Journal of Agricultural and Applied Economics (2022), **54**, 461–479
doi:10.1017/aae.2022.18

RESEARCH ARTICLE

Costs, Benefits, and Welfare Implications of USAID Investment in Agricultural Research through U.S. Universities

Timothy J. Dalton[1]* and Keith Fuglie[2]

[1]Department of Agricultural Economics, Kansas State University, Manhattan, KS, USA and [2]Economic Research Service, United States Department of Agriculture, Washington, DC, USA
*Corresponding author. Email: tdalton@k-state.edu

Abstract
The U.S. Agency for International Development has invested limited funds in international agricultural research through U.S. universities. We present a meta-analysis of impact case studies from this investment. The median net present value of economic impacts at purchasing power parity is PPP$8.4 billion compared to a cumulative investment of US$1.24 billion over 1978–2018. About four-fifths of these economic benefits accrued to individuals with incomes under $5.50/day and about 29% to those in extreme poverty. In addition to these limited case studies evaluating financial benefits and costs, we present several types of additional non-economic benefits.

Keywords: agriculture; development; international; investment; research

JEL classifications: O1; O3; Q1

Introduction

Over the past five decades, the government of the United States, through the U.S. Agency for International Development (USAID), has invested limited funds in international agricultural research to enhance global food security. Some funds have been invested in the Consultative Group on International Agricultural Research. Other funds have been used to link researchers in the U.S. university community, the Department of Agriculture, and the private sector with counterparts in low- and middle-income nations with an aim to increase food system performance by improving crop, livestock, fisheries, and natural resource productivity. One of the most important vehicles for USAID's international efforts has been the Collaborative Research Support Program (CRSP) which originated in 1978 and rebranded in 2012 as the Feed the Future Innovation Labs (FtFIL).

Investment in agricultural research, and the development of novel innovations, is widely acknowledged as an important strategy to promote food security and economic development in low-income countries. Technological innovation increases agricultural productivity, enhances resilience of local food supply, and stimulates production of greater surpluses thereby freeing labor, capital, and additional resources for usage in other areas of the economy (Hayami and Ruttan, 1985; Mellor, 2017). However, the path from research investment to innovation and impact is not always successful. Scientific inquiry can lead to a dead end, or novel innovations are not always adopted because of behavioral, economic, or resource barriers. These challenges and barriers make investment in agricultural research risky. Nor, even when successful, are all research investments likely to have similar levels of economic or poverty impact. This will depend on their nature, scale of diffusion, and who adopts them.

Increasingly, research managers, donors (and their constituents), and scientists are demanding evidence of the value of investment in agricultural research in order to evaluate funding allocation decisions. Previous studies have found large variation in returns among specific research projects, although returns have been high on average. Alston et al. (2002) reviewed the benefits and costs of agricultural research from 289 studies from around the world and found an average internal rate of return of 54% per year. A more recent review of 492 studies (Rao, Hurley, and Pardey, 2019) found that agricultural research has earned similar average rates of return in developing and developed countries, and average returns have remained high over time. Even in relatively austere agro-ecological environments, returns to agricultural research have often been high. Zereyesus and Dalton (2017) estimated an annual rate of return between 54–76% on a narrower set of innovations targeting sorghum and millet in semi-arid areas of the world. As far as USAID's investment in the CRSP and FtFIL system, there have been a few studies that have evaluated the impacts of individual projects, and recently, Glauber, Kraybill, and Mercier (2019) reviewed evidence on how these projects may sometimes produce reciprocal economic benefits for the United States. However, there has been no review of the documented returns and economic impact of USAID investment in the CRSP and FtFIL system in developing countries. The purpose of this study is to contribute to filling this void.

While the CRSP and FtFIL programs have existed for more than 40 years, evidence on the impact of these investments on global agricultural development is lacking. The program continues to pursue multiple objectives that include human and institutional development, technological innovation, public policy support, nutritional improvement, and natural resource management, among others (USAID, 2012). Focal areas and programmatic content have changed over time. As such, evaluation of the program presents several challenges. We approach this challenge by conducting a meta-analysis of published impact studies conducted by various programs and innovation labs. As such, this is not a comprehensive evaluation of all research and development activities conducted throughout the history of CRSP and FtFIL. It is opportunistic and relies upon the past initiatives of programs to document their activities, outputs, and impacts. This meta-analysis is compared against historical investment patterns in CRSP and FtFIL to suggest that despite having a limited number of studies that evaluated impacts from past R&D projects (certainly not a comprehensive perspective), these studies document societal benefits that are 5.2–8.5 times greater than the total investment by USAID over the life of these programs. Moreover, it is highly likely that most of these impacts led directly to higher incomes and less poverty among households at the lowest end of the income strata.

