular measures used to implement the policy. Economists would contribute greatly by identifying for policy makers what these goals might be.

Finally, research priorities cannot be established in isolation from other policy measures. Economic policy, for example, can either cancel out the expected goals of a research program or reinforce them. Similarly, economic policy can provide alternative means of easing output constraints, as illustrated by the road-building program in Brazil.

Economic policy is also important as a means of offsetting some of the social costs of the research program. Technical change which prematurely releases labor to the nonfarm sector can impose serious costs on particular groups in the society. These costs should enter the calculus of research priorities. Moreover, to the extent that effective programs are implemented to deal with them, the benefits of the research program will be larger.

NOTES

1. An important landmark on the way was the Minnesota Symposium, the predecessor to the present conference. See Walter L. Fishel, ed., *Resource Allocation in Agricultural Research* (Minneapolis: University of Minnesota Press, 1971).

2. For more detail on these issues see G. Edward Schuh, "Some Economic Considerations for Establishing Priorities in Agricultural Research," paper presented at Ford Foundation Seminar of Program Advisors in Agriculture, Mexico City, November 1972.

3. Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: Johns Hopkins University Press, 1971).

4. For an excellent review of the concepts of economic surplus and their use in applied research, see J. M. Currie, John A. Murphy, and Andrew Schmitz, "The Concept of Economic Surplus and Its Use in Economic Analysis," *Economic Journal*, 81:324 (December 1971), 741-799.

5. Zvi Griliches, "Research Cost and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, 66:5 (October 1958), 419-431. W. L. Peterson, "Returns to Poultry Research in the United States," *Journal of Farm Economics*, 49:3 (August 1967), 656-669. H. W. Ayer and G. Edward Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in São Paulo, Brazil," *American Journal of Agricultural Economics*, 54:4 (November 1972), 557-569.

6. For the derivation of a two-stage production function, see K. Sato, "A Two-Level Constant-Elasticity-of-Substitution Production Function," *Review of Economic Studies*, 34:2 (April 1967), 201-218, and Alain de Janvry, "A Socioeconomic Model of Induced Innovations for Argentine Agricultural Development," *Quarterly Journal of Economics*, 87:3 (August 1973), 410-435.

7. The interested reader can find the analytical equations in J. P. Ramalho de Castro, "An Economic Model for Establishing Priorities for Agricultural Research and a Test for the Brazilian Economy," Ph.D. thesis (Lafayette: Purdue University, 1974).

8. The important coffee crop was excluded from the analysis because government intervention in this sector has been great and because Brazil still occupies a dominant position in world coffee markets. The small-country hypothesis would not be valid.

9. Murray Brown, *On the Theory and Measurement of Technological Change* (London: Cambridge University Press, 1966), chapter 5.

10. The 1960 Agricultural Census indicated that 76 percent of Brazilian farms were using only human power, while less than 1 percent were using some mechanical power. See G. Edward Schuh, *The Agricultural Development of Brazil* (New York: Praeger, 1970), p. 154.

11. These points were suggested by J. H. Sanders in "Mechanization and Employment in Brazilian Agriculture, 1950-1971," Ph.D. thesis (Minneapolis: University of Minnesota, 1973), p. 14, and Appendix F.

12. In fitting the models it was assumed that all fertilizers were used for crop production. This is a reasonable 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 Peter Knight, *Brazilian Agricultural Technology and Trade: A Study of Five Commodities* (New York: Praeger, 1971).

13. The cerrado soils are for the most part highly leached out latosols with a high de-

gree of acidity, low nutrient levels, and apparently some problems of toxicity. They cover large areas of Brazil, and very little is known about them.

14. Sanders, "Mechanization and Employment."

15. For a succinct treatment of the general equilibrium model, see Harry G. Johnson, *The Two-Sector Model of General Equilibrium* (Chicago: Aldine Atherton, 1971).

25

Measuring the Impact of Economic Factors on the Direction of Technical Change

Hans P. Binswanger

This chapter looks at recent theoretical and empirical advances in the theory of induced innovation, with respect particularly to the direction of technical change. The first section discusses the mechanisms of induced innovation and the potential roles of economic factors and fundamental biases in determining the direction of technical change. The second section explores the question of whether the agricultural sectors of different countries have developed along technological paths of different factor intensities or whether the observed factor ratio differences simply reflect ordinary substitution adjustments to differences in factor prices. The third section assesses the relative importance of factor prices and fundamental biases in determining the direction of technical change.

Mechanisms of Induced Innovation

In agriculture, the term *induced innovation* has been used by Hayami and Ruttan essentially to indicate that factor scarcities or factor prices influence the direction of technical change for a particular commodity.[1] It is hypothesized that technical change is directed toward saving the progressively scarce or more expensive factors, i.e., saving proportionately more of the scarce factor than of the abundant factor per unit of output at constant factor prices. (Many technical changes reduce input requirements of all factors per unit of

output and therefore "save" all factors. In economics, however, we define a technical change as labor saving only if it reduces labor requirements to a greater degree than it reduces the requirements of other factors.) In this chapter, consistent with recent advances in the theory of induced innovation, the term *induced innovation* is used more broadly than before and includes the response of the rate and direction of technical change to final demand conditions and to factor scarcities.[2]

The response of the rate of technical change to final demand conditions has been empirically well established by Schmookler, Griliches, Lucas, and Ben-Zion.[3] As a result we can concentrate here on the factors which induce biases in the direction of technical change.

The factor intensity of agriculture as a sector of the economy is determined, in the absence of research, by two sets of forces: the choice of the commodity mix of output and the choice of technique for each commodity. Intrinsically different factor ratios are associated with different agricultural commodities. Vegetables, tree crops, and livestock typically have a higher labor/land or labor/capital ratio in all economic environments than do most grain crops. The theory of comparative advantage states that countries with high labor/land or labor/capital ratios will concentrate on the more labor-intensive agricultural commodities and that agricultural output as a whole will be produced in countries with lower land/labor or capital/labor ratios than in countries with small labor endowments. Moreover, for each commodity produced, countries with low wage rates will use more labor-intensive techniques than countries with high wage rates; this tends also to decrease the sectoral land/labor and capital/labor ratios.

If a country with relatively abundant labor decides to subsidize capital (e.g., through tractor subsidies, subsidized credit, tax preferences, or overvalued exchange rates), it will distort both the choice of commodities and the choice of technique for each commodity such that the aggregate capital/labor ratio increases. Whether this increase comes primarily from a change in commodity mix or from a change in the technique of each commodity depends on the elasticity of substitution among factors in the production of each commodity. If the elasticities of substitution are low, the aggregate factor ratio changes primarily as a result of the change in commodity mix. If the elasticities are high, however, the aggregate factor ratio changes primarily as a function of a change in the technique used for each commodity.[4]

Research has an impact on the agricultural factor ratios through its effects both on the commodity mix and on optimal factor ratios within each commodity. Research on a labor-intensive commodity which results in neutral technical change for this commodity will, at existing factor and goods prices, increase the profitability of the commodity compared with all other commodi-

ties. Cultivators will tend to produce more of the commodity which experiences rapid technical change by reallocating land and capital resources to the improved commodity. If they can hire more labor at the going rate, the aggregate land/labor intensities of agriculture will decrease despite the neutrality of the technical change in the particular commodity.

Abel and Welsch have shown (in chapter 22) that for a labor-intensive country it makes sense to concentrate research resources on the labor-intensive commodities in which the country has comparative advantage. Even before research, such a country or region will have produced relatively more of the labor-intensive commodity owing to its comparative advantage. The factor productivity increase, therefore, would apply to a larger volume of output in the labor-intensive commodity than in the capital-intensive commodity, and the rate of return to research on the former would be higher. This is the first mechanism of induced innovation by which factor scarcities affect agricultural factor intensity.

In addition, research can alter factor intensities of production of a given commodity. I have recently worked out a microeconomic model of this type of induced innovation mechanism.[5] The model is based on a view of technological research and discovery similar to that of Kislev's (see chapter 10). Kislev's model asks the question, what quantity of resources shall be allocated to a single yield-increasing line of research? In my model it is assumed that, to increase the productivity of a given commodity, researchers have a choice of several research strategies or research lines. Each line of research has different implications for the factor ratios of the commodity, and the researcher chooses the combination of research lines which leads to the maximum reduction of costs of production at the existing factor prices. It can then be shown that the higher labor prices are in in relation to land or capital prices, the greater will be the allocation of research resources to those lines of research which tend to save labor and the smaller the allocation of resources to the lines of research which tend to save capital or land. This means that the higher the cost of labor, the higher will be the labor-saving bias of technical change.

Sometimes, because they do not look at factor prices in making their research decision, researchers and research administrators claim that the mechanism just described is not realistic. However, for such a framework to operate it is not even necessary that the research resource allocator be conscientiously trying to save the relatively more expensive factors. If he makes his research resource allocation decision on the basis of expected benefits from a research project, he will automatically tend to favor those research lines which either favor the high-priced commodity or save the high-priced factor. The reason for this is that the payoffs of any research are the product of in-

creases in output and reductions in input requirements (owing to the innovation) weighted by the prices of the output and the inputs. Since the prices enter as weights, projects which result in increases in output of expensive commodities or which save primarily the expensive factors will have higher payoffs than projects which affect primarily inexpensive outputs and inputs.[6]

What has been said so far establishes the potential responsiveness of the factor ratio to factor prices through a mechanism of induced innovation. However, this mechanism might be empirically irrelevant if research possibilities themselves were severely biased and allowed the researcher little choice in research strategy. Research possibilities might be such that research projects on capital-intensive commodities and in capital-intensive directions would always be easier to carry out than research projects on labor-intensive commodities and in labor-intensive directions. In such a situation, induced innovation at best could only partly offset the fundamental bias of innovation possibilities. Efficient labor-using paths for technical change would not exist. On the other hand, if technical change possibilities were completely neutral toward commodities and toward biases within commodities, and if the potential research lines had a wide variety of factor-saving implications, there would be many different paths of efficient technical change from which countries could choose according to their factor scarcities. For example, considerable attention has been given recently to the effect of fertilizer availability and price on the attractiveness of studying biological nitrogen fixation. Technical change evolving from such exploration would be commercial fertilizer saving. Whether such technical changes will occur in the future will be determined both by the price of fertilizer and by biological research possibilities. If for some biological reason, nitrogen fixation cannot be brought about in crops other than legumes, and if there is a biological barrier to the amount of nitrogen fixation by legumes, technical change possibilities would preclude a substantial fertilizer-saving bias from this source even if fertilizer prices rose considerably. Such problems could also make induced labor-using biases empirically irrelevant.

