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Methods for Setting Agricultural Research Priorities:

Report of a Bellagio Conference

by

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ABSTRACT

This paper reports on a conference on "Methods for Setting Agricultural Research Priorities" held at Bellagio, Italy in July 1987. However, it is not a conference report in the usual sense of recording what transpired. This report instead draws heavily on papers given at the conference to define the nature and scope of the priority setting problem, identify important issues, and summarize the current research concerned with developing methods for setting research priorities (see list of conference papers in reference section). The focus is on the use of these technologies in developing countries.

A common theme that emerges from previous reviews and this report is that mathematical models are excessively demanding of data and analytical skills which are especially scarce in developing countries. The simpler and more popular analytical techniques include <u>congruence or parity models</u>, <u>the weighted criteria or scoring approach</u>, and <u>expected economic surplus models.</u> The choice among these will hinge on the objectives, the economic importance of the decision, the nature of the research institution, and the time, data, and financial resources available to do the analysis. While net benefits are often calculated on the basis of economic efficiency, a growing number of studies have introduced weights designed to reflect the importance of equity, food security, environmental issues, or other factors deemed to be important.

Examples of priority setting models are presented to illustrate the range of settings - research institute, national research program, international setting - for which various priority setting models are being tested.

The report concludes with a discussion of the limitations of priority setting models and procedures. Obtaining useful results depends perhaps less on the choice of model than on the knowledge and data base, and the ability of the investigator to communicate with scientists, research administrators, producers, and others to obtain the necessary information to evaluate future benefits.

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INTRODUCTION

Publicly supported agricultural research has come to be recognized as a key element in agricultural development since semi-dwarf wheat and rice varieties, fertilizer, and irrigation led to rapid growth in India, China and a number of other countries during the 1960s and '70s. National governments and international assistance agencies now regularly identify research as a crucial component of agricultural growth, and leading theorists on agricultural development agree that agricultural research is important for growth (Hayami and Ruttan, 1985; Barker and Herdt, 1982, 1985; Mellor, 1976; Eicher, 1984), although they are careful to point out that it is but one among a number of necessary conditions. However, as development assistance funds become scarce, questions about which research to fund are becoming more pervasive.

Some efforts have been made by agricultural economists to confront the question of what priorities should be set among alternatives for agricultural research, and on the closely related question of how scarce funds should be allocated among the possible alternatives. Many natural scientists, however, resist the idea that information systematically assembled and analyzed can help in setting research priorities. In fact, agricultural researchers

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frequently argue that because of the serendipitous nature of research and scientific discovery, it is impossible to estimate potential benefits, set priorities, and allocated resources so as to enhance the social benefits from research.

This paper, reflects the opposite premise. It summarizes a number of different methods for setting research priorities, the results of work by economists who have been involved over a period of years in efforts to improve techniques and procedures designed to assist international agricultural research administrators in setting priorities and allocating resources.

The focus of the paper is on developing countries. However, the techniques used are to a large extent refinements of procedures applied in the developed countries in the 1960s and 1970s. For the United States, this work is summarized in the 1971 publication by Fishel (ed.) Resource Allocation in Agricultural Research. A second volume in 1977, Arndt, Dalrymple, and Ruttan, Resource Allocation and Productivity in National and International and International Agricultural Research, covers the experience in both developed and developing countries.

Many of these early efforts at modeling research resource allocation proved to be too cumbersome and time consuming to be institutionalized as a regular part of the research planning process. Thus, much of the recent effort presented here has been toward the development of simple procedures that can be handled on microcomputers. The objective in describing and illustrating these procedures is to show both their potential and limitations.

The terms "priorities" and "allocation" are often used interchangeably in the literature and to some extent in what follows. However, strictly speaking, "setting priorities" means ranking alternatives from most important to least important, while allocating means deciding on the level of expenditure on each alternative. If alternatives are discreet, fixed-cost actions, they can be undertaken sequentially: the first, then the second, and so forth. Often more than one alternative can be undertaken at a time; so priorities indicate which among the possible set should be funded.

"Allocation" is the determination of how much is to be expended on each alternative. Allocation is identical to priority setting only if each alternative has a single, fixed, cost. Because many alternatives can be undertaken at different rates or levels, allocation represents an additional problem even after priorities are established. The whole process of developing approaches, setting priorities, allocating funds, and evaluating productivity of research is known as "research resource allocation" or "research on research;" much of the recent literature in the field is listed in the references section.

Techniques to identify research priorities and allocate research funds require factual information, subjective judgments about future events, and systematic ways to bring these together. Few national or international research organizations have adopted and used any of these analytical procedures, but growing budgetary pressures on research programs, recent advances in analytical techniques, and the ready availability of microcomputers creates a new opportunity for developing and using them.

Research resource allocation exercises may meet four needs:

(1) to enhance communications and understanding of the priority setting process among scientists, research administrators, politicians, farmers, and others with a concern or stake in the research process.

(2) to better justify research and enhance political and financial support.

(3) to develop a structured basis for priority setting as a guide to research resource allocation.

(4) to identify the data needs for more adequate decisionmaking.

These four objectives reflect a number of concerns with the current state of the art. Analytical models have been improved, but lack of data often limits researchers in the choice of model. That is, the success of any procedure depends perhaps less on the choice of model than on the knowledge and data base, and on the ability of investigators to communicate with scientists, research administrators, producers, and others to obtain the necessary information to evaluate future benefits. Finally, there is a need to communicate to the public at large, to politicians, to finance ministers, and to funding agencies the potential benefits from agricultural research (or alternatively the losses that may follow from neglect of research investment).

This paper presents several analytical techniques and procedures currently being used to assist in research priority setting. An attempt has been made to clarify technical terms and to minimize the use of technical jargon so that the article can be read by economists and non-economists alike. The following section describes the nature of the priority setting problem. Section three sets forth the scope of priority setting research. The fourth section describes the various analytical procedures and models being employed. The fifth illustrates the use of these models in three distinctly different case studies. The sixth section emphasizes the limitations of the modeling approach and identifies areas for further research. Most of the material is adapted or extracted from papers presented at a Rockefeller Foundation sponsored conference held at Bellagio, Italy in July 1987.

THE NATURE OF THE PRIORITY SETTING PROBLEM

Any research planning activity must address three questions:

(1) What are the possibilities of advancing knowledge or technology if research is conducted on a particular commodity, problem, or discipline? (Ruttan, 1982 p. 263).

(2) What is the demand for such knowledge or technology on the part of user groups? (Norton and Ganoza, 1986 pp.10-11).

(3) What will be the value to society of the knowledge or technology if the research effort is successful? (Ruttan, 1982 p. 263).

Agricultural scientists are best qualified to judge whether research on a specific area will produce new knowledge or technology, how long the process will take with a given budget, and the likely chances of success. To what degree is it possible to predict the outcome of a research investment? In the early 1960s, the

United States made the judgement that within the decade it could place a man on the moon even though certain technical knowledge to achieve this was not yet available. Although one has to be cautious about "promising the moon", agricultural scientists are capable of ranking the degree of difficulty and likelihood of success in solving specific problems (even in areas which would be considered fairly basic research), or in determining which environments or which crops have the greatest potential for production gains. Opinions will differ, but for most categories of problems there is broad consensus. Even though serendipity may prove the predictions wrong, the speed with which most research problems are solved depends on both the quantity and quality of resources applied.

Agricultural scientists, however, are often very poor at judging the demand for their products. Usually there is little communication between researchers and end users. Extension services and private sector companies lack the capacity to provide adequate feedback to research workers. Researchers frequently complain that farmers are unwilling to adopt what they, the scientists, regard as superior technologies. The growth of farming systems research and the call for "appropriate technologies" for small farmers are a reflection of the communications gap between research workers and farmers.

The value that a society places on new knowledge and new technology depends on the society's development goals. The link between development and research goals is not always clear. This is because research administrators find it easier to set goals in terms of supply oriented targets, e.g., increasing production or yield of a specific crop, than in terms of national development goals. On the other hand ministers of agriculture and those higher up in government administration are concerned with specific social or economic objectives such as raising farm incomes, increasing foreign exchange earnings, or widening the distributional benefits of research. Thus, there is frequently another gap in communication between the research community and those concerned with setting national development goals.

An effective research administrator, in establishing his research goals, must take into account both the demands of end users for appropriate technology and the demands of society for technology in keeping with development goals. Therefore, the research planning process requires close communication and collaboration among government administrators and planners, research administrators, biological and social scientists, and extension workers, farmers, and other end users. This is a "tall order." The success of any research priority setting effort will depend in large measure on how well the researcher is able to communicate with scientists and non-scientists alike to obtain answers to any or all of the three questions posed at the beginning of this section. If priority setting research is to be institutionalized, there must be a continuing effort to enhance communications among all levels concerned with the research, technology development, and adoption process.

As noted previously, research administrators prefer to orient research goals toward supply targets and find it convenient to organize research activities around commodity programs. Priority setting studies conducted by economists also tend to follow a commodity orientation because potential benefits can be readily quantified. In addition to commodities there are three other convenient dimensions across which research systems may allocate research funds: (i) by resource - e.g., soil, water, fertilizer, labor; (ii) among stages or levels in farm production - e.g., credit, farm production, post harvest technology, marketing; and (iv) among academic disciplines - e.g., genetics, plant breeding, pathology, entomology, economics (Ruttan, 1982, p. 265). The four dimensions clearly are not independent, but the number of permutations of commodity, resource, stage, and discipline is very large, and even with a formal model would be difficult to handle. Therefore, while it is obvious that commodity provides only part of the basis for making resource allocations, most of the work done to date begins with commodities.

