TECHNOLOGY, IMPACT AND AGRICULTURAL TRANSFORMATION: LESSONS LEARNED FROM IMPACT ASSESSMENTS

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INTRODUCTION

Stagnant African agricultural productivity over the last 20 years has called into question the ability of African agricultural research to generate meaningful productivity increases. Yet, agricultural research is important because it leads to the discovery and diffusion of new technology, which plays a critical role in increasing agricultural productivity and facilitating general economic development. The agricultural sector can stimulate overall development by: (1) providing food via market channels; (2) creating demand for the products of the non-farm sector; (3) supplying capital, especially for the development of the non-farm sector; (4) providing labor for the expansion of non-farm activities; and (5) supplying foreign exchange from export earnings in order to facilitate the purchase of critical inputs from abroad (Ramalho de Castro and Schuh, 1977; Mellor, 1976). The joint development of these five activities constitutes most of what we call agricultural transformation. Successfully completing these activities transforms agriculture from an isolated, subsistence sector into one that is integrated with and contributing to the non-agricultural economy. Stimulating such a transformation begins with the first activity, producing food in excess of that needed by the farm population. This requires improvements in agricultural labor productivity and per capita production.

The current paper reviews the available rate-of-return (ROR) evidence on the impacts of research on productivity, production and the welfare of individuals in the agricultural sector. The paper then proceeds to draw lessons about the possibilities of using research to stimulate agricultural transformation. The specific objectives are:

1. To determine if agricultural research has significant, people-level impacts in sub-Saharan Africa.

2. To determine if agricultural research can contribute to agricultural transformation in sub-Saharan Africa? If not, what are the constraints?

EVIDENCE FROM RATE-OF-RETURN STUDIES

What is a Rate-of-Return?

The rate-of-return is an valuative measure of long-term investments. It 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.[1] 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 benefits measured in ROR studies usually quantify people-level impacts: they measure the improvement in welfare of producers and consumers.[2] Surely this is the ultimate goal of development activities. However, it is possible to have important, people-level impact on subsistence farmers without generating a structural transformation. Consequently, in

summarizing the literature, an attempt will be made to connect measured impacts with possibilities for agricultural transformation. To do this, the following questions are addressed:

1. Does agricultural research have significant, people-level impact?

2. Does agricultural research contribute to agricultural transformation? If not, what are the constraints?

Lessons Learned from Non-African ROR Studies.

A recent literature review by Daniels *et al.* examined ROR and selected non-ROR studies; much of this subsection is drawn from that review. The review discovered 79 research ROR studies in developed countries, 66 in Latin America, and 25 in Asia.[3] Careful study of over 100 of these studies, and subsequent research by the author (see also Oehmke and Sterns), has led to the following lessons.

Returns to research are consistently high. This is the most fundamental lesson learned from ROR studies conducted in developed countries, Asia, and Latin America. ROR studies indicate that investment in agricultural research has provided consistently high payoffs across countries, commodities and time periods, with rates of return often in excess of 30 percent and sometimes over 100 percent. The implication is that agricultural research generally performs well. While the high RORs to agricultural research in other parts of the world suggest potentially high RORs to African agricultural research, several questions merit further discussion.

Do ROR studies Overestimate Research Benefits? It is argued that ROR studies overstate the benefits from research since researchers seldom seek out research failures for evaluation. While true for some evaluations of specific research projects, 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 an overly positive picture of the impact of agricultural research.

Does the Structure of the Research Institution Make a Difference? Many studies highlight the importance of management in the research institution: it affects efficiency. A strong, well-developed and articulated research program has positive effects on economic returns to research in Brazil (Ayer and Schuh), India (Evenson and Jha), Japan (Akino and Hayami), and the Philippines (Flores-Moya, *et al.*). Evenson *et al.* 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.* attributed the negligible ROR to cotton research in Colombia to the poor organization of research and resulting 'unnecessary' research activities. Increasing research expenditures would not improve research efficiency in situations such as the Colombian case, unless the expenditures are linked to greater specialization and better research coordination and organization.

How quickly can research generate meaningful results? Schweikhardt argues that "it is good for both the public and the scientist to be patient with research work (Schweikhardt, p. 92). This conclusion is based in part on the observation that "it takes ten years at least to establish one agricultural fact (H. H. Goodell, as quoted by Scwheikhardt, p. 92). Cleaver argues that "the idea that a research project of five years will produce anything of use, has no basis in experience (Cleaver, p. 8)." Pardey and Craig present empirical evidence that research lags may be as long as thirty years. Consequently it may be too soon to expect agricultural revolutions to arise from African agricultural research.

Who benefits from research? Given limited resources, there is always a tradeoff between research programs oriented to meet the needs of different groups. Previous studies reveal that for domestically consumed commodities, consumers rather than producers 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. However, in subsistence economies, the distinction between producer and consumer is moot, and almost all improved techniques generating benefits help the subsistence farmer.

Some studies contend that technological advances increase income concentration due to a tendency to favor large farmers, thereby polarizing rural populations. Hayami and Herdt (1977) have demonstrated that 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.

Is there an important link between research and agricultural transformation? None of the ROR studies explicitly address this question. However, some interesting anecdotes emerge.

Schmitz and Seckler indicate that the invention of the mechanical tomato harvester released labor from agriculture, generated benefits to consumers in the form of lower prices, and that the benefits were sufficient to generate a large, positive ROR to the underlying research even when the estimated harm to the displaced laborers was included as a cost. In a separate activity, the University of California (who sponsored the research) was sued for damages to the displaced laborers. The lesson is that the transformation of a commodity sub-sector is neither easy nor uniformly beneficial.

Griliches's analysis of maize research in the U.S. indicates that it is one of the most successful research activities anywhere. Maize (corn) in the U.S. is used as livestock feed, and there are excellent markets for transferring output from specialized corn farmers to specialize cattle livestock feeders. In the green revolution of the Punjab and other areas of India, new wheat varieties had impacts on consumption and agricultural transformation due in part to the existence of marketing and government mechanisms for transferring output from surplus producers to urban areas with high food demand (ref.). The lesson is that well-functioning markets may play a crucial role in determining in if and how agricultural productivity increases will influence agricultural transformation.

From a somewhat different perspective, it is worthwhile to examine the contribution that research has made to transformation in non-African regions of the world. A concise synopsis is provided by Mellor (1976):

> It is wheat that has dramatized the green revolution [in India]. The increase in wheat production illustrates the potentials of an outstanding research breakthrough applied in a locale with an impressive indigenous experimental system, with scope for rapid expansion of an effectively irrigated area, and with a well-developed set of institutions and physical facilities for the efficient transmission of knowledge, production inputs, and output (p. 52)."

Two points are clear: research was an integral part of the revolution, but a research breakthrough without positive, complementary influences would not have sufficed to generate a revolution on the scale that was seen. Mellor's description of rice production provides an interesting contrast:

> The lack of a green revolution in rice is due to the high proportion of acreage with poor control of water; an inadequate research system; and the wide dispersion of production over the country. The first circumstance sharply limits the total acreage of rice that can respond effectively to new technology; the second and third explain why practical technical innovation has been slow in forthcoming and will continue to be so (Mellor, p. 56).

Again it appears that an efficiently functioning research and TDT system is an important component, but that other parts of the agricultural sector must also be in place before a transformation occurs.

Applications to Africa.

The consistently high returns found in Latin American, Asian and developed country studies suggests that African agricultural research may yield high returns. However, African differs from Latin America and Asia in several ways, including its agroecology, specific environmental constraints, lack of physical infrastructure, market constraints, and the lack of a long research tradition. For reasons outlined in Oehmke and Sterns, these idiosyncracies suggest that returns to African agricultural research may not be as high as found in other parts of the world.