A Two-Factor Test of Induced Innovation in Six Countries

The empirical tests described in this and the following section have been inspired by and are partly based on the work of Hayami and Ruttan.[7] Because the tests look at the responsiveness of aggregate factor ratios or factor shares to economic forces, changes in commodity mix cannot be distinguished from changes in factor mix for given commodities. Of the two tests reported, the first is based on a comparison of technical change paths among six countries

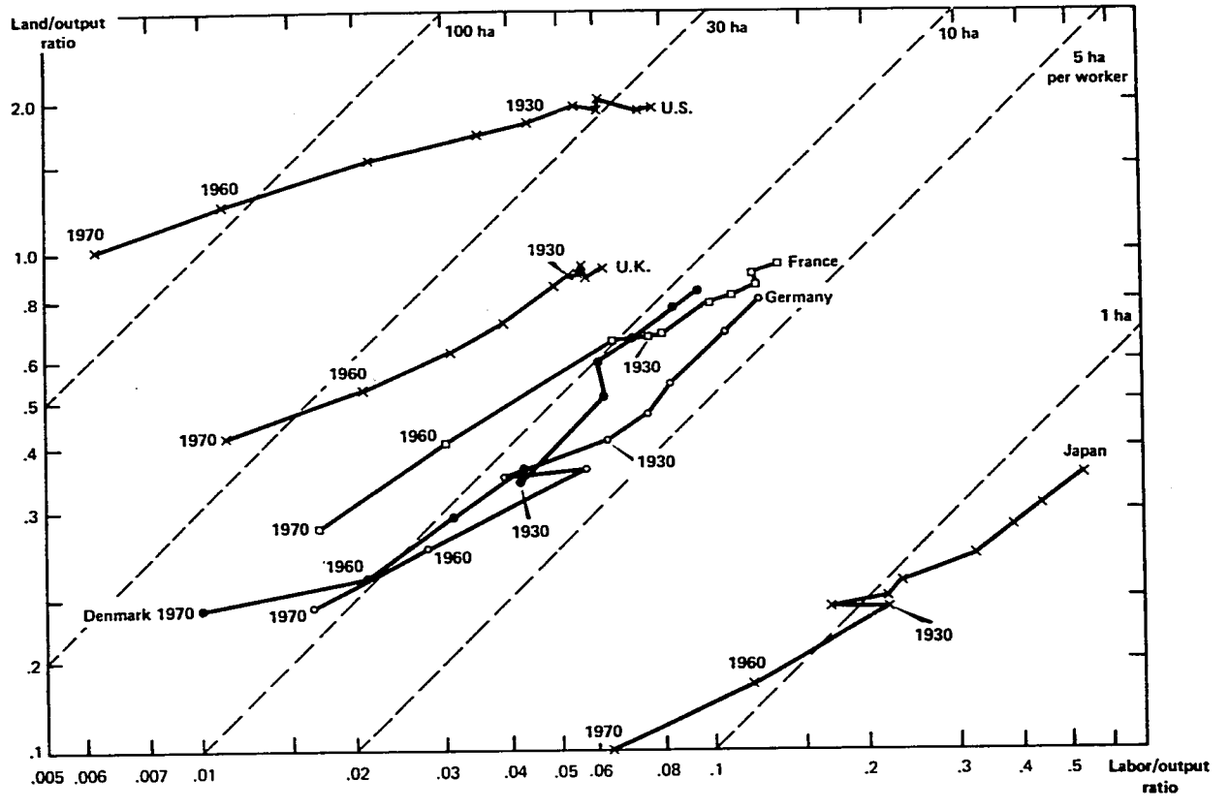

Figure 25-1. Input/output ratios for the United States, Great Britain, France, Germany, Denmark, and Japan, 1880-1970. Double logarithmic scale. Diagonals are land/labor ratios.
Source: Vernon W. Ruttan et al., "Factor Productivity and Growth: A Historical Interpretation," in *Induced Innovation: Technology, Institutions and Development*, eds. Hans P. Binswanger and Vernon W. Ruttan (Baltimore: © The Johns Hopkins University Press, in press).

and addresses the question of whether the paths are really different, i.e., whether there is a wide array of choices with respect to factor ratios. The second and more powerful test shows that fundamental biases of technical change possibilities explain a substantial part of the observed biases. It also reveals, however, that factor prices are capable of offsetting or increasing fundamental biases substantially; it thus demonstrates the empirical relevance of the induced innovation hypothesis.

Figure 25-1 traces the paths of input-output combinations for six countries from 1880 to 1970 in full logarithmic scale. Constant land/labor ratios are represented by the diagonal lines. Movements of the input-output combination toward the lower left-hand corner are technical advances. Equidistant inward movements correspond to equal rates of productivity improvements. From this figure we can see that all countries experienced substantial productivity advances during the period. However, for the United States the rate of productivity increase between 1930 and 1970 far exceeded the rate of productivity increase before 1930. In Great Britain there was practically no technical change before 1930.

The differences in land/labor ratios are enormous, as can be seen in Figure 25-2. The land/labor ratios are plotted in semilogarithmic scale. (Equal *slope* of lines indicates equal *rate* of increase in factor ratios.) The United States ratio exceeded the Japanese ratio by a factor of 30 in 1880 and by a factor of 102 in 1970; i.e., the differences in land/labor ratios increased substantially over time.

Figures 25-1 and 25-2 cannot by themselves answer the question whether the increases in factor ratios over time are caused by biases of technical change or by decreases in the price of land relative to that of labor. Neither can they answer the question whether the different land/labor ratios among countries reflect that the countries were using technologies with inherently different factor ratios or whether the factor ratio differences simply reflect factor substitution owing to price differences within a technology having identical factor intensities.

It is useful at this point to state the problem that must be solved in any test of induced innovation. In Figure 25-3, assume that the labor/land factor ratio in Japan can be represented by a line from the origin through P and that the labor/land factor ratio in the United States can be represented by a line from the origin through Q. Assume also that the slope of the line BB represents relative factor prices in Japan, where land is expensive in relation to labor, while the slope of CC represents the relative factor prices in the United States where labor is expensive in relation to land. If the substitution possibilities of the available agricultural technology can be represented by an isoquant map with little curvature, such as I_0^* and I_1^*, the differences in factor ratios be-

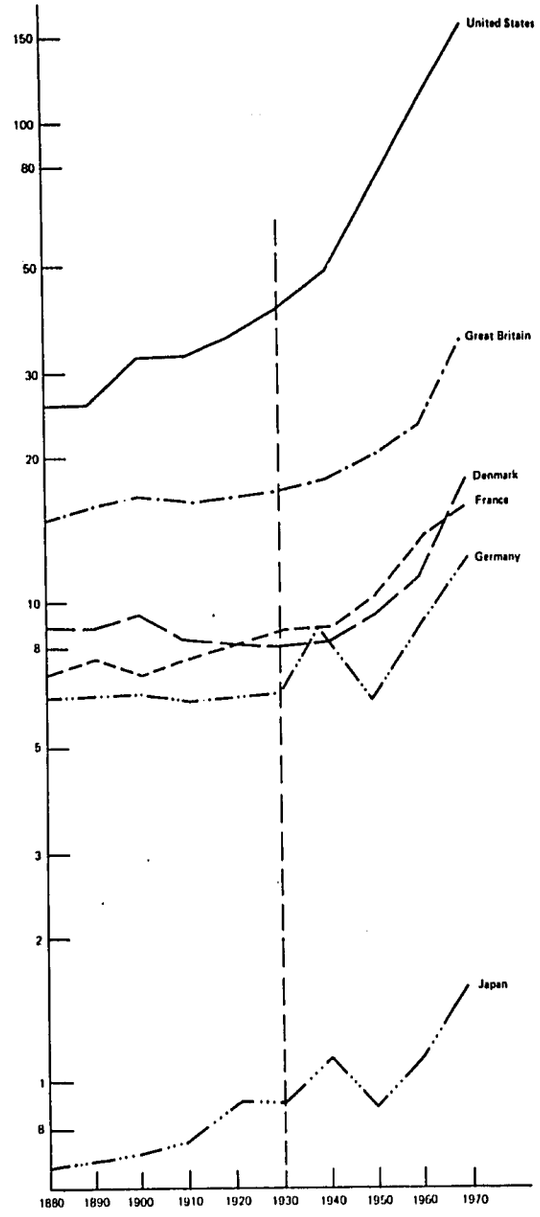

Figure 25-2. Agricultural land in hectares per male worker, 1880-1970, semi-log scale.
Source: Vernon W. Ruttan et al., "Factor Productivity and Growth: A Historical Interpretation," in *Induced Innovation: Technology, Institutions and Development*, eds. Hans P. Binswanger and Vernon W. Ruttan (Baltimore: © The Johns Hopkins University Press, in press).

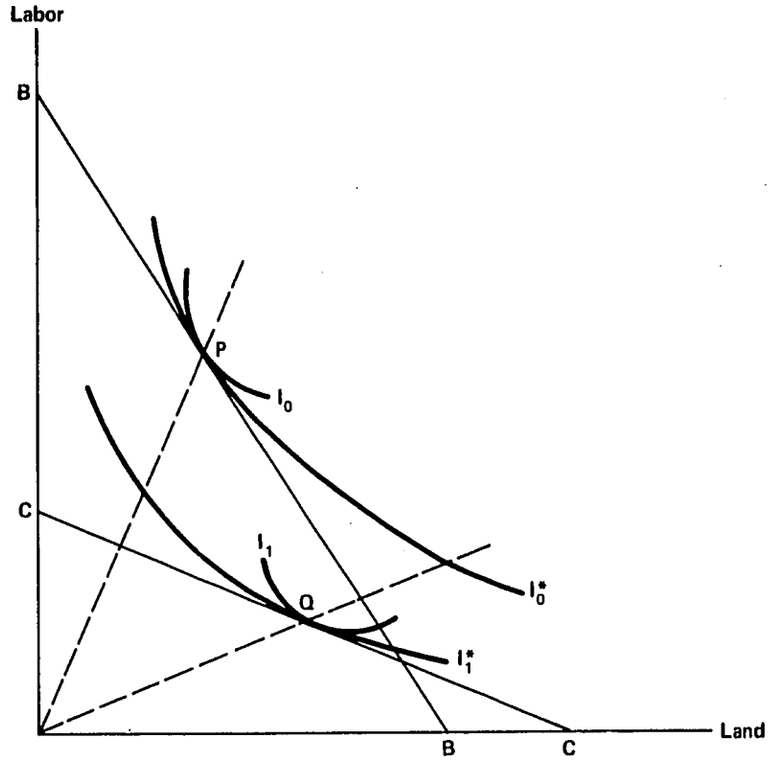

Figure 25-3. The problem of identifying causes of factor ratio differences.

tween Japan and the United States could be explained by simple substitution along production functions with equal factor-intensity characteristics (but not necessarily equal efficiency) caused by the differences in relative factor prices. If, however, the possibilities of substitution between labor and land are represented by I_0 in Japan and I_1 in the United States, the points P and Q would not represent alternative factor combinations along production functions with equal factor intensity. The difference between the isoquant set $\{I_0, I_1\}$ and the isoquant set $\{I_0^*, I_1^*\}$ is that the elasticity of substitution of the latter is much larger than that of the former. Therefore, the two-factor test to differentiate between technological factor intensities and simple factor substitution builds on the concept of pairwise elasticity of substitution between land and labor. The test involves an implicit assumption that the production process is separable between land and labor and all other factors. This assumption implies that the land/labor ratio is independent of changes in the prices of other inputs. To the extent that the land/labor ratio is influenced by

other factor prices – the price of farm machinery, for example – the assumption of separability does introduce a bias into the simple induced innovation test used in this chapter.[8]