Background on U.S. Investment through the CRSPs and Innovation Labs

The CRSP was authorized by a Congressional Amendment to the Foreign Service Act in 1975 and formally launched in 1977. The program, created under Title XII of the Act, provided the primary vehicle for university linkages with foreign collaborators in agricultural, nutritional, and natural resource management research. The primary objectives of the Congressional authorization, again renewed in 2000, sought to "achieve the mutual goals among nations of ensuring food security, human health, agricultural growth, trade expansion, and the wise use of natural resources" through the mobilization of "the capacities of the United States land-grant universities, other eligible universities, and public and private partners in the United States and other countries" (22 U.S.C 2220). Foundational to the Act was the emphasis on multiple objectives of research, teaching, and extension, common with the 1862 Morrill Act establishing the land-grant university system (22 U.S.C. 2220a Section 297 of Public Law 94-161). More recently, in 2016, the Global

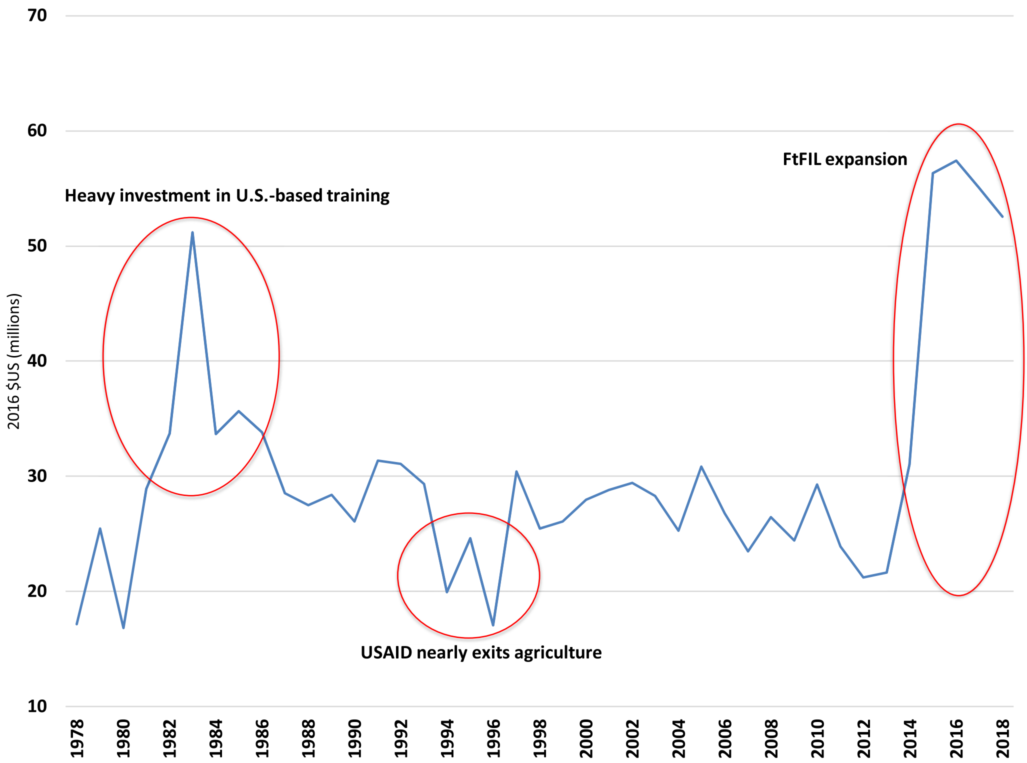

Figure 1. CRSP and Innovation Lab investment from 1978–2018 (US$ 2016).

Food Security Act was signed into law with bipartisan support thereby reaffirming Federal government's commitment to international agricultural research and development consistent with the original mandate. This Act was reauthorized into law in 2018 for an additional 5 years (PL 114-195).

Annual funding allocations since 1978 to the CRSP program and Innovation Labs, in constant 2016 dollars, are presented in Figure 1. The annual investment in research and development is highly variable over time with three distinct points in time worth mentioning. After inauguration of the CRSP mechanism in 1977 and as new programs were formed, there was a large increase in funding towards long-term training for several institution-building programs at foreign universities and agricultural research institutes. A little more than a decade later, USAID nearly exited agricultural development and CRSP funding fell to its lowest level in nearly 20 years. Funding recovered at the end of the century and then trended lower until the launch of the Feed the Future Initiative in 2010. Funding increased to a new high where it has remained since the passage of the Global Food Security Act of 2016. Overall, USAID invested approximately US$1.24 billion in the CRSP and FtFIL programs between 1978 and 2018.[1]

During the Feed the Future phase of the program, numerous new Innovation Labs were commissioned and labs that date to the CRSP era were reorganized. Investments were targeted at the most pressing agricultural challenges facing food security globally as well as toward specific issues of importance to countries that were the focus of the Feed the Future initiative. Figure 2 disaggregates total funding into its component areas identified by the title of the investment, broadly divided into nine areas representing cereal crops, grain legumes, horticulture, livestock,

---

[1] Each year is expressed in 2016 equivalent dollars.