These same idiosyncracies suggest that it may also be harder for Africa to achieve an agricultural transformation that it was for Latin America or Asia. For example, the quotation from Mellor suggests that the availability of input and output markets were irrigation were important contributors to the wheat revolution in Asia. Numerous studies have noted the poor quality of African marketing infrastructure as a constraint to adoption of improved techniques. It would be no surprise if the lack of markets decreases the returns to agricultural research in Africa and/or retard agricultural transformation.

Lessons Learned from African ROR Studies.

Although less than a dozen ex post ROR studies have focused on African research efforts, these studies suggest that research in Africa has acceptable RORs (Table 1). With a single exception, these studies indicate positive returns, many in excess of 30 percent. This is consistent with the fundamental lesson learned from non-African studies. Returns to research are consistently positive, although not generally as large as in the non-African cases. The ROR numbers are large enough, in general, to indicate that investments in agricultural TDT stack up well compared to alternative uses of funds. Since this finding may be contrary to the expectation of some participants in this symposium, it is worthwhile to consider in an African context the questions raised about non-African ROR studies.

Do ROR studies overestimate research benefits? Following criticism of earlier ROR studies, a deliberate effort has been made not to select only success stories for evaluation. For example, the seven countries (Cameroon, Kenya, Mali, Malawi, Niger, Uganda and Zambia) in which USAID has commissioned ROR studies were chosen on the basis of geographic location and similar criteria, none of which was expected success. In fact, after choosing the countries, it was expected that research impact would be at best marginal in Cameroon, Malawi, Niger and Uganda. The ROR in to cowpea Cameroon is positive (Sterns), and the positive projected ROR in Niger (Mazzucato) shows the potential for this research activity. While RORs for Malawi and Uganda are not yet available, preliminary indications for Malawi are that significant progress has been made in the past five years, with considerable potential for significant benefits over the next two to twenty years. Since the USAID project in Malawi was not expected to have a significant impact on maize production until 1995 (Project Paper), current developments are extremely positive. Uganda was not expected to be a success story due to recent periods of civil unrest, and the effect of unrest such as seen in Uganda clearly swamps any technology effects. Nonetheless, significant progress toward achieving impact has been made.

The regional work of Judd and Evenson, reported in the second day of the conference, includes all available expenditures. This captures failures as well as successes. Similarly to the non-African ROR studies, the positive impacts of research found at the regional level indicate that African RORs are not overestimated due to a bias in selecting only success stories for evaluation.

Table 1. Summary of ROR studies for African agricultural research.

AUTHOR(S)	YEAR	COUNTRY	COMMODITY	TIME PERIOD	ROR
			EX POST STUDIES		
Abidogun	1982	Nigeria	Cocoa	-	42
Makau	1984	Kenya	Wheat	1924-74	33
Evenson	1987	Africa	Maize & Staple Crops	1962-80	30-40
Karanja	1990	Kenya	Maize	1955-88	40-60
Mazzucato	1991	Kenya	Maize	/[1]	58-60
/[2]	1992	Niger	Cowpea, Millet & Sorghum	1975-91	< 0
Schwartz, Sterns & Oehmke	1992	Senegal	Cowpea	1981-86	33-92
Sterns	1992	Cameroon	Cowpea	1979-92	2
Boughton & Teme	1992	Mali	Maize	1969-91	135
			STUDIES USING CURRENT RESEARCH COSTS & PROJECTED BENEFITS		
Norgaard	1988	Africa	Cassava	1977-2003	149:1[2]
Ahmed & Sanders	1991	Sudan	Sorghum	1977-2013	22-39
Mazzucato	1992	Niger	Cowpea, Millet & Sorghum	1976-2010	7-21
Sterns	1992	Cameroon	Cowpea	1969-98	15

[1] Parameter estimation using 1955-1988 data, ROR for research undertaken in 1978 as an example.
[2] Benefit:Cost ratio.

Does the structure of African research institutions make a difference? Some of the disparity between the high and low ROR numbers presented in table 1 can be attributed to differences in

research (and extension) tradition. Mazzucato argues that the limited impacts to date found in Niger is due to the costs of building up a program whose benefits are expected to come in the future, and thus that the ROR number using projected benefits is the appropriate measure. Moreover, since the projected benefits are based on currently adopted techniques, any improved techniques developed and transferred before 2010 will increase the ROR. The modest value of the projected ROR is attributed in part to the low rainfall that persists throughout most of Niger, and the lack of varieties suitable for the Nigerien climatic conditions available from other national or international research organizations. In contrast, Boughton finds a high ROR to maize research in southern Mali, due in large part to the efforts of the cotton extension service, CMDT (cotton farmers also grow maize, mostly for subsistence). The extension service is a vertically integrated, well-funded and efficiently-operated parastatal, and can distribute maize seed and complementary inputs at low cost. Most of the agronomic recommendations examined by Boughton came from research and extension services in other West African countries, and IITA made important contributions of germplasm used in the variety. It appears as if the high ROR is attributable, at least in part, to these institutional arrangements. For example, extending the 1969 costs backwards to 1962 reduces the estimated ROR from 135 percent to 56 percent. This sensitivity analysis could be interpreted as accounting for some of the research start-up costs (author's interpretation).

How quickly can African agricultural research generate results? While available evidence is quite limited, it appears that the time lags in Africa are at least as long as those in other parts of the world. Conceptually, there is little reason to think that they would be different. Empirically, Choe and Oehmke find that the impacts of Kenyan maize research on yields continue for up to fifteen years from the date of the research (for an established program); this is somewhat longer than suggested by the institutional literature on the subject (c.f. Karanja, 1992). Moreover, the strength of the research tradition apparently is an important factor determining the impacts of research. For example, only a few years ago Kidd labeled Malawian research a failure. More recently, Smale has argued that the period of "failure" is in reality a period in which research programs were initialized and built, that such activities were successful, and that the payoffs to such activities are beginning to be realized and will be continued in the near future.

Relationships Among Research, Measured Impacts, and Agricultural Transformation.

After reviewing the literature on rates of return to agricultural research, the following generalizations about the relationships among research, measured impacts, and agricultural transformation emerge:

1. (Congruence Rule). The higher a commodity's value of production, the greater the returns to research on that commodity, ceteris paribus.

2. (Embodiment of Results). Many if not most research outputs are at least partially embodied in physical capital, inputs or outputs.

3. (Capital Availability). The impacts of agricultural research and technical change increase as the availability of physical, human and social capital increases.

4. (Vertical Diversity). Agricultural transformation is enhanced by research which induces technical change in commodity storage, processing and marketing.

The congruence rule is well known, and has gained wide acceptance since Ruttan's exposition. In the context of subsistence agriculture, this rule suggests that the major thrust of research should be toward staple commodities. However, it does not mean that other crops or animals should be neglected. For example, the studies by Schwartz *et al.* and Sterns and Bernsten suggest that modestly-funded, cowpea research programs can generate reasonable returns. An amendment to this rule might be to consider potential value rather than current value. This is consistent with the concept as presented by Ruttan, and will be taken up in more detail in conjunction with the fourth lesson.

The second lesson is corroborated by numerous examples of embodiment. Improved livestock breeds are adopted only after the farmer invests in a new animal, which is a capital investment. Hybrid and improved variety seeds are an example of research results which are embodied in physical inputs. Even agronomic recommendations may have an aspect of embodiment: for example, improvements in tillage techniques may require investments in plows or animals, each of which is a capital investment.

The third lesson follows in a straightforward manner from the second. If research outcomes are at least partially embodied, then farmers and others can take advantage of these outcomes only if they have access to the physical capital embodying the results. Empirical studies have confirmed the positive impact of farmers' human capital on farm productivity. Nor is it controversial to argue that increases in social capital, such as the establishment of rules facilitating transactions in agricultural commodities or legal resolutions of disputes, and enhance the adoption of improved techniques can generate a wider distribution of the benefits associated with these techniques.

The first three lessons apply in a straightforward manner to subsistence agriculture. Research designs which account for these three lessons are more likely to achieve success in easing the constraints faced by subsistence farmers. Some examples of impact on subsistence farming include: Operation Cowpea, Cowpea in Cameroon, Maize in Mali and possibly Malawi, Oilseeds in Uganda? However, research which is successful in alleviating the constraints faced by subsistence farmers may not contribute to agricultural transformation. An excellent example is maintenance research, which surmounts new problems arising in subsistence agriculture, and maintains productivity in the face of negative forces which, without the research, would have caused productivity to decline. Yet there may be no observable increase in productivity, no increase of product available in urban markets, and no release of labor to nonagricultural activities. Further discussion of this point is made in Elon Gilbert's contribution to this symposium. A second example is Operation Cowpea. This activity was designed to alleviate calorie deficits arising from drought-related problems, and was particularly successful at increasing food availability during the hungry season before the traditional harvest. This impact of this on farm families is clear. However, there was little effect on agricultural transformation: the program was designed for a specific need in the existing farming system and not to change the nature of farming as would happen in agricultural transformation.

Vertical diversification, the fourth relationship, presents a somewhat different perspective from that found in some research institutions. Post-harvest research can increased the quantity of agricultural product that moves through market channels, increasing farm incomes and providing food for the non-agricultural sector. Research focussed on pre-harvest techniques is an important contributor to improved welfare for farm households, and a prerequisite to stimulating agricultural transformation, but it may not be sufficient to sustain agricultural transformation For example, the cowpea research in Cameroon has helped subsistence farmers feed themselves during the hungry season immediately preceding the traditional harvest of long-cycle millet, sorghum or pulses. While this certainly has positive impacts on the farm household, it may do little to encourage agricultural transformation.

Part of transformation is the exchange of agricultural outputs for nonagricultural products. This exchange is eased by tailoring the agricultural products to the demands of on-agricultural consumers. Meeting these demands may require storage, processing, marketing or other post-harvest activities; each of these activities may require TDT to achieve the objective. Failure to meet consumer demands may limit the opportunities for marketing the agricultural product; this may limit adoption of improved on-farm techniques. For example, the unfavorable processing characteristics of dent maize and the absence of a strong cash market may have limited the adoption of dent hybrids in Malawi. In Cameroon, the extension service reduced its recommended area planted to cowpea by 50 percent because insects prevented storage of grain for sale on the cash market. In each case, TDT activities are addressing these post-harvest constraints. In Malawi, hybrid flint maize varieties with superior processing characteristics have been developed and released; in Cameroon, research activities are currently investigating improved storage techniques. These new activities represent a departure from the view that the primary concern is to increase yields or other aspects of farm productivity, to the broader view that TDT should increase both pre-harvest and post-harvest productivity.

WHAT HAPPENED TO THE AGRICULTURAL TRANSFORMATION?

The Focus Has Been on Smallholder and Subsistence Farming.

A primary concern of current and past TDT activities has been to improve the productive capacity and food security of smallholders and other subsistence farmers. Successful TDT may enable a region of smallholders to feed themselves better, but does not necessarily provide a market outlet for excess production. Without a market or comparable outlet, the region may remain primarily a subsistence farming region.

Research Fundings Is Small Relative to Expectations.

Few African countries spend more than 1 percent of gross agricultural product on research. Yet research and other TDT organizations are asked not just to keep food output growing at the same rate as population, but to outpace population growth and contribute to increasing per capita incomes. This means increasing the value of output at a rate of 5 to 7 percent per year. While increases in the labor force and other inputs contribute somewhat to the increase in

output, it may be that up to one-half of the desired growth is expected to come from technical progress. In other words, at current funding levels, research may have to generate RORs in excess of 200-300 percent to achieve the objectives which policy makers set forth. This is clearly an unrealistic expectation.

Complementary Physical, Human and Social Capital is Poor.

Modern agriculture is intensive in its use of physical capital. The human capital requirements of managing modern farms are also large. In contrast, few African farmers have ready access to the means of increasing their human capital. For example, the Kenyan resettlement programs established more equitable access by subsistence farmers to land that had once been used by large-scale commercial farmers for wheat production. However, the large-scale farmers had been required by law to attend Egerton agricultural college. No provision was made to encourage the new smallholders to attend Egerton, nor is it clear that the institution is designed to handle that number of students. Makanda suggest that the consequent decline in farmer human capital has contributed to the stagnation of wheat area and production.

The need for agricultural output markets has already been established. In addition, markets for inputs such as fertilizer and other chemicals, implements and equipment parts, and other agricultural inputs are important to continue increases in agricultural productivity. Enforceable contractual arrangements for inputs and outputs would encourage the use of such markets. Many African countries lack the necessary contracts: for example, it is often hard to enforce repayment of a loan or credit, particularly if the crop is poor.

CONCLUSIONS

TDT Has Had Quantifiable Impacts at the People Level.

This conclusion is clearly warranted from the African ROR studies, each of which finds evidence of increases in the welfare of farm households, attributable to TDT activities. These impacts are enhanced by their timing: development of short-cycle varieties often provides food during the hungry season before the traditional harvest period, improving the food security of the household. In addition, by lowering the costs of production, successful TDT activities can lower food prices, improving the food security of poor consumers who are net purchasers of food in the market.

The Magnitude of the Impacts is Large Enough to Justify the Investments Made.

A positive ROR which exceeds the costs of obtaining funds (as a percent of funds disbursed) suggests that the investment has been worthwhile. With two exceptions, the evaluations of benefits to date reveal RORs exceeding most measures of the costs of obtaining funds. For the two exceptions (Niger, Cameroon), the projected future benefits are sufficient to justify the past investments in the program.

TDT has had only modest effects in stimulating agricultural transformation. There are a few examples in which increases in agricultural productivity due to TDT occur concurrently with expanded use of input and output markets, with a reasonable indication that the productivity increase is a contributing factor to the expanded market use. Nonetheless, these examples cover limited geographic areas and limited numbers of people. There is little evidence that Africa is starting on a broad-based agricultural transformation.

Research diversification into postharvest areas could provide greater stimulus to agricultural transformation. Increases in agricultural productivity are prerequisite to agricultural transformation, but are not sufficient in themselves. The more successful examples of TDT are those in which farmer and consumer needs are addressed. The examples of innovations that looked promising at the farm level but failed to achieve impact are examples of innovations lacking in complementarity with existing input or output markets. When it is simply a case of missing markets, it is an open question whether the increase is agricultural productivity is sufficient to stimulate development of the needed markers, and the answer depends on a host of factors, including macroeconomic and agricultural policies, social infrastructure from contracting and resolving contract disputes, physical infrastructure, *etc.* When markets are available, noncomplementarity often takes the form of high-yielding varieties which have unfavorable post-harvest characteristics, such as poor storage of processing features.

Consequently, post-harvest research may be important in taking full advantage of improved pre-harvest techniques.

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ENDNOTES

1. 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 if this measure is available.

2. For example, the Akino-Hayami formula approximates the change in social surplus. For discussion of the relationships between measures of surplus individual welfare, see Schmitz et al. or Mishan.

3. These numbers indicate the studies identified in the Daniels et al. paper. There may be other published or unpublished studies which were not located by Daniels et al., and have not been identified in the research underlying the current paper.