The test is somewhat complicated by absolute efficiency difference between periods or countries. Referring again to Figure 25-3, let P and Q represent the input-output combinations in two different time periods in the same country (or two different countries at the same time). Further, let BB and CC represent the respective factor/price ratios in the two time periods (or the two countries). Q has a higher land/labor ratio than P and a lower relative land price. Now construct a homothetic isoquant map which is tangent to BB at P and tangent to CC at Q. These would be the two production functions if the factor ratio change between P and Q could be explained by ordinary factor price substitution and neutral technical change over time (or equality of factor intensities of the production functions in two countries at a given time). Pairwise elasticity of substitution of this isoquant map can be measured from the factor ratios and factor/price ratios (see the mathematical footnotes in Tables 25-2 and 25-3), and we call it the *Necessary Elasticity of Substitution* (σ_N) to explain factor ratio differences by differences in relative prices. Suppose now that we have an econometric estimate σ' of the elasticity of substitution between land and labor for agriculture and that isoquants with σ' tangent to BB at P and to CC at Q would look like I_0 and I_1 instead of I_0^* and I_1^*. The shift of I_0 to I_1 represents a labor-saving technical change over time (or true factor intensity differences between two countries at a given time). Hence, if σ_N is sufficiently larger than σ' we can reject the hypotheses of both neutral technical change and equal factor intensities.

Estimates of a pairwise elasticity of substitution between land and labor are not available in the literature. However, I have provided estimates of a full set of factor demand elasticities for the United States, and Mundlak has developed a methodology to compute pairwise elasticities of substitution from factor demand elasticities.[9] Using Mundlak's method, I have computed an elasticity of substitution between land and labor (σ') to be 0.67. Thus a 10 percent change in the labor/land price ratio leads to a 6.7 percent change in the land/labor use ratio. For reasons given in footnote 10, $\sigma' = .67$ is a central value for the elasticity of substitution, but depending on the nature of the price rises it may exceed it or fall short of it.[10] Furthermore, a statistical error is attached to the estimate. Therefore, the critical value for rejecting the hypothesis of neutral shift or identical factor intensities will be taken as twice the estimated value, i.e., the hypothesis will be rejected if σ_N exceeds 1.34 for any comparison of points with different factor intensities.

This test is first applied to each country individually over time to see whether biases occurred along the path of each country. Japan is not included in

Table 25-1. Land/Labor Ratios and Land Price/Labor Price Ratios

Year	U.S.	Great Britain	France	Germany	Denmark	Japan
			Agricultural Land/Worker (A/L)			
1880 . . .	25.4	14.7	7.0	6.34	8.91	0.659
1930 . . .	40.5	19.7	8.8	6.46	8.17	0.908
1960 . . .	109.5	23.3	13.4	8.83	10.21	1.131
1970 . . .	160.5	33.5	16.2	12.20	17.92	1.573
			Price of Agricultural Land/Daily Wage Rate[a] (P_A/P_L)			
1880 . . .	181.0	995.0	780.0	967.00	381.00	1874
1930 . . .	115.0	189.0	264.0	589.00	228.00	2920
1960 . . .	108.0	211.0	166.0	378.00	166.00	2954
1970 . . .	108.0	203.0	212.0	244.00	177.00	1315

Source: Vernon W. Ruttan et al., "Factor Productivity and Growth: A Historical Interpretation," in *Induced Innovation: Technology, Institutions and Development*, eds. Hans P. Binswanger and Vernon W. Ruttan (Baltimore: © The Johns Hopkins University Press, in press).

[a] Price of land is price of agricultural land without buildings, except for Denmark, where buildings are included in the price. Price of labor is daily wage rate without room and board.

this time-series test because the comparability of its factor price data over time is doubtful.

Next the test is applied to all the countries at a given point in time to see whether the factor intensities of their production functions differ. Denmark is excluded from the comparison because its factor price series is based on a land price concept different from those of other countries.

The data on factor intensities and relative prices are given in Table 25-1.

The Paths of the Land/Labor Ratio in Five Countries

Table 25-1 shows that between 1880 and 1930 in the United States the land/labor ratio rose from 24.5 to 40.5, while the corresponding price ratio fell from 181 to 115. In Table 25-2 it is shown that the necessary elasticity of substitution to explain the drop in the land/labor ratio (A/L) by simple price effects is 1.03. This falls short of the critical value of 1.34. Therefore, the hypothesis that technical change was neutral during this period cannot be rejected. However, the necessary elasticity of substitution jumps to 16.5 for the period 1930-60, and in the sixties the relative price ratio does not change, while the land/labor ratio continues to rise. Therefore, change has been strongly biased in a labor-saving direction since 1930.

In Great Britain, France, Germany, and Denmark the necessary elasticity was very low between 1880 and 1930, which implies neutral technical change. In Denmark the changes in factor ratios and relative prices even imply labor-

Table 25-2. Necessary Elasticity of Substitution (σ_N)[a] to Explain the Interperiod Changes in Land/Labor Ratios by Price Effects within Selected Countries[b]

Time Period	U.S.	Great Britain	France	Germany	Denmark
1880-1930	1.03	0.16	0.20	0.04	e
1930-60	16.50*	d*	0.90	0.70	0.70
1960-70	e*	9.43*	d*	0.74	d*

* Significantly labor saving.

[a] $$\sigma_N = \frac{\text{Percentage change in land/labor ratio between two periods}}{\text{Percentage change of labor price/land price ratio}}$$

with geometric means as a basis for the two percentage changes, i.e.,

$$\sigma_N = \frac{(A/L)_{i+1} - (A/L)_i}{(P_L/P_A)_i - (P_L/P_A)_{i+1}} \times \sqrt{\frac{(P_L/P_A)_{i+1}\,(P_L/P_A)_i}{(A/L)_{i+1}\,(A/L)_i}}$$

where i = 1880, 1930, 1960, 1970.

[b] The critical ratio to reject hypothesis of neutral technical change is 1.34.

[c] No price change, technical change labor saving.

[d] Price ratio and land/labor ratio rise, which implies labor-saving technical change. (No common isoquant map can be constructed through P and Q in Figure 25-3 in this case.)

[e] Land/labor ratio declines very slightly but price declines much more, which implies labor-using technical change.

saving technical change, and that may be the case also in the other European countries where the necessary elasticities of substitution are exceedingly small.

Between 1930 and 1960 Great Britain experienced labor-saving technical change, while technical change remained neutral in the other European countries. In the 1960s technical change in Great Britain, Denmark, and France was labor saving but it remained neutral in Germany. Labor-saving technical change (relative to land) is therefore a recent phenomenon for Europe, and in Germany it never occurred at all.

The Cross Section Comparison of Factor Intensities

The comparison of factor intensities and factor prices across countries is shown in Table 25-3 with the necessary elasticities to explain the factor ratio differences among the countries. All the necessary elasticities of substitution of the comparison between the United States and Japan exceed the critical value of 1.34. Therefore Japan and the United States must have used technologies with different factor intensities throughout the period. This confirms the induced innovation hypothesis because the high wage country did use a more labor-intensive technology than the low wage country.

Table 25-3. Test of Differences in Technological Paths: Necessary Elasticity of Substitution[a] to Explain Differences in Land/Labor Ratio by Price Ratio Differences[b]

Item	1880	1930	1960	1970
U.S. vs. other countries				
Japan	2.08*	1.35*	1.93*	3.12*
Great Britain	0.29	1.47*	2.50*	2.70*
France	0.87	1.96*	5.79*	4.13*
Germany	0.80	1.16	2.42*	4.00*
Japan vs. Europe				
Great Britain	7.01*	1.21	1.24	2.04*
France	3.26*	0.92	0.79	1.39*
Germany	4.13*	1.29	1.00	1.28
Great Britain vs. continental Europe				
France	c*	2.47*	c*	17.12*
Germany	c*	0.98*	1.71*	5.72*
Continental Europe				
France vs. Germany	0.46	0.38	0.50	2.02*

* The paths of the two different countries differ significantly in land/labor intensity.

[a] $$\sigma_N = \frac{(A/L)_i - (A/L)_j}{(P_L/P_A)_j - (P_L/P_A)_i} \times \sqrt{\frac{(P_L/P_A)_i\,(P_L/P_A)_j}{(A/L)_i\,(A/L)_j}}$$

where i and j are the different countries in the same year.

[b] Critical value to reject hypothesis of equal technology: 1.34, i.e., twice the value of σ for equiproportional changes in P_A and P_L.

[c] Denotes cases where the country with the higher land/labor ratio also has the higher land price/labor price ratio. Such behavior is possible only if the country with the higher land/labor ratio employs a more land intensive technology, i.e., the hypothesis of equal technology is rejected. No common isoquant maps can be constructed through points P and Q in Figure 25-3.

In 1880 the United States and the European countries were apparently on essentially the same production function. This is not implausible given the state of mechanical technology in the late nineteenth century. By 1930, however, differences between the European and United States production functions had clearly emerged, as indicated by the increases in the necessary elasticities of substitution. Even in 1930, however, the hypothesis of similar production functions cannot be rejected for the United States-Germany comparison. Because after 1930 technical change became extremely labor-saving in the United States, European technology differed very strongly from United States technology in 1960 and again in 1970.

The differences in factor ratios between United States and European agri-

culture thus reflect differences not only in relative factor prices but in the production functions available to United States and European farmers.

In the second section of Table 25-3 the test is carried out for Japan in comparison with Europe. In 1880 European technology was much less labor intensive than Japanese technology. But neutral or labor-using technical change in Europe together with neutral or possibly labor-saving technical change in Japan brought the technologies much closer by 1930. By 1970, however, labor-saving technical change in the United Kingdom and France had become strong enough to make their technologies clearly different from Japanese technology again. In Germany the technical change remained neutral, however, and by 1970 it seems likely that differences in factor ratios between Japanese and German agriculture are accounted for primarily by differences in factor prices.

The third section of Table 25-3 shows that British technology was almost always less labor intensive than French and German technology, except for Germany in 1930, when the test fails. The fourth section indicates that Germany and France were using the same technology until 1960. Thereafter labor-saving technical change in France moved the two technologies apart.

Implications for the Induced Innovation Hypothesis on the Basis of the Time Series and Cross Section Comparison

We can distinguish essentially four paths for technology:

1. The United States, starting from a position similar to Europe, developed away from Europe in a strongly labor-saving direction.

2. Great Britain also experienced strong labor-saving technical change after 1930, but its technology remains much more labor intensive than the technology of the United States. British technology was also less labor intensive than the technology of continental Europe and Japan.