THE SCOPE OF PRIORITY SETTING RESEARCH

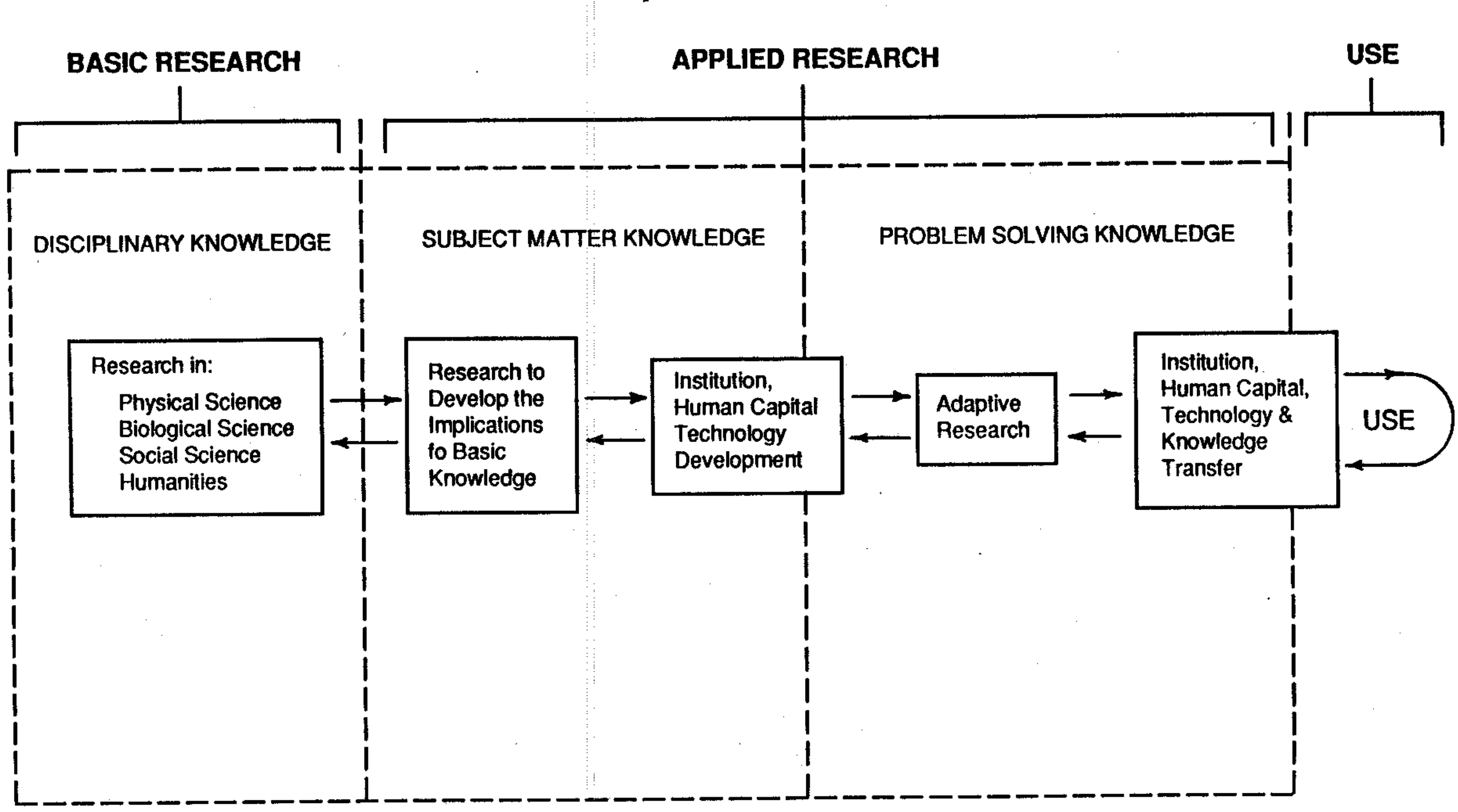
Priority setting studies vary widely in scope. They range from allocation problems at the commodity-specific project level to allocation problems at the program level which may cut across commodities, groups of commodities, research problem areas, disciplines, or regions. The scope of priority setting research may be categorized by: (i) the nature of the research system, (ii) the level of priority setting within the system, (iii) the geographic area or ecological zone covered, (iv) the time horizon, (v) the commodity or research area, and (vi) the problem areas within a commodity.

The elements of an agricultural research system are shown in Figure 1 (Bonnen, 1986). In developed countries there is a fairly even division of expenditure between basic and applied research. Most developing countries do not have the capacity to conduct basic research, and their capacity to conduct applied research varies widely. In these countries, private sector applied research is conducted mainly by multinational corporations which usually focus on crops they export. The international agricultural research centers have focused on the development of technologies for major food crops and livestock which could be adapted by national research programs for local dissemination.

National research policy increasingly has to embrace international dimensions involving both public and private sectors. Exploiting complementarities and opportunities offered by international agencies is an increasingly complex and demanding role for national research policy makers (Davis and Ryan). If international research centers and donor agencies are to effectively complement the research efforts of national programs, they must be thoroughly familiar with national research strategies and policies.

One main issue at stake for national research systems is how much money will be allocated either by the national government or by external donor agencies. Despite the high rate of return to research

Figure 1.
The Creation-Development-Utilization of Knowledge



investment documented in many studies, the decline in research budgets since the early 1980s suggests that national and international research organizations have not been successful in convincing those who control finances of the need for stronger research support.

In national programs, priorities are established in at least four levels as illustrated in Figure 2 (Javier):

At the cabinet/parliament level where national development goals are determined.

At the level of the ministry of agriculture where sectoral objectives are set out.

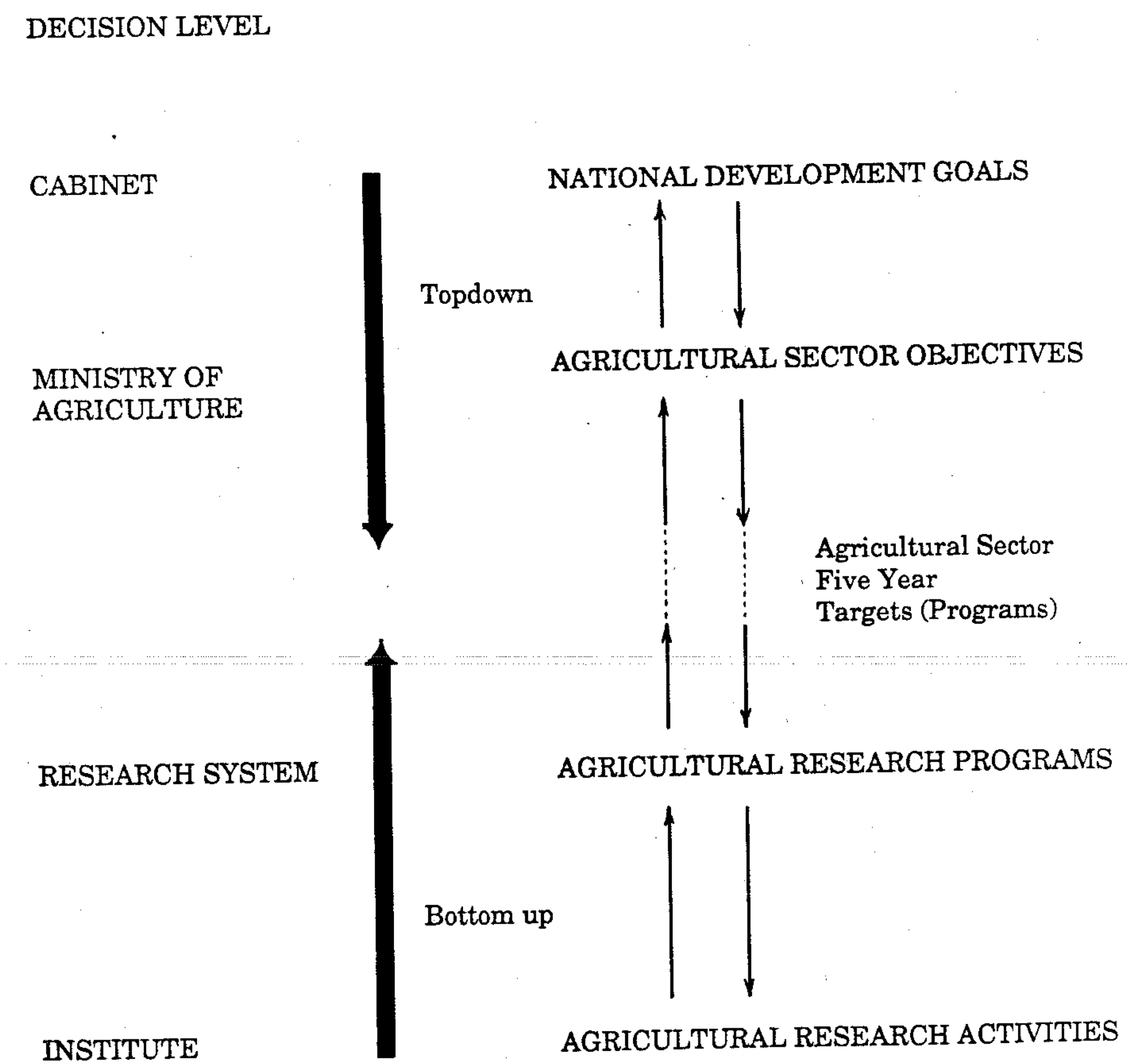
At the national research system level where agricultural research programs are built.

At the level of the implementing research institutions which decide on their respective research activities.

The process should be iterative, with a flow of information from the top down and from the bottom up as shown in Fig. 2. But as noted in the previous section, there tends to be a gap in communication between the cabinet/ministry levels where national and sectoral goals are handed down and the system/institute levels where the research agenda is built from the bottom up. Javier suggests that the process could be better integrated if there were more precise statements which formed a bridge between development goals and research agenda. For example, development goals set forth in the five year plan could be translated into formal agricultural sector targets such as the following:

Increase rice production by 10 percent to keep up with population growth and provide for food reserves.

Figure 2. Program Priority Setting in Agricultural Research



Source: Javier, Bellagio Conference, 1987

Increase maize production by 30 percent to reduce import requirements and save foreign exchange.

Each such goal then has to be translated into corresponding action goals for research, extension, agricultural credit, and other sub-sectors. There is a difficulty with this approach because it fails to consider at least two of the three questions mentioned earlier which any research planning activity must address: what are the prospects for success if research funds are invested, and does the country have a comparative advantage in the commodity to make the research valuable to society? Therefore, it would be hard to use these targets as a basis for guiding research investments. To the contrary, feedback from research planning could lead to the establishment of more realistic development targets.

Research programs may cut across countries, regions, and ecologies. International agricultural research centers (IARCs), for example, typically want to know what priority should be given to each target ecology, each of a specific set of commodities, and each research problem within a commodity. These issues may be examined jointly or independently. For example, a study was undertaken to examine priority for funding ILCA livestock research across four African ecologies (McIntire); a study also was undertaken by the Rockefeller Foundation and IRRI to determine the relative importance of 63 rice research problems across four Asian ecologies (Herdt and Riely).

The planning horizon may vary from a single year to five or ten years. Plans with a five to ten year horizon are commonly referred to as long run or strategic and those with a one to two year horizon as short run or _current_. The major difference is that in the long run fewer resources are fixed and the broad direction and focus of research can be changed. The important question that all research administrators should ask is: "what should be the nature of our research activities ten years from now?" This will affect decisions on staffing pattern and on budget allocations for capital as well as operating expenses.

ANALYTICAL PROCEDURES AND MODELS

Economists have used a wide range of analytical techniques to assist in agricultural research priority setting, ranging from very simple weighting schemes to sophisticated models. They have also used different terminology in referring to the same technique, and frequently combine two or three techniques in the same study, often making it difficult for the uninitiated to understand the procedures being followed. In this section we discuss the various analytical techniques and try to clarify the terminology; then in the following section we provide illustrations of some of the techniques. Most approaches can be used both to examine how resources are used (_ex post_ analysis) and to prescribe how resources ought to be used (_ex ante_ analysis). We are concerned here mainly with the latter applications.

