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THE IMPACT OF AGRICULTURAL RESEARCH: A REVIEW OF THE *EX-POST* ASSESSMENT LITERATURE WITH IMPLICATIONS FOR AFRICA

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ABSTRACT

THE IMPACT OF AGRICULTURAL RESEARCH:
A REVIEW OF THE *EX-POST* ASSESSMENT LITERATURE WITH IMPLICATIONS FOR AFRICA

This paper reviews the literature on *ex-post* evaluation of agricultural research with emphasis on the implications for African research policy. Both rate of return (ROR) and non-ROR studies are included. The ROR literature reveals a paucity of information on the performance of African agricultural research. Only four rate of return studies for sub-Saharan Africa were identified, compared to a far greater number for developed countries, Latin America, and Asia. The non-ROR studies, while offering recommendations for improvements in research institutions, do not allow a rigorous comparison of research impact due to the variety of methodologies employed and their qualitative nature.

Several implications for African research policy can be drawn from the literature. First, the large majority of studies around the world reveal that research benefits far exceed costs, however, success depends crucially on complementary infrastructure, institutions, and government policies. This is particularly important in Africa where institutions and infrastructure vary widely in structure and effectiveness. Second, more African ROR studies are necessary in a wide array of agro-climatic and economic environments to identify conditions for effective research. Third, the appropriate evaluation methodology depends on available resources and objectives. In order of increasing sophistication and cost, the alternatives include descriptive studies, average ROR studies, and marginal ROR studies. Fourth, governments need to consider producer *and consumer* benefits of agricultural research when allocating funds among projects. And finally, sustained investments in research and continuity are required to achieve the anticipated payoffs.

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I. INTRODUCTION

From 1970 to 1985 food production in Africa grew at half the rate of population growth (Eicher, 1988). Food aid alone cannot fill this gap. Production must increase to meet the long-term needs of the population. The increase in African agricultural productivity over the last 20 years has called into question the performance of African agricultural research. While there is a substantial literature evaluating the performance of agricultural research in the U.S., Asia and Latin America, relatively little is known about the payoffs to African agricultural research. To date, only four rate of return (ROR) studies have been identified in Africa, compared to 79 in developed countries, 66 in Latin America and 25 studies in Asia (Tables 1-4)[1].

Agricultural research is important because it leads to the discovery and diffusion of new technology, which plays a critical role in facilitating general economic development. The agriculture sector can stimulate overall development by: (1) providing food; (2) supplying capital, especially for the development of the nonfarm sector; (3) providing labor for the expansion of nonfarm activities; (4) supplying foreign exchange from export earnings in order to facilitate the purchase of critical inputs from abroad; and (5) providing a market for the products of the non-farm sector (Ramalho de Castro and Schuh, 1977; Mellor, 1976).

The development of cost-saving technology is a key to this process. First, new technology can help to convert agriculture from a subsistence to a surplus-producing sector. Second, appropriate technical change and agricultural growth will promote a network of consumption, production and fiscal linkages between agriculture and non-agricultural sectors which will lead to overall development of the economy.

Evaluating agricultural research is a complex task, given the need to assess its impact on agricultural productivity as well as to place it in the context of the more general development issues outlined above. In addition, the impact of technology is greatly affected by complementary institutions which play a major role in technology diffusion -- including markets, transportation infrastructure, pricing policies, and financial and extension services. In Africa, these institutions are frequently weak, or provide disincentives to adoption which reduces the ROR to agricultural research. Thus, especially in sub-Saharan Africa, success in agricultural research depends heavily on the level of development of the whole array of agricultural institutions.

The objectives of this paper are:

1) to critically review the worldwide literature on *ex-post* evaluation of agricultural research, conducted over the past 40 years, focusing on methodologies used in Asian and Latin American studies; and

2) to delineate the important issues involved in performance-based assessment of African agricultural research systems, in an effort to appraise the applicability of current research evaluation methods for assessing these issues.[2]

EX-POST EVALUATION OF AGRICULTURAL RESEARCH: ECONOMIC FOUNDATIONS

WHAT IS A RATE OF RETURN?

Rate of return (ROR) is an evaluative measure of long-term investments. It is an appropriate measure for projects having costs and benefits which vary over time, as long as the costs are incurred predominantly in the early stages of the project, and the benefits accrue primarily in the later stages. The ROR is a single number which summarizes the time pattern and relative sizes of the benefits and costs associated with the project. The ROR can be thought of as the rate of interest which a bank would have to pay to generate the same net return as the research project, if the research funds were instead deposited in the bank[3]. Since the ROR is expressed as a percentage, it is independent of monetary units or project capitalization. Hence, this measure makes it easy to compare different projects.

The ROR to a research project can be calculated as an average rate or as a marginal rate. The average or internal rate of return (ARR) takes the research expenditure as given and calculates a ROR to the project (or program) in its entirety. This is appropriate for *ex-post* evaluation, and provides information on which projects were successful. However, the ARR measure is not always helpful in determining if the allocation of research dollars among projects was appropriate.[4]

According to economic theory, the optimal allocation of research resources occurs when the last dollar spent on each project generates the same returns. For example, consider a research director who is allocating a budget between two projects, A and B.[5] Suppose that by dividing the available money, the last dollar spent on A will generate gross returns of $1.50, while the last dollar spent on B will generate returns of $2.00. The director should reallocate one dollar of funding from A to B. This will cost $1.50 in lost returns from project A, but will increase returns from project B by $2.00, for a net improvement of $0.50. If the returns to the last dollars spent on each project are still different, further reallocations can improve overall returns. When the returns to the last dollars are equal, the allocation of research resources is optimal because the combined projects yield the highest return possible.

The marginal rate of return (MROR) quantifies the return to the last dollar invested in the research project. This is usually accomplished by econometric estimation of an algebraic relationship between research expenditures and a supply function (or its equivalent). The relationship describes how research expenditures shift the supply curve. It is then possible to calculate shifts in the supply curve attributable to the last dollar invested in the project, and the social benefits arising from these shifts (see next section). These benefits are used to calculate the ROR to the last (marginal) dollar, and is considered to be the MROR for the project. Calculation of a MROR is more ambitious than calculation of an ARR, requiring more data, a computer and econometric software.

THE SOCIAL SURPLUS PARADIGM

The social surplus paradigm is a method for measuring the benefits of research and has played a crucial role in evaluating research. The idea of social surplus is easily expressed in terms of a supply and demand diagram of the market for an agricultural output, such as cassava.

The cassava market is depicted in Figure 1. The curve labelled S represents an "inverse supply curve:" $S=S(Q)$.[6] For any quantity Q produced, the height of this curve is the cost of producing the Qth unit of cassava. Hence, for each unit of cassava produced, the price, P, less the cost of production, S(Q), equals the profit.[7] The aggregate profit to all producers is the sum (integral) of P-S(Q) over all units produced, and is represented in Figure 1 by that portion of the shaded area lying above the supply curve S and below the price line $P=P_e$.

These profits will be distributed to owners of productive inputs as higher rents earned by owners of durable inputs, higher prices for non-durable inputs, or higher implicit returns to non-traded inputs such as labor supplied by the farm household. Owners of inelastically supplied inputs[8] will receive the largest proportion of the profits.

Curve D in Figure 1 represents an "inverse demand curve", D=D(Q). For each unit Q the height of D at Q approximates the maximum amount that any consumer is willing to pay to consume that Q^{th} unit of cassava. The height of demand curve, D(Q) minus the price paid for the Qth unit equals the net gain to consumers from consumption of that Q^{th} unit. The aggregate net gain to consumers from eating Q_e units of cassava equals the sum (integral) of the gain from eating each unit, and are represented in Figure 1 by that portion of the shaded area lying above the $P-P_e$ price line and under the demand curve. This area represents the consumers' gains from trade in and consumption of cassava.

The entire shaded area in Figure 1 equals the gain to producers plus the gain to consumers. This area is called social surplus, and it represents societal gains from trade in cassava (where "trade" includes production, exchange and consumption).

Successful research generates improved production techniques or inputs -- that is, techniques or inputs which lower production costs. These lower costs shift the supply curve downward, as depicted in Figure 2 by the shift from S to S'. As in Figure 1, social surplus is represented by the area between the supply and demand curves. However, after the research and adoption of the research outputs, the relevant supply curve is S'. The shaded area represents the increase in social surplus due to the shift from S to S'. This increase is the social benefit attributable to research.[9]

INDEX NUMBER AND PRODUCTION FUNCTION APPROACHES

The *ex-post* agricultural research evaluation methods have steadily improved over the last 35 years. Two basic methodologies -- the index number approach and the production function approach -- have dominated the scene. Economists have used the index number approach to calculate the net benefits to consumers and producers from individual inventions or single crops. In contrast, at a higherlevel of aggregation, economists have fitted production functions to identify the returns to the overall research input.[10] These two approaches are briefly describe below.[11]

Index Number Methods

The index number approach attributes the downward shifts in the long-run supply function of the commodity to the new, more efficient inputs created by research; and, thus, measures the resulting social surplus, comprising consumer and producer surplus. This approach involves: 1) specifying the supply and demand functions, which require estimates of elasticities that can be obtained from previous studies; 2) estimating productivity indexes to measure the shifts in the supply schedule; and 3) developing a formula that measures the change in social surplus generated by increases in productivity. The formula is often simplified and based on data on percentage yield increases before and after the innovation.

The changes in social surplus are gross benefits attributable to research. To obtain net benefits, research expenditures are subtracted from the calculated gross benefits. To assess the efficiency of resource allocations to research, the ARR is calculated as the discount rate that makes the present value of the net benefits' stream equal to zero.

Figure 1. The measurement of social surplus.