3. Continental Europe experienced essentially neutral technical change, or possibly even labor-using technical change, throughout the period, except for France and Denmark in the 1960s.

4. Japan started from an extremely labor-intensive position. Its technical change must have been either neutral or possibly slightly labor saving.

The tests therefore confirm the induced innovation hypothesis. Indeed, the United States, with the highest relative wage rate, developed on the least labor-intensive path, while Japan, with the lowest relative wage rate, had the most labor-intensive technology. The European countries, with labor price levels between those of the United States and Japan, also used technologies with intermediate factor intensities. Furthermore, given the often high values for the necessary elasticities of substitution, the technology differences must have been quite substantial.

Although the tests performed in this section clearly establish that the

paths of factor ratios of technology are guided by factor scarcities, there are some observations which are not consistent with the simple version of the induced innovation hypothesis. For example, the United States followed a more labor-saving path with respect to its initial land/labor ratio than did the four European countries despite the fact that in the United States the decline in the price of land relative to that of labor was less rapid than it was in Europe (see Figure 25-4). A simple induced innovation framework which assumes that all biases are caused exclusively by factor prices would predict that Europe should have more labor-saving technical change than the United States.

There are several factors that may account for the less than complete consistency between the induced innovation hypothesis and the observed difference in factor price and resource use ratios. One possibility is that there are fundamental biases in innovation possibilities in the labor-saving direction which were only partly offset, in the case of Japan, by technical change induced by the rising relative price of land. A second possibility is that the effect of changing relative prices on the direction of technical change may sometimes be offset by the low cost of borrowing from countries with differing factor price ratios. Finally, differential rates of growth in demand may induce technical change through changes in the factor/product price ratios.

The impact of technology transfer on borrowing from countries with different factor/price ratios may be particularly important for the countries with extreme differences in factor/price and use ratios such as Japan and the United States. If a country starts the process of modernization from an extremely labor-intensive position, as Japan did in the 1880s or as some of today's developing countries are doing, the only technologies which it can transfer or borrow from other countries will be more labor saving than those which would be induced by its own factor endowments and price ratios. Similarly, if a country starts the process of modernization from an extremely labor-extensive position, as in the case of the United States in the post-Civil War period, it is likely that the technologies which it borrows will be more land saving than those which would be induced by its own factor endowments and price ratios. In such situations it is unlikely that the inducement process will be able to offset more than partially the combination of fundamental bias and transfer bias. At this stage we are not able to provide quantitative estimates of the effect of the fundamental and transfer biases.

A Many-Factor Test of Induced Bias in United States Agriculture

The test discussed in the last section established the existence of different paths of technology. This section provides a more powerful test of induced

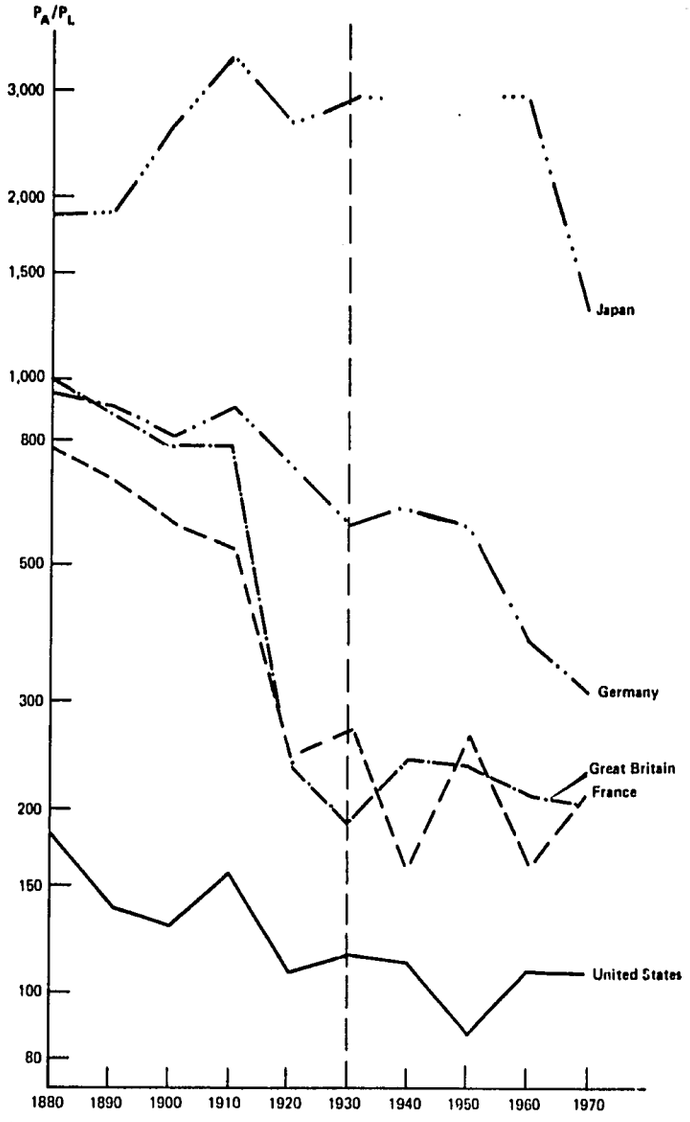

Figure 25-4. Price of land relative to daily wage rate, 1880-1970.
Source: Vernon W. Ruttan et al., "Factor Productivity and Growth: A Historical Interpretation," in *Induced Innovation: Technology, Institutions and Development*, eds. Hans P. Binswanger and Vernon W. Ruttan (Baltimore: © The Johns Hopkins University Press, in press).

innovation in United States agriculture. The methodology used overcomes one flaw of the earlier test in which a many-factor production process was treated as if it were a two-factor process. As a consequence, the test neglected the influence of prices other than of land and labor on the land/labor ratio. In this section a true many-factor framework is employed.

The test is based on directly measured biases of technical change instead of factor ratios. Biases are measured for the United States agricultural sector from 1912 to 1968, and for five factors (land, labor, machinery, fertilizer, other inputs). Once these biases are measured they can be compared with the trends in factor prices to see whether factor-saving biases correspond to rising factor prices and factor-using biases correspond to declining factor prices.

One problem with testing the inducement mechanism is that factor prices may be endogenous to agriculture. Suppose technical change biases were very responsive to factor price changes, and suppose, in the absence of technical change, that the land price has a tendency to increase. If such an increase were followed by technical change in a land-saving direction, the land price would rise less than it would in the absence of technical change, and in an extreme case it might even fall. This problem makes it impossible from *ex-post* empirical data to show that it was the factor price which caused the bias and not some land-saving bias in the innovation possibilities. However, if a factor price is exogenous to agriculture, this problem does not arise and the test proposed can properly identify causal relationships.

The price of land can be treated as endogenous. Therefore, we will neglect the series of land biases in the test, but for the other four factors the prices are governed in the long run primarily by the nonagricultural labor market and by cost conditions in the input-supplying industries. The biases of these four factors will be compared with the prices of the factors. The logic of the test is as follows: Suppose, first, that innovation possibilities are neutral, i.e., that in the absence of factor price influences the direction of technical change would be neutral. In this case induced innovation would be supported if we found that the factors with rising prices experienced a factor-saving bias while the factors with falling prices experienced a factor-using bias.

When innovation possibilities are not neutral – and we would expect this after the results of the last section – the situation is more complicated. In such a case it is possible that a factor with a rising price might experience a factor-using bias. At most, induced innovation can partly offset the fundamental bias. Indeed, the fact of a rising factor price together with a factor-using bias *establishes that innovation possibilities cannot have been neutral.*

In such a situation we have to look at the turning points of factor prices and of biases. A sharp increase of a slowly rising price should, after some time,

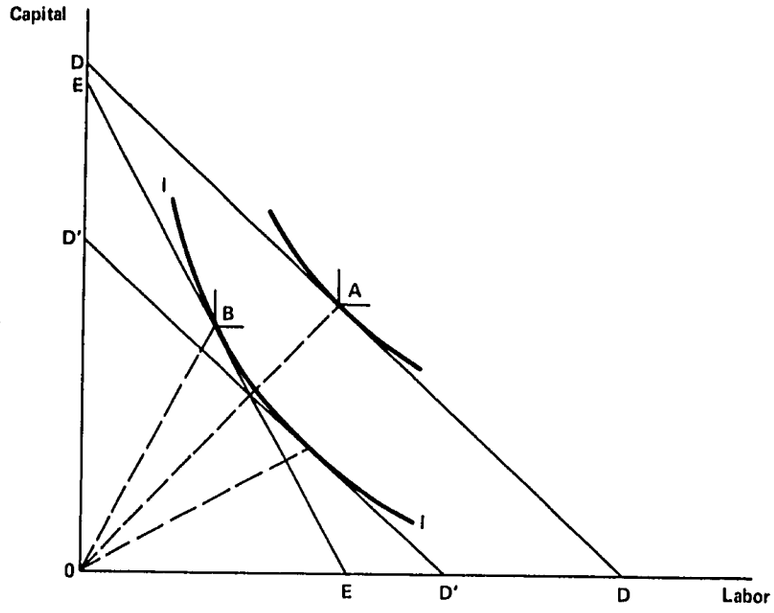

Figure 25-5. The measurement problem of biases.

be followed by a reduction in the factor-using bias to establish the presence of induced innovation. Such behavior would be consistent with a causal relationship between factor prices and biases in the direction of technical change.

The Measurement of Technical Change Biases

The basic problem of measuring biases in the Hicksian sense is most easily explained in a two-factor case.[11] The empirical difficulty of measuring biases arises from the fact that factor prices change over time, i.e., the observed changes in the factor ratio are due to two causes: (1) ordinary factor substitution along a given production function; and (2) biased technical change. Figure 25-5 illustrates this problem.

From economic data we can know the factor ratios OA and OB (for one unit of output) in two periods of time. We can also know the factor prices which prevailed during those two periods, namely, those corresponding to DD and EE. If we knew that the production function was of fixed proportions we would know that the entire change of the factor ratio between these periods was caused by technical change, and measuring biases according to (1) would be very simple. The move from A to B would have been a labor-saving technical change. But with a neoclassical production function, the observed data

alone cannot tell us this. Suppose the elasticity of substitution was very large, as for the isoquant II. At equal factor prices D'D' the capital/labor ratio would have decreased, i.e., technical change would have been labor using. The observed capital/labor ratio nevertheless decreased owing *to the rise of labor prices from* DD *to* EE. To measure biases, therefore, we need to know the parameters of the production process. In the two-factor CES case we have to know the elasticity of substitution to be able to split the observed factor ratio changes into two components, one owing to price changes and the other owing to technical change.

A similar procedure applies to the many-factor case, where we also have to know the substitution parameters of the production process to estimate biases. When many factors are present, factor share changes become a better starting point for measuring biases than factor ratio differences, and it becomes necessary to split the share changes into components owing to ordinary factor substitution and to biases, respectively. The method for this is described in Appendix 25-1.