Single Criterion Models

A fairly simple approach is to allocate resources in proportion to the value of the commodity produced. This has been referred to as the _parity_ model of research resource allocation or _congruence_ analysis (Ruttan 1982). In this approach, two fairly strong assumptions are made: that there is an equal probability of success and equal expected payoff per dollar invested in each commodity. The optimal allocation then is one in which the proportion of research funds invested on each commodity is equal to the proportion of current output value generated by each commodity. When used as an ex post technique, the analysis attempts to establish the degree of congruence between the share of total research investment among commodities and the share of total value represented by the respective commodities value normally being measured as "gross value" or "gross value added"). For example, if maize represents 20 percent of value of agricultural production, then complete or perfect congruence would imply that 20 percent of research funds should be allocated to maize, and so on for all commodities.

Examples of ex post studies employing this analysis include Boyce and Evenson 1975, and Salmon 1983. Norton and Ganoza 1986 used this approach in an ex ante study by setting guidelines first by applying the value of production criterion and then following this up with a set of questions which decision-makers can ask themselves during annual research planning meetings.

Of course, criteria other than value of output may be chosen as the basis for congruence analysis. Pineiro and Moscardi 1984 use nutritional output, and von Oppen and Ryan 1981 use physical output. Longmire and Winkelmann 1985 used an empirical analysis of comparative advantage (domestic resource cost analysis) to assess the likely economic value of research on different commodities in different regions. The criterion may be chosen so as to reflect greater concern with production or with equity (e.g., employment generated), but most studies use a production criterion.

Weighted Criteria Models

Several studies have established multiple criteria for ranking priorities because of the desire to consider a wide variety of factors that do, or perhaps should influence research selection. This use of several criteria in a weighted or unweighted combination is referred to as the scoring approach. It contrasts with congruence approach which is based on a single factor.

The relative weights attached to each criterion to arrive at a final list of research priorities are sometimes left implicit or unstated. A recent example is the priority-setting study for the international agricultural research centers conducted by the Technical Advisory Committee of the Consultative Group for International Agricultural Research (CGIAR, 1985). In that case they established a principal goal, and a series of criteria organized in three groups: relevance, productivity, and efficiency. Tables with quantitative information and rankings of commodities for each criterion were presented followed by a table which gives a final ranking of commodities after aggregating across criteria. However, the weights used to aggregate were not explicitly provided (Norton).

There are numerous examples of studies which have incorporated multiple criteria but also explicitly specified and utilized a set of weights to aggregate across criteria and obtain a final ranking of research priorities. Applications of the scoring approach are found in studies by Paulson and Kaldor 1968, Mahlstede 1971, Williamson 1971, Shumway and McCraken 1975, and von Oppen and Ryan 1985. The interest in this approach seems to have peaked in the United States with the above papers of the early 1970s. These tended to be large, one-time studies requiring a considerable amount of time on the part of both researchers and administrators in the state experiment stations. More recently, improvement in techniques using micro-computer spread-sheets, and USAID interest have led to applications of scoring models in the Dominican Republic by Moscoso Coutu, Bandy, and Norton (ISA, 1986), in Ecuador by Espinosa, Norton, and Gross 1986, and in Uruguay by Ferreira, Norton, and Valverde (CIAAB, 1987).

Expected Economic Surplus Models

Benefit-cost analysis and consumer-producer surplus calculations are two common and related approaches for research priority-setting. Benefit-cost analysis makes use of measures such as benefit-cost ratios, and internal rates of return, and involves, at least implicitly, the calculation of economic surplus. However, the explicit calculation of economic (consumer and producer) surplus may or may not involve the subsequent application of these benefit-cost measures. There is a large body of literature using the benefit-cost measures in *ex post* analyses of returns to research. Only a few studies, for example, Araji, Sim, and Gardner 1978, and Barker and Herdt 1982, have used benefit-cost (without explicit calculation of economic surplus) to estimate future benefits.

The consumer-producer surplus model is illustrated in Figure 3. Agricultural research results in per unit cost reduction and/or yield increases which shift the supply curve down and to the right from S to S'. Consumer surplus gains are illustrated as the shaded area in the left hand diagram. Consumers gain because they receive more product at a lower cost. Producer surplus gains and losses are illustrated in the middle diagram. Producers receive gains from increased production at lower cost, but losses from the lower price received per unit. Net producer surplus may be positive or negative. The total change in economic surplus is illustrated in the right hand graph and represents the summation of the producer and consumer surplus.

It can be seen that the magnitude of the price change and hence the proportioning of benefits between producers and consumers depends on the slope of the supply and demand functions and the nature of the supply shift. The more steeply sloped (inelastic) the demand function, the more likely that benefits from a widely adopted technological innovation are going to accrue to consumers.

Figure 4 shows an extreme case in which it is assumed that the demand function is perfectly elastic, that price remains constant, and therefore all benefits accrue to producers. This is the case which is often implicitly assumed when benefit-cost analysis is performed without explicit calculation of economic-surplus, as for example in the case of most feasibility studies for irrigation projects. This would be an appropriate assumption for a single project or research activity where the total shift in supply due to

Figure 3. Consumer-Producer Surplus

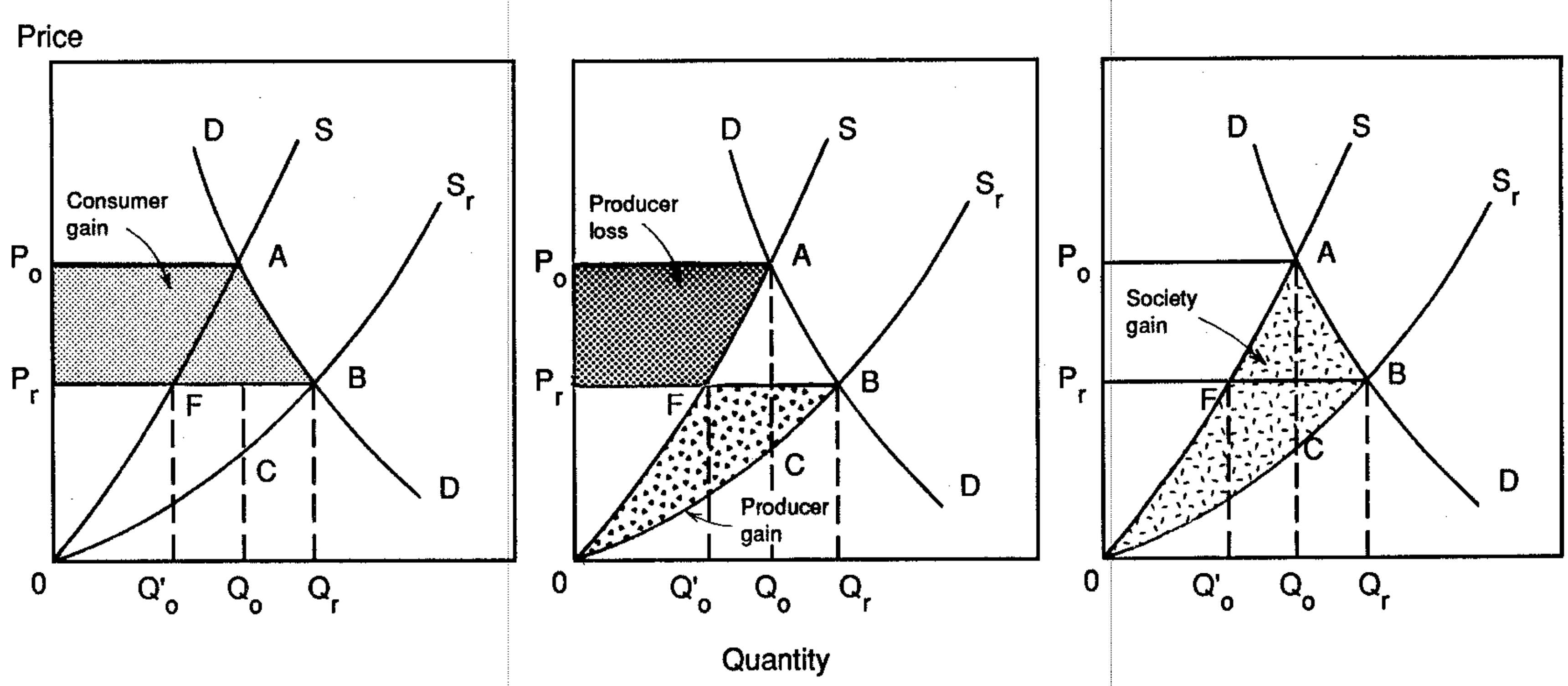
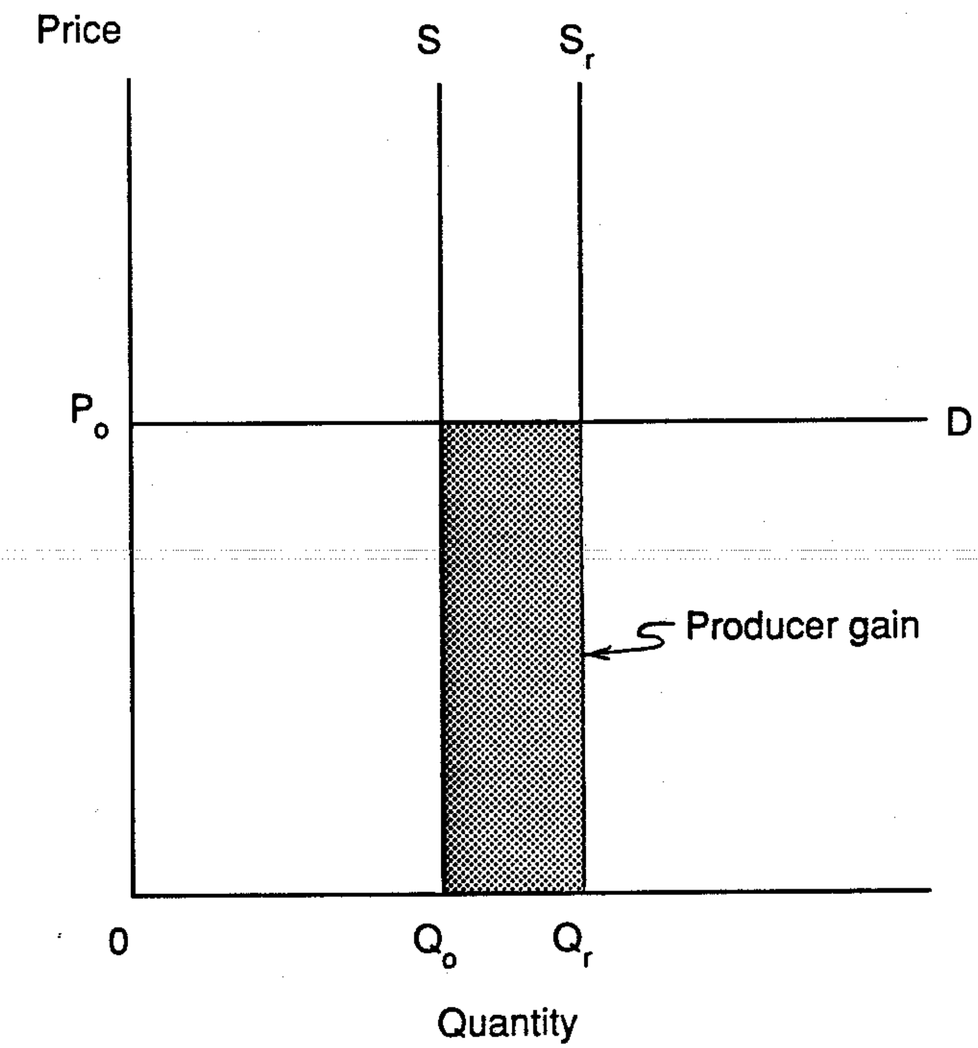


Figure 4. Benefit-Cost



adoption was not great enough to affect price, or in the case where exports or subsidies permit prices to be maintained at pre-innovation levels, or where prices are determined in the world market and the innovation does not affect world prices.