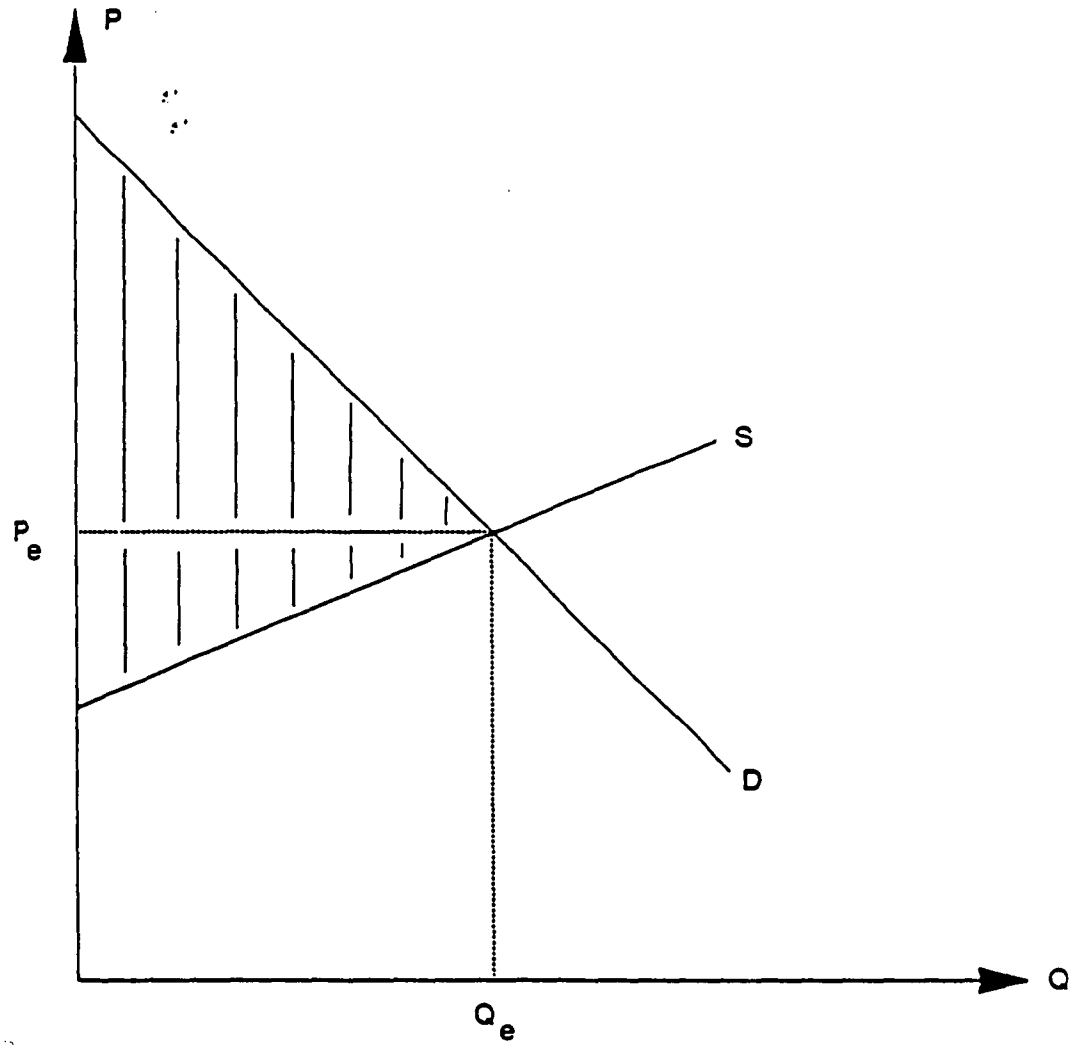
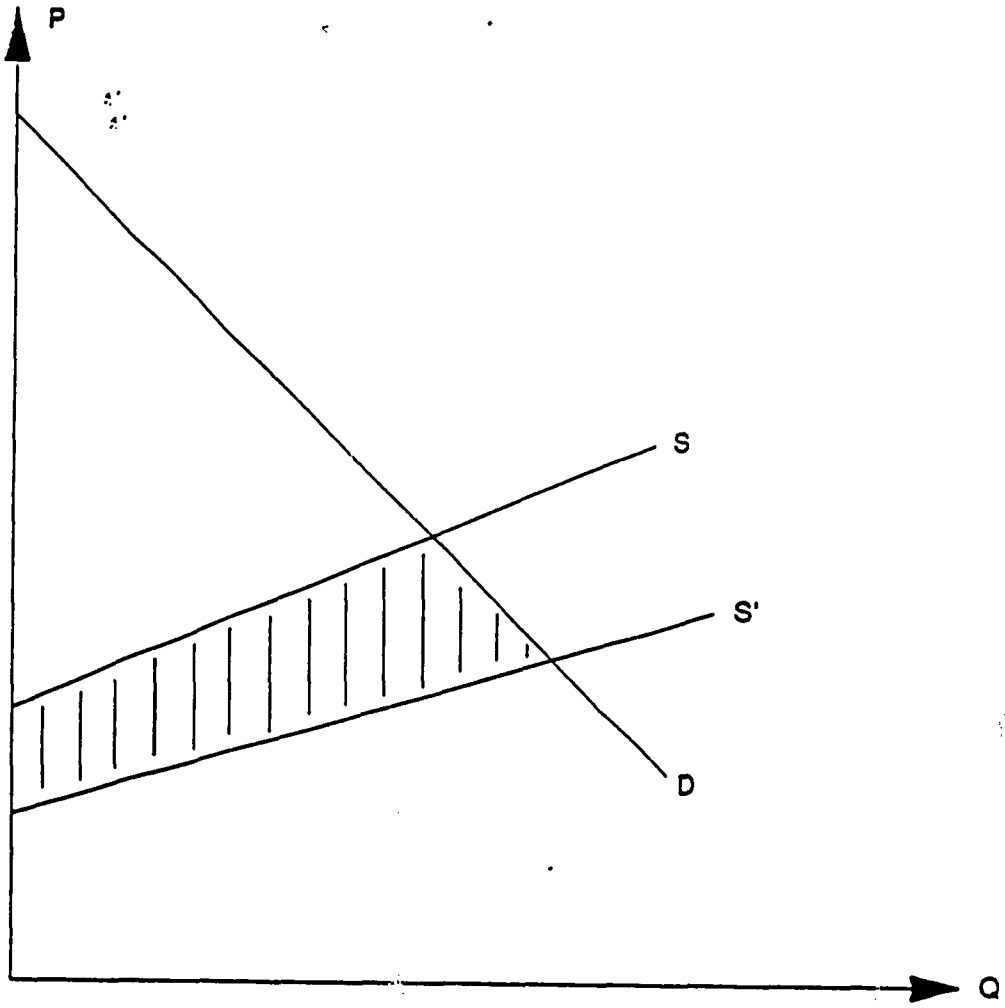


Figure 2. The contribution of research to social surplus.



Production Function Methods

The production function methods, developed after the index number approach, include research as a separate variable in an aggregate production function; thereby estimating its marginal product. But, profit and supply functions can also be used to estimate productivity increases (Capalbo and Antle, 1988).

Most production function approach studies have used a Cobb-Douglas functional form. Agricultural output is made a function of conventional inputs (land, fertilizer, machinery, etc.) and accumulated research capital. The latter is defined as the sum of past research expenditures.

Using econometric techniques, regressions are run to obtain coefficients of all variables. Once these coefficients are estimated, a two-step procedure is used to find the MRR to agricultural research. First, the value marginal product (VMP) of research is found by multiplying the research production coefficient by the average product of research. The second step involves determining the discount rate (MRR), which equates the discounted flow of these benefits with the discounted research costs.

FOUNDATIONS AND EARLY DEVELOPMENTS

This section briefly reviews the major studies which laid the foundation for the ROR methodology, focusing on quantifying social benefits. More general reviews are found in Norton and Davis' (1981) analysis of the economic assumptions and changes in methodologies (including functional specifications); and in the Ruttan (1982) and Hayami and Ruttan (1985) summaries of ROR estimates and their interpretation in a global research context.

Schultz (1953) first attempted to quantify the ROR to agricultural research. He approximated social benefits by comparing the costs of producing 1950 outputs using 1910 techniques with the actual cost of producing 1950 outputs. Schultz assumed that the benefits of research equal these cost savings, estimated at U.S.$ 9.6 billion (using 1910-1914 price weights). While this procedure gives only a crude approximation of social surplus,[12] it has been applied in developing countries because its data requirements are modest.

Griliches (1958) measured returns to research by estimating the value of the increase in yields as the net social surplus to society. He found that the most important determinant of the absolute social gain from a percentage increase in yield depended on the value of the crop (or its relative importance). He also argued that public investment in research should depend not only on a high social rate of return, but also on a lower comparative private return.

Akino and Hayami (1975) refined the approach used in the previous studies to estimate the social ROR to public investment in rice breeding research in Japan, and the distribution of benefits among producers and consumers. Their method provided a more concise formula to estimate the change in social welfare which has been applied in subsequent studies. The results suggested that under the assumption of autarky (no international trade), consumers gain from research while producers suffer a loss. Alternatively, assuming there is a large international market and that the country cannot affect the price in this market, producers will gain while consumers will experience no change in welfare. Akino and Hayami made one of the first attempts to link ROR to institutional structure -- attributing the high ROR to Japan's institutional innovation of decentralized research units.

METHODOLOGICAL IMPROVEMENTS

The ARR methodology has several shortcomings. For example, benefits can only be calculated for the total investment, rather than small increases in the research budget. Thus, policy makers can only use the ARR technique to estimate the return to an entire project expenditure -- not how much to increase research spending.