Results

The data and results in Table 25-4, for price-corrected factor shares, and in Figure 25-6 indicate the existence of a very strong fertilizer-using bias, accompanied by a rapid decline of the price of fertilizer relative to the price of agricultural output in the United States since 1912. Over a long period of time it is safe to assume that the fertilizer price is governed by cost conditions in the fertilizer industry, i.e., that it is exogenous to agriculture. The behavior of the fertilizer bias is thus consistent with the induced innovation hypothesis.

It is also reasonable to assume that the price of labor to a great extent is governed by wage rates in the nonagricultural sector and is exogenous to agriculture. The price of labor increased throughout the period but at a much more rapid rate after about 1940. Up to 1944 technical change was labor neutral, but thereafter a strong labor-saving bias did exist.[12] This is again consistent with the induced innovation hypothesis. Between 1944 and 1968 the observed labor share dropped from almost 39.5 percent to 15.8 percent, i.e., a drop of 23.7 percent. Biased technical change alone could have explained a drop of almost 14 percent. This means that about two-thirds of the drop in the labor share must be explained by biased technical change and only one-third by simple price substitution effects.

In the long run, the price of machinery is governed primarily by cost conditions in the machinery-producing and machinery-repairing industries, as well as by fuel costs, and it is therefore also regarded as exogenous to agriculture. The overall rise of machinery prices was about the same as for labor prices, and a substantial part of it occurred before 1948. After 1948 the rate

of the price rise accelerated. But despite that price rise, technical change was machinery using, not saving. Had innovation possibilities been neutral, this could not have happened. Innovation possibilities must have been machinery using regardless of the role of factor prices in determining biases. Any price-induced bias would have been machinery saving, not machinery using.

Fertilizer and labor biases are consistent with the hypothesis of neutral innovation possibilities and with the hypothesis that factor prices account for most of the biases, but the machinery bias contradicts this. It is even possible that the labor and fertilizer biases were primarily fundamental biases and that the corresponding price changes were coincidental rather than causative.

Table 25-4. Price-Corrected Shares (S_i'), Actual Factor Shares, and Factor Prices Used in Computing (S_i')

Year	Land	Labor	Machinery	Fertilizer	Other
		Price-Corrected Factor Shares a_i^{*a}			
1912 . . .	21.0	38.3	10.9	1.9	28.0
1916 . . .	21.2	36.7	11.6	1.8	28.7
1920 . . .	19.6	39.3	9.3	2.1	29.7
1924 . . .	20.0	39.7	10.3	2.2	27.8
1928 . . .	18.1	41.4	10.4	2.7	27.4
1932 . . .	18.8	40.3	14.3	2.7	24.0
1936 . . .	18.9	32.5	16.3	3.0	29.3
1940 . . .	16.8	34.3	17.6	3.9	27.5
1944 . . .	16.5	38.4	16.1	4.8	24.2
1948 . . .	17.1	37.2	13.9	5.1	26.7
1952 . . .	16.5	29.8	19.7	5.7	28.3
1956 . . .	16.3	30.6	23.1	6.5	23.4
1960 . . .	17.1	27.2	23.4	6.1	26.1
1964 . . .	17.8	25.8	22.4	6.7	27.3
1968 . . .	19.1	25.3	23.1	7.2	25.3
		Actual Factor Shares a_i			
1912 . . .	21.0	38.3	10.9	1.9	28.0
1916 . . .	21.6	36.5	11.6	1.9	28.4
1920 . . .	17.3	40.5	10.1	2.0	30.1
1924 . . .	19.7	38.5	10.3	1.7	29.7
1928 . . .	15.9	40.9	10.2	1.9	31.1
1932 . . .	18.6	37.6	12.6	1.6	29.7
1936 . . .	14.9	34.7	14.5	2.2	33.7
1940 . . .	12.0	35.3	15.1	2.3	35.2
1944 . . .	8.5	39.5	14.0	2.3	35.6
1948 . . .	9.4	37.7	12.2	2.4	38.3
1952 . . .	9.8	29.7	17.5	3.0	40.0
1956 . . .	11.5	27.4	20.1	3.3	37.8
1960 . . .	15.6	21.3	19.8	2.9	40.4
1964 . . .	17.5	18.3	18.5	3.3	42.3
1968 . . .	20.4	15.8	19.1	3.6	41.1

Table 25-4 – continued

Year	Land	Labor	Machinery	Fertilizer	Other
			Factor Prices[b]		
1912 . . .	100.0	100.0	100.0	100.0	100.0
1916 . . .	113.3	106.8	110.0	105.7	103.8
1920 . . .	79.0	104.3	81.3	85.7	115.0
1924 . . .	119.0	134.5	111.7	93.1	106.6
1928 . . .	104.8	154.1	128.5	90.0	118.9
1932 . . .	160.8	194.7	231.5	128.6	101.5
1936 . . .	69.4	113.4	189.2	99.6	110.9
1940 . . .	87.3	179.0	288.8	103.4	160.1
1944 . . .	65.2	217.2	244.2	63.0	211.7
1948 . . .	73.0	247.8	226.6	50.4	222.8
1952 . . .	91.3	274.3	301.1	53.6	214.6
1956 . . .	145.8	407.9	423.7	65.9	229.6
1960 . . .	254.1	502.7	550.3	63.0	241.5
1964 . . .	338.1	610.0	651.2	63.2	270.9
1968 . . .	481.0	766.9	735.8	58.2	280.4

Source: Hans P. Binswanger, "The Measurement of Technical Change Biases with Many Factors of Production," *American Economic Review*, 64 (December 1974), 973.

[a] Model A estimates.

[b] Relative to agricultural output prices (1912 = 100).

But the view that biases are generally caused by non-neutral innovation possibilities and not by factor prices is contradicted by the time sequence of turning points in factor prices and biases. The labor price rise strongly accelerated at the start of World War II, and it was some six to ten years later that a strong labor-saving bias emerged. Similarly, the machinery price rose rapidly between 1948 and 1952, and, again, it was about six years later that the machinery-using bias disappeared. Evenson has found a mean lag, between research initiation and benefits, of between 5½ and 8½ years in agriculture, which would support causality in the observations above.[13] It is unlikely that these changes are coincidental.

The series on land prices and biases cannot give us much more information on the induced innovation hypothesis because the land price is largely endogenous to agriculture. It is worth noting that land prices fluctuate widely, but there was apparently very little bias with respect to land.

The price of other inputs declined by about 40 percent during and after World War II but did not change much before and after. However, there was no discernible bias with respect to this conglomeration of factors.

The clearest conclusion to be drawn from the series is that fundamental biases in innovation possibilities were an important source of the machinery-using bias in United States agriculture.

There can be no question that large, sustained changes in factor prices have

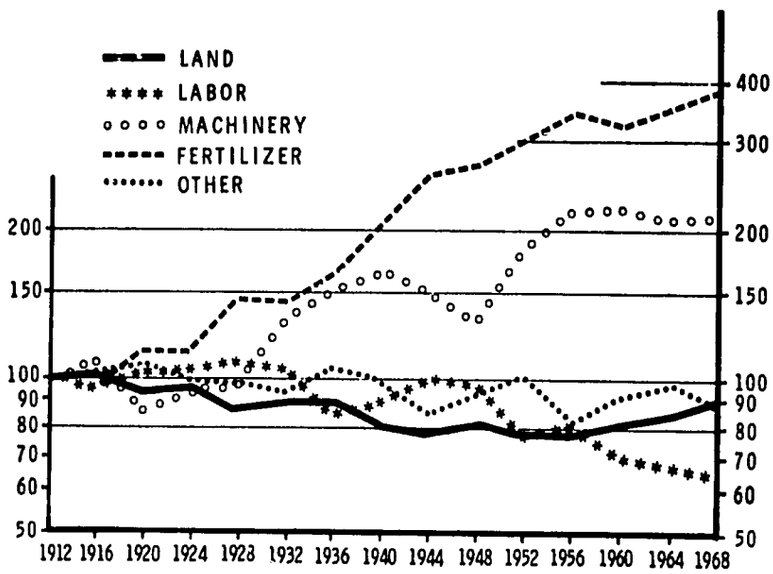

Figure 25-6. United States indices of biases in technical change, estimates of $S'_{it}/S_{i,\,1912}$ (1912 = 100).
Source: Hans P. Binswanger, "The Measurement of Technical Change Biases with Many Factors of Production," *American Economic Review*, 64:6 (December 1974), 972.

had a strong impact on the direction of technical change. In comparison with the prices of the four other inputs, the fertilizer price fell throughout most of the period. This fall was accompanied by a strong fertilizer-using bias. Similarly, about eight years after labor prices began to rise rapidly, a very strong labor-saving bias emerged. In about the same length of time, after an acceleration in the price of machinery, the machinery-using bias which had been caused by biased innovation possibilities disappeared.

Conclusions

The conscious effort of researchers and research administrators to choose projects that will maximize the returns from the research investment in their own economic environment puts the theory of induced innovation on fairly firm theoretical foundations. It has been shown that the research resource allocation mechanism used by researchers does not have to be complicated to make the direction of technical change responsive to factors and goods prices.

Once this is recognized, the empirical question remains whether innovation

possibilities are flexible enough to make available to different countries paths of efficient technical change with factor ratios which can accommodate widely different factor endowments. The comparison of the development paths of six agriculturally advanced countries has shown that technology is indeed flexible enough to accommodate widely different factor ratios consistent with factor scarcities.

The comparison of factor prices with measured biases in the United States from 1912 to 1961 further confirms that fundamental biases in innovation possibilities play at least as important a role in determining the biases of technical change over time within a country as do economic factors. This seems to be particularly the case for mechanical technology, with technical change possibilities strongly biased in favor of more intensive use of machines. On the other hand, the United States series on factor prices and biases shows that factor prices do indeed either generate biases in technical change or dampen exogenous biases to make the technical change more consistent with economic factors than would be the case in the absence of induced innovation. This is fairly strong support for the empirical relevance of induced innovation.

APPENDIX

Appendix 25-1. The Methodology of the Many-Factor Test of Induced Innovation

In the two-factor case biases can be measured with the following measurement equation:

$$Q' = (k^* - \ell^*) + \sigma(r^* - w^*) \tag{1}$$

where k^* and l^* are observed proportional rates of change of K and L and r^* and w^* are rates of change of the capital rental rate and wage rate, and $\sigma(r^* - w^*)$ is the component of the capital/labor ratio change which is due to ordinary factor substitution.[14]

The measurement of biases thus consists of two steps: (A) Measure the elasticity of substitution in an independent sample. (B) Apply equation (1) to time-series data to measure the biases.

In the many-factor cases the procedure is similar to this two-step procedure. However, the biases must now be defined in terms of factor shares:

$$B_i = \frac{dS_i'}{dt} \times \frac{1}{S_i} \begin{matrix} < \\ = \\ > \end{matrix} 0 \rightarrow \begin{matrix} \text{(i-saving)} \\ \text{(neutral)} \\ \text{(i-using)} \end{matrix} \tag{2}$$

where dS_i' is the factor share change which would have occurred in the absence of factor price changes, while S_i is the actual factor share in total costs of production.