Early producer-consumer surplus analyses made no distinction among classes within the two broad groups of producers and consumers. However, with the growing concern for equity, increasing attention is being given to analytical refinements which make it possible to identify benefits to poor producers and poor consumers. Also, producers are themselves consumers. If producers consume a large fraction of what they produce, they reap benefits in their roles as consumers, and somewhat counter-intuitively, their gains are larger the smaller the proportion of their output of the commodity they sell (Hayami and Herdt 1977).

As is the case with cost-benefit approaches, the consumer-producer surplus models have been used much more extensively in ex post analyses applied to research evaluation than in ex ante priority setting exercises. Examples of ex ante applications include Davis, Oram, and Ryan 1986, and Norton, Ganoza, and Pomareda 1987.

Mathematical Models

Two classes of models fall into this category, mathematical programming and simulation. These approaches are more demanding in terms of data and analytical capability than the models discussed previously.

In mathematical programming, a research portfolio is selected by maximizing a multiple goal objective function given the resource constraints of the research system. A good example of this method is a study by Russell 1977 in the United Kingdom. He used goal-programming to maximize the contributions of the research program to several goals given the constraints of budget, human resources, state of knowledge, and certain policies. This procedure uses similar information to the scoring models, and weights are placed on goals or criteria, but the model selects an optimal research portfolio rather than simply ranking research areas (Norton and Pardey, 1987).

Simulation models vary in their construction, but a good example is provided by Pinstrup-Andersen and Franklin, 1977. Their model was designed to project the contributions and costs of alternative research activities. They established goals and then projected changes in supply, demand for inputs, and demand for output needed to meet these goals. They identified needed technologies, time requirements and financial costs, and the probability of research success and adoption. Finally, they specified scientists' working objectives. The model is very thorough, but the time and resources required to collect the data and conduct the analysis were so great as to limit the use and the extension of this approach (Norton and Pardey, 1987).

Choosing Among Approaches

Recent literature reviews which discuss the various ex ante approaches described above include Schuh and Tollini 1979, Norton and Davis 1981, Ruttan 1982, and Anderson and Parton 1983. A common theme that emerges from these reviews and our own is that the mathematical models are excessively demanding of data and analytical capability, which are especially scarce in developing countries (Davis, Oram, and Ryan 1986). However, they have the advantage that they tend to minimize the extent of scientific subjectivity which is required for establishing both aggregate research priorities and project priorities (Shumway 1980).

Among the simpler and more popular analytical techniques, the choice will hinge on the objectives, the economic importance of the decision, the nature of the research institutions, and the time, data, and financial resources available to do the analysis. The transfer of new technologies depends on how suitable these technologies are for local conditions. The same is true for institutional innovations such as improved research priority setting procedures (Norton).

In short there is need for a flexible set of approaches that can be tailored to the specific situation. When very few resources are available for the decision-making process, the time frame is short, and the economic importance of a particular decision is small, then <u>single criterion models</u> and guidelines may be adequate. However, for most strategic planning at the national level multiple goals and criteria are important and <u>weighted criteria models</u> may be helpful. If the number of commodities to consider is small and the research outputs relatively easy to quantify then <u>expected economic surplus models</u> may be useful.

It is important to recognize the relationship between weighted criteria and expected economic surplus methods. In both methods, the analyst must rely heavily on agricultural researchers and others for technical information regarding the direct effects of research, probability of success, and expected adoption rates. In expected economic surplus models the net benefits are usually calculated strictly on the basis of economic efficiency. However, if the problem is set up in a sufficiently disaggregated way, it is possible to apply weights on the basis of problem, environmental region, or commodity which take into consideration equity, food security, or other factors deemed to be important. It is often useful to compare the weighted results with the unweighted based strictly on economic efficiency, and to calculate the opportunity cost of placing weights on non-efficiency criteria.

Finally, as will become evident in the following section, it is possible in any given study to employ a mix of approaches. For example, weighted criteria may be used to screen and identify the most important commodities and then expected economic surplus calculated for these commodities. Alternatively, benefits can be calculated and then weighted to reflect the importance of non-efficiency criteria.

ILLUSTRATIVE EXAMPLES OF PRIORITY SETTING ANALYSES

Three examples of priority setting studies are described in this section. The examples chosen were presented at the Rockefeller Foundation conference in Bellagio and in other forums in considerably more detail. Our main purpose in selecting these examples is to illustrate the range of situations in which the various priority setting methodologies are being tested.

Prioritizing Research for a Single Commodity: A Benefit-Cost Analysis of Rice

The success in raising rice production in Asia over the past two decades has led to a whole series of questions regarding future priorities for rice research. At the national level there is the question of how research resources should be divided between rice - the primary food crop for most Asian countries -and other commodities. Within the rice programs the question is how to allocate resources among different problems.

The International Rice Research Institute (IRRI) began conducting a series of strategic planning exercises in the late 1970s. These exercises have led to a clearer definition of problems and issues. First, it became obvious that the technology based on fertilizer and semi-dwarf varieties was far more successful in irrigated than in non-irrigated environments. In fact, in many of the rainfed and upland environments farmers had received no benefit from the new technology. For more than a decade IRRI has been engaged in research to define rice growing ecologies as a basis for targeting research efforts to remove constraints to increased production in unfavorable environments.

More recently, concern has been expressed that there has been no increase in yield potential of rice in the tropics since the release of the first of the modern IRRI rice varieties, IR8, in 1966. This raises the question of how much emphasis should be given to basic research in rice to raise the yield ceiling?

The Rockefeller Foundation, recognizing the potential benefits of biotechnology in solving both the basic and applied problems identified above, began funding a program in biotechnology in rice in 1985. But to decide how to allocate funds for biotechnology research, they needed answers to two questions: (1) what were the most important problems in rice research? and (2) among these most important problems, which were most suitable for biotechnology?

Herdt and Riely, using a combination of weighting procedures and benefit-cost analysis, have attempted to answer these two questions. The procedures and findings of their study are summarized in the remainder of this section.

Data Collection and Model Implementation

Herdt and Reily outline six steps to make the model operational.

Step 1: Identify the Problems Which Constrain Rice Productivity. Problems were identified in four rice growing ecologies (irrigated, rainfed, deep water, and upland) in six regions of the developing world (China, Southeast Asia, Other Asia, Sub-Saharan Africa, Latin America and Middle East/North Africa). Much of this assessment was accomplished through individual and group interviews with current and former staff members of the International Rice Research Institute who are familiar with Asia where 90 percent of the world's rice is produced. For the purpose of this exercise the list of potential research problems was limited to those factors which could be addressed through genetic crop improvement. The final list of problems included: 16 rice diseases, 24 insects that attack rice, 8 soil problems, 8 temperature and water related problems, 7 other problems including birds, rodents, and weeds, and 6 long-term opportunities for increasing rice production by radical redesign of the rice plant.

Step 2: Determine the Importance of the Problems. That is to say, what impact would a solution to each problem have on productivity. In cases where a problem results in a yield loss the severity of loss can be estimated by asking knowledgeable scientists to estimate the proportion of the area affected by each problem and the yield foregone in the effected areas. For example, in a given region what proportion of the area is affected by tungro virus and what is the yield loss in the affected area? An alternative to estimating the absolute level of loss in this manner is to determine the relative severity of the problem. This can be done through an intensity scoring approach. For example, the severity of the tungro virus problem in a region can be scored on a scale of 0 to 9 and compared with scores for other problems. These scores can then be used as weights in determining what proportion of the potential yield increase in a region could be achieved by solving a specific problem. In this study, different approaches were used with different groups in estimating the severity of problems in South and Southeast Asia.

Since only one commodity is involved, the various problems could be ranked according to the current quantity of output foregone. There was considerable agreement on the relative importance of problems. The problems causing the greatest production loss were those that were prevalent over a wide geographic area. However, the estimated magnitude of potential gain in production from solving a specific problem varied widely depending on the approach chosen. The results reported in Table 1 are based on the judgement of former IRRI scientists who were asked to estimate the percent of total area affected and the yield loss for each problem. Only the 10 most important problems contributing to the current quantity of output foregone are shown in Column 1 of the table.

Step 3: Determine Expected Private Benefits. Since we are dealing with a single product rice, the impact on its price due to a change in production (via the demand elasticity) is the same for all sources of productivity gains. Expected private benefits are calculated by multiplying a constant price by the estimated increase in rice quantity resulting from the solution of each problem.

Step 4: Assign Externality and Equity Weights. In the case of environmental externalities, controlling insects and diseases through introduction of genetic resistance was assumed to be preferable to using pesticides. The benefit was arbitrarily considered to be equal to the value of rice currently lost to pests (i.e., the estimated benefit was determined by multiplying the reduction in yield loss by 2). Likewise, genetic drought resistance was arbitrarily assumed to have external benefits equal to twice the

Table 1. Rank Ordering of the Ten "Most Important" Constraints and Foregone Opportunities That Keep Rice Production in Developing Countries Lower Than It Might Be, Based on Four Different Criteria of Judgement.

Rank	Current quality of output foregone		Value of output foregone weighted for equity and externality		Net present value of investing $200,000/year on each problem		Net present value of investing $200,000 year for equity, and and externality		Net present value of investing $200,000/yr weighted for equity, and biotechnology	
	Problem	Thou. mt.	Problem	$Mil.	Problem	$Mil.	Problem	$Mil.	Problem	$Mil.
1	Weeds	1,699	Drought/ Blast	8,537	Tungro Virus	1,627	Brown Planthopper	1,944	Tungro	6,905
2	Tungro Virus	1,534	Tungro Virus	7,907	Brown Planthopper	1,435	Tungro Virus	1,726	Submergence	3,369
3	Drought/ Blast	1,423	Weeds	7,103	Drought/ Blast	1,182	Gall Midge	1,292	Gall Midge	2,583
4	Lodging	1,092	Brown Plant-hopper	5,361	Lodging	1,158	Lodging	1,228	Cytoplasmic Male Sterility	2,322
5	Brown Planthopper	1,059	Gall Midge	4,216	Weeds	1,105	Cytoplasmic Male Sterility	1,161	Brown Planthopper	1,944
6	Cytoplas-mic Male Sterility	1,032	Cytoplas-mic Male Sterility	3,335	Cytoplas-mic Male Sterility	1,095	Drought/ Blast	1,085	Lodging Resistance	1,228
7	Submergence	750	Lodging	3,106	Gall Midge	954	Yellow Stemborer	945	Drought/ Blast	1,085
8	Gall Midge	704	Yellow Stemborer	2,918	Submergence	795	Submergence	842	Seedling Vigor	1,080
9	Birds	601	Submergence	2,608	Yellow	698	Weeds	718	Waterlogging	1,048
10	Yellow Stemborer	516	Drought At Anthesis	2,156	Seedling Vigor	510	Seedling	540	Yellow	945

Source: Herdt and Riely, Bellagio Conference, 1987.

value of production losses prevented because it reduces the need to construct irrigation (i.e., the estimated benefit was determined by multiplying the reduction in yield loss by 2).