The literature highlights several issues associated with measuring the benefits of a marginal research dollar; including isolating the contribution of research to reducing production costs, specifying appropriate forms of supply shifts, accommodating market imperfections in the social surplus framework, and assessing the distributional consequences of agricultural research.

Estimating the Marginal Benefit of Research

To determine the optimal allocation of funds, it is necessary to know the marginal benefit of the last research dollar (in Figure 2, the part of the shift from S to S that is attributable to the marginal dollar of research investment). Using econometric techniques to estimate supply functions (or the equivalent), economists have made significant progress in determining this marginal shift.

The earliest MRR calculation was Griliches' (1964) estimate of 35-40% for aggregate U.S. agricultural research from 1949-59. Griliches also found that education of the farm labor force was a significant variable in explaining increased agricultural productivity. Using time-series and cross-section data for the same period, Evenson (1967) estimated a 47% MRR to aggregate U.S. agricultural research, after accounting for changes in input quality. He postulated that research increases productivity through many small changes in input quality, rather than via major breakthroughs. Also, he estimated that research investments require 6 to 7 1/2 years before effecting production.

Isolating the Effect of Research on Reducing Production Costs

Two issues are important in isolating the effect of research on reducing production costs. First, it is necessary to distinguish the impact of the research project under evaluation from the effects of other research investments, extension, improvements in input and output marketing infrastructure, and other forces that reduce production costs. In terms of Figure 2, one must ascertain how much of the shift of the supply curve from S to S′ is attributable to the research project under evaluation.

Evenson and Kislev (1973) separate research into indigenous research and research done in other countries, but adaptable to home country conditions. Using cross-country data on wheat and maize, they are able to determine the contribution of each type of research to yield increases.

Evenson and Binswanger (1978) disaggregate research into scientific and applied research. Using publications as a proxy for research output, they calculate research output across countries, and for nine major geoclimatological zones and 45 regions (sub-zones) in the world. Based on an econometric estimation of cereal grains production, which used research outputs as explanatory variables (among others); they isolated differences between scientific and applied research, identified a strong complementarity between the two, and determined the contribution of regional and zonal research to country production. Although RORs are not calculated, these results clearly show the ability of econometric techniques to isolate the effects of different types of research, and of research carried out in different geoclimatic areas.

Pray and Echeverria (1988) attempt to quantify the effects of private sector research, by estimating a corn yield production function for 50 countries over a 25-year period. The results indicated that private foreign research and seed imports were significant variables. While they concluded that private research may be an important source of improved technology and that private research and development should be included when assessing the impact of public research and development; more sophisticated models are necessary to accurately test the role of private research.

Modeling Supply Shifts

Although it is possible to estimate supply functions to isolate the contribution of research, specification of the functional form of the supply curve is crucial to the results. Misspecification of the supply shift can inaccurately quantify

research benefits and misrepresent the distribution of benefits between producers and consumers. In terms of Figure 2, the location and shape of the S′ curve depends on how research is included in the supply function.

Lindner and Jarrett (1978) argued that previous studies produced biased results because they paid insufficient attention to how the supply curve shifted. They derived an alternative formula for measuring social surplus which did not assume a particular type of supply shift. Comparing Griliches (1958) formula to their own, they reported that Griliches overestimated the ROR to hybrid corn research by at least 50-100%. Similar comparisons with Peterson's (1967) formula suggested that he overestimated social surplus by more than 150%. They also noted that Akino and Hayami's assumption of a pivotal shift predetermined their conclusions about the distributional consequences of research.

While agreeing that previous work overestimated research benefits, Rose (1980) argued that Lindner and Jarrett improperly incorporated the additional information into the supply model, leading them to underestimate benefits. Rose also doubted that supply shifts could actually be identified. Using three examples, Miller *et al.* (1988) demonstrated that the nature of the supply shift will predetermine the change in producer welfare, independently of the empirical data.

Modeling Market Imperfections

The social surplus, depicted in Figure 2, depends on the assumption that the market is in equilibrium. Since most governments intervene in their agricultural sectors, the equilibrium assumption is untenable. Hence, the evaluation of research within the social surplus paradigm needs to accommodate the effects of policy interventions.

Alston *et al.* (1988) examined the impacts of quotas, target prices, and production subsidies on the benefits of research and on government costs. They found that consumers and the rest of the world receive no research benefits if there is a quota, although producers and the government gain. In the case of a target price with deficiency payments, both producers and consumers benefit greatly from research. However, the government's expenditures for deficiency payments rise when production increases due to successful research. Finally, a production subsidy for an export good maintains net world benefits as a result of increases in government subsidy payments; however, net domestic benefits are reduced. Alston *et al.* conclude that since government interventions modify the pattern of benefits, relative to those obtained under free trade, they should be accounted for in the ROR measurement.

Oehmke (1988) used algebraic and numerical simulation methods to show how interactions between agricultural research programs and agricultural price interventions affect the ROR to research. By examining target prices in a large open economy and output subsidies in both an importing and closed economy, he found that most studies underestimate research costs, causing an upward bias in estimated RORs. A divergence as high as 100% on ROR estimates was found by comparing benefits without the intervention versus benefits which account for market and government budget effects. Voon and Edwards (1990) argue that this divergence is much smaller, but provide no quantification. Oehmke (1990) extended his earlier analysis to suggest that the type of research (commodity orientation, germplasm development verses fertilizer use, etc.) undertaken by an optimal program will depend on the type of policy intervention. While Alston *et al.* and Oehmke focus on government interventions, but the idea that market distortions affect the benefits and costs of research applies equally to markets distortions caused by non-governmental factors.

Modeling Distributional Consequences

Improvements in modelling the distributional consequences of research include measuring the costs of labor displacement by improved techniques, measuring the gains to farmers as consumers, gains across countries, gains to different types

of farmers, and separating the gains to farmers from those to input suppliers.

Schmitz and Seckler (1970) appraise the effect of the mechanical tomato harvester on production efficiency and worker welfare. Even if producers as a group benefit from the introduction of a technique, mechanization may hurt farm owners whose holdings are too small to use the machinery or landless farm laborers. Schmitz and Seckler explicitly account for the social cost of labor displacement by estimating net social benefits as the value of inputs saved minus costs incurred by displaced workers. Labor displacement costs were then estimated under alternative levels of compensation needed to offset the impact of technological change. Even with the compensation for displaced workers, the ROR remained attractive (16-28%).

Ayer and Schuh (1972) measured the ROR to cotton research in Brazil and the distribution of benefits among producers and consumers. They attributed the 80-100%[13] ROR to institutional arrangements that facilitated varietal adoption, use of demonstration fields and the research focus to increase both quality and yield. This was the earliest study we found that attributed a high research ROR to interactions between research and technology transfer. Their finding that producers received 60% of the research benefits is consistent with the general pattern in which consumers gain most from research on food crops and crops exported by large countries; while producers obtain significant research benefits from improvements in cash crops when those improvements are location-specific and hence have little effect on total market supply. Saylor (1974) noted that the benefits of Brazilian cotton research were not captured entirely by Brazilian society but accrued also to world society, an effect Ayer and Schuh did not accounted for.

Hayami and Herdt (1977) investigated the impact of technological change on income distribution for semi-subsistence farmers who both sell and consume their own produce. While a price reduction due to technological improvements typically benefits consumers, semi-subsistence farmers internalize these benefits because they themselves are consumers. Hayami and Herdt demonstrated that farmers marketing a small portion of their produce benefit more than those selling a larger portion; thereby narrowing the income gap between large and small farmers. Consumer incomes are also equalized as poor consumers (who spend a larger portion of their income on food) gain more from lower food prices than rich consumers. Applying this model to the Philippine rice economy, Hayami and Herdt demonstrated that the modern rice technology transferred income from large commercial farmers and landlords to the urban poor and rural landless.

Scobie and Posada (1978) measured the distributional impact of rice research in Colombia. They extended the Ayer and Schuh methodology by distinguishing between upland and irrigated rice producers and consumers and found a high ROR, with benefits predominantly accruing to consumers. Early adopters made temporary gains by taking advantage of the higher yields at the initial market price. However, as more producers adopted the variety, supply increased, eventually reducing prices to the point where producers suffered a loss. A more complete breakdown of benefits and losses showed that benefits were biased toward lower income consumer groups which consume more rice and are taxed less than higher income consumers. Among producers, small (low income) upland farmers were most severely affected. Overall, this study extended the ROR approach to estimate: (1) the incidence of research costs to different groups; (2) the distributional impact on consumers and producer households by income strata; and (3) the differential impacts of technological change on two classes of producers.

Edwards and Freebairn (1984) also attempted to measure the distributional impact of research. However, their study focused on 'spillover' effects -- the gains to other nations from research originating in one country. Agreeing with Saylor's criticism of the Ayer and Schuh paper, they argued that a research advance reduces costs in several countries. Therefore, they included sectors for both the home country and the rest of the world in their model. The analysis

suggested that the estimate of home country benefits should be reduced if those benefits lower production costs in other countries. However, in the case of imported goods, a reduction in cost for other countries increases benefits in the home country. Thus, Edwards and Freebairn suggested that to maximize its own welfare, an individual country should devote a higher proportion of research funding to import industries.

Gardner (1989) focused on the distributional consequences of research programs on producers and input suppliers. He argued that increases in producer welfare, resulting from technological change, include gains to producers and gains to suppliers who sell agricultural inputs. Gardner concludes that consumers gain from research, while producers and input suppliers may gain or lose. For an innovation that makes purchased inputs less costly, farmers gain if the purchased inputs do not replace those supplied by the farmers (including farm labor). Within a country, farmers also gain from research that increases productivity in that country more than in the rest of the world, giving farmers in the country a cost advantage over their competitors.

INSIGHTS GAINED FROM RATE OF RETURN STUDIES

The following section highlights lessons learned from ROR studies conducted in developed countries, Asia, and Latin America, and their implications for the assessment of African agricultural research. Then, four African ROR studies and one regional rate of return study are reviewed in detail.

NON-AFRICAN ROR STUDIES

In addition to the studies reviewed in the previous section, many other ROR studies have been conducted throughout the world.

Description of Studies Conducted

Table I summarizes these studies, showing for each the author, the year the results were published, the methodology, country, commodity, period analyzed, and the results. The table is categorized according to African, Asian, Latin American, and developed country studies. Within these categories, studies are grouped according to method, average rate of return or index method (IN), and marginal rate of return or production function method (PF).

Lessons Learned

ROR studies in developed countries, Latin America, and Asia indicates that investment in agricultural research has provided consistently high payoffs across countries, commodities and time periods -- suggesting that agricultural research generally performs well. While the high ROR to agricultural research in other parts of the world suggests a potentially high ROR to African agricultural research, there are several questions frequently raised about ROR evaluations that merit further discussion.

Do ROR Studies Overestimate Research Benefits?. It is sometimes argued that ROR studies overstate the benefits from research since researchers seldom seek out research failures for evaluation. While possibly true for past evaluations of specific commodity research, aggregate studies from Asia and Latin America -- measuring the impact of a country's total investment in agricultural research (including successful and unsuccessful projects) -- also indicate high payoffs to agricultural research. Thus, ROR studies do not present a overly positive picture of the impact of agricultural research.

What Is the Most Important Determinant of Research Benefits? Griliches (1958) and Bredahl and Peterson (1976) found that the total value of the crop is an important determinant of absolute social benefit from research. These studies show that, *ceteris paribus*, the payoff to research is relatively greater for

commodities with a larger absolute value of output. However, this does not mean that research on low value commodities will not yield a high return. For example, in Senegal Schwartz *et al.* (1989) found a high ROR for cowpea.

What Factors Affect Research Efficiency? The high ROR attests to the efficiency of agricultural research and reflects the economies of scale inherent in the process of producing knowledge and information. In developing future research strategies, it is important to know which factors have contributed to this high return to research.

Many studies highlight the importance of institutional arrangements. A strong, well-developed and articulated research program has had positive effects on economic returns to research in Brazil (Ayer and Schuh, 1972), India (Evenson and Jha, 1973), Japan (Akino and Hayami, 1975), and the Philippines (Flores-Moya *et al.*, 1978). Evenson *et al.* (1979) also attribute high returns to agricultural research in the USA to close interaction in the research system among scientists advancing knowledge, scientists inventing technology, and farmers producing food. In contrast, Hertford *et al.* (1977) attributed the negligible ROR to cotton research in Colombia to the poor organization of research implied by 'unnecessary' research activities. Increasing research expenditures would not have improved research efficiency in these countries, without greater specialization and better research coordination and organization.

Although none of the studies assess the effect of infrastructure, the impact of research in Asia, Latin America, and North America was substantially increased by complementary investments in irrigation, drainage and similar investments that preceded or were developed in conjunction with the research system. For example, in Asia and Latin America, high-yielding varieties were developed at the same time as a delivery system for fertilizers. Therefore, to obtain high payoffs from agricultural research, a country must also invest in physical infrastructure.

Who Benefits From Research? Given limited resources, there is always a tradeoff between research programs oriented to meet the needs of different groups. Research priorities should reflect the overall national development strategy. Previous studies reveal that for domestically consumed commodities, consumers are the main beneficiaries. Hence, commodity research should give priority to staple food crops, if the intent is to assure that a large share of benefits go to low income consumers who spend proportionately more income on food.

Some studies contend that technological advances increase income concentration income due to a tendency to favor 'large' farmers, thereby polarizing rural populations. Hayami and Herdt (1977) have demonstrated that the modern rice technology did not adversely affect small farmers and the rural poor. Although early adopters were often large farmers, other groups soon adopted the new rice technology. Thus, new technology can improve income distribution if it increases the supply a major food staple more rapidly than the demand.

Implications for Africa

The consistently high returns found in Latin American, Asian and developed country studies suggests that research may give a high ROR in Africa. However, several factors need to be considered when relating these studies to Africa.

Environmental Constraints. Approximately 80% or more of sub-Saharan Africa's rainfed crop and range lands have experienced moderate desertification, defined as the loss of up to 25% of land productivity, with some areas facing even more severe problems (World Resources, 1988-89). This loss in productive capacity is among the worst in the world. In the face of declining land productivity, research may be hard pressed to just maintain current productivity levels.

Physical Infrastructural Constraints. In Africa, many countries have under invested in physical infrastructure. Since countries in other regions of the

world invested in infrastructure as they invested in their research systems, physical infrastructure was largely in place by the time research results were ready for diffusion. For example, Scobie and Posada's (1978) ROR study of rice research in Colombia noted that irrigation infrastructure was in place prior to the development of the new technology. In the U.S., the success of hybrid corn research was partly due to the earlier installation of drainage tiles in farm fields which transformed the Midwest from swampland to productive cropland.[14] Similarly, throughout Asia hundreds of years of investing in irrigation contributed to the impact of the green revolution in rice.

Lack of a Long Research Tradition. Most of the research evaluated in Latin America, Asia and developed countries was conducted in countries with long agricultural research traditions. Japan, India, and Indonesia all reaped substantial benefits after decades of sustained support to agriculture, including the establishment of agricultural colleges. In the U.S., the first land-grant college specializing in agricultural research and teaching was established in 1855, and 35 were in place by 1870. While all of the evaluations of U.S. research focus on the 20th century, it benefitted from 50 to 100 years of institutional development.

In contrast, African national agricultural research systems (NARS) and agricultural universities are relative new. With independence came the desire to conduct research to help smallholders increase food crop production, as well as train African scientists and administrators. In many cases the change in emphasis caused a slowdown in observable research outputs. NARS require time and flexibility to refocus on their broadened mandate and to train African personnel to take over as expatriates leave. Furthermore, fiscal constraints -- reflected in low civil service salaries and small operating budgets -- make it difficult for NARS to retain their top scientists, which disrupts the continuity of research programs (Lipton, 1988). Although these problems clearly need solutions, they constitute typical growing pains of young research systems.

Unachievable Goals. The African NARS are young institutions working under difficult conditions in environmentally sensitive areas. Often these institutions, along with other components of the international research system, have been given impossible mandates. Developed countries, as well as African politicians, sometimes set unattainable goals. For example, Landell-Mills *et al.* argue that "The primary source of [African economic] growth, at least for the next decade, can only be agricultural production. The [World Bank] proposes a target agricultural growth rate of 4% annually ..." (Landell-Mills *et al.*, 1989, p. 27). In contrast, from 1950 to 1982, U.S. agricultural productivity grew at a compound annual rate of less than 2% (Evenson *et al.*, 1987). Given the difficulty of working in African conditions, the target of 4% average annual agricultural growth is unrealistic.

Implications for Assessing African Agricultural Research

Schweikhardt argues that "it is good for both the public and the scientist to be patient with research work" (Schweikhardt, 1983, p. 92). This conclusion is partly based on the observation that "it takes 10 years at least to establish one agricultural fact" (H. H. Goodell in Schweikhardt, 1983, p. 92), yet some African NARS are less than ten years old.

Thus, the transformation of African agriculture into a modern, highly productive system is still decades away. While this does not mean that research with a low ROR is acceptable in Africa, it does mean that African research should be evaluated in terms of how adequately these NARS achieve realistic goals.

More realistic goals for African NARS include institutional development, training of African scientists, and the emergence of new techniques which increase the profitability of farming. In some instances, success may be merely holding productivity constant while combatting further environmental deterioration. In

other cases, success may mean large productivity increases. As African NARS mature, we should see an increasing number of research success stories.

AFRICAN ROR STUDIES

Although only four ROR studies have focused on African research efforts, these studies suggest that research in Africa has acceptable RORs.

Descriptions of Studies Conducted

Cowpea in Senegal. In 1985 "Operation Cowpeas" imported 700 mt of an improved California cowpea variety (CB-5) and in 1986 a smaller program distributed a West African cowpea variety (58-57. The seed and complementary inputs (ie. fertilizer, insecticides and sprayers) were distributed to farmers at little or no cost. The Bean and Cowpea Collaborative Research Support Program -- a cooperative effort of the Senegalese government, the University of California at Riverside; and Michigan State University -- provided research support. Schwartz *et al.* (1989) estimated an average ROR of 60-80% to the combined cowpea research and promotion program.

Mealybug Control in Africa. The mealybug, accidentally introduced into Africa in the 1970s, reduces cassava yields by 43-65%. In Ghana, losses were estimated at U.S. $58-106 million. The International Institute for Tropical Agriculture undertook research to control mealybug, via a South American parasitic wasp which was subsequently reared and released in Africa. By 1987 the wasp effectively controlled mealybug in 90% of the cassava-growing regions. Norgaard (1988) estimated that this program had a benefit/cost ratio of 149:1. Because data and time were insufficient to estimate the cassava supply curve shift, he limited the analysis to a "reasonable, least favorable" case.

Cotton in French West Africa. In Burkina Faso, Cote d'Ivoire, and Togo; the World Bank carried out a study (World Bank, 1988)[15] to characterize successful cotton development programs, estimate their impact on smallholders, and identify constraints on project sustainability. For projects in the three countries, estimated ARRs were 31, 37, 11 and 41%, respectively, assuming benefits continue into the future. The high returns were attributed to a package of assistance for cotton which included technological development, input supply networks, timely cash payments to farmers, and support to autonomous institutions. In related work, Lele *et al.* (1989) concurred that institutional factors such as extension, availability of inputs, marketing, processing, and capitalization of the cotton sector were "fundamental in explaining sustained cotton production growth in francophone countries" (Lele *et al.*, 1989, p. 5). Low cotton prices and exchange rates in 1986 depressed the RORs to as low as 5%, and low to negative returns are predicted unless prices and exchange rates recover (Lele, 1989, p. 8).

Aggregate Regional and Commodity Estimates. Using data for 24 countries in Asia, Latin America and Africa, Evenson (1987) estimated implied RORs to national research investments by region for different commodity groups. Econometric techniques were used to obtain productivity elasticities for research investments. These were converted to income streams over time (using estimates of the proportion of commodity value spent on research) and the ROR which equated the earnings stream to the initial investment, was calculated. The implied RORs ranged from 30-40% for maize and staple crops in Africa and maize in Latin America, to 60-70% for maize and cereals in Latin America, cereals in Asia and staple crops in Asia. The study also found that International Agricultural Research Center (IARC) investment stimulated national research investment in most commodities more than a comparable amount of direct aid, probably because IARC research made national research more productive.

Research and Extension in Africa. In another study, Evenson (1985) used similar techniques to separate the effect of research and extension investments on the productivity of major commodities grown in West and East/Southern Africa. He

found that NARS investments had significant production impacts on wheat, rice, cotton, sugar, cassava, potatoes and sweet potatoes. East/Southern Africa showed larger wheat, maize and groundnut impacts than West Africa, but lower impacts for other crops. IARC investments had an impact on wheat, potato and sweet potato production in East/West/Southern Africa; on beans in East/Southern Africa; and on rice in West Africa. Generally, NARS -- and to a lesser extent IARC research -- had less impacts on productivity in West Africa than in other developing countries. The analysis also suggest that many of the smaller research systems, such as those found in West Africa, are probably having little or no productivity impact.

The results from Evenson's studies are important because they estimate returns to aggregate national and IARC research efforts by commodity group, not individual projects. Therefore, they are not susceptible to the criticism that RORs are high because only successful projects are analyzed. Thus, these studies suggest that African research is performing well, despite the small increases in overall agricultural productivity.

Lessons Learned

Given the limited number of African studies, it is impossible to draw strong, general conclusions about the ROR to African agricultural research. Yet, they highlight important success stories and it is likely that additional ROR studies would identify more examples of successful research investments in Africa. As the NARS mature, we expect to see an increasing number of successful research efforts. However, the success of national and regional research agendas will depend not only on the way the research systems mature, but also on overcoming the critical resource and environmental constraints facing Africa.

INSIGHTS GAINED FROM DESCRIPTIVE ASSESSMENTS OF AFRICAN RESEARCH

Numerous descriptive studies have attempted to assess the impact of agricultural research. This section draws from reports summarizing the research experience of the World Bank, United States Agency for International Development (USAID), and the Consultative Group for International Agricultural Research (CGIAR); and assessments conducted in several African countries. While these reports do not cover all types of non-rate of return evaluations, they illustrate the type of analysis that has been carried out.

DONOR ASSESSMENTS OF RESEARCH INVESTMENTS

The CGIAR Review

In 1988 the CGIAR completed an evaluation of the impact of the 13 CGIAR agricultural research centers (Anderson, Herdt and Scobie, 1988).

Wheat. The study found that by 1982-83 high-yielding wheat varieties, largely developed by CIMMYT and its predecessors, were grown on 48.5 million ha in developing countries. By 1983 modern varieties had increased wheat production in developing countries by 18 million mt annually, compared to 1970. However, wheat is a major crop in only Ethiopia, Kenya and Zimbabwe. While many other African countries have a great interest in improved wheat technology, high temperature tolerant varieties have yet to be developed (Dalrymple, 1986a cited in Anderson, Herdt and Scobie, 1988).

Rice. By 1986, modern rice varieties -- initially developed by the International Rice Research Institute (IRRI) -- were grown on an estimated 76 million ha in Africa, Asia and Latin America. By 1986 modern varieties had increased rice production in developing countries by 23 million mt annually, compared to 1970. While rice is an important crop in Burkina Faso, Ghana, Madagascar, Mali, Nigeria, Senegal and Tanzania, in Africa rice is usually grown on in the uplands. Modern rice technology has had minimal impact in Africa because most of IRRI's research has focused on developing improved varieties for irrigated environments.

Available information indicates that improved varieties were planted on 75% of Tanzania's total irrigated rice area of 15,000 ha (1984), on 60,000 ha in Nigeria (1984), and on more than 70,000 ha in Senegal in 1983 (Dalrymple, 1986b, cited in Anderson, Herdt and Scobie, 1988).

Maize. Plant breeders at the CGIAR centers have developed more than 200 new maize varieties which are being grown on more than 6 million ha worldwide. In general, CGIAR maize research has been less successful than wheat and rice research. This is partly because maize varieties are relatively environment specific and the crop is grown under diverse local conditions, compared to wheat and rice which are grown under relatively homogeneous irrigated conditions. Zimbabwe, Kenya, Malawi and Tanzania are using germplasm from CGIAR centers to develop new inbred lines, composites and streak virus-resistant varieties. Nigeria has released two maize varieties from IITA with resistance to tropical rust and lowland blight. By 1984 these varieties were grown on an estimated 1 million ha in Nigeria, and the same varieties released in the Cameroon were grown on 10,000-15,000 ha (Okoro and Onuoka, 1985, and Lyonga and Pamo, 1985, cited in Anderson *et al.*, 1988).

Other Crops. CGIAR centers have also developed new varieties of other food crops, including cassava, field beans, potatoes, pearl millet, sorghum and cowpeas. In Africa, Ethiopia, Kenya and Burkina Faso have each released several ICRISAT-derived sorghum varieties (Anderson *et al.*, 1988). Also, ICRISAT has collaborated with Susan's national research program to develop a promising hybrid sorghum, discussed in more detail later in this chapter.

Criticisms. The CGIAR system has been criticized on several grounds, which help to explain its rather limited impact on sub-Saharan African agriculture. First, IRRI's and CIMMYT's early success in improving irrigated rice and wheat yields, was partly due to the existence of a large body of technical knowledge gained through research on these crops in developing countries and the homogeneity of the production environment. Rapid progress in improving these crops led to the establishment of other centers and raised expectations that plant breeding could rapidly increase yields of other crops. This strategy failed to recognize that subsistence crops such as maize, beans, potatoes, cassava and legumes are typically grown under diverse ecological conditions which require environment specific varieties adapted to local conditions. It has proved more difficult to develop improved varieties of Africa's subsistence crops that are suitable for widescale dissemination (Simmonds, 1981, cited in Anderson *et al.*, 1988).
Some critics argue that initially the CGIAR centers were insufficiently aware of the actual conditions in farmers' fields. For example, scientists were slow to realize that in Latin American, maize is intercropped and serves as a support for crops such as beans. Thus, maize stalks must be strong and widely spaced -- rather than slim and closely spaced as in U.S. agriculture. Another criticism is that initially the CGIAR centers concentrated too much on developing new varieties which require fertilizer, water, pesticides and machinery -- failing to recognize that poor farmers in developing countries cannot afford these inputs (Anderson *et al.*, 1988).

<u>The World Bank Review</u>
In 1985, concern about the low level of World Bank support for research and extension; and the relative efficiency of different approaches supported by the World Bank, prompted a major review of research support for 128 projects in 10 member countries (World Bank, 1985). The study criticized the Bank's failure to consider the long-term sustainability of the research services beyond the initial investment period. Also, while the projects were successful in building physical facilities, they failed to improve facility management or strengthen institutional structures. Major weaknesses cited included (1) limited recipient country input into project design, (2) weak coordination of support for research with support for improving credit, marketing, training, and input supply and distribution, (3) institutional separation of research and extension, and (4) a

concentration of support for adaptive research, even when support for basic research was more appropriate.

The study also observed that the more successful research systems had a strong central organization responsible for research; carried out decentralized regional research; and staff actively participated in translating research results into farmer recommendations. These findings generated several recommendations for improving the Bank's support of research and extension; including a need for: (1) more in-depth assessment of social, political, and cultural constraints in each country to make projects more consistent with reality, (2) more active participation of borrowers in project preparation, and (3) giving greater priority to manpower and research management training.

USAID Reviews

Two studies assessed USAID's experience in agricultural research. Development Alternatives, Inc. (DAI, 1982) examined 131 evaluations of 48 agricultural research projects and observed that while 21 of the projects explicitly focused on small farmers, only 8 attempted to analyze small farmer constraints. Research design and implementation were cited as problems in 15 of 39 projects. In 9 projects, USAID was criticized for having insufficient technical expertise to supervise the projects and in 24 projects, local government support was lacking. Finally, counterpart shortages, unsuccessful training, and USAID procurement delays were cited as problems in one-third of all projects. USAID research project evaluations were criticized for failing to provide a sufficient quality and quantity of data to facilitate rigorous comparison of projects. Also, most evaluations failed to analyze why some approaches had succeeded and others had failed.

Murphy (1983) analyzed project and impact evaluations conducted by interdisciplinary teams; and interviewed USAID officers, host government officials, and experts from the agricultural research community. Murphy found that USAID assistance to regional and national research institutions was highly successful in training researchers and establishing or expanding research facilities. However, research effectiveness and sustainability was often hampered by managerial weaknesses, unfavorable government policies, and an inadequate awareness of farm level conditions. Murphy recommended that: (1) projects give increased attention maintaining a continuous dialogue between politicians, administrators and researchers to sustain essential host government support, (2) since government policies and infrastructure will determine the extent to which new technology is adopted, these should be considered in research project design; and (3) since research should be farmer-oriented, projects must establish a two-way information system between researchers, extension agents, and farmers. Also, she observed that poor management of limited resources, particularly high attrition of skilled staff, can undermine the sustainability of a program; and that coordination among researchers and other development agents was the key to success.