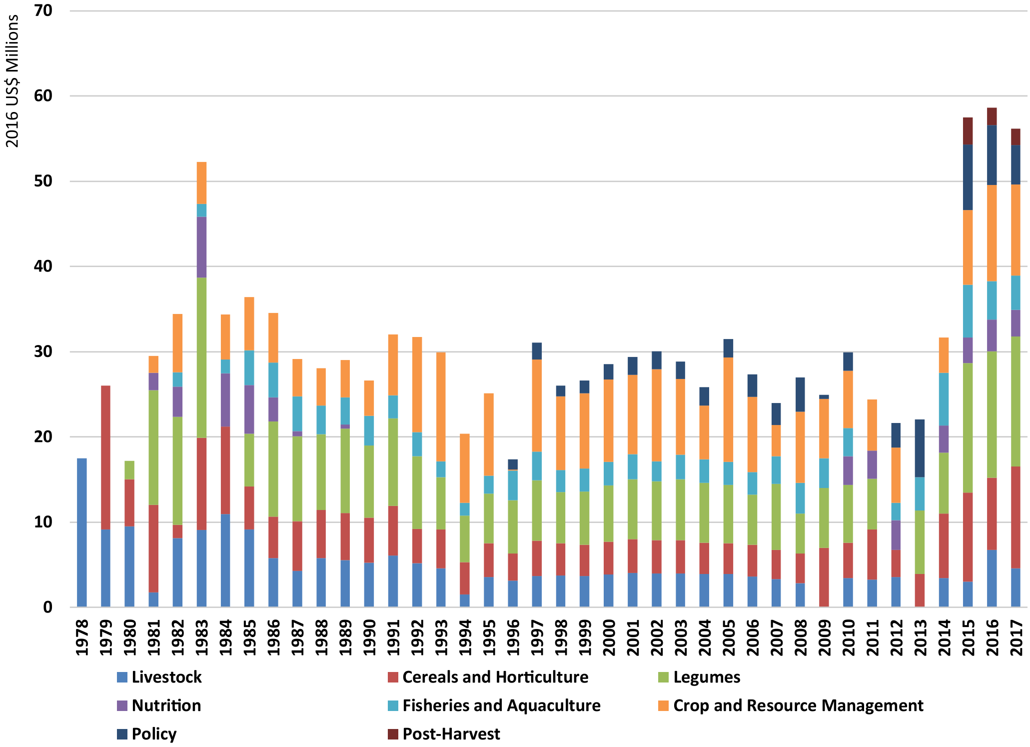

Figure 2. Distribution of CRSP and Innovation Lab funding by year and programmatic area (US$ 2016).

fisheries, post-harvest loss prevention, crop and natural resource management, human nutrition, and policy. Research on crops, livestock, and natural resource management has accounted for about 82% of program expenditures, with research on fisheries, policy, nutrition, and post-harvest loss prevention making up the remainder. These are direct allocations to specific CRSP or ILs and thus do not capture how the programs and labs allocated funds to activities. This categorization does not account for investment that was directed at "cross-cutting" thematic areas. An example would be research that aims to lower child malnutrition by increasing smallholder dairy productivity would be assigned to livestock though its major aim or theme is nutrition.

Methods and Data for Meta-Analysis

Meta-analyses can be used to synthesize multiple studies over a similar topic and have been used in several studies on the returns to agricultural research (Alston et al., 2000, 2002; Maredia and Raitzer, 2010; Raitzer and Kelley, 2008; Rao, Hurley, and Pardey, 2019; Zereyesus and Dalton, 2017). Best practices for doing so have been established for the social sciences (Stanley et al., 2013). We follow these practices to maximize the number of data points under consideration, to minimize compilation and coding errors, and to improve overall transparency and quality of the analysis.

Beginning in July 2017, a literature review identified several hundred reports that evaluated the impact of CRSP or Innovation Lab technological innovations.[2] Online search engines such as Google Scholar, economic literature databases such as EconLit, AgEconSearch, JSTOR, and Agricola were used for the search. Key words such as "CRSP," "Innovation Lab," "rate of return,"

---

[2] The authors thank anonymous reviewers who helped to identify additional studies.

"impact," "costs and benefits" were combined in strings to identify the studies. "Snowballing" of the manuscripts was conducted to identify additional sources until no new studies were revealed. The studies, dating from 1993 to 2016, covered a broad range of innovations, used varying evaluation techniques, and were conducted under differing assumptions.

The reviewed studies include publications in peer-reviewed journals, book chapters, and evaluation and impact reports, as well as unpublished papers (such as a M.S. and Ph.D. theses or other gray literature). We then evaluated each study to determine whether they included information on the costs and benefits of a CRSP or FtFIL innovation. Many reports were not included in the meta-analysis because of their qualitative nature or lack of transparency on assumptions and data. We then screened for eligibility based on the analyst's assumptions underlying the calculation of benefits and costs, clear attribution to U.S. investment, and the geographical impact of the research. Studies that described spillover benefits into the United States were excluded, as were any studies with only *ex ante* assessments (i.e., where estimates of benefits were based only on anticipated or potential uptake of the innovation by users). The screening and eligibility assessment resulted in 46 studies with measurable *ex post* economic impacts in developing countries. These form the core of our meta-analysis. See Appendix A for a list of these studies plus four others referred to in this review.

The studies focused on the benefits to farmers and consumers from the process of technological innovation. None of these studies included benefits and costs associated with other elements of the collaborative programs such as human and institutional capacity development, nutritional, or environmental effects, although some described these impacts qualitatively. A few studies overlapped, meaning they evaluated the same technology but with varying degrees of evidence on adoption. Redundant estimates of benefits from the same technologies were removed, as were any studies that relied on strictly *ex ante* assumptions about technology adoption (i.e., inclusion in the meta-analysis required evidence that substantial farmer adoption had actually occurred). The approach of this review is to aggregate the unique economic impacts identified by these case studies and contrast this against the total investment by USAID in research and development through the CRSP and FtFIL mechanisms, considering the uncertainty surrounding some of the estimates of impact.

Table 1 lists the studies identified through the literature search on the economic impacts of CRSP and FtFIL research. These are sorted according to their topical focus, geographical area, and commodity. In most of these impact analyses, there is considerable uncertainty about the precise value of the welfare effect of the innovation. Studies are often conducted before the innovation reached obsolescence so the estimates of future stream of benefits must be made under varying assumptions on the roll-out of benefits and the scale of their effects. Benefit estimation is also affected by market characteristics, such as elasticities of supply and demand, which are not known with certainty. Most studies provide a range of benefit estimates based on different assumptions about the underlying parameters used in the calculation. The meta-analysis considers these assumptions by treating each scenario or sensitivity analysis as an estimate of the true value of the impact estimate. To estimate the value of the benefits from these innovations, Monte Carlo simulation is conducted where each scenario of a study is randomly sampled as the impact estimate of the study. The total value of the impact from all 46 case studies is then recalculated by sampling with replacement 500 times. This approach generates a distribution of estimated total impact that represents all possible combinations of outcomes rather than a point estimate at each study's mean. This allows for the exploration of all the varying assumptions present in each case study and hence pessimistic or optimistic "what-if" scenarios. The Monte Carlo simulation was conducted using the Simetar spreadsheet add-on program.

It should be evident from the list of studies in Table 1 that the coverage of the impact studies identified in this review does not reflect the distribution of the investment across the CRSP and FtFIL research portfolio described in Figure 2. Thirty-two percent of the impact studies are on Integrated Pest Management (IPM) innovations for a variety of crop species, including vegetables and fruits, 36% on varietal improvement in grain legumes, 11% on cereal crop varieties, 19% on

Table 1. List of studies on economic impacts of CSRP-IL research

	Region			
Technology	Africa	Asia	Latin America	Europe & USA
Integrated pest management	20. Hristovka 2009; Uganda; Tomato	10. Debass 2000; Bangladesh; Vegetables, maize	20. Hristovka 2009; Ecuador; Plantain	08. Daku 2002; Albania; Olive
	37. Nouhoheflin 2009; Senegal; Tomato	17. Fransisco 2002; Philippines; Eggplant	47. Sparger 2011; Honduras; Vegetables	20. Hristovka 2009; Albania; Tomato
	42. Reyes 2013; Burkina Faso; Cowpea	38. Rakshit 2011; Bangladesh; Curcurbits	45. Secor 2012; Honduras; Onions	
		33. Myrick 2014; India; Fruit, cassava	06. Cole 2002; Ecuador; Potato	
		34. Natarajan 2013; India; Onion	02. Baez 2004; Ecuador; Plantain	
	36. Norton 2016; Vegetable IPM global synthesis			
Crop varieties	44. Schwartz 1993; Senegal; Cowpea	07. Cuyno 2001; Philippines; Eggplant	21. Jaen 2011; El Salv. & Nicaragua; Sorghum	13. Eddleman undated; USA; Sorghum
	23. Magen 2012; Senegal; Cowpea	07. Mutoc 2003; Philippines; Eggplant	20. Gomez 2012; Honduras; Sorghum	14. