

PART 4

Measuring and Improving Effectiveness

THE ROLE OF IMPACT ASSESSMENT IN EVALUATING AGRICULTURAL R&D

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Assessments of the impacts of agricultural research after the fact (that is, ex post) are conducted for many reasons. For example, results can be used to determine the effectiveness of previous investments, provide accountability, or justify future research. Several impact studies, many focusing on Africa, have assessed the impacts of national agricultural research system (NARS) programs and projects over time. Donors and governments want to measure the contribution of agricultural research to their own objectives and to compare that contribution with alternative investments.

To facilitate these comparisons, research evaluators need a clear understanding of donor objectives, including income gains to producers and consumers—termed “efficiency objective”—and other goals, such as reducing poverty, enhancing food security, or improving nutrition and health outcomes—all of which are termed “nonefficiency objectives.” To facilitate decisionmaking when allocating funds to agricultural research programs, impacts of agricultural research can be projected prior to research investments being made (that is, ex ante) and these alternative investment choices can be prioritized through structured impact assessment. Effective impact analysis linked to a robust monitoring and evaluation (M&E) system can instruct research managers about how and why certain investments have larger impacts than others; this information can then be used to improve the design of research programs (Chapter 12, this volume).

Evaluations of previous or projected research benefits entail costs, require skills in impact assessment, and necessitate attention to data collection and analysis. Confounding factors influence research benefits, and the outcomes and impacts of many types of research—especially those related to research-induced institutional change—are difficult to measure. The impact pathway leading from agricultural research investments to nonefficiency outcomes,

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such as poverty reduction or nutritional improvement, is long and winding. Analysts need a clear map of these pathways if they are to successfully account for confounding factors and identify causal linkages. Many models of research evaluation exist, including in-house and independent assessments, each of which has its own advantages and disadvantages. Research evaluation often focuses on quantifying impacts, usually across multiple dimensions; however, decisionmakers generally want to know why research succeeds or fails. Conventional agricultural research evaluation often falls short of providing this information. Despite these challenges, progress has been made in assessing the impacts of agricultural research in Africa.

The purpose of this chapter is to review experience with impact assessment of agricultural research in Africa south of the Sahara (SSA). The analysis emphasizes *ex post* assessment, but lessons for *ex ante* analysis and priority setting are also presented. Methods used to evaluate agricultural research are briefly described and critiqued. Thereafter, empirical evidence on the benefits of agricultural research in Africa is summarized and categorized by type of research. Finally, lessons are drawn for the role of impact assessment for agricultural research in Africa.

Measuring Impacts of Agricultural Research

Impact assessments of agricultural research must identify the appropriate counterfactual (what would have happened without the research), measure the effect(s) of the research intervention, and add up those effects over the target population. The counterfactual can be a moving target because multiple simultaneous and sequenced interventions occur over time. Some research-based technology or institutional interventions depend on relatively few complementary factors, but others will fail to be adopted without them. Observed outcomes may be caused primarily by nonresearch factors, and accounting for these factors is essential to establishing impact.

Various methods have been used to identify the effects of research, but how carefully those methods are applied can influence the credibility of *ex post* research evaluation studies. The time it takes to complete agricultural research and to diffuse its results differs by technology, commodity, and regulatory process, and the adoption time path must be carefully estimated to generate credible impact assessments (Box 11.1). Spillovers of technologies across countries further complicate the analysis (Chapter 14, this volume).

Assessments of agricultural research impacts are under increased scrutiny because policymakers demand increasingly convincing evidence of impact and

BOX 11.1 Three basic approaches to quantifying ex post agricultural research impacts

Three basic approaches have been used to quantify ex post impacts of agricultural research. One is to use secondary (usually time-series) data at the national level and assess the aggregate productivity effects of research using a production function, cost function, or profit function approach. Results may then be included in a benefit-cost analysis that assesses benefits to producers and consumers over time. The second method is to gather producer-level data and estimate rates of adoption and farm-level impacts to determine the micro-level effects of research interventions. These effects are then combined with market-level data and models to produce estimates of aggregated impacts on producers and consumers, which again are included in a benefit-cost analysis. The third approach is to use data from experimental trials to estimate impacts with and without the effects of the research. Such data are then used to construct budgets or are combined with adoption estimates and market-level data and models to calculate the aggregate effects on producers and consumers and rates of return to research investments in a cost-benefit analysis. The first two methods use econometric methods, whereas the third simply uses calculations.

Source: Authors.

accountability. From a methodological perspective, this pressure builds from two related threads. First, statistical methods for assessing treatment effects (that is, the first-level effects of a research intervention) using observational data have improved dramatically over time (Imbens and Wooldridge 2009), and general conditions for the identification of causal effects are now widely understood. Second, the revolution in behavioral economics and the now-widespread application of randomized controlled trials (RCTs) have led to credible estimates of causal effects of many development investments (Datta and Mullainathan 2012).

Advances in causal estimation mean that measures of agricultural research impacts need to compete with highly credible estimates from other realms. For example, the impacts of bed nets, deworming in schools, and other interventions are widely accepted in the health and education sectors. Agricultural research impacts need to be similarly credible. Impact assessment outside of agricultural research is moving beyond solely measuring economic impacts to identifying linkages along an impact pathway embedded in a “theory of change” (see, for example, the International Initiative for Impact Evaluation [3ie] website at www.3ieimpact.org/en and Chapter 12, this volume). As linkages along the chain of changes often

depend on behavioral responses, behavioral economics has a large role to play in these assessments. The theory of change approach changes the focus from pure impacts to how and why impacts occur.

A subtle shift has also occurred in the interest of policymakers beyond rates of return and estimated net present values of producer and consumer income change. Increased evidence of nonefficiency impacts (such as impacts on poverty and on the value of nutritional, environmental, and health benefits) is now needed. In response, the agricultural research evaluation community is developing improved methods for estimating nonefficiency impacts, but the challenge of establishing clear causality complicates their application.