SPECIFIC COUNTRY-COMMODITY ASSESSMENTS

This section reviews several evaluations (non-ROR) of African agriculture research systems. Although these examples illustrate that agricultural research has been quite successful in several countries, formal ROR studies are needed to quantify these research impacts in Africa in order to show policy makers and donors that research is a high return and necessary investment in the future. In addition, these studies identify several important research evaluation issues and provide insights as to the role of agricultural research in Africa.

Improved Varieties in Mali

Mali's agricultural research system faces many problems that are common to sub-Saharan Africa. Although no *ex-post* ROR studies exist for Mali, descriptive assessments are available.

Atwood and Elliot (1989) reviewed USAID studies to assess the role and impact of agricultural research. They estimated that yield increases, due to the adoption of improved varieties, produced net annual benefits of $U.S. 16 million. In addition, they argued that increased agricultural productivity would raise farm and non-farm incomes -- citing a World Bank study which reported that a 10% increase in farm incomes increased non-farm incomes by 5%, due to linkages between the two sectors. They further noted that although some food imports may be necessary, Mali has a comparative advantage in food crops which they should use to avoid large imports. Atwood and Elliot cited three major accomplishments that would generate a continued stream of improved technology: (1) the availability of high potential breeding material developed over a 12-year period, (2) a strong on-farm trials program, and (3) the identification of key field crop constraints (ie. pests, soil moisture, and fertility). They concluded by emphasizing that the research system needed continued support to gain additional experience, develop linkages, and to exploit available breeding materials.

Staatz's (1989) review of factors that influence new technology adoption rates in Mali identified several technology development issues. First, the profitability of new technology depends not only on the yield increase, but also on the market price structure for inputs and outputs. Using a hypothetical example, he illustrated that traditional varieties may actually be more profitable than new varieties, if they require less labor or less costly inputs. He further argued that adoption of the new varieties based on yield increases alone may lead to a "price-led" development strategy, induced by government controlled-price increases. Higher prices would raise the cost of living for net food purchasers, and may lead to demands for higher wages. Second, although new technology may increase yields, higher risk -- due to unstable yields, rainfall patterns, or input market instability -- may slow their adoption. For example, nonadoption due to undeveloped rural input markets may be mistaken as a credit constraint. Staatz recommended that technical and social scientists work together to address these issues when designing and evaluating new technology.

Cowpea in Senegal and Mali

In 1985, "Operation Cowpea" distributed an imported seed variety (California CB-5) and complementary insecticides, sprayers, and fertilizers at little or no cost to Senegalese farmers. The $US 1 million project was largely financed by FAO and implemented by the extension service (SODEVA) through producer groups and village cooperatives, and with technical and administrative support from a joint EEC-Senegal team. The promotion was continued in 1986, primarily with a local variety (58-57) at a cost of U.S. $ 0.6 million (1986). The project increased yields over 70% and more than tripled total production. (Bingen *et al.*, 1988; and Schwartz *et al.*, 1989).

In 1980 the Mali government imported cowpea varieties from the International Institute for Tropical Agriculture (IITA) in cooperation with the Semi-Arid Food Grains Research and Development (SAFGRAD) program; and SAFGRAD conducted multi-locational trials. Analysis of the adoption of imported cowpea varieties in the Cinzana area found that the yields of participating farmers -- who also applied complementary inputs (e.g. insecticides) -- averaged 700-800kg/ha, compared to 250-300 kg/ha for traditional varieties.

The Senegal and Mali evaluations showed that: (1) successful diffusion of new technology depends on the existence of viable input and output market (2) research and extension were important in Senegal, but diffusion occurred outside formal institutions in Mali (3) access to credit encourages adoption (Mali) as does free input distribution (Senegal), and (4) farmers will adopt minor (non-staple) crops if they fit into a niche in the farming system (short duration makes cowpeas a good early food source). Also, in both countries a lack of data (production, yields, area planted, nutritional preference, consumption patterns, research and extension costs) was a major constraint to better understanding the impact of research.

Maize in Kenya

Johnson's (1979) evaluation of USAID support to Kenyan maize research demonstrated the potential for public and private sector cooperation. The foundations for hybrid maize research was laid in 1955. Subsequent research, funded by USAID and other donors at the Kitale Research Station, led to the release of a hybrid maize variety in 1964 that increased yields by 40%. Large and small farmers widely adopted Kitale maize, even though they had to purchase seeds every year. This success was largely due to: (1) the aggressive private firm, the Kenya Seed Company, which produced, distributed, and promoted the seed throughout the country via their private shopkeeper network, (2) extension demonstrations of improved cultivation practices, and (3) incentives provided by the government-supported official price and marketing system. By 1977, most smallholders in the high potential Central, Rift Valley and Western Provinces grew hybrid maize; and their production surpassed that of larger farmers--making Kenya nearly self-sufficiency in maize.

Despite its initial success, the breeding program deteriorated in the 1970s. USAID shifted its emphasis to post-harvest grain storage and provided limited support for maize research after 1974. Funding was further reduced, following the 1977 breakup of the East African Community. As Kenyan scientists left the program, due to low salaries and inadequate benefits, research productivity declined -- resulting in very few new releases from 1976 to 1986 (Johnson *et al.*, 1979; Karanja, 1990, personal communication).

Beginning in 1986, USAID committed approximately US$ 1.5 million annually to support Kenya'a new Agricultural Research Institute (KARI) and is again having a major impact on maize research. In the last two years, several new hybrids have been released. One new release -- developed jointly by the agricultural research service, the Kitale Research Station and the Kenya Seed Company -- yields 3-13% over previously released hybrids, or 43-53% over the old local variety in high-potential areas. In addition, the program has developed new varieties for marginal areas (Karanja, 1990, personal communication).

Maize in Zimbabwe

Between 1979 and 1985, Zimbabwe increased per capita cereal production by 80%. Maize production more than doubled, with most of the production gains contributed by smallholders -- making Zimbabwe a significant maize exporter to neighboring countries. (Rohrbach, 1988).

In both Kenya and Zimbabwe, long-term sustained support to maize breeding has been a critical factor. In Southern Rhodesia (now Zimbabwe), hybrid maize research was initiated in 1932. The first hybrid, SR-1, was released to farmers 17 years later, making Southern Rhodesia the first country after the United States to produce hybrid corn commercially. In 1960 the program released SR-52 -- a high-yielding, long season (150-day) white variety derived from local parents. SR-52 remained the dominant commercial variety for more than two decades and is still the second most important variety (Eicher, 1984). A recent shorter duration (130-day) maize hybrid release, R-201, is widely used by smallholders. While only 30% of the smallholder maize area was planted to hybrids in 1979, by 1986 the area had increased to nearly 80% (Rohrbach, 1988).

Hybrid Sorghum in Sudan

Sudan's successful hybrid sorghum research program also testifies to the importance of research continuity and the role of the private sector in seed multiplication and distribution. Hybrid sorghum research began in the early 1960s, but showed limited success until 1977, when the ICRISAT-Sudan Cooperative Program for Sorghum and Millet Improvement was initiated and the first full-time sorghum breeder was hired. Sustained support from the United Nations Development Program (UNDP), ICRISAT, and the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL) provided Sudan's fledgling program access to germplasm, staff training, and technical assistance.

Between 1979 and 1982, over 3,000 experimental hybrids were evaluated under both irrigated and rainfed conditions. These trials led to the release of Hageen Dura-1 (now HV-1), a hybrid that yielded 150% more than improved local varieties under both irrigated and rainfed conditions. By 1985, farmers planted over 29,000 ha of HV-1 (Ejeta, 1988). More recently, the program has evaluated new commercial hybrids and pure line varieties which promise to outyield HV-1 (Obilana, personal communication, 1990).

The development of HV-1 has spawned an infant seed industry. USAID has encouraged and supported seed multiplication by private firms, as well as arranging for offshore production and delivery of HV-1 seed by U.S. firms to make up the shortfall. In 1983 there were no private seed companies in Sudan; but by 1985 there were 12; and local hybrid sorghum seed production had grown from 3 to 2,500 mt (Ejeta, 1988).

RESEARCH POLICY IMPLICATIONS FOR AFRICA

The results and insights reported in the rate of return literature have important policy implications that are pertinent to Africa.

1. In most parts of the world, agricultural research has had a high pay-off, but infrastructure, institutions, and government policies crucially effect the success of agricultural research.

All non-African ROR studies reviewed found high returns to agricultural research, with estimated RORs of at least 11%[16]. These results imply that the evaluated research projects and programs have been successful, and suggests that there is underinvestment in agricultural research for the selected commodities in the countries studied.

Both the ROR and Non-ROR studies highlight the need to analyze the interaction between research and complementary factors such as infrastructure, institutions, and government policies[17]. Particularly in Africa -- where inter-country differences are great -- the effects of extension, private research, input and output markets, credit, the structure of the research institution, and other forces that affect the benefits and costs of research are poorly understood. To effectively design research programs, additional research is needed to determine which factors are most important and to quantify their effects on research effectiveness.

2. There are few quantitative evaluations of African agricultural research.

Very few ROR research evaluations have been undertaken in Africa. Although the results of the studies reported are encouraging, additional ROR studies are required to increase our understanding of African agricultural research and its effectiveness.

3. No single evaluation techniques is appropriate for all situations

The techniques reviewed in this paper differ according to results (outputs), issues which the techniques can incorporate into their assessment, and data requirements (see Appendix I for comparisons). The tradeoffs between desired outputs, costs and availability of data must be considered when selecting a ROR methodology.

4. Consumers are the major beneficiaries of agricultural research.

While new seed-chemical technology has been adopted by both small and large farmers, the primary effect of research is to lower production costs. This benefit is ultimately passed onto consumers in the form of lower prices.

Estimates of the ROR to research should consider this consequence, particularly if the government goal includes equity.

5. Sustained investments in research are required to achieve the anticipated payoffs.

Research has a long gestation period. Most African NARS are relatively young and face significant manpower and resource constraints. Donor support is required to help finance both training and technical assistance to African agricultural research systems to build the critical mass of staff expertise necessary to conduct successful agricultural research.

6. Continuity and coordination of donor agricultural research investment is necessary.

Although many donors have invested in African agricultural research over the past twenty years, the capricious nature of project selection and renewal leads to limited results. As stated above, research has a long gestation period which may require 10 to 20 years of support for *one research topic*. Short-term projects or projects which change focus every three to five year cannot guarantee technological advancement. Additionally, coordination among donors is necessary to pool resources within a country rather than several different projects placing heavy demands on the limited human capital available.

TABLE 1. Summary of Returns to Agricultural Research Studies for Africa.

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Abidogun	1982	IN	Nigeria	Cocoa	-	42
Evenson	1987	1/	Africa	Staple Crops	Maize and 1962-1980	30-40
Norgaard	1988	IN	Africa		Cassava	1977-2003
149:1 2/						
Schwartz	1989	IN	Senegal		Cowpea	1981-2015
63						
et al.						

1 Calculated from production elasticities.
2 Benefit/cost ratio.

Sources: See Appendix II.

TABLE 2. Summary of Returns to Agricultural Research Studies for Asia.

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Akino & Hayami	1975	IN	Japan	Rice	1915-50	25-27
		IN	Japan	Rice	1930-61	73-75
Pee	1977	IN	Malaysia	Rubber	1932-73	24
Pray	1978	IN	Punjab (Br.India)	Research+ Extension	1906-56	34-44
		IN	Punjab (Pakistan)	Research+ Extension	1948-63	23-37
	1980	IN	Bangladesh	Wheat+ Rice	1961-77	30-35
Nagy	1981	IN	Pakistan	Maize	1967-81	19
Khan and Akbari	1986	IN	Pakistan	Aggregate+ Extension	1955-81	36
Unnevehr	1986	IN	S.E. Asia	Rice	1983-84	61
Nagy	1987	IN	Pakistan	Wheat	1967-81	58
Tang	1963	PF	Japan	Aggregate	1880-1938	35
Evenson & Jha	1973	PF	India	Aggregate	1953-71	40
Kahlon,Bal	1977	PF	India	Aggregate	1960-61	63
Saxena & Jha		PF	Philippines	Rice	1966-75	
Flores,	1978	PF	Philippines	Rice	1966-75	27
Evenson & Hayami		PF	Tropics	Rice	1966-75	46-71
Evenson & Flores	1978	PF	Asia-national	Rice	1950-65	32-39
		PF	Asia-national	Rice	1966-75	73-78
		PF	Asia-Int'l	Rice	1966-75	74-102
Nagy	1985	PF	Pakistan	Aggregate	1959-79	64.5
Librero and Perez	1987	PF	Philippines	Maize	1956-83	27-48
				Maize+ Extension	1956-83	27-43
Salmon	1987	PF	Indonesia	Rice	1972-77	133
Pray & Ahmad	1987	PF	Bangladesh	Aggregate	1948-81	100+
Evenson	1987	PF	India	Aggregate	1959-75	100+

Sources: See Appendix II.

TABLE 3. Summary of Returns to Agricultural Research Studies for Latin America.

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Barletta	1970	IN	Mexico	Wheat	1943-63	90
		IN	Mexico	Maize	1943-63	35
Ayer	1970	IN	Brazil	Cotton	1924-67	77+
Ayer & Schuh	1972	IN	Brazil	Cotton	1924-85	80-107
Hines	1972	IN	Peru	Maize	1954-67	35-40
		IN	Peru	Maize + Cultivation	1954-67	50-55
Monteiro	1975	IN	Brazil	Cocoa	1923-74	16-18
		IN	Brazil	Cocoa	1958-74	60-79
		IN	Brazil	Cocoa	1958-85	61-79
		IN	Brazil	Cocoa	1923-85	19-20
Fonseca	1976	IN	Brazil	Coffee	1933-95	23-27
		IN	Brazil	Coffee + Extension	1933-95	17-22
Hertford *et al.*	1977	IN	Colombia	Rice	1957-72	60-82
		IN	Colombia	Soybeans	1960-71	79-96
		IN	Colombia	Wheat	1953-73	11-12
		IN	Colombia	Cotton	1953-72	none
Wennergren & Whittaker	1977	IN	Bolivia	Sheep	1966-75	44
		IN	Bolivia	Wheat	1966-75	48
Scobie & Posada	1978	IN	Colombia	Rice	1957-64	79-96
Moricochi	1980	IN	Brazil (Sao Paulo)	Citrus + Extension	1933-85	18-28
Avila	1981	IN	Brazil (R.G. Sul)	Irrig.Rice +Extension	1959-78	83-114
		IN	Brazil (R.G. Sul)	Irrig.Rice	1959-78	87-119
		IN	Brazil (Central)	Irrig.Rice	1959-78	87
		IN	Brazil (N. Coast)	Irrig.Rice	1959-78	107
		IN	Brazil (S. Coast)	Irrig.Rice	1959-78	115
		IN	Brazil (Frontier)	Irrig.Rice	1959-78	119
		IN	Brazil (R.G. Sul)	Irrig.Rice	1959-78	107
		IN	Brazil (Central)	Irrig.Rice +Extension	1959-78	83
		IN	Brazil (N. Coast)	Irrig.Rice	1959-78	92
		IN	Brazil (S. Coast)	Irrig.Rice	1959-78	111
		IN	Brazil (Frontier)	Irrig.Rice	1959-78	114

TABLE 3 (con't). Summary of Returns to Agricultural Research Studies for Latin America.

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Avila	1981	IN	Brazil (R.sG. Sul)	Irrig.Rice	1959-78	96
Cruz *et al.*	1982	IN	Brazil EMBRAPA	Physical Capital	1974-81	53
		IN	Brazil EMBRAPA	Total Investment	1974-92	22-43
Ribeiro	1982	IN	Brazil (Minas Gerais)		1974-94	69
		IN	Brazil(Minas Gerais)	Cotton	1974-94	48
		IN	Brazil(Minas Gerais)	Soybeans	1974-94	36
Yrarrazaval *et al.*	1982	IN	Chile	Wheat	1949-77	21-28
		IN	Chile	Maize	1940-77	32-34
Avila *et al.*	1983	IN	Brazil EMBRAPA	Human Capital	1974-96	22-30
		IN	Brazil EMBRAPA/SCPA	PROCENSUL I	1977-96	27
		IN	Brazil EMBRAPA	South Cent. Region	1974-96	38
Cruz & Avila	1983	IN	Brazil EMBRAPA/IBRD	Total Investment	1977-82	20
		IN	Brazil EMBRAPA	Aggregate	1977-91	38
Martinez & Sain	1983	IN	Panama (P.Caisan)	Maize on-farm res.	1979-82	188-332
Ambrosi & Cruz	1984	IN	Brazil EMBRAPA/CNPT	Wheat	1974-82	59
		IN	Brazil EMBRAPA/CNPT	Wheat	1974-90	74
		IN	Brazil EMBRAPA/CNPT	Wheat(+ Phys.Capital)	1982	40
Pinazza et al.	1984	IN	Brazil(Sao Paulo)	Sugarcane	1972-82	35
Roessing	1984	IN	Brazil EMBRAPA/CNPS	Soybeans	1975-82	45-62
Ayres	1985	IN	Brazil	Soybeans	1955-83	46
		IN	Brazil	Soybeans	1955-83	48-49
		IN	Brazil (Parana)	Soybeans	1955-83	51
		IN	Brazil (R.G.Sul)	Soybeans	1955-83	51-53
		IN	Brazil (S.Catarina)	Soybeans	1955-83	29-31

TABLE 3 (con't). Summary of Returns to Agricultural Research Studies for Latin America

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Ayres	1985	IN	Brazil (Sao Paulo)	Soybeans	1955-83	23-24
Luz Barbosa *et al.*	1988	IN	Brazil EMBRAPA Region	Aggregate	1974-97	40.5
Echeverría	1988	IN	Uruguay Extension	Rice +	1965-85	52
Barletta	1970	PF	Mexico	Crops	1943-63	45-93
Elias (revised by Cordomi)	1971	PF	Argentina	Sugarcane+ Extension	1943-63	33-49
del Rey (revised by Cordomi)	1975	PF	Argentina	Sugarcane+ Extension	1943-64	35-41
Evenson	1982	PF	Brazil	Aggregate	19..-74	69
Feijoo (revised by Cordomi)	1984	PF	Argentina	Aggregate+ Extension	1950-80	41
Muchnik	1985	?	Latin America	Rice	1968-90	89
Romano	1988	PF	Colombia	Aggregate	1960-82	50

Sources: See Appendix II.

TABLE 4. Summary of Returns to Agricultural Research Studies for Developed Countries.