The CES production function usually used in the two-factor case is inappropriate in the many-factor case, where it implies the constraint that all partial elasticities of substitution are identical between all pairs of factors. This was considered to be too restrictive.

The basic idea outlined here was applied to the translog cost function of Christensen, Jorgensen, and Lau. The details of this procedure are fairly complicated.[15] The approach leads to a basic estimation equation of the biases as follows:

$$dS_i' = dS_i - \sum \gamma_{ij} \, d\ln W_j \tag{3}$$

where dS_i' are the share changes which would have occurred in the absence of factor price changes, dS_i are the actual share changes, γ_{ij} are the substitution parameters of the production process, and $d\ln W_j$ are the proportional changes of factor prices. The method thus consists of subtracting from the observed share changes that part which was caused by changing factor prices.

The resulting dS_i' can be substituted into the discrete equivalent of equation (3) to compute rates of biases. Here, however, we compute series S_i', which shows how the shares would have developed after the initial year (1912) in the absence of factor price changes:

$$S_i' = S_{i,1912} + \sum_{i=0}^{t} \Delta S_{it}'. \tag{4}$$

These series are presented in the section on U.S. vs. other countries of Table 25-3. Series of standardized values, i.e., $R_{it} = S_{it}'/S_{i,\,1912}$ are presented in Figure 25-3, which is in semilogarithmic scale. Hence, the slope of the lines indicates biases according to equation (2), while the position of the line shows the cumulative bias since 1912.

NOTES

1. Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: Johns Hopkins University Press, 1971).

2. Hans P. Binswanger and Vernon W. Ruttan, eds., *Induced Innovation: Technology, Institutions and Development* (Baltimore: The Johns Hopkins University Press, in press).

3. Jacob Schmookler, *Invention and Economic Growth* (Cambridge, Mass.: Harvard University Press, 1966); Zvi Griliches, "Hybrid Corn: An Explanation of the Economics

of Technical Change," *Econometrica*, 25 (October 1957), 501-522; R. E. Lucas, "Tests of a Capital Theoretical Model of Technological Change," *Review of Economic Studies*, 34 (January 1967), 175-190; Uri Ben-Zion, "Aggregate Demand and the Rate of Technical Change," in Binswanger and Ruttan, *Induced Innovation*.

4. For an example of the effect of tractor subsidies on factor ratios, regional comparative advantage, and income distribution, see John H. Sanders, "Biased Choice of Technology in Brazil," in Binswanger and Ruttan, *Induced Innovation*.

5. Hans P. Binswanger, "A Microeconomic Approach to Induced Innovation," *Economic Journal*, 84 (December 1974), 940-958.

6. For example, suppose the research administrator has the choice between two research projects, A and B. A only reduces capital or land requirements from K_0 to K_1, while B only reduces labor requirements from L_0 to L_1. In a one-period model the benefits from A and B, respectively, are

$$P_A = (K_0 - K_1)R$$

$$P_B = (L_0 - L_1)W$$

where R and W are the capital rental rate and the wage rate. If the projects have equal benefits, i.e., if

$$(K_0 - K_1)R = (L_0 - L_1)W$$

or

$$\frac{K_0 - K_1}{L_0 - L_1} = \frac{W}{R},$$

the decision-maker will have no basis for choice. If, however, he lives in an economy where the wage/rental ratio exceeds the critical ratio, he will choose Project A; he will choose Project B if the wage/rental ratio falls short of the critical ratio.

7. Hayami and Ruttan, *Agricultural Development*.

8. Simulations in a more complex model were performed to assess the possible size of such biases with various assumptions about the size of a full set of cross elasticities of factor demand. It turned out that the effects of changes in prices other than of land and labor generally had very little impact on the land/labor ratio and that consequently biases could be expected to be small.

9. Hans P. Binswanger, "A Cost Function Approach to the Measurement of Factor Demand Elasticities and Elasticities of Substitution," *American Journal of Agricultural Economics*, 56 (May 1974), 377-386. Yair Mundlak, "Elasticities of Substitution and the Theory of Derived Demand," *Review of Economic Studies*, 35 (April 1968), 225-236.

10. The conversion formula is

$$\sigma_{ij} = \frac{(\eta_{ii} - \eta_{ji})\ \mathrm{dlog}\ P_i + (\eta_{ij} - \eta_{jj})\ \mathrm{dlog}\ P_j}{\mathrm{dlog}\ P_i - \mathrm{dlog}\ P_j}$$

where η_{ij} are partial factor demand elasticities and dlog P_i are proportional changes in factor prices. For given factor demand elasticities the size of σ_{ij} depends on the extent to which the factor price ratio change comes from a change in P_i or a change in P_j. Table 2 of Binswanger, "A Cost Function Approach" gives the following values for the factor demand elasticities of A and L: $\eta_{AA} = -.3356$; $\eta_{LA} = .0308$; $\eta_{AL} = .0613$; $\eta_{LL} = -.9109$. These values imply the following values for σ_{AL}.

Price ratio change owing to	σ_{AL}^*
Change in P_A only	.37
Change in P_L only	.96
Equiproportional change in P_A and P_L or P_K and P_L	.67

In the international comparisons the precise source of the change in the factor price ratio is unknown. Equiproportionality of changes in the two prices involved will be assumed.

11. We define the Hicksian bias B′ as the change in factor ratios which would have occurred had factor prices stayed stable:

$$B' = \frac{d(K/L)}{dt} \times \frac{t}{K/L} \left| \text{Factor prices} \begin{array}{l} > \text{(labor saving)} \\ = \text{(neutral)} \\ < \text{(labor using)} \end{array} \right.$$

where K is capital and L is labor.

12. Lianos also found a labor-saving bias in agriculture. See Theodore P. Lianos, "The Relative Share of Labor in United States Agriculture 1949-1968," *American Journal of Agricultural Economics*, 53 (August 1971), 411-422.

13. Robert E. Evenson, "The Contribution of Agricultural Research to Agricultural Production," Ph.D. dissertation, University of Chicago, University Microfilms, Ann Arbor, Michigan, 1968.

14. Proof of equation (1): Ryuzo Sato, "The Estimation of Biased Technical Progress and the Production Function," *International Economic Review* (June 1970), 179-207, shows that rates of augmentation can be measured as follows:

$$a^* = \frac{\sigma r^* - y^* + k^*}{1 - \sigma}; \quad b^* = \frac{\sigma w^* - y^* + l^*}{1 - \sigma}. \tag{a}$$

Robert Solow proved much earlier that the bias is related to factor augmentation rates as follows:

$$A' = (1 - \sigma)(a^* - b^*). \tag{b}$$

Substituting (a) into (b) leads to equation (1).

15. Hans P. Binswanger, "The Measurement of Technical Change Biases with Many Factors of Production," *American Economic Review*, 64 (December 1974), 964-976.

26

Inducement of Technological and Institutional Innovations: An Interpretative Framework

Alain de Janvry

The economic structure of a social system can, in its essence, be characterized by two features: the level of development of its capacity to produce; and the way in which people relate to one another in their respective functions in the production process.

The capacity to produce is determined by the quantitative and qualitative stock of productive resources. Recent empirical studies have shown that the qualitative attribute of resources is indeed a fundamental source of output and productivity growth. For physical capital, this attribute takes the form of technological change; for human capital, it takes the form of increased labor skills. Since it affects both output and productivity, the rate and bias in the growth of the qualitative attribute of resources are major determinants of output growth and of changes in income levels and in the distribution of income. As a result, whoever controls the production of new technologies and skills largely determines the pace and nature of economic development. Ultimately, then, it is the social structure which conditions the rate and bias of technological and skill innovations, and these innovations are, in turn, powerful determinants of change in the social structure.

The earlier chapters in this section have focused primarily on the environmental, technological, and economic considerations that affect the direction of technical change. In this chapter institutional considerations will be examined as well. The ways in which people relate to each other in their respective functions in the production process are translated into a set of institu-

tions that characterize and establish guidelines for these relationships. Most important are those institutions which specify the rights of ownership and which define the functions and the scope of action of the state. These institutions condition the rate and bias in technological and skill innovations and the impact of such innovations on growth and income. And, reciprocally, technological and skill innovations are powerful inducers of institutional innovations. (Throughout this chapter, for the sake of simplicity, the term *technological innovation* will be used to refer to both technological and skill innovations.)

Technological and institutional innovations are thus so closely interrelated that any change in one ultimately presses for change in the other. Which one first induces change – a question that has been raised repeatedly in the recent literature on agricultural technology – is a chicken-and-egg-type question to which only history can provide an answer. In some instances, output stagnation induces institutional change to restore the dynamics of accumulation. Here institutional change precedes technological change. Examples are the urban-induced land reform programs that followed the Punta del Este Conference in Latin America.

In other instances, the dynamics of accumulation, fueled by technological innovations, creates sharp social antagonisms that lead to institutional innovations. Examples are the peasant-led land reforms in Mexico and Bolivia and, to some extent, the initial impact of the green revolution. Here technological change precedes institutional change.

Having recognized both the endogenous nature of technological and institutional innovations within a social system and their reciprocal relationship, we now turn to the specification of a simple but, we believe, useful model of the generation of technological and institutional innovations.[1] The technological innovations considered here are those which are generated by the public sector through fundamental and applied research. In agriculture, the public sector has a major responsibility in technological innovation. As a consequence, technological and institutional innovations assume the nature of public goods, and the following model is one of supply and demand for public goods in general. Since a social system can be characterized largely by its technological and institutional structures, however, a model of supply and demand for technological and institutional change is actually an approximation of a general model of the dynamics of change in social systems.

A Dialectical Model of Technological and Institutional Innovations

After having definitely shelved the teachings of historical materialism, neoclassical economists have recently begun to theorize on the very question that

is central to historical materialism: the dialectical relationship between productive forces and social relations of production and the way in which this dialectic explains the evolution from one mode of production to another; or, in other words, the relationship between technological and institutional innovations and the process through which these innovations occur.

Using the neoclassical apparatus, Hayami and Ruttan have developed a path-breaking theory of the inducement of technological and institutional innovations. Their model is linear, and its starting points are the stock of scientific knowledge – conceptualized as defining the Innovation Possibility Frontier (IPF) in the factor space – and the relative factor scarcities. Through the market mechanism, changes in relative factor scarcities determine changes in relative factor prices; these changes lead to a search within the IPF for new cost-minimizing technologies which will, of course, tend to be biased toward saving the most expensive factor. Institutional changes may, in turn, be induced by technological change in order "to enable both individuals and society to take fuller advantage of new technical opportunities under favorable market conditions."[2] The causal sequence is thus from technological to institutional change.

While useful, this model does not fully explain the process of technological and institutional change or stagnation. By its nature, a linear model cannot describe a reciprocal relationship, such as we have suggested exists between technological and institutional change. Moreover, the model in question does not uncover the dynamics of the interrelationships between supply of and demand for innovations, nor can it articulate the parameters that affect both supply and demand.

The alternative model depicted in Figure 26-1 conceptualizes the generation of technological and institutional innovations by the public sector as a dynamic process of circular and cumulative causation. In this process both the socioeconomic structure (the infrastructure) and the politico-bureaucratic structure (the superstructure) are given explicit roles. The central node of the model is a "payoff matrix" which identifies the net economic gains and losses that are expected to result from the provision of a given set of public goods (technological and institutional innovations) to a given set of interest groups in society. Some of the alternatives considered within this matrix are technological choices among commodities (e.g., food versus cash crops, cereals versus livestock); among regions (e.g., irrigated versus dry land, fertile versus marginal lands); and among technological biases (land-saving biochemicals versus labor-saving mechanical devices, modern versus intermediate mechanical techniques, etc.). Interest groups include, in particular, commercial farmers, traditional landed elites, subsistence farmers, landless agricultural workers, industrial employers, urban workers at different income levels, exporters, and government. Each social group expects to derive a specific income gain or loss

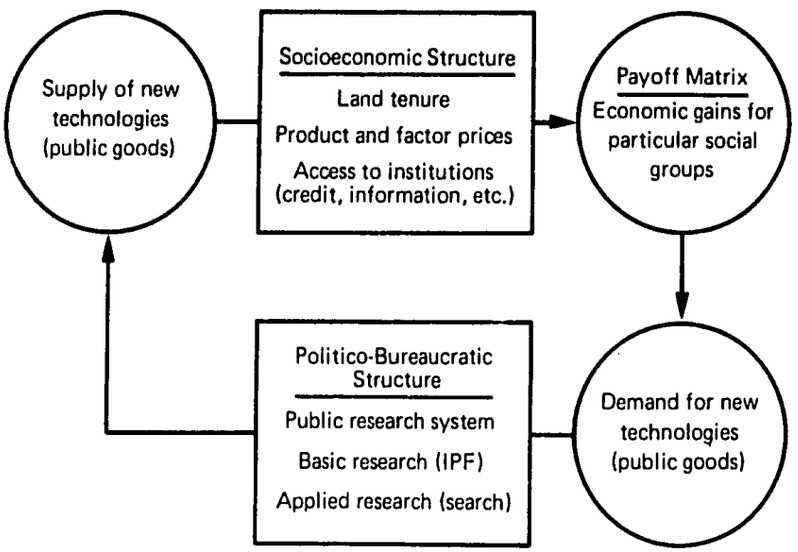

Figure 26-1. The inducement and diffusion of technological innovations (public goods).

from each particular public good. These incomes are the "payoffs" that constitute the entries in the public goods-social groups matrix. In this model the economic base of society determines its evolution.

The supply and demand mechanism for public goods is centered on the payoff matrix and conditioned by the socioeconomic structure on the one hand and by the politico-administrative structure on the other. Specifically, the demand for new public goods originates from the matrix of expected payoffs: each social group will pressure the politico-administrative structure for public goods to be (or not to be) generated depending upon the corresponding payoffs it expects to derive. Here the relative power of a social group over the politico-administrative structure determines whether the group's demands for a supply of a particular public good will be satisfied. In the case of technology, pressure on the politico-administrative structure induces allocations of funds and of human capital to research institutions and to particular lines of research. The level of scientific knowledge and the quantity of physical and human capital allocated to basic research will determine the position of the IPF. The amount of such capital allocated to applied research will determine the intensity of search for new cost-minimizing activities within the IPF. And the *organization* of national research systems will condition the way in

which they will respond, in terms of both intensity and bias, to the set of demands made upon them.

The resulting supply of public goods creates, through the socioeconomic structure, specific payoffs for each social group. For agricultural technology these payoffs are determined by (1) the physical impact of the innovation in terms of yield effect and/or resource-saving and resource-substitution effects; (2) the diffusion effect, conditioned largely by the nature of the technological innovation and the particular positions of different social groups in the socioeconomic structure (the land tenure system and the degree of access each group has to institutions of credit, information, marketing, etc., are determining factors); and (3) the terms-of-trade effect, which determines the economic value of the physical and diffusion effects. All three effects – physical, diffusion, and price – are, of course, interdependent and together determine the entries of the payoff matrix as products of the interaction between supply of specific new technologies and the socioeconomic structure.

New expected payoffs induce further demands for new public goods. In activating this process, the organization of the research system is, again, of major importance because it influences the formation of such new expectations through the dialectical interactions it maintains with social groups.

Productivity of a national research system should thus be measured by the entries of the payoff matrix relative to costs incurred by the research system. If other costs are incurred in creating the observed payoff effects – for example, in the diffusion of new technology or the implementation of institutional changes – care must be taken to charge these costs against the resulting payoffs also.

The payoff matrix thus reveals the material base of the dynamics – or lack of dynamics – of the inducement and diffusion of technological innovations. It also indicates that, unless one makes severe value judgments and aggregates all payoffs into one net effect, care must be taken to identify the specific social effects of the gains and losses from technology in order to estimate the economic and social significance of such technology. Even if the aggregate payoff is used as a criterion of net social gain from technology, care must still be taken to identify possible negative payoffs (such as loss of employment and income for some social groups) in order to write them off from the total payoff and to determine needed economic compensations. Indeed, the commonly used net social gain measure is but a global approximation of the payoff matrix which largely hides the specific socioeconomic effects of technology as well as the reasons why technological innovations and change did or did not occur.

This model of the inducement of technological and institutional innovations is thus useful at the conceptual level. It permits the classification of a

wealth of factors known to affect the process of innovation: the material incentives to innovate, the socioeconomic structure, the politico-bureaucratic structure, etc. It also helps to locate the blockage factors to innovation: on the demand or on the supply side; on the effective translation of demand into supply or in the materialization of supply into actual payoffs.

But this model's capacity extends beyond conceptualization. By quantifying the payoff matrix, it can actually become a powerful instrument for policy analysis and decision-making. To determine the material significance for society of alternative technological and institutional options is, however, a difficult task and one of central concern to economists and other social scientists. Although we do not pretend to resolve this question here, we can provide some guidelines on how quantification of the payoff matrix may proceed.

Estimation of the Payoff Matrix for Public Goods

The payoff vector for a public good is obtained as the change in net per capita income for each social class between the pre-public good and the post-public good situation. If the only impact on incomes between two time periods is due to the public good, *ex-post* observation of the changes in per capita incomes provides the payoff vector. But other changes have usually also occurred during the time interval; moreover, we may want to predict, *ex ante*, the expected payoff from alternative courses of action. In both instances, estimation of the payoff vector will require construction of a model that can explain the process by which personal incomes are generated and account for the changes in personal incomes brought about by introduction of the public good.

To devise such a model we propose to proceed in two stages: (1) constructing national accounts that make explicit the flows of income and expenditures for different social groups; and (2) simulating – through partial modeling – the impact that the public good has on these flows and hence ultimately on individual incomes.

Constructing Socioeconomic National Accounts

Unfortunately, the standard national account systems and input-output tables do not provide information on income and expenditure flow for social groups, being disaggregated only by types of economic activities. What is needed instead is a system of socioeconomic national accounts where a disaggregation by social class is nested within the standard disaggregation by economic sector.

To provide an example, I have constructed such an accounting system for

Chile using data compiled by Echeverria.[3] Included are four economic sectors (agricultural, nonagricultural, foreign, and financial), two types of land tenure (commercial farms, classified by the Inter-American Committee for Agricultural Development (CIDA), as large and medium multifamily farms; and peasant farms, categorized by CIDA as family and subfamily farms);[4] and three social classes within each type of tenure (the owners, the semiproletarians who receive part of their wage as the usufruct of a plot of land, and the proletarians whose whole wage is in cash). It is unfortunate that, for lack of data, the government sector must be omitted here, since its inclusion would have made it possible to account for income transfers through taxes and subsidies.

In Table 26-1 the rows correspond to income and the columns to expenditures. For the producing sectors the columns give a breakdown of the value of goods in "constant" capital (C = cost of intermediate products and depreciation of the stock of capital), "variable" capital (V = cost of the labor force), and "surplus value" (S = interest, dividends, rents, and profits). Semiproletarians are remunerated partly in land rights (VL), partly in consumption goods (VK), and the remainder in cash (VC). The land rights generate income for the semiproletarians and enter as costs for the owners valued at the opportunity cost of land for them. The payments in kind enter as income and cost for the owners and as income and expenditure for the semiproletarians. Among the columns that show the entrepreneurial activities of the owners and semiproletarians, those to the left (C, VC, VK, VL) account for production costs and those to the right account for consumption and savings, that is, for the use made of net income. The surplus value is used, in part, for consumption purposes (SC) and, in part, for savings (SS).

For each social group gross income is the sum over columns. The net income of owners and semiproletarians is the difference between gross income and the sum over rows of production costs. As Table 26-1 shows, the net income per commercial farm owner is twenty-three times higher than that of the peasant owners, fifty-two times higher than that of their semiproletarian workers, and eighty-four times higher than that of proletarians.

Simulating the Effect of Public Goods

What now has to be simulated is the impact that the introduction of a specific public good can have on the per capita net income vector. To do so, we must represent the effect of this public good on the flows of funds in the type of socioeconomic accounts referred to above.

Consider, for example, the contrast Hayami and Ruttan have drawn between two broad alternative technological options: mechanical technology (which is labor saving and yield neutral) and biochemical technology (which is land saving and, hence, yield increasing).[5] The market and distributional effects for

Table 26-1. Socioeconomic National Accounts for Chile in 1962

Category	Commercial Farms (1,000 escudos)											Peasant Farms (1,000 escudos)										
	Owners						Semiproletarians				Proletarians	Owners						Semiproletarians				Proletarians
	C	VC	VK	VL	SC	SS	C	VK	SC	SS		C	VC	VK	VL	SC	SS	C	VK	SC	SS	
Commercial farms																						
Owners	36.1		12.2	32.5	14.7		13.1		20.7		4.5	9.3				39.2		1.1		1.8		1.1
Semiproletarians		36.6			27.9		13.1	12.2	82.6		1.4											0.4
Proletarians		11.3																				
Peasant farms																						
Owners					4.4						1.4	25.0		1.1	2.8	11.7						0.4
Semiproletarians					2.4						0.1		3.2					1.1	1.1	7.2		
Proletarians													2.8									
Nonagricultural sector																						
Owners	123.0				131.5		34.3		59.4		3.9	25.0				31.2		3.0		5.2		1.0
Proletarians																						
Foreign sector																						
Imports	21.3				9.9																	
Financial sector																						
Savings						108.2				11.1							3.6				0.9	
Total expenditure	180.4	47.9	12.2	32.5	190.8	108.2	60.5	12.2	162.7	11.1	11.3	59.3	6.0	1.1	2.8	82.1	3.6	5.2	1.1	14.2	0.9	2.9

Table 26-1 — continued

Category	Nonagricultural Sector (1,000 escudos)					Foreign Sector (exports, 1,000 escudos)	Financial Sector (investment, 1,000 escudos)	Gross Income (1,000 escudos)	Net Income (1,000 escudos)	Active Population (1,000 persons)	Net Income per Active Person (escudos)
	Owners										
	C	V	SC	SA	Proletarians						
Commercial farms											
Owners	59.3		78.8		202.7	26.9	24.1	578.1	305.1	51.6	5,913.0
Semiproletarians					61.3		11.1	246.6	186.1	162.3	114.6
Proletarians								11.3	11.3	158.6	71.0
Peasant farms											
Owners	14.5		23.6		60.6		3.6	149.1	79.9	310.5	257.0
Semiproletarians					5.3		1.0	21.4	16.2	13.3	1,218.0
Proletarians								2.8	2.8	41.3	68
Nonagricultural sector											
Owners	2,538.8		2,793.9		1,837.6	637.9	598.7	8,824.4	3,243.0	402.6	8,055.0
Proletarians		2,403.8						2,403.8	2,403.8	1,761.7	1,365.0
Foreign sector											
Imports	565.0		54.0		236.3		251 2	1,137.7			
Financial sector											
Savings				765.8				889.6			
Total expenditure	3,177.6	2,403.8	2,950.3	765.8	2,403.8	664.8	889.7	14,264.8		2,901.9	

both types of technology in closed and open economies are depicted in Figure 26-2 (for further elaboration see chapter 6). The case of the open economy is characteristic also of an economy where price-support programs exist. In Figures 26-2.3 and 26-2.4 the supply function becomes horizontal at the minimum average variable cost level below which firms would discontinue production.

Mechanical innovations (Figures 26-2.3 and 2.4). Under the assumptions of our model, mechanization is purely cost reducing, and the resulting net social gains (NSG) accrue wholly to landowners in both closed (Figure 26-2.3) and open (Figure 26-2.4) economies, since welfare gains are capitalized in land values.[6] In this case the technological "treadmill" that coerces nonadopters into change materializes through rising land values. Adopters of mechanical innovations bid up the price of land, internalizing the welfare gains from mechanization in land values, and thus raise both the opportunity cost of holding land for owner-operators and the rent for tenants. The rise in opportunity costs forces all those that have not mechanized to do so or abandon agriculture.

Biochemical innovations (Figures 26-2.1 and 2.2). In a closed economy the net social gains from biochemicals that result from lower food prices (Figure 26-2.1) will accrue, in the form of cheaper wage goods, to consumers or to industrial employers according to the relative social power of the two groups. They accrue to landowners in an open or farm price-supported economy (Figure 26-2.2). In the open-market case, we[illegible] gains to the whole economy arise only from increased exportable surpluses and the effect that higher foreign exchange earnings have on economic growth through the import multiplier. In the price-support case, welfare gains to landowners result from increased government costs of protectionism and thus imply an income transfer from taxpayers to landowners.

The dynamic diffusion mechanism of new biochemical techniques in the closed free-market economy (Figure 26-2.1) occurs through the Cochrane and Owen "Mill-Marshallian" treadmill of falling product prices.[7] By contrast, the diffusion mechanism occurs through the land-market treadmill in the open and in the farm price-supported economies (Figure 26-2.2). The well-known observation that, in the United States, "the net result of technological advance concurrently with public farm programs, such as we have had in the past 30 years, is mainly a continuous rise in farm real estate values"[8] indicates that this second mechanism may have been the effective one.

Conflicts of Interest and Solutions

Definite conflicts of interest exist among social groups in the use of mechanical versus biochemical techniques in the closed economy. Because no

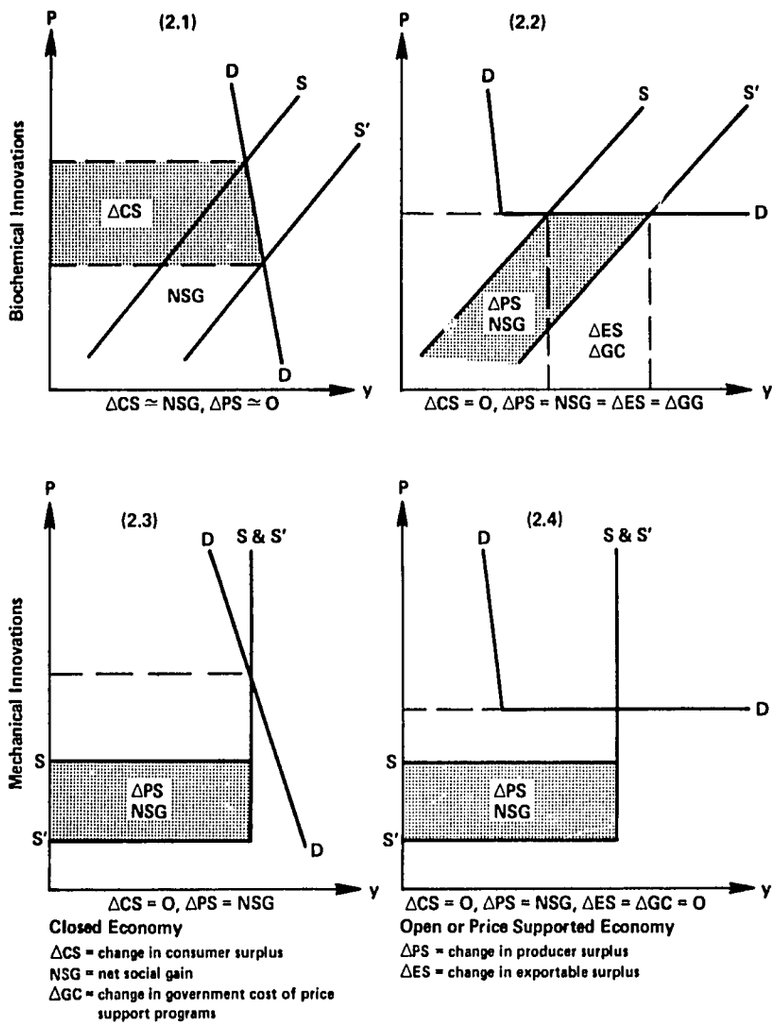

Figure 26-2. Social distribution of the economic surplus from agricultural technology.

solution exists in the game between employers-consumers and landlords over the choice between mechanical versus biological technologies, resolution of this contradiction will hinge upon the relative social power of landlords, industrial employers, and consumers. It is only when the industrial entrepreneurs' class is also the land-owning class, as Stavenhagen claims to be the case

in most Latin American countries,[9] and when workers' (consumers') power is weak, that a single social class can capture the benefits both of biochemicals, through lower wage-goods and increased surplus values in industry, and of machinery, through increased land-rent earnings.

In the open and price-supported economies, by contrast, solutions exist that are of opposite nature.

In the open economy, while mechanical technology benefits only landlords, biochemicals increase the welfare both of (1) landlords, through higher land rents, and of (2) the economy at large (or at least of the industrial entrepreneurs' class), through growth resulting from relaxation of foreign exchange bottlenecks. Hence, unless landlords have specific reasons for preferring to derive gains through mechanical rather than biological technologies (which can be expected to be the case under the *latifundia* tenure system because mechanization reinforces the owner's power over farm workers, while biochemicals would weaken it and eventually jeopardize the survival of the extant social order), class and sectoral coalitions of interests would lead to choosing a technological path dominated by biochemicals.

In the price-supported economy, biochemicals still benefit landlords but require income transfers from taxpayers to them. By contrast, mechanical technologies benefit landlords while being neutral on consumer, employer, and taxpayer welfares. As a consequence, class coalitions, when they exist, will tend to pursue mechanical rather than biochemical means of technological development.

Summary

A model has been developed that specifies the dialectical process through which technological and institutional changes occur. In this model, the economic payoff that each social group expects to derive from the change provides the rational basis from which demands for such change arise. The politico-bureaucratic structure of society determines how these demands are transformed into an actual supply of new technologies and institutions. And the socioeconomic structure translates that supply into actual payoffs for each social group.

Identification and quantification of the payoff matrix are major tasks confronting social scientists because they give the key to the *ex-post* analysis of the evolution of social systems as well as to the *ex-ante* evaluation of projects of technological and institutional change. An attempt was made to indicate how such a matrix could be obtained by constructing socioeconomic accounts and identifying in those accounts the impact on per capita incomes of technological and institutional changes.

NOTES

1. If external influences are important – which is generally the case in the less developed countries – the social system in question exceeds national boundaries.

2. Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: Johns Hopkins University Press, 1971), pp. 59-60.

3. R. Echeverria, *Polltica de precios y redistribución de ingresos agricolas* (Santiago, Chile: Instituto de Capacitación e Investigación en Reforma Agraria, 1972).

4. S. Barraclough, ed., *Agrarian Structure in Latin America* (Toronto: Lexington Books, 1973).

5. In accordance with this contrast, an aggregate two-stage production function for the agricultural sector can be specified where (1) there are four inputs – labor, land, labor-saving capital (machinery), and land-saving capital (biochemicals) denoted by L, T, K_L, and K_T, respectively; (2) L and K_L are highly substitutable and so are T and K_T; and (3) substitution possibilities between K_T or T and L or K_L are low. Consequently, with an inelastic aggregate land supply and a constant level of land-saving capital items, K_L can be only mildly output increasing since the output effect is blocked by the fixed land and land-saving inputs. Under these circumstances, mechanization is essentially labor displacing. Also, with an inelastic land supply and a constant level of labor-saving capital items, K_T is highly output increasing as long as the elasticity of supply of labor is high.

The aggregate production function for agriculture can be written then as a two-stage function:

$$Y = TF\ [f_T(T^*, K_T^*), f_L(L^*, K_L^*)]$$

where T is an index of neutral technological change and the asterisk denotes inputs measured in effective units that are related to the nominal input units through a factor-augmenting coefficient of technological change. The subfunction, f_T, is an index of "land" inputs, while f_L is an index of "power" inputs. The distributive effects of technology can be analyzed under the assumptions that land is in completely inelastic aggregate supply in the short run and that the internal market demand for agricultural products has a price elasticity of less than one. Also, to contrast the different impacts of machinery and of biochemicals, technological changes and shifts in factor supplies of these two types of capital goods can be analyzed separately, if the level of use of the other capital good is always held constant.

6. The inelasticity of supply in these two figures, which reflects the model's assumptions, implies that the marginal productivity of labor in agriculture is zero when land and land-saving capital are in fixed supply.

7. W. W. Cochrane, *Farm Prices: Myth and Reality* (Minneapolis: University of Minnesota Press, 1958); W. Owen, "The Double Developmental Squeeze on Agriculture," *American Economic Review*, 56:1 (May 1966), 43-70.

8. W. B. Black, "Discussion: Income Effects of Innovations – The Case of Labor in Agriculture," *Journal of Farm Economics*, 48:2 (May 1966), 338.

9. R. Stavenhagen, "Seven Fallacies about Latin America," *Latin America Reform or Revolution*, eds. J. Petras and M. Zeitlin (Greenwich, Conn.: Fawcett, 1968), pp. 13-31.