Assessing the Counterfactual

When secondary, national-level data are used to estimate production, productivity, cost, or profit levels, establishing clear causal links between research investments and these outcomes is difficult. Aggregate estimates subsume the entire research impact pathway and provide no information about factors affecting the variability of returns to research. They can also fail to control for how unobservable variables affect both research expenditure and outcome variables, which likely leads to an upward bias in measuring the returns to research. This bias is compounded by rate of return computations, as noted below. In the African context, the quality of secondary data is also a constraining factor.

When producer-level data are used to calculate rates of adoption, levels of impact, or budgets, observed outcomes may be affected by nonrandomly assigned confounding factors that can bias the results. When observational survey data are used to measure the impacts of research-generated technologies, establishing the counterfactual is difficult because it is impossible to observe the same farmers as both adopters and nonadopters at the same time. Measurement of the causal effect of adoption on the outcome must include a credible counterfactual.

One means of including a credible counterfactual is through matching—identifying nonadopter(s) in the sample who have characteristics sufficiently similar to each adopter, and comparing the difference in outcomes between the adopter and the matched group of nonadopters. An alternative approach to eliminate bias is through a two-stage analysis using instrumental variables. In the first stage, the determinants of adoption are estimated, and in the second stage, the impacts of adoption on the outcome are estimated. These and other alternatives require different assumptions, but are used to purge the impact estimates of nonrandom selection bias. The external validity of measured effects depends on the credibility of the counterfactual and the strategy to identify the effect of interest.

With many nonresearch interventions, RCTs have been run to hold confounding factors constant and reduce the potential for selection bias. RCTs are less practical for measuring ex post impacts of agricultural research for many reasons, including the need to conduct the research in the fields of farmers who are willing to cooperate over multiple years. Agricultural research treatments are often complex, with multiple interventions made simultaneously or sequenced over several years. The impacts of technology adoption, such as changes in market prices, are often only evident over many years, and the long time lag between a variety's release and manifestation of its full impacts makes RCTs less suitable (Norton and Alwang 2012). Hence, approaches using observational data are more frequently used for assessing the impacts of agricultural research.

One of the few studies that has used RCTs to obtain estimated impacts of technology adoption was conducted by Duflo, Kremer, and Robinson (2008), who employed an RCT to examine the effects of fertilizer adoption in Kenya. The study examined a simple fertilizer technology, and the evaluation was very expensive. RCTs are potentially useful in agricultural research evaluation for assessing microlevel impacts of simple interventions that have been developed but not yet disseminated. However, they are less useful for other research evaluations because of

1. spillovers from the treated to the untreated group;
2. the difficulty in convincing subjects to participate and, if they do, keeping them in full compliance or in the trial at all;
3. ethical considerations, such as those associated with keeping a potentially valuable intervention away from part of the population during the trial;
4. their high cost once the diversity of the smallholder population of farm households is considered in combination with the complexity of some of the interventions;
5. the difficulty of running RCTs when multiple interventions are sequenced into the population during the assessment period; and
6. the need to set up the RCT before any participant households are selected, which can be a long time before micro-impacts can be assessed (Norton and Alwang 2012).

Some of these issues can be addressed by using pilot programs or phasing in an intervention, randomizing villages rather than individuals to

reduce spillovers, or randomly assigning subjects who receive an announcement or incentive to encourage participation (Duflo, Kremer, and Robinson 2008). However, the severity of the problems differs by type of intervention. The reality is that, given the complexity of and length of time required to develop agricultural research interventions, RCTs are of limited use for agricultural research evaluation. In most cases, use of observational data and non-RCT approaches is the only option for ex post research impact evaluation.

Another means of assessing the counterfactual is to combine estimates of technology adoption or dissemination with simple per-unit budgets using data generated from randomized experimental plots (as opposed to randomized farms or villages). This method uses various techniques to measure the technology spread, and assigns each adopting land unit a treatment effect that corresponds to the difference between the unit cost of production of the new technology and the unit cost of production of the control (usually representing standard farmer practices). The advantage of this approach is that it uses both experimental data from randomized trials and observational data on adoption to produce an upper-bound estimate of economic impacts of adoption. The main disadvantage is that the phenomenon of yield gaps between experimental trials and actual outcomes in farmers' fields is nearly universally recognized. The sizes of these gaps can be large, leading to a substantial upward bias.

Agricultural Market and General Equilibrium Effects

Whether RCTs or alternative approaches are used to control for the first-level counterfactual, results are often combined with market models, such as economic surplus models, to assess the aggregate level and distribution of economic benefits of research to producers and consumers, as output prices as well as production may change. The lower commodity price resulting from additional technology-induced production is a major reason why consumers are often the primary beneficiaries of agricultural research. These price effects are especially large for basic staples, which have inelastic demands. Agricultural productivity growth can also lead to general equilibrium effects in the rest of the economy, as the nonagricultural sector is stimulated by the lower food prices and labor markets are affected (Hareau et al. 2005). Relatively few impact studies on agricultural research in Africa have assessed the effects of specific research programs and technologies on labor markets and nonfarm growth, but in the aggregate the impacts can be substantial.

Discounting Agricultural Research Benefits over Time

Aggregate or market-level income (economic surplus) changes to producers and consumers resulting from agricultural research generally occur over several years. Therefore, the income changes can be discounted to account for the fact that income received sooner is worth more than income received later. Results are presented as internal rates of return (IRRs) to research expenditures or net present values (NPVs) (Box 11.2). IRRs should be considered only as rough approximations.

- First, IRRs may be based on projects and programs of various sizes. A high rate of return realized for a small research project may not carry over if the project is scaled up. Economists often use NPVs rather than rates of return to rank investments for that reason.
- Second, IRR calculations assume that returns can be reinvested over time at the calculated IRR (Alston et al. 2011; Rao, Hurley, and Pardey 2012). However, it may make more sense to assume that the returns can be reinvested in the future at the rate of return on alternative social investments. Rao, Hurley, and Pardey (2012) recalculate the rates of return to agricultural research for a large set of studies globally assuming the reinvestment rate is 3 percent. This modified IRR calculation reduces the average rate

BOX 11.2 Internal rate of return, net present value, and real social rate of return

Net present value (NPV) is the sum of discounted benefits and costs over time:

$$NPV = \sum_{t=0}^T \frac{(B_t - C_t)}{(1 + r)^t},$$

where B_t and C_t are benefits and costs in year t , r is the discount (interest) rate, and T is the time horizon. The internal rate of return (IRR) is the discount rate that reduces the NPV to zero:

$$\sum_{t=0}^T \frac{(B_t - C_t)}{(1 + IRR)^t} = 0$$

The IRR is a real rate of return (and does not include inflation). The real social rate of return includes the value of all (not just private) benefits and costs to society, including those resulting from health and environmental effects.

Source: Authors.

of return to agricultural research from 33 percent to 12 percent—still a decent return, but lower than the previous estimates.

- Third, IRRs can also be skewed upward when the benefits analysis focuses on a specific country and does not account for spill-ins of research knowledge from other sources (such as CGIAR). The resulting calculation of the return can be a legitimate estimate for the country in question, but would not apply to the world as a whole.

Perhaps in part because of the potential for bias, fewer studies over time have reported IRRs. Many of them estimate the NPV of agricultural research investments in which a real social rate of return of 3–5 percent is typically used to discount costs and benefits. NPV calculations still require proper accounting for research costs, and, when spill-ins of research knowledge occur, a careful effort must be made to attribute costs and benefits to specific research expenditures.

Looking Beyond Efficiency Benefits and Rates of Return

Agricultural research produces many types of technologies and institutional changes. The most common type of research to be evaluated in Africa is genetic improvement; however, other types of research such as pest management, conservation agriculture, and policy research have also been evaluated. Most of the assessments have focused on total income effects, but some have addressed poverty, nutritional, health, environmental, and other types of benefits.

When policymakers are interested in nonefficiency impacts, alternative and often complementary approaches are needed. Methods may include assessment of changes in poverty indexes (Moyo et al. 2007), calculations of changes in disability-adjusted life years (DALYs, a widely accepted measure of health outcomes) (Meenakshi et al. 2010; Nguema et al. 2011), and use of contingent valuation or choice experiments to place value on nonmarket benefits of improved technologies (Bonabona-Wabbi, Taylor, and Norton 2014; Vaiknoras, Norton, and Alwang 2015). In evaluating agricultural research benefits that are not productivity enhancing, the task of accurately and cost-effectively measuring what would have occurred without the research can be a challenge. Consequently there are fewer empirical results for these types of studies, although, as discussed below, the literature is growing.

Ex Ante Impact Assessment and Priority Setting

Ex post research impact assessment provides information that supports accountability in agricultural research, while ex ante assessment can support decisionmaking in program selection and funding. Structured priority-setting

methods that include economic evaluation may lead to better judgments and expose poor ones. While these methods are no substitute for the judgments of scientists and administrators, they provide a mechanism for considering scientific and economic data that would otherwise be difficult to use (Alston, Norton, and Pardey 1995). Few agricultural research systems in Africa use structured priority-setting methods on a regular basis, although several have used them on occasion. Methods range from simple scoring activities to economic surplus analyses and mathematical programming (Ceesay et al. 1989; Teri, Mugogo, and Norton 1990; KARI 1991; Mills 1998; Mutangadura and Norton 1999; Thornton et al. 2000; Diagne et al. 2009; Manyong, Sanogo, Alene 2009; Wood and Anderson 2009).

Most *ex ante* impact analyses of agricultural research do not involve a full priority-setting analysis and process for a research system. They involve assessments of specific research topics or themes to help decisionmakers choose from among a limited set of research options or decide whether to continue supporting particular lines of research. Some of these analyses involve formal cost-benefit analysis (Rudi et al. 2010), but most are published in reports rather than refereed journals (see, for example, Norton and Philips 2011). Unless there is a unique twist to a method, journals seldom publish speculation, which is essentially what *ex ante* analysis represents. In fact, few fully fledged priority-setting analyses are published, except as the occasional book chapter. The purpose of *ex ante* or priority-setting studies is not publication, but improved decisionmaking.

Impact Evaluations of Agricultural Research in Africa

Several papers have summarized the results of previous agricultural research evaluations, including results for Africa. For example, Alston et al. (2000a, 2000b) summarized the results of studies that calculated rates of return to agricultural research and were completed by 1997. They also conducted a meta-analysis of the rates of return, and examined various factors that influenced those returns.¹ One such factor is the level of aggregation, because the lower the level of aggregation of research programs, the higher the variance in rates of return. Most research projects yield a zero rate of

1 The authors compared rates of return for studies that differ by econometric versus noneconometric approach, by research focus, by time period, by *ex post* versus *ex ante* analysis, by average versus marginal rate of return calculations, by real versus nominal rate of return calculations, and by level of aggregation of the programs evaluated.

return, and the estimated benefit from an aggregate research program is the average of the benefits from many projects with zero benefits, some with modest gains, and a few with high (and in some cases astronomical) gains. Many agricultural research evaluation studies assess the benefits of specific projects or technologies. Those studies seldom list the unsuccessful projects; hence, the level of aggregation is a critical factor when comparing studies on rates of return.² The overall mean rate of return for all regions in the Alston et al. (2000b) study was 99 percent, which was skewed upward by a few studies with very high estimated returns, as their median return was 48 percent.

Alston et al. (2000b) included in their study a summary of results from 48 studies for Africa. Those studies provided 188 estimates of rates of return to agricultural research. The estimated rates of return ranged from -100 to 1,490 percent, with a mean rate of return of 49 percent and a median return of 34 percent, which are a little lower than the average returns for all regions but are still high. Evenson and Gollin (2003) reported a similar 37 percent median rate of return in studies that evaluated economic benefits to all types of agricultural research in Africa.

Since the late 1990s, several additional evaluations of agricultural research in Africa have been conducted, including some studies of the environmental, poverty, and nutritional benefits of research. Four significant review studies that report agricultural research benefits for Africa have been published. Evenson and Gollin (2003) summarized the benefits of crop genetic improvement not only in Africa, but also around the world. Maredia and Raitzer (2006) presented evidence of the benefits of research undertaken by CGIAR and NARS partners in SSA. Renkow and Byerlee (2010) examined the impacts of CGIAR research in Africa and other regions, with the benefits categorized by type of research, such as genetic improvement, pest management, natural resource management, and policy analysis. Walker and Alwang (2015) report on a major effort to examine the inputs (research infrastructure), outputs (variety releases), outcomes (diffusion), and impacts of crop varietal improvement research in Africa between 1998 and 2011. They also describe country-to-country spillovers in adoption that are so important for many SSA crops and analyze the role of international agricultural research centers in supporting SSA research.

2 For example, Alston et al. (2000b) averaged results from studies that reported returns from individual projects, but did not include the reported zero returns for many of the projects mentioned in the same studies, hence biasing upward the overall results.

Impacts of Varietal Development in Africa

Evenson and Gollin (2003) found 92 million hectares were planted with modern varieties in SSA in 1998, representing 23 percent of the area devoted to the 10 crops considered (wheat, maize, rice, sorghum, millet, barley, lentils, beans, cassava, and potatoes). More than 1,150 varietal releases were made between 1965 and 1998. They estimated that the total genetic improvement contribution to yield growth over the period was 0.28 percent per year, which was less than half of the rate of growth for developing countries as a whole. They found significant adoption of improved maize varieties and hybrids in SSA, with 36 percent of the maize area planted with modern varieties in West and Central Africa, and 52 percent in East and Southern Africa in the late 1990s. Alene et al. (2009) updated the numbers for West and Central Africa for 2005, and found 60 percent of the maize area planted with modern varieties at that time.

Walker and Alwang (2015) update the Evenson and Gollin (2003) study, focusing on agricultural research and its impacts in SSA. Their findings show significant variability by crop and by country, but overall the stock of improved varieties in SSA has increased and continues to increase over time. More than 1,400 varietal releases occurred in SSA between 1998 and 2011 for the 20 crops on which they report. Using a more consistent methodology and investigating diffusion for twice as many crops as Evenson and Gollin (2003), they estimate that, as of 2011, 35 percent of SSA cropland (more than 107 million hectares) is planted to improved varieties. Adoption rates range from a high of about 90 percent of planted area for soybeans to around 5 percent for bananas and field peas. The volume identifies crop-specific constraints to wide adoption (for instance, 40-year-old groundnut varieties are still widely planted in West Africa, and sorghum varieties based on *Paramecium caudatum* types cannot compete with the dominant Guinean materials prevalent in the region). Fuglie and Marder (2015) found that diffusion of these varieties accounted for an overall average productivity gain on adopting areas of about 47 percent, and contributed to about 15 percent of the growth in food crop production in SSA between 1980 and 2010. By 2010, the higher productivity of improved food crop varieties had added US\$6.2 billion to the yearly value of agricultural production in SSA.³

Many evaluations are part ex post and part ex ante in the sense that the research has been completed, and the varieties have begun to be, but have

3 All currency is in US dollars, unless specifically noted otherwise.

not yet fully been, adopted. Therefore, the person doing the analysis uses both ex post data and ex ante adoption projections. For example, Kalyebara et al. (2008) estimated that improved common bean varieties (*Phaseolus vulgaris*) were adopted on about half of the total bean area in East, Central, and Southern Africa over 17 years beginning in 1986, but they project benefits out to 2015. The benefits from this combination of ex post and ex ante analysis were estimated at \$200 million (in 1986 dollars) on a research investment of \$16 million.

Maredia and Raitzer (2006) reviewed impact studies of agricultural research on SSA in which CGIAR centers played a role. They found 52 studies, of which 34 involved improved crop varieties; of these, 16 studies assessed the benefits of the research at an aggregate level. Using only data from the most rigorous studies, they conducted a meta-analysis of the economic benefits of crop genetic improvement in eight crops (beans, cassava, maize, millet, potato, rice, sorghum, and wheat) and conservatively estimated \$2.4 billion in economic benefits from 1978 to 2004 (in 2004 dollars).

Rusike et al. (2010) employed a combination of methods, including difference in differences, propensity score matching, and Heckman's treatment effects model, to assess the impacts of cassava research for development in Malawi. The normal selection bias associated with who adopted improved cassava varieties was compounded by issues of distinguishing the effects of relative price changes in cassava versus maize resulting from the country's structural adjustment program; the collapse of input, credit, and maize markets; changes in labor markets resulting from HIV/AIDS; and other factors. Assessing the impacts of agricultural research on development involves consideration of the whole innovation system with its input and output markets, extension service, farmers' organizations, and other groups in the value chain, in addition to the normal experimental work on improved planting materials. It involves careful attention to the pathways through which research eventually leads to impacts on development outcomes.

Rusike et al. (2010) tested hypotheses related to the effects of research on yields and on area planted with cassava, as well as market and institutional restrictions on scaling up the supply of cassava. They estimated the impacts of cassava research on caloric intake and food security, and evaluated the number of additional months that households were able to meet minimum caloric requirements from home-produced cassava and maize staples. The average treatment effect was about eight months or a 66 percent increase in months meeting the minimum. They found that, by 1995, yearly yields in the mostly cassava-growing and -consuming districts first exposed to the program were

about 23 percent higher than they would have been in the absence of the program. Controlling for other observable factors, they found that the productivity of the area cropped to cassava was about 14 percent higher in those districts.

Recognizing that policymakers increasingly demand information on distributional impacts, a few studies have examined the impacts of crop genetic improvement on poverty reduction (Moyo et al. 2007; Alene et al. 2009; Larochelle et al. 2015; Zeng et al. 2015). Moyo et al. (2007) evaluated the total economic benefits of rosette virus-resistant peanut varieties developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in partnership with NARS and US universities, and then apportioned those benefits to poor people in Uganda based on the production and consumption of peanuts. Total benefits of \$34–\$62 million (in 2000 dollars) were estimated, and the poverty headcount index decreased by 0.5–1.0 percentage points in the study area under most assumptions. Alene et al. (2009) found a poverty reduction of 0.1 percent in 1981 to more than 1.26 percentage points in 2004 for improved maize varieties in West and Central Africa, with an average poverty reduction of 0.75 percentage points. This last figure represents an average of 740,000 people lifted out of poverty each year. The impacts were greatest in Benin, Ghana, and Nigeria, where maize accounted for more than 10 percent of total agricultural production.

Zeng et al. (2015) assessed the yield, income, and poverty impacts of improved maize varieties in Ethiopia developed jointly by the International Maize and Wheat Improvement Center and the Ethiopian NARS. Because maize varieties are often adopted on some, but not all, plots on individual farms, they used plot-level rather than household farm-level estimates of varietal adoption, and allowed for heterogeneity in treatment effects in terms of yield gains across plots and farm households. The authors used an instrumental variables approach as the main identification strategy, and applied a backward derivation procedure in an economic surplus framework to identify the counterfactual price level from which the counterfactual income distribution was estimated. The authors assessed treatment effects, and computed poverty impacts as the differences between the observed and the counterfactual income distributions. They found that 42 percent of the producers were full adopters, 14 percent were partial adopters, and the rest were nonadopters. Adopting improved maize varieties in Ethiopia resulted in a 1.0–1.5 percent decrease in the overall poverty headcount ratio. A 2.4–2.6 percent decrease in the poverty depth index, and a 2.7–3.1 percent decrease in the poverty severity index (using the \$1.25 a day poverty line).

Larochelle et al. (2015) examined the impacts of improved bean varieties on poverty and food security in Rwanda and Uganda. They conducted a treatment effect, economic surplus, and poverty analysis similar to that conducted by Zeng et al. (2015). Poverty in 2011 would have been about 0.4 and 0.1 percentage points higher in Rwanda and Uganda, respectively, in the absence of varietal improvement. A measure of household dietary diversity was developed to examine the effects of the improved bean varieties on food security among rural households. Food insecurity would have been substantially higher in Rwanda without the introduction of improved bean varieties, and noticeable impacts were also found in Uganda.

Limited work has been devoted to assessing the effects of varietal improvement on reducing yield variability, even as agricultural researchers have placed increased importance on innovations to reduce this variability. Yield stability is important to farmers, whose food security and livelihoods depend on it. Research that builds in resistance to insects and diseases, drought, or salinity can be especially helpful to poor farmers. While research could increase yield risk, especially if the genetic base is narrowed, evidence suggests that risk has decreased over time, as resistance to stresses has been built into improved varieties, at least for maize and wheat (Gollin 2006).

Additional evaluation of the benefits of yield stability is needed and will likely be forthcoming as adaptation to climate change increases in importance. Methods for economic evaluation of research that reduces yield variance have been developed and applied in *ex ante* analysis for drought-tolerant crop varieties in East and Central Africa (Kostandini, Mills, and Mykerezi 2011), but the methods have not been applied in *ex post* analysis. Part of the difficulty is that vulnerability measurement generally requires panel data, but panel studies of adequate size to make inferences to populations are extremely costly.

Several recent studies have assessed the nutritional benefits of consumption of biofortified crops (Low et al. 2007; Meenakshi et al. 2007, 2010; Gunaratna et al. 2010; Nguema et al. 2011). The challenge from an impact assessment perspective is to establish a causal link along an extended impact pathway from research on biofortification, through household-level adoption and subsequent impacts on productivity, income, and consumption. While strong evidence exists that increased consumption of micronutrients helps improve nutritional status, this linkage is only the end of a long causal pathway. As a result, few *ex post* studies exist to convincingly link research on biofortification to nutritional outcomes.

The HarvestPlus project has produced several studies, some of which evaluated the potential impacts of biofortification with provitamin A, iron,

and zinc for several staple crops in Africa (for example, Meenakshi et al. 2010). Many of these studies are ex ante assessments and calculate DALYs. For example, Meenakshi et al. (2010) projected the benefits of vitamin A-enhanced cassava in the Democratic Republic of the Congo and in Nigeria, maize in Ethiopia and Kenya, and sweet potatoes in Uganda. Nguema et al. (2011) projected the benefits of vitamin A- and iron-enhanced cassava in Nigeria and Kenya using a DALY approach and economic surplus analysis.

One useful feature of the DALY approach is that it facilitates analysis of cost-effectiveness, because improved varieties can be compared with other interventions, such as fortification and supplementation. A meta-analysis of nine studies of the benefits to malnourished children of quality protein maize found an average rate of height gain of 9 percent and an average weight gain of 12 percent (Gunaratna et al. 2010). Low et al. (2007) conducted an experiment with 850 households in Mozambique and reported a significant increase in vitamin A intake among young children who consumed orange-fleshed sweet potatoes. Microlevel assessments of nutritional benefits are necessary, but are not sufficient to establish a causal link between particular kinds of agricultural research and nutrition gains. There is clear need to broaden the analysis to the entire impact pathway.