In the case of equity it was hypothesized that farmers in less favorable environments (e.g. upland) were more "needy" than farmers in favorable environments (e.g. irrigated). The reduction in yield losses from the solution of problems in rainfed and deepwater rice were multiplied by 2, and in upland rice by 3 to reflect these equity considerations. Based upon the weighted value of output foregone, drought/blast, because it is prevalent in the upland areas, becomes the most important constraint (Column 2 of Table 1).

Step 5: Calculate Net Present Values. Net present values (NPV) were calculated for unweighted and weighted expected returns to research. NPV incorporates in a single value the effects of research costs, producer costs, economic benefits (including externality and equity consideration if desired), and the time required to find a solution to the problem. The NPV procedures use a social rate of time preference, or interest rate which reflects society's valuation of future benefits compared to present ones. The higher the interest rate, the greater the preference given to projects which have a quick pay-off. The use of a relatively low five percent interest rate in this study tended to favor projects with a long gestation period. It was assumed for each problem that an annual research investment of $200,000 would be made until the problem was solved. Based on interviews with scientists problems were estimated to take from 5 to 20 years to solve depending on the degree of difficulty. It was comparatively easy to obtain information from scientists regarding the relative degree of difficulty in solving the range of research problems to use as a basis for assigning the time lags. Researchers estimate that it will require less time to obtain solutions to tungro virus and brown planthopper than to blast, which is why the former two problems rank above drought/blast in the NPV rankings (Columns 3 and 4 in Table 1).

Step 6: Apply Additional Weights to Reflect the Potential for Biotechnology. A two step weighting process was used to determine first, the effectiveness of existing techniques for solving the problem, and then the potential for using biotechnology. As in the previous weighting, multiplicative weights were assigned at each step. For each problem, effectiveness of existing techniques was assigned one of the following four weights: effective and sustainable, 0.5; effective but not sustainable, 1.0; ineffective even with sustainable research, 2.0; ineffective because no sustainable research conducted, 1.0. For example, tungro virus received a weight of 2 because efforts to control this virus disease have generally not been successful over the long term. Weeds received a weight of 1 because little attention has been given to the control of weeds through genetic crop improvement.

Also, for each problem the potential for success using biotechnology was assigned the following three weights: effectiveness likely to be high, 2.0; effectiveness unknown, 1.0; biotechnology not likely to be effective, 0.5 (the weight for weeds was based on the potential for built-in genetic control of weeds, not for genetic herbicide resistance by rice). For example, tungro virus received a weight of 2, and weeds a weight of 0.5. Multiplying the weights for success of conventional methods by the weights for biotechnology effectiveness results in a score of 4 for tungro virus and 0.5 for weeds. These weights for biotechnology potential are then multiplied by weighted NPV making it possible to rank problems according to potential payoff for biotechnology. In Table 1 tungro virus is the number one problem that might be effectively addressed by biotechnology research, whereas the weed problem, recognized as the major source of production loss (col. 1), is not among the top ten problems that might be effectively addressed with biotechnology. Herdt and Riely stressed the illustrative nature of much of the data used, especially the judgments about biotechnology effectiveness and the effectiveness of "conventional" research.

In summary, in this analysis assumptions were made about: (1) the contribution of the problem to loss in production, (2) externality and equity factors which might lead public policy to favor one region or the solution of one problem over another, (3) the time that might be required to reach a solution to the problem, and (4) the appropriateness of using biotechnology to solve the problem. The analysis relies very heavily on the knowledge and judgement of rice scientists, particularly those who have worked in Asia which accounts for the bulk of the world's rice production. The exercise is not designed to create new knowledge, but to organize and assimilate existing knowledge. Relative to many other crops, the knowledge base for Asian rice is extremely high, which enhances confidence in the utility of this exercise as an aid to research resource allocation.

Allocating Research Resources

The need for research priority setting involves both the need for establishing priorities (ordinal ranking) and for allocating research resources (cardinal ordering). The economic efficiency based allocation rule for research resources would be to distribute those resources among research problems until the benefits gained on the last dollar spent in every research effort are equal. The uncertainty of scientific research, however, makes it difficult to judge the time over which an investment should be discounted. An inverse relationship exists between level of investment and time to success, although its appropriate specification is unclear.

One alternative for allocating resources to problems is to follow a "congruence" rule. For example, this might imply allocating resources according to the percentage contribution of the problem solution to the total NPV of all problem solutions. Any one of the last three columns of Table 1 (depending on the desired weighting) could be used as a basis for determining the estimated percent contribution to total benefits resulting from the solution of a given problem.

The congruence approach is illustrated in Table 2 based on NPV (Column 3 in Table 1). The investment figures have been calculated on the basis of an annual research budget of $13.6 million allocated over 49 problem areas. (The 19 problem areas which made no contribution to NPV received no budget). If the cut off point were set at

Table 2. Allocation of Annual Research Funds Based on Two Separate Criteria.

Rank	Congruence with Percent of Total NPV[a]		Breakeven Investment	
	Problem	Research Investment ($ thousand)	Problem	Research Investment ($ thousand)
1	Tungro Virus	1,530	Brown Planthopper	2,220
2	Brown Planthopper	1,360	Gall Midge	1,460
3	Drought/Blast	1,110	Tungro Virus	1,400
4	Lodging	1,090	Yellow Stemborer	1,070
5	Weeds	1,040	Lodging	990
6	Cytoplasmic Male Sterility	1,030	Cytoplasmic Male Sterility	940
7	Gall Midge	990	Drought/Blast	760
8	Submergence	750	Submergence	680
9	Yellow Stemborer	660	Weeds	590
10	Seedling Vigor	480	Seedling Vigor	449

a Seventeen of the 68 problems have an investment above the minimum $200,000 level, 19 of the 68 problems make no contribution to NPV.

Source: Herdt and Riely, Bellagio Conference, 1987.

a minimum annual research investment of $200,000, then only 17 projects would be funded.

Another way to address the allocation problem is to calculate the level of investment that would set net present value of research on each problem equal to zero, given all the parameters. That is, to calculate the level of investment such that all research efforts would just break even. (This is similar to calculating the internal rate of return except the level of investment instead of the interest rate is the unknown value to be determined). This method eliminates any bias arising from the initial investment level decision. The proportion of each problem's break-even to the total break-even investment is then an indication of the appropriate relative magnitude of research investments.

The break even approach is illustrated in Table 2. Although the ten most important problems are the same using both congruence and break even, the priority ordering and funding allocation changes considerably.

Prioritizing Research for National Programs: A Weighted Criteria Approach in the Dominican Republic, Ecuador, and Uruguay

The growing interest in research priority setting is reflected in the fact that three Latin American governments obtained external assistance in this area in 1986 and 1987. Priority setting research was undertaken in the Dominican Republic and Uruguay with the help of consultants from the International Service for National Agricultural Research (ISNAR), and in Ecuador with the assistance of consultants from USAID. The purpose of the studies was to apply a procedure for prioritizing agricultural research by commodity and by major research area. No attempt was made to prioritize research projects.

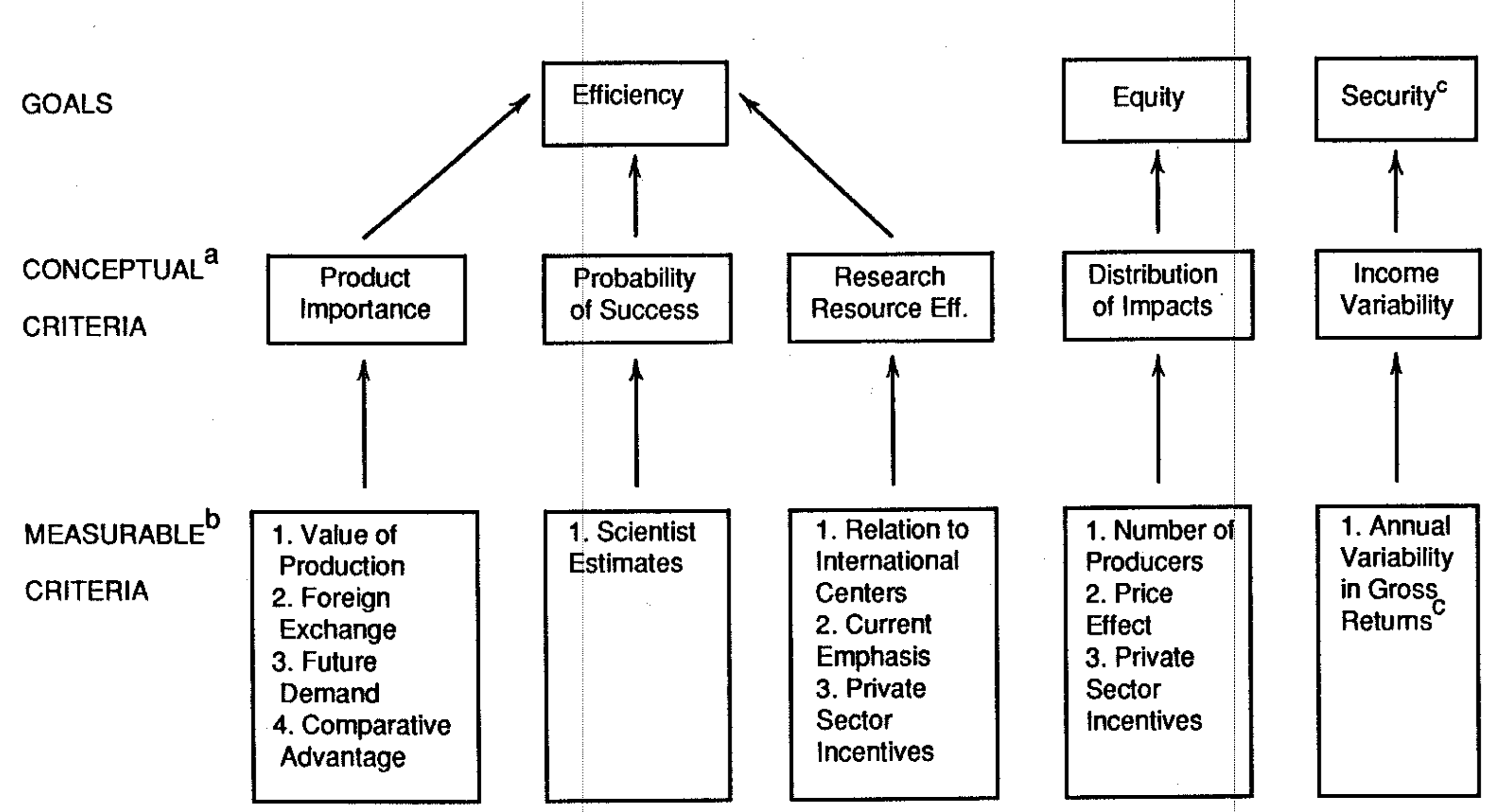
The research was undertaken in the Dominican Republic by the Instituto Superior de Agricultura (ISA, 1986), in Ecuador by the Instituto National de Investigation Agropecuaria (INIAP) (Espoinosa 1986), and in Uruguay by the Centro de Investigation Agricola Alberto Boerger" (CIAAB, 1987). Two outside analysts collaborated in all three projects, and an evaluation of the approach occurred (Norton and Pardey, 1987).

The procedure employed in each study was similar. National goals for research systems were elicited and a series of criteria established which relate to those goals. Separate criteria were developed for commodities and for research areas, and weights were elicited from decision-makers to established the relative importance of criteria. Commodities and research areas were ranked according to each criterion, and these rankings were multiplied by the elicited weights to arrive at research priorities.

Establishing Goals and Criteria

Three goals were identified in these studies: (1) to raise the average level of income in the country, (2) to increase the well-being of low income groups in society, and (3) to reduce year-to-year income fluctuations in the country, especially on the down side. These goals are referred to Fig. 5 as "efficiency," "equity,"

Figure 5. Conceptual Elements in the Weighted Criteria Model for Ranking Research Priorities by Commodity



Notes:

[a]In future studies, an additional conceptual criteria under the security goal might be 'health'.

[b]Nutritional criteria such as grams of protein or kilocalories could be included as additional measures of Distributional impacts

[c]Not used in Dominican Republic, Ecuador, and Uruguay studies

Source: Norton and Pardey, 1987

and "security." In the Dominican Republic, the local consultants identified these as goals, while in Ecuador and Uruguay it was done by the director of the national research agencies.

One or more "conceptual criteria" were identified which intuitively seemed to contribute toward the goals; further a number of "measurable criteria" were chosen which were thought to measure whether particular commodities or research areas contributed to the attainment of the conceptual criteria and hence the goals. A large number of criteria were discussed in each country: 15 were eventually used in the Dominican Republic, 14 in Ecuador, and 10 in Uruguay. Identification of specific criteria was accomplished through discussions among the national research directors, local analysts involved in the studies, and outside consultants. Refinements were made in successive studies to increase the independence of criteria by reducing the correlation among them, and to remove criteria which were questionable measures of whether research contributed to the stated goals.

Commodity Criteria were divided into four conceptual groups: product importance, probability of success, efficiency in use of research resources, and distribution of impact (Figure 5). The first three of these groups relate to the efficiency or income level goal, and the last to the equity or distributional level. In none of the studies were criteria included which represented the third goal (reduced income fluctuations). The feeling was that the entire set of criteria as a group served to reduce the emphasis placed on a single or a few crops and obviated the need to consider income variability. While this appeared to be the case for these particular studies, future weighted criteria studies may want to add criteria which explicitly rank commodities from lowest to highest with respect to variability of annual gross income, price, or yield.

The group of criteria referred to as product importance included for the Uruguay study: value of production, generation of savings in foreign exchange, expected future demand change, and comparative advantage. The major criterion used to measure probability of success was the potential for success as indicated by the researchers themselves. The group of criteria referred to as efficiency in the use of resources include: the relationship to research in international centers, the degree of emphasis on the commodity in the current research program, and the incentive for the private sector to conduct the research. The group of criteria related to the distribution of research impact include: number of producers, and the effect of increased productivity on the price of the product. The Dominican Republic and Ecuador studies also included the value of home consumption as a criterion. The rationale for including each of these criterion is included in Norton 1987 along with a discussion of other criterion which were considered but not included or were included in the earlier Dominican Republic and Ecuador studies but dropped in Uruguay (these include protein and calorie content of commodities, land area, employment generation, and other variables closely correlated with the included variables).

Research Area Criteria were as follows: (1) whether the research would likely cause an increase in the use of abundant resources relative to scarce resources, (2) the quantity and severity of research problems, (3) non-duplication with transferable research from outside the country, (4) the extent of private-sector incentives to conduct research, and (5) current emphasis in the research program. These criteria all relate to the income growth (efficiency) goal (Figure 5). It is difficult to identify research criteria which measure whether particular types of research effect income distribution or variability. Although criteria related to security could be included, they were not.

Data Collection and Model Implementation

Data used in this analysis include both quantitative data on the value of production, number of farms, value of exports and imports, person-years devoted to research on different commodities, etc., as well as qualitative or subjective information on such factors as probability of success, private-sector incentives, severity of problems, etc. Furthermore, weights had to be elicited from research directors as described below to place relative emphasis on the various criteria. The steps in the process are outlined by Norton as follows:

Step 1: Develop Commodity and Research Area Lists. In the Dominican Republic information was collected on 74 commodities, in Ecuador on 44, and in Uruguay on 21. There were nine research program areas in the Dominican Republic, 16 in Ecuador, and 16 in Uruguay. Decisions on which commodities and program areas to include in the analysis were made by the local analysts conducting the study in the Dominican Republic, by the local analyst and the technical director for research at INIAP in Ecuador, and by the local analysts and the two national research and extension directors in Uruguay.

Step 2: Collect Quantitative and Qualitative Data on Chosen Criteria. Information on quantitative criteria (most of it related to commodities) was gathered from local and FAO secondary data sources. Tables were constructed showing a ranking of commodities for each criterion. Information needed for the qualitative criteria was obtained through interviews with scientists and administrators at both the national and regional experiment stations.

Step 3: Elicit Weights on Criteria. Relative weights to place on the different criteria were obtained from national and regional research system administrators. In Ecuador, a total of 34 people were used to obtain the weights, including both national and regional research directors as well as research program leaders. These individuals were interviewed separately and their opinions averaged. Weights were established separately for commodity and research area criteria. In Uruguay, by contrast, only seven system and station directors were used to determine the weights. A Delphi procedure was used in which the seven directors were shown the average of the groups. This provided an opportunity for some directors to adjust their weights.

Step 4: Establish Ranking by Commodity and by Research Area. This involved a two stage process. First, the weighted criteria were used to rank commodities according to their relative importance. Then priorities were established for each research area. The steps for ranking research priorities by commodity are summarized below:

a) The commodities were ranked for each criterion for which quantitative data were available. These rankings were multiplied by the weights assigned to each criterion and then the weighted criteria were added across to arrive at one sub-ranking, based on quantitative criteria, for each commodity.

b) Each commodity was given a high, low, or none designation for each qualitative (subjective) criterion. The response which implied a need for greater research priority was assigned the number 2, intermediate response was assigned 1, and low research priority was assigned 0. The weights assigned to each qualitative criterion were then multiplied by these numbers, and the results were added across each criteria to arrive at a qualitative sub-ranking for each commodity.

c) Finally, the sub-rankings for quantitative and qualitative criteria were given their corresponding weights and then added together to arrive at a final ranking by commodity.

The same procedure outlined in steps b, and c above was followed to rank research priorities by research area.

Step 5: Analyze and Interpret Results. In the Dominican Republic the results of this weighted criteria analysis were used to determine a small set of commodities and research areas with the highest priority. Further assessment was then made of human, physical, administrative, and other resources needed to structure research programs focused on the priority commodities and research topics. In Ecuador and Uruguay, the prioritized list of commodities was split into a high-priority group, intermediate-priority group, and low-priority group. Research area priorities were identified for each region of the country.

In the Dominican Republic, a team of consultants followed up the initial priority setting exercise with an additional analysis and discussion at the experiment station level and eventually recommended the establishment of five national commodity programs and one additional major research program. In Ecuador, the prioritized lists were distributed and discussed with the Ministry of Agriculture, the Ecuadorian Foundation for Agricultural Research, the Commission on Science and Technology, and USAID. This was followed by further analyses. In Uruguay, the results from the first run of the model were discussed with research directors. The directors made small changes to the weights placed on criteria and the model was rerun to give a new prioritized list. Personnel in CIAAB undertook additional "sensitivity" analysis, and are developing implementation plans.

As a result of these studies, there seems to be a recognition in all three countries that priority setting is an iterative process. Much of the models value stems from the fact that it encourages a discussion of relevant criteria among decision makers. Furthermore, the impact on the ordering of priorities due to a change in criteria or assumptions can be quickly calculated as the discussion proceeds.

An Assessment of the Weighted Criteria Models

A number of strengths and weaknesses in the procedures used in the three studies discussed above were identified. The first strength was the ability in the analysis to incorporate both quantitative and qualitative information related to a set of multiple goals and criteria in order to prioritize a long list of commodities and research areas in a relatively short period of time. Second, the procedure proved relatively easy for both research administrators and the local analysts to understand. Third, the analysis in Ecuador and Uruguay involved research system administrators at several stages, and this allowed them to consciously identify the tradeoffs in the choice of goals and criteria. Fourth, the use of spreadsheet programs in Ecuador and Uruguay facilitated sensitivity analysis after an original set of priorities was determined. (Computer spread-sheets could be used by analysts in both countries without much difficulty). Norton, however, believes that additional work would be justified to develop a menu-driven program in which an analyst responds to a set of computer assisted questions which leads him or her through the procedure). Fifth, the system provided a relatively objective assessment of priorities because individuals were not allowed to rank commodities or research areas directly, but had to weigh criteria.

The first weakness, inherent in all _ex ante_ priority setting exercises, is the need for a large amount of subjective judgement. Although this more formal approach has greater objectivity than unstructured judgement, there is subjectiveness in the responses to many of the questions and the weights placed on criteria. Second, it proved difficult to identify independent criteria. For example, in Fig. 5 there tends to be a high degree of correlation between some measures such as _value of production_ and _future demand_. Third, some of the criteria, such as _comparative advantage_ and potential _future demand_ for the product, were difficult to explain to the interviewees. In Uruguay, questions related to these two criteria were answered by a small group of economists in the ministries of agriculture and trade. In the Ecuador and Uruguay studies, in contrast to the earlier study in the Dominican Republic, more attention was devoted to assessing the most appropriate people for answering specific questions. Despite these efforts, some disagreement surfaced about the weights placed on criteria. In Uruguay, decision-makers were given the opportunity to change their weights after reviewing the initial results. This demonstrated the implications of placing different weights on the various goals and criteria.

In summary, the experience gained from these three studies made it clear that it is preferable to work directly with those individuals who have direct responsibility for the allocation of research resources. Although the Dominican Republic study was conducted by a very competent set of consultants from the local agricultural university, the procedure has not been institutionalized nor the results utilized in the research planning process. By contrast, in Ecuador and especially in Uruguay, administrators responsible for making research resource allocations have been more directly involved in the analyses, have been able to study solutions, and have been able to revise initial assumptions and recalculate the priorities. There is, thus, a much greater likelihood that this technique will become an integral part of the research planning and priority setting process.