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Griliches	1958	IN	USA	Hybrid Corn	1940-55	35-40
		IN	USA	Hybrid Sorghum	1940-57	20
Peterson	1967	IN	USA	Poultry	1915-60	21-25
Schmitz & Seckler	1970	IN	USA	Tomato Harvester: Compensation to displaced labor	1958-69	
				Yes		37-46
				No		16-28
Peterson & Fitzharris	1977	IN	USA	Aggregate	1937-42	50
		IN	USA	Aggregate	1947-52	51
		IN	USA	Aggregate	1957-62	49
		IN	USA	Aggregate	1957-72	34
Kislev & Hoffman	1978	IN	Israel	Wheat	1954-73	125-150
				Dry farming		94-113
				Field crops		13-16
Zentner	1982	IN	Canada	Wheat+ Extension	1946-79	30-39
Herruzo	1985	IN	Spain	Rice	1941-80	17
Furtan & Ulrich	1985	IN	Canada	Wheat	1950-83	29
				Rapeseed		51
				Barley		22
				Alfalfa		14
Brinkman & Prentice	1985	IN	Canada	Aggregate+ Educ., private R&D	1950-72	66
Eveleens & Scobie	1986		N.Zealand	Aggregate	1926/7 to 1983/4	30
Finn 1/	1987	IN	Canada	Wheat		29:1
				Barley		11:1
				Rapeseed		42:1
				Forages		3:1
Horbasz, Fox & Brinkman	1988	IN	Canada	Sheep		10-25
Zachariah, Fox & Brinkman	1989	IN	Canada	Broilers	1968-84	52-60
Griliches	1964	PF	USA	Aggregate	1949-59	35-40
Latimer	1964	PF	USA	Aggregate	1949-59	not sig.
Peterson	1967	PF	USA	Poultry	1915-60	21
Evenson	1968	PF	USA	Aggregate	1949-59	47
Duncan	1972	PF	Australia	Pasture Improvement	1948-69	58-68

TABLE 4 (con't). Summary of Returns to Agricultural Research Studies for Developed Countries.

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Cline 1/	1975	PF	USA	Aggregate	1939-48	41-50
		PF	USA	Research +		
		PF	USA	Extension	1949-58	39-47
					1959-68	32-39
					1969-72	28-35
Peterson & Bredahl	1975	PF	USA	Aggregate	1937-42	50
					1947-57	51
					1957-62	49
					1967-72	34
Bredahl & Peterson	1976	PF	USA	Cash Grains	1969	36
		PF	USA	Poultry	1969	37
		PF	USA	Dairy	1969	43
		PF	USA	Livestock	1969	47
Lu & Cline	1977	PF	USA	Aggregate	1938-48	30
		PF	USA	Aggregate	1949-59	28
		PF	USA	Aggregate	1959-69	26
		PF	USA	Aggregate	1969-72	24
Lu, Quance & Liu	1978	PF	USA	Aggregate	1939-72	25
Nagy & Furtan	1978	PF	Canada	Rape Seed	1960-75	95-110
Lu, Cline & Quance	1979	PF	USA	Aggregate + Extension	1939-72	25
Davis	1979	PF	USA	Aggregate	1949-59	66-100
		PF	USA	Aggregate	1964-74	37
Evenson & Welch	1979	PF	USA	Crop + Livestock	1964	55
Evenson	1979	PF	USA	Aggregate	1868-1926	65
		PF	USA	Technology-oriented	1927-50	95
		PF	USA	Science-oriented	1927-50	110
		PF	USA	Science-oriented	1948-71	45

TABLE 4 (con't). Summary of Returns to Agricultural Research Studies for Developed Countries.

AUTHOR(S)	YR	METHOD	COUNTRY	COMMODITY	PERIOD	RESULT(%)
Evenson	1979	PF	Southern USA	Technology-oriented	1948-71	130
		PF	Northern USA	Technology-oriented	1948-71	93
		PF	Western USA	Technology-oriented	1948-71	95
		PF	USA	Farm Management Research & Agricultural Extension	1948-71	110
White *et al.*	1979	PF	USA	Aggregate	1929-77	28-37
Davis & Peterson	1981	PF	USA	Aggregate	1949-74	37-100
Norton	1981	PF	USA	Cash Grains	1969	
					9-yr.lag	31-57
					5-yr.lag	44-85
				Poultry	9-yr.lag	30-56
				Dairy	9-yr.lag	27-50
					5-yr.lag	33-62
				Livestock	5-yr.lag	56-111
					9-yr.lag	66-132
Sundquist *et al.*	1981	PF	USA	Maize	1977	115
				Wheat		97
				Soybean		118
Smith *et al.*	1983	PF	USA	Dairy	1978	25
				Poultry		61
				Livestock		22
Doyle & Ridout	1985	PF	UK	Aggregate	1966-80	10-30
Braha & Tweeten	1986	PF	USA	Aggregate	1959-82	47
Thirtle & Bottomley	1988	PF	UK	Aggregate		70

1/ Calculated benefit-cost ratios.

Sources: See Appendix II.

ENDNOTES

1. These numbers indicate the studies identified through a literature search described in the succeeding endnote. We acknowledge that there may be other published and unpublished studies which were not located at the time this paper was completed.

2. To achieve these objectives, a review of the ex-post and ex-ante rate of return literature and the non-rate of return literature was undertaken. This included a search of several databases: AGRIS, AGRIS INTERNATIONAL, AGRICOLA, CAB, and DAI. Past summaries of agricultural research evaluations were also reviewed and updated.

3. The appropriate comparison is with the cost of obtaining government funds. If available, interest rates on Treasury notes or bonds, or on sovereign debt, are appropriate measures of the cost of obtaining funds. Alternatively, one could use the welfare cost of raising government funds through taxation (see Browning) if this measure is available.

4. Later we will see that in an ex-ante context, estimated average ROR's do not help with the allocation of funds to potentially successful projects.

5. We are implicitly assuming decreasing returns to each research project.

6. Here the term "inverse" refers to the expression of supply price as a function of quantity, rather than the more common expression of quantity supplied is a function of price.

7. Here we are referring to non-economic or accounting profit.

8. An input is inelastically supplied if a 1% increase in the price of the input leads to an increase in the quantity supplied of less than 1%.

9. For simplicity we are assuming that the supply shift is attributed directly to research. In reality, research, extension, input supply infrastructure and other forces will influence the adoption of research results, so that the contribution of research to the supply shift is obfuscated. These matters are discussed more fully in the following sections.

10. Although, conventionally index number approach is used at a commodity level and production function approach at an aggregate level, either technique may be employed at any level of aggregation.

11. Studies within each group differ as to the exact methods used to calculate the benefits, as per their assumptions. The methodology for each approach has evolved through time as more dimensions were added to evaluating research. This is discussed in the next section. This section provides an overview of the basic procedures associated with each method.

12. Schultz's cost savings equal social surplus when the demand curve is vertical and the 1910 and 1950 supply cures are parallel.

13. Musalem (1974) noted that the estimates were based on controlled experiments which would tend to overestimate true yields.

14. Pavelis estimates that in 1930 the value of physical capital used to improve the natural resource base (drainage tile, irrigation ditches, etc.) was $\$7.5x10^2$ (1929 dollars).

15. The study estimated returns to cotton development projects, not to research alone. The projects included technical packages, extension services, foreign technical assistance, village group formation for collecting cotton, and women's group activities.

17. For example, Akino and Hayami argued that decentralized research units in Japan contributed to research efficiency. In Africa, the World Bank (1985) recommended a strong centralized structure with decentralization of regional research. It is likely that the degree of centralization will depend on the size of the country, the degree of agroclimatic diversity within the country, agroclimatic similarity to neighboring countries, financial situation and other factors.

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APPENDIX I. SUMMARY OF CURRENT METHODOLOGIES FOR EVALUATING AGRICULTURAL RESEARCH

I. ALTERNATIVE EX-POST ASSESSMENT OF RESEARCH METHODOLOGIES

A. *EX-POST* INDEX NUMBER

The index number methodology generates an average rate of return to previous investment in research. This methodology is most appropriate for assessing the impact of an entire investment, rather than incremental changes in funding. This technique can address issues related to distributional impacts, economic policy impacts, commodity research returns, and aggregate research returns.

Data requirements include time-series data on research and related expenditures: prices, quantities, yields, cost of improved inputs, and expenditures over the life of the project. It is also important to determine price elasticities of supply and demand, which may be available from other studies. Compared to the alternative *ex-post* technique, the production function, the index number has lower data requirements.

Personnel requirements for the index number methodology are low in terms of researcher, scientist, and administrator time), compared to the production function method. This is an important consideration in Africa, given the limited staff in many African NARS and the high demand on their time.

B. EX-POST PRODUCTION FUNCTION

The production function approach generates a marginal rate of return to investment in research. This technique is appropriate for estimating the impact of changes in the level or allocation of funds. It can address the same issues as the index method, as well as issues related to research/extension interaction, adaptive research returns, physical and market infrastructure, spillover effects, and the interaction between public and private research.

Data requirements for the production function technique are the same as the index number, however cross-section input and output data may be used in place of time-series data.

This technique is demanding of researcher time, but requirements for administrator and scientist time are relatively low.

APPENDIX II. COMPARISON OF THE INDEX AND PRODUCTION FUNCTION METHODS[1]

Technique	Index Method	Production Function Method
Data Requirements	Prices Quantity Yields Expenditures over the life of the project Cost of improved inputs	High quality time series or cross section (agronomic) data on inputs/outputs Research expenditures Optional Enhancements: -extension data -spillover effects -human capital -private research -distributional effects
Issues that can be analyzed	Distributional impacts Economic and policy trade impacts Commodity research returns Aggregate research returns	Distributional Impacts Economic and policy trade impacts Commodity research returns Aggregate research returns Research/Extension interaction Adaptive research returns Physical and Market Infrastructure Basic research returns Separation of basic and applied research Spillover effects Public/private sector interaction

[1] Part of this table is adapted from Table I in Norton and Davis (1989).

APPENDIX III. SOURCES FOR TABLES 1-4: EX-POST RATE OF RETURN STUDIES

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