Impacts of Pest Management Research in Africa

Two types of pest management research have been subject to economic impact assessment: classical biological control (CBC) and integrated pest management (IPM). CBC involves controlling a pest in its new environment by introducing a natural enemy from its original geographical environment. The most famous case of CBC was the introduction of a parasitic wasp (*Apoanagyrus lopezi*) into Africa from Paraguay to control the cassava mealybug (*Phenacoccus manihoti*) in more than two-dozen countries. Zeddies et al. (2001) estimated at least \$9 billion in benefits (in 1994 dollars) for 27 countries discounted over 40 years. Coulibaly et al. (2004) estimated significant economic benefits to CBC for cassava green mites, mango mealybug, and water hyacinth. In fact, CBC has produced the largest economic benefits that have been measured ex post for agricultural research in Africa. The methods used to evaluate those benefits were simple cost-benefit analyses, but the results are credible because the pest-related losses and pesticide costs were easy to measure, and farm-level savings could be aggregated across all the farms whose exposure was eliminated by CBC. Because the parasitic wasps naturally multiply and require no active intervention by farmers, the issue of adoption measurement for this single-component technology was relatively simple.

Assessing the impacts of IPM is more difficult. Indeed, IPM is a package of technologies that includes components (such as improved varieties with insect and disease resistance, CBCs, and other types of biological control) and management practices (such as altered timing for planting, grafting on resistant rootstocks, use of pheromone traps, and reduced toxicity pesticides when pesticides are required). A specific IPM research program may include only a portion of these and other component technologies. Impact assessment in the context of IPM will help identify components and packages with the most potential for scaling up. It may also be used by research managers to identify fruitful lines of future IPM research or to help decide between investments in IPM research and other alternatives.

Several IPM evaluations in the past have evaluated farmer field schools (FFSs), which involve training programs for groups of around 25 farmers that take them through the whole crop season with weekly meetings. However, FFS is primarily a training program and not an agricultural research program, even though farmers do test some things on their own. Evidence is now clear that at a cost of \$20–\$60 per participant, FFS is a relatively expensive way to train large numbers of farmers, even if those who participate benefit economically (Feder, Murgai, and Quizon 2004; Ricker-Gilbert et al. 2008). The key to broader benefits from FFS is farmer-to-farmer spread—which should occur as FFS-trained farmers interact with their friends and neighbors—but there is little convincing evidence of this spread.

Economic evaluations of IPM research programs have found significant and large benefits in many countries around the world, but relatively few ex post impact studies have been conducted in Africa, except for individual component technologies, such as CBC for cassava mealybug (Zeddies et al. 2001); disease-resistant varieties, such as for rosette virus on groundnuts (Moyo et al. 2007); and a host-free period for virus control in tomatoes (Nouhoheflin 2010). Evaluations that have been conducted are part ex post and part ex ante studies using economic surplus analysis (for example, Debass 2001).

Impacts of Natural Resource Management and Other Types of Research

Relatively few assessments have been conducted of the benefits of natural resource management (NRM) research related to agriculture in Africa or in other developing countries. Most NRM research in agriculture has focused on managing pests while minimizing pesticide use, reducing erosion, sequestering carbon in the soil, and conserving water. Examples include impact assessments of conservation agriculture (Nkala, Mango, and Zikhali 2011), zero

tillage (Dalton, Yahaya, and Nabb 2014), and tree fallow (Ajayi et al. 2007) to reduce erosion, sequester carbon, and conserve water. Ajayi et al. (2007) estimated an NPV of \$2–\$20 million, with an IRR of 3–20 percent for tree fallow in maize in Zambia. Dalton, Yahaya, and Nabb (2014) estimated a 35 percent increase in net returns for no-till compared with conventional tillage in Nyoli, Ghana. And Nkala, Mango, and Zilhali (2011) assessed the impacts of conservation agriculture on productivity, household incomes, and food security in Mozambique. Farmers who used conservation agriculture were 53 percent more likely to experience an increase in productivity, but impacts on income and food security were not significantly different for those who used conservation agriculture and those who did not.

Most of these studies have measured the benefits of the technologies in terms of their contributions to income through agricultural productivity gains rather than environmental improvement, and most of the measured benefits occur on relatively small acreages. Part of the difficulty in assessing environmental benefits is that they are not priced in the market. Such methods as contingent valuation and choice experiments suffer from potential problems with hypothetical bias and limited geographical applicability. Choice experiments have recently grown in popularity in developing countries, including examples in Africa, and the method holds potential for future ex post evaluations (Bennett and Birol 2010). Other difficulties in assessing benefits of NRM are that biophysical measurement is difficult and costly, the environment is multifaceted, and many benefits occur at higher scales than plots or farms. Simulation modeling is one approach for addressing some of these issues.

Other types of agricultural research, such as policy analysis, have been evaluated as well, but relatively few of these studies have quantitatively estimated economic benefits, especially in Africa. Valuing policy research involves valuing information, and it is difficult to apportion credit for a policy change and to assess the counterfactual.

Benefits of Private Agricultural Research

Few studies measure the impacts of private agricultural research in Africa. Several studies do assess farm-level profit or the risk effects of specific technologies, such as seed and fertilizer generated and sold by private firms (for example, Regier, Dalton, and Williams 2012); however, no parallel set of published analyses calculates rates of return to research by private firms. Pray, Gisselquist, and Nagarajan (2011) report almost 1,300 cultivars registered from private firms in Kenya, Senegal, South Africa, Tanzania, and Zambia, with more than 100 of them in South Africa. They also report more than

\$62 million (in 2008 dollars) spent on agricultural research in those countries, with more than \$50 million spent in South Africa alone. Regier, Dalton, and Williams (2012) report data on increased yields and profits, and on reduced pesticide use associated with adoption of genetically modified crops in Burkino Faso and South Africa; however, they do not report on returns to research for the private firms that conducted the research. Nevertheless, it is clear that private investments in agricultural research for Africa have increased in recent years, and those investments are likely to have yielded social as well as private returns, particularly in South Africa.

Lessons for Evaluating the Impacts of Agricultural Research in Africa

The Need for Ex Post Evaluation

A body of evidence is developing on the benefits of agricultural research in Africa, despite the complexity and heterogeneity of its rainfed, smallholder agriculture. The evaluation studies usually rely on observational data, and increasingly employ improved techniques to identify causal linkages between research investments and their impacts. The critical challenge in such cases is to find a plausible strategy to identify the impact of adoption on observed changes at the field and household levels across a diverse agroecological and social landscape.

The best studies carefully evaluate their identification strategy and test its underlying assumptions. The adoption–impact relationship generally involves unobservable factors that estimation strategies must account for. Identifying the treatment effects requires a clear map of the impact pathway, which itself depends on the underlying theory of change. Investigating linkages along the pathway will expand the value of such assessments and help research managers understand why certain programs work, while others do not. This investigation may involve expanding the tools used for impact assessment; for example, RCTs can be used to evaluate alternative dissemination and education practices, even if they are less useful for evaluating agricultural research itself.

Nevertheless, most studies of the impacts of agricultural research are still at least partly *ex ante* because of a relative dearth of *ex post* evidence for many crops, types of livestock, countries, and types of research. Evidence of the impacts of agricultural research programs aimed at environmental, health, nutrition, and poverty objectives is scarce, despite the significant and

increasing investments in these types of programs. Future funding for agricultural research will depend on filling the gap between the demand for and the supply of these types of evaluation studies. It is not necessary to evaluate all research projects, because evaluation costs money; however, impact assessment for a representative sample of research projects and improved technologies can demonstrate the return on investment, so as to maintain the flow of research resources. Evaluating a sample of various types of projects can also provide evidence about relative payoffs.

Methodological difficulties in measuring the benefits of certain types of research, such as NRM and policy studies, should not necessarily be taken as evidence that those areas are poor investments. Instead, they should stimulate research to overcome those difficulties, both for investigators and for data providers—such as the Agricultural Science and Technology Indicators initiative of the International Food Policy Research Institute—that can document the size of the research investments across topical areas.

Trade-offs between Cost and Credibility

The cost of conducting impact assessments of agricultural research differs substantially, depending on such factors as the depth and credibility of the analyses, the complexity of the interventions, the nature of the farming systems, the types of impacts assessed, and whether the evaluation is conducted *ex ante* or *ex post*. The least costly impact assessments (a few thousand dollars) are *ex ante* evaluations that (1) gather secondary price and quantity data on the commodities involved for a single geographic area, and (2) obtain expert opinions of costs, yield changes, and expected rates and timing of adoption of the technologies. Simple spreadsheets can be used to assess the market-level benefits and costs and to generate NPVs or IRRs for the research. Geographic price and technology spillovers can be included for a relatively small additional cost. The level of precision can be improved (at additional cost) if on-farm cost and return data are gathered in experiments with the new technologies as a substitute for expert opinions.

Once the interventions are completed (for example, the varieties are released), expert opinion on adoption can be replaced with expert panel elicitation or data from farm-household surveys. These surveys can be conducted once or over several years (with accompanying differences in costs). Developing a sample frame for such surveys is complicated, because a true measure of adoption should include evidence from all areas where adoption may have occurred. The research needs to begin with information about the geography of the potential spread of the technology.

The impact studies in Walker and Alwang (2015) used similar methodologies to generate samples representative of specific crop production in specific countries. That study's diffusion estimates were largely based on expert panels convened in each country; diffusion estimates from expert panels sometimes match the estimates from representative household surveys very well, but do not match well in others (Walker and Alwang 2015). The smaller and more diverse the farms and research interventions, the higher the associated costs of tracking diffusion will be (Alwang 2015). Tracing the impacts through a value chain and into factor and product markets adds additional costs, as does incorporating risk with respect to model parameters. Conducting an RCT may add little to substantial costs (thousands to millions of dollars), depending on the complexity of the technologies, the diversity of the agroecological and social environments, and the stage of the research. For many types of social science or NRM research, data-intensive simulation models or other approaches that do not involve farm-household-level surveys may be useful.

The question is often asked, what will be the cost to conduct an impact assessment of agricultural research in a specific country or region of SSA? The answer is that it depends on the breadth of the questions (for example, the types of impacts and interventions), and how much precision is desired. A recent tendency in the development literature is to improve precision in impact assessments by targeting narrow interventions that lend themselves to RCTs (often at a cost that exceeds \$1 million). Few agricultural research interventions are simple or narrow; agricultural research evaluation budgets are typically small; and, for these and other reasons described above, few of the interventions have been evaluated with RCTs.

Impact evaluations of research targeting environmental improvement or policy change can involve valuing information that has direct effects off-farm. Even if such evaluations can be undertaken by NARS, the costs can be substantial.

The Importance of Multidisciplinary Interactions

Many impact evaluations of agricultural research require a basic understanding of the research itself, together with data on yields, input costs, and other factors. One way to acquire that understanding is to conduct multidisciplinary research that includes an impact assessment evaluator as part of the research team. Certain types of evaluation tools, such as RCTs, can be applied only if the research being evaluated is designed with impact evaluation in mind from the start. The lack of involvement early in the research process is

one reason why there are so few impact evaluations. Therefore, embedding evaluators into agricultural research teams can be useful.

Using the Results of Impact Assessments

Impact assessments are useful not only for justifying research investments, but also for designing a research portfolio around the highest payoff activities. However, the difficulty in measuring the benefits of some types of agricultural research implies a need for caution. Funding agencies may be tempted to fund only activities with measurable impacts and, in the process, may skew the research program toward easily quantifiable, as opposed to high-payoff, research. Some of the highest-payoff research activities can be risky, with outcomes that are difficult to measure. In addition, many donors are interested in nonefficiency objectives, and measuring the trade-off between aggregate efficiency impacts and other impacts can represent an obstacle.

Ex Ante Impact Assessment and Priority Setting

Several lessons emerge from ex ante/priority-setting studies, including those completed in Africa.

- First, scoring is the method most commonly used for structured research priority setting, but it is also the easiest to abuse. It is popular because it facilitates a process in which stakeholders are involved in discussions and in weighting and ranking programs. Scoring is easy to abuse because, unless careful attention is devoted to defining research-system objectives, measuring impacts against those objectives, and deciding whose weights count, the results can be an odd ranking based on weighting apples against oranges.
- Second, the impacts of some types of research (such as policy research) on some objectives (such as environmental objectives) are inherently more difficult to measure than others, and yet must be, if all programs are to be compared.
- Third, ex ante impact assessment of major programs is useful, but structured priority-setting analysis can be costly and may best be reserved for strategic planning, possibly every five years. Mutangadura and Norton (1999) is a good example of a study that would be difficult to duplicate every year, because it involved hundreds of impact assessments for multiple commodities, types of research, regions, and farm types. Nevertheless, such studies can be very useful for periodic decisionmaking.

- Fourth, the presence of both geographical spillovers in agricultural research and regional research programs means that donor priorities often need to be set at levels higher than for a specific country, and regional priorities must be reconciled with country-level priorities.
- Fifth, priority setting requires specific economic analysis skills, which must be institutionalized or purchased when a study is conducted. Priority setting at CGIAR centers often draws on internal capacity for analysis, but country-level studies often involve outside consultants when major priority-setting analyses are completed. Internal *ex ante* and *ex post* impact assessment capacity needs improvement in many research systems.

Where feasible, a useful mechanism for setting agricultural priorities is to project the NPV of research benefits by program, making use of economic surplus and geographic information system (GIS) tools. In some cases, trade-offs in meeting efficiency versus nonefficiency objectives can be assessed in this framework. However, the increased emphasis over time on project-specific as opposed to program-core funding has reduced the use of this approach for priority setting, although the techniques are still useful for market-level economic evaluations of some projects. Projecting impact pathways for technologies and policy changes is useful in almost all cases. For programs and objectives for which economic surplus is difficult to measure, alternative measures—even if in physical terms—can be used, and then the economic value sacrificed can be projected for programs that shrink when others expand.

Building Capacity for Impact Assessment

Impact assessment requires economic evaluation skills, an ability for evaluators to work jointly with biological scientists and understand the basics of the research being evaluated, financial resources for the evaluations, and a solid plan for collecting and managing data. Many evaluations in NARS and in international agricultural research centers fail on the last point. Few systems systematically collect and store the necessary data for either *ex ante* or *ex post* analysis. The first step in a workable data system is to maintain a close working relationship between the evaluators and other scientists, so that the appropriate data are properly collected.

Conclusion

The number of *ex post* impact assessments of agricultural research has grown over time. In addition to economic gains from productivity growth, the types

of benefits being assessed have broadened in the past decade to include nutritional improvement, poverty reduction, and NRM. Estimated returns to agricultural research in Africa—often in the range of 20–40 percent for rates of return, or 8–18 percent if calculated with a modified IRR formula—suggest that research is a high-payoff development intervention, even if the total number of evaluations is relatively small. Many research benefits accrue to consumers as a result of the (lower) output price effects associated with the additional production that results from the new technologies. Increasing evidence is also confirming the substantial poverty-reducing and nutritional benefits of agricultural research.

Pressure is building to improve the credibility of agricultural research evaluations to provide solid evidence of the effectiveness of alternative investments (such as in health and education). As a result, increased attention has been devoted over time in research evaluations to identifying a causal relationship between agricultural research and outcomes. With observational data, this identification relies on statistical techniques, often with untestable underlying assumptions. As a result, a relatively small percentage of all agricultural research programs has been subjected to rigorous economic impact evaluation. Evaluation methods that are popular for other types of interventions, such as RCTs, hold less promise for agricultural research because of the complexity and simultaneous nature of many research interventions, the lag lengths involved with agricultural research, and the need to conduct on-farm testing on the plots of willing (and, hence, nonrandom) farmers. Nevertheless, once new agricultural practices are in the diffusion process, they may be amenable to RCTs.

Because of the continual need for impact evaluations, agricultural research institutions may employ in-house evaluation experts. Such experts may be involved at all stages of the research process, or they may conduct evaluations when the need arises without prior involvement in the research. Use of such experts can increase the odds that the evaluators will understand the research being evaluated, may improve the quality of the data collected by the research system, and may facilitate midstream adjustments to a research project when the need arises. However, in-house experts also may become captive to the interests of the scientists or administrators—or at least it may appear that way—reducing the credibility of the impact analysis. While the use of outside experts can reduce this problem, it may be at the expense of a full understanding of the research or the possibility of timely midstream redirection. A combination of both internal and external impact evaluation may be the solution for some programs.

Ex ante economic evaluations of component technologies are as common as or more common than ex post evaluations; however, few of them are used for systemwide research priority setting. Priority-setting exercises can be expensive for agricultural research systems, in terms of both time and money; hence, they are most useful for strategic planning every few years. Economic surplus analysis, GIS, and trade-off analysis are perhaps the preferred methods for such priority setting.

Many, if not most, evaluations of agricultural research and development do not include quantitative impact assessment. Instead, they involve qualitative evaluations of program impacts or assessments of whether research programs accomplish their objectives. As assessment methods improve, and as funding sources demand more quantitative evidence of impact, the number and quality of impact assessments of agricultural research are likely to increase.

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