Norton believes that it may be useful to combine the weighted criteria and the expected economic surplus approaches. The expected economic surplus criteria explicitly assumes that the research goal is raising the level of income (efficiency). However, in recent studies these models have been refined to permit the disaggregation of groups of producers, for example by farm size or similar criteria. This makes it possible to weight the distribution of benefits using equity criteria.

The expected economic surplus approach captures most of the criteria in the weighted criteria approach (Fig. 5) and removes the need to weight individual criteria. It is still necessary to weight the efficiency and equity goals, but as can be seen in the analysis of Herdt and Riely, equity (or other) weights can be applied to the calculated economic benefits. Because economic surplus models are difficult to apply to more than 20 commodities due to data requirements, a weighted criteria model could be used as a first step to narrow down the list of alternatives. Economic surplus procedures could then be applied to the highest ranked alternatives.

Prioritizing Research for International Donor Agencies: An Economic Surplus Approach

The Australian Centre for International Agricultural Research (ACIAR) was established in 1982 with the objective of encouraging and supporting research on agricultural problems in developing countries in fields in which Australia has a special competence

(ACIAR 1985). In order to assist in identifying and prioritizing projects for financial support, ACIAR has undertaken a joint study with the International Food Policy Research Institute (IFPRI) (see Davis, Oram, and Ryan 1986). This ex ante analysis of aggregate commodity and regional priorities in agricultural research makes use of the concepts of economic surplus couched in an international trade model (Davis and Ryan). The framework allows for differential probabilities of research success and ceiling adoption levels among commodities and regions.

Furthermore, the model used permits the assumption that research and technology development in one country may have an impact on other countries and regions. If, for example, as illustrated in Figure 3, the supply function for a country shifts downward and to the right as a consequence of the introduction of new technology, this approach assumes that the impact of this technological change may spillover into other countries. The spillover effects can be realized: (i) through effects of increased production on world market prices and in turn on other national prices, (ii) through the adoption of the technology in other countries, or (iii) through the transfer of scientific knowledge to other countries (Davis and Ryan). An important feature of this model involves the incorporation of spillover effects.

Data Collection and Model Implementation

Davis, Oram, and Ryan 1986 indicate that there are nine steps to make their model operational:

Step 1: Selection of Commodities. Select commodities to be studied and assemble data by country on area, production, and consumption of those commodities.

Step 2: Identify Climatic Divisions and Agro-ecological Zones. Define the major climatic divisions from which significant production of the commodities under study originates, and identify agro-ecological zones within each climatic division.

Step 3: Locate Major Crop/climatic Associations. Tabulate the major crop/climatic associations and the countries where those associations predominate in each principal geographical region.

Step 4: Assign Countries to Agro-ecological Zones. Subdivide countries by agro-ecological zones for each commodity and identify the percentage distribution of its area and/or production by agro-ecological zones.

Step 5: Group Countries Located in Similar Agro-ecological Zones. For each commodity, group the countries within each major geographical region which have the bulk of their area and/or production located in closely similar agro-ecological zones. These groups of countries are defined for the purpose of this study as "ecologically homogeneous regions."

Step 6: Estimate and Rank the Probability of Research Success. For each country in each homogeneous region as defined in Step 5 above, estimate the probability of success of research undertaken there on each commodity, and rank. If there are major differences in ranking among countries, a region should be divided into subzones to improve homogeneity.

Step 7: Estimate the Likelihood of Adoption. For each commodity in each homogeneous region derived from Step 5 and 6, estimate the likelihood of adoption of research results in each country and rank. Repeat subdivision and regrouping as in Step 6 to improve homogeneity where necessary.

Step 8: Identify the Spillover Benefits. Construct matrix tables identifying the spillover benefits from research undertaken in any one homogeneous region, to all other regions producing the same commodity.

Step 9: Assemble Necessary Economic Data and Compute. Assemble data on prices, transport costs, and price elasticities of supply and demand for each commodity, and compute benefits of research on each commodity within each region and from spillover benefits.

Global and Regional Benefits from Agricultural Research

A scanning of the steps above indicates that the development of this global model of research benefits has been a formidable task. In contrast to the previous two studies described, the Davis, Oram, Ryan model has taken a matter of years, not months, to develop. For each of 25 commodities, estimates have been made of the benefits of research in between 30 and 60 countries/regions. The distribution of these benefits between producers and consumers has also been estimated.

Davis and Ryan point out that it has been necessary to condense this information to make it useful for research resource allocation decision-makers. The form this condensed information takes depends on the objectives of the organization, i.e. whether the organization is concerned with global/international, regional, or national benefits and impacts. Because the model was designed principally for the use of the Australian Centre for International Agricultural Research (ACIAR), we discuss the results of the model from the perspective of this organization.

ACIAR reviews its research program on the basis of the seven geographical regions of the world. The first half of Table 3 summarizes the results obtained from the initial 12 commodities by presenting the average international research benefits for all developing countries and for developing countries in each of the seven geographical regions. The average benefits are the simple means for all developing regions (China being treated as a separate region).

Globally rice is expected to provide considerably larger average international benefits from research than any of the other commodities considered. Although the average international benefits to potato and wheat are high, they are considerably less than for rice. This primarily reflects the pervasiveness of rice production in the developing world. Judgments about likelihood of research success, rate of adoption, and particularly spillover effects are crucial. The second half of Table 3 shows that with few exceptions, spillover accounts for the major portion of research benefits. For example, 96 percent of the benefits from investment in rice research in Africa are computed to be captured by countries outside of Africa based on the assumptions incorporated in the model. For all of the

Table 3. The Expected Present Value of International Benefits and Spillover Benefit Proportions - Global and Regional Averages.

Commodity	All Developing	S. Asia	Southeast Asia	China	S. Pacific/FNG	Africa	W. Asia N. Africa	Latin America
	Average International Benefits ($U.S. Million)							
Rice	674	1038	844	2334	0	333	400	442
Potato	309	338	341	1311	19	72	402	242
Wheat	269	312	108	542	0	57	421	283
Sugar	137	201	142	203	148	71	133	155
Maize	135	140	144	728	0	59	147	170
Banana/Plant	128	114	161	114	120	104	24	147
Pulses	119	203	115	328	0	62	102	137
Sweet Potato	111	150	113	447	12	63	39	130
Sheep/Goat	65	103	113	164	0	36	91	102
Coconut	55	60	86	0	46	31	0	47
Sorghum	48	114	19	149	0	36	26	56
Groundnut	29	50	28	73	0	23	15	29
	Average Spillover Benefits (percentages)							
Rice	74	73	79	15	--	96	88	94
Potato	86	92	98	45	100	96	92	92
Wheat	81	60	100	60	--	98	94	94
Sugar	74	54	88	68	95	92	80	65
Maize	80	86	93	52	--	92	90	76
Banana/Plant	81	85	87	97	97	78	92	71
Pulses	81	63	94	41	--	94	79	91
Sweet Potato	81	95	91	3	92	97	100	98
Sheep/Goat	83	72	94	72	--	86	70	92
Coconut	82	72	67	--	98	94	--	96
Sorghum	77	54	95	63	--	86	96	80
Groundnut	79	64	93	49	--	87	93	93

Source: Davis and Ryan, Bellagio Conference, 1987.

commodities listed the spillover benefits represent 74 percent or more of the total benefits.

In West Asia and North Africa the benefits from wheat and potatoes are about equal to the benefits from rice. However, for nearly all other regions except the South Pacific the general ordering of benefits by commodity is fairly similar, with rice, potato, and wheat tending to top the list and coconut, sorghum, and groundnut falling near the bottom. Of course, there are many commodities not on the list; this model like others is mute on such commodities.

The distribution of research benefits between different groups is often an important consideration for policymakers. Table 4 separates the share of benefits going to the producers and consumers of these commodities, and further disaggregates these groups into developing and developed countries. In addition it shows the share of benefits accruing to developing country producers as either gains or losses. The latter will occur when research spillover gains are outweighed by the effects of a decline in world price due to the adoption of the new technology.

If the distribution of benefits for each commodity is examined (Table 4), the complexities of decision making designed to achieve greater equity between the four identified groups are apparent. In the case of rice, for example, developing country consumers receive a substantial share of the benefits, 44 percent. Developing country producers receive a net of 53 percent of the benefits (71 minus 18), but there are a significant number of losers. Research on commodi-

Table 4. Global and Regional Distribution Effects of Research Investment (Percentages).

Commodity	Share of Benefits Received by Each Group - Average of All Developing Countries						
	Developing	Developed	Total	Developing Gainers	Developing Losers	Developed	Total
Rice	44	3	47	71	-19	1	54
Potato	16	40	56	52	-3	-4	45
Wheat	22	24	46	46	-5	13	54
Sugar	31	28	59	60	-11	-6	43
Maize	15	22	37	60	-6	9	63
Banana/Plant	41	5	46	57	-3	0	54
Pulses	28	8	36	71	-4	-1	66
Sweet Potato	47	0	47	56	-3	0	53
Sheep Goat	45	31	76	52	-9	-17	26
Coconut	37	6	43	58	-1	0	57
Sorghum	24	11	35	63	-4	2	61
Groundnut	38	7	45	57	-4	2	55

Source: Davis and Ryan, Bellagio Conference, 1987.

ties such as banana/plantain, pulses, sweet potato, coconut, and groundnuts tends to minimize the potential losses to developing country producers. However, banana/plantain, pulses, and sweet potato will give much higher total benefits than coconuts or groundnuts (Table 3). Despite the more favorable distribution of benefits for banana/plantain or sweet potato research as opposed to rice research, it should be kept in mind that the benefits from rice research are five times greater than from either of the other two crops.

Development of Global and Regional Research Priorities

The information generated in Table 3 can be used to produce global (average of all developing countries) and regional priority orderings by commodity. Table 5 illustrates one such priority ordering. Four commodity priority groups have been defined. In this illustration the present value of total benefits is used as the allocation criteria. Group I included the commodities having the largest expected economic benefits from investment in research, and Group IV the smallest.

The numbers in parentheses indicates the relative magnitude of benefits among commodities. For example, for "all developing countries" it would take 23 times as much investment in groundnut as in rice research to achieve the same total benefits. (Davis and Ryan, p. 17).

The bottom row in Table 5 provides an indication of the relative benefits from the top priority research area across regions. Rice in China, the crop and region with the highest

Table 5. Global/Regional Research Priority Commodity Groupings: International Perspective.

Priority Groups	All Developing Regions	S. Asia	S.E. Asia	China	S. Pacific/ PNG[a]	Africa	W. Asia N. Africa	Latin America
I	Rice (1)[b] Potato (2) Wheat (3)	Rice (1) Potato (3) Wheat (3)	Rice (1) Potato (3)	Rice (1) Potato (2) Maize (3)	Sugar (1) Banana/ Plantain (1)	Rice (1) Banana/ Plantain (3)	Wheat (1) Potato (1) Rice (1)	Rice (1) Wheat (2) Potato (2)
II	Sugar (5) Maize (5) Banana/ Plantain (5) Pulses (6) Sweet Potato (6)	Pulses (5) Sugar (5) Sweet Potato (7) Maize (7)	Banana/ Plantain (5) Maize (6) Sugar (6)	Wheat (4) Sweet Potato (5) Pulses (7)	Coconut (3)	Potato (5) Sugar (5) Sweet Potato (5) Pulses (5)	Maize (3) Sugar (3) Pulses (4)	Maize (3) Sugar (3) Banana/ Plantain (3)
III	Sheep/Goat Meat (10) Coconut (12) Sorghum (14)	Sorghum (9) Banana/ Plantain (9) Sheep/Goat Meat (10)	Pulses (7) Sweet Potato (7) Wheat (8) Coconut (10)	Sugar (11) Sheep/ Goat Meat (14) Sorghum (16)	Potato (8) Sweet Potato (12)	Maize (6) Wheat (6)	Sheep/Goat Meat (5)	Pulses (4) Sweet Potato (4) Sheep/Goat Meat (4)
IV	Groundnut (23)	Coconut (17) Groundnut (21)	Sheep/ Goat Meat (27) Groundnut (30) Sorghum (44)	Banana/ Plantain (20) Ground- nut (32)		Sheep/ Goat Meat (9) Sorghum (9) Coconut (10) Ground- nut (14)	Sweet Potato (11) Sorghum (16) Groundnut (30)	Sorghum (8) Coconut (9) Groundnut (15)
Relativeness Between Regions[c]		2.2	2.7	1.0	15	7	5	5

a For the South Pacific some of the other seven commodities may enter regional priority groupings if the international spillover effects are included. At this stage, estimation of these parameters has not been undertaken because of the very small levels of production of these commodities in this region.

b Numbers in parentheses represent within-region benefit relativities.

c Rice in China, the region with the highest expected benefit, is used as the nummeraire and is compared with the highest expected payoff commodity in each of the other regions.

Source: Davis and Ryan, Bellagio Conference.

expected benefits, is used as the numeraire. The model estimates that rice research in China would provide 2.7 times the benefits of the same level of investment for rice research in South East Asia or 15 times the benefits from the same level of investment in sugar cane research in the South Pacific/PNG. The numbers in parentheses can, if multiplied by the numbers in the bottom row of Table 5, be used as approximate indicators of the opportunity cost of undertaking research on different commodities within regions, or among different regions for a particular commodity.

For many research resource allocation discussions, the summary of information provided in Tables 3, 4 and 5 will not provide sufficient detail and the more detailed tables on which these summaries have been based are likely to be required. However, this summary of commodity research priority orderings will be useful in general discussions and as a means of clarifying the objectives of the organizations which are faced with the task of establishing priorities.

An Integrated Procedure for Priority Assessment in ACIAR

How does an institution utilize the commodity/regional priorities which emerge from the empirical analysis summarized in the previous tables? ACIAR is in the process of attempting this. Davis and Ryan describe how such an agency, which was established to implement the international objectives of Australia's research policy, is institutionalizing the information.

Currently ACIAR has 11 Research Programs (plant improvement, plant protection, farming systems, livestock etc.) embracing 92 collaborative projects in 17 developing countries. Based on the guidelines set by their Policy Advisory Council (PAC), over half of the budget is allocated to countries in Southeast Asia.

The major program areas are plant improvement, post harvest technology, and livestock; each accounting for over 15 percent of the total annual budget. The existing program balance has come about as a result of the implicit consideration of: (i) the frequency of requests for collaboration in different programs, (ii) the availability of scientific expertise in Australia, (iii) the disciplinary mix of ACIAR staff, (iv) project feasibility studies, and (v) the need to achieve congruence with PAC's regional guidelines.

In order to make use of the Davis, Oram, and Ryan model, there is a clear need for ACIAR to adopt a more explicit approach to priority setting, which can be done as follows. The ACIAR project portfolio should be classed in the four commodity groups identified in Table 5 with the share of actual ACIAR expenditure on current projects accruing to the four commodity priority groups in each region calculated over the life of the project. Then the commodity group shares for each program and for ACIAR as a whole should be calculated.

With the ACIAR portfolio reorganized in this manner to conform with Table 5, the existing portfolio and proposed new projects can be examined for congruence with the results of the model. Gaps in support or inconsistencies may suggest the need to reexamine the model as well as ACIAR priorities. As suggested above the model results may be very sensitive to assumptions about spillover effects, probability of success, and adoption levels. An iterative process between the model and existing priorities should lead to the improvement of the assumptions, the model, and ACIAR priority setting procedures.

LIMITATIONS OF PRIORITY SETTING MODELS

There is a clear rational for developing procedures which will assist authorities in determining what priorities should be set among alternatives for research investments, and on the closely related question of how scarce funds should be allocated among the possible alternatives. Agencies which could benefit from such analyses include international agricultural research centers, national research programs, and international donor agencies. We have presented illustrations of how priority setting models are being used to assist these agencies. The methodologies we have described, although tested in a number of situations, have yet to be institutionalized in the planning process of research organizations. This sections describes some of the limitations of priority setting models which have restricted their wide adoption, and outlines the areas where more research is needed to enhance their utility. The discussion will make it clear why the results of these analyses should be used by research managers only in conjunction with other information sources.

Organizational Priorities

Current priority setting methodologies are designed to establish the order of importance among competing programs. However, they do not capture the essence of other types of activities which can be broadly defined as organizational in nature (Javier). Under this heading Javier included opportunity activities, strategic planning, and research entrepreneurship activities.

Opportunity activities are research investments which offer a chance for quick payoff. It is recognized that continuing political support for research depends in large measure on demonstrated success. A research organization must provide evidence of its relevance to the present to be assured of resources now and in the future.

Strategic planning is a major institutional exercise. Priority setting and resource allocation should be handled within the context of the strategic plan. The priority setting exercise as an input to the strategic plan may require shifts in structure, staffing pattern, governance, and management of the research organization. One of the key issues to be decided in strategic planning is the planned level of capability. What is the current scientific capability of the research institution, and what should be the capacity ten or twenty years from now? Capability in research falls into different grades of intensity and sophistication. As explained by Javier at the simplest level, one simply has the capability to monitor technological developments elsewhere, and to introduce, test, and adapt these technologies to local

In the global model developed by Davis, Oram, and Ryan, assumptions regarding potential payoffs seem to have depended largely on the judgement of the analysts. Because of the size and scope of such models, there is limited opportunity for interactions among analysts, scientists, and policy makers, and there is bound to be more question about the soundness of the assumptions on which the model is based.

Handling Non-commodity Program Priorities

It was noted earlier that most of the analyses conducted to date have been focused on establishing priorities for commodities. However, there are at least three other convenient dimensions across which research systems may allocate research funds: by resources, among stages or levels of farm production, and among academic disciplines. In organizing by commodity, a number of areas may be overlooked, such as erosion, environmental degradation, integrated pest management, post-harvest technology, land reform, and policy analysis which may deserve research funding.

It is possible to build at least some of these areas into the research objectives of the commodity programs. For example, special attention can be given to the adaptive research needs of tribal regions and major land reform districts, but still within the context of the major commodities produced by those communities and in those districts (Javier). Nevertheless, a commodity-based model is unlikely to give adequate coverage to all non-commodity research issues.

The Priority Setting Process

The process of priority setting and resource allocation involves moving from strategic to tactical or operational choices. We have stressed earlier that the success of priority setting analyses depends less on the actual choice of analytical approach than on the knowledge and data base, and on the ability of analysts, scientists, research administrators and others to communicate with each other. It is only through such communication that appropriate research goals and reliable judgments about research payoffs can be established.

As we can see from the illustrations in the previous section, it is easier to achieve the necessary dialogue at the research institution level, than at the national or international level. For example, in Herdt and Riely's analysis of priorities for rice research, most of the data used in the model were based on the judgement of scientists at the International Rice Research Institute regarding the likely success and payoffs from specific research activities. Moreover, relative to many other crops grown in the tropics, there is considerably more information and knowledge about rice.

Setting priorities for commodities at the national level, as illustrated by Norton et. al., involves discussions primarily with policy makers and research administrators in an effort to establish weights for national goals. Choosing who should make subjective political as well as scientific judgments becomes more difficult.

conditions. At the intermediate level is the ability to conduct applied research and generate new technology. Finally, advanced research organizations have the ability to conduct basic and strategic research on agricultural problems. A different level of intensity and sophistication almost certainly will be desired for different commodities, depending on their national importance.

Research entrepreneurship activities should be designed to provide special incentives and research grants to scientists adjudged to be outstanding in their respective fields. Such grants can also be used to redress the bias against research in the basic natural sciences, the social sciences, and the humanities.

The three types of activities described above are but some of the organizational priorities which national research systems may have to address. It is possible to encompass the activities within the general framework of the research priority setting analysis. For example, just as in the case of research programs, priorities can be set for investment in organizational activities based on: chance of success, quick maturity, visibility, cost, and economic impact.

Allocating Resources to Program and Organizational Priorities

As with the case of non-commodity program areas, organizational priorities also "in theory" can be included in commodity programs. However, it is probably fair to say that most priority setting exercises give scant consideration to organizational issues. In short, the commodity approach has its limits, and very important concerns are lost or barely addressed.

To overcome the short-comings of the commodity approach, Javier suggests that resources available for research be treated as an investment fund with several program-priority and organizational-priority portfolios. An _a priori_ allocation of resources would be made across portfolios. Then, criteria and relative weights would be developed for each portfolio. Projected resource requirements would be determined for each allocation cell based on the cost of conducting the research at a planned level, and the capacity to absorb resources effectively.

Further Work

In this final section of the paper we suggest a number of areas where further research is needed in order to improve the effectiveness of priority setting analyses.

From the discussion of the previous section, clearly more research is needed to develop procedures which will reduce the limitations of the commodity approach. There are a significant number of what might be regarded as "second-order" allocation issues such as the balance between: program and organizational priorities, basic and applied research, human and financial resources, capital and operating funds, mix of disciplines etc. These and other issues must be handled within the priority setting framework.

More attention must be given to the entire process of eliciting information from research administrators, scientists and others with respect to research potential, weights, ranks etc. in order to reduce subjectivity. As can be seen from our three case illustrations, this problem becomes more acute as the size and scope of the model increases.

We need to be able to assess _a priori_ for a given situation which of the alternative analytical approaches are most appropriate. For example, for what situations (global, international agricultural research centers, large and small national research programs) is the expected economic surplus approach to be preferred over the single and weighted criteria models? Studies should be conducted in which alternative models are used to address the same priority setting problem.

Finally, we need to incorporate the concept of comparative advantage in priority setting models. What is a country's comparative advantage in producing the commodity, and in conducting research on the commodity? To what degree will the "spillover effect" of a countries research benefit other countries? Alternatively, how effectively can a country adapt technology from other countries?

In summary, the purpose of priority setting analysis is to improve the efficiency with which we allocate research resources to increase the benefits from research investment. Considerable work has been done in the past two decades in developing priority setting models. Recent efforts have been focused on developing simple techniques that can be easily handled or even self-taught through the use of micro-computers. Nevertheless, further research will be required before these techniques become an integral part of the research planning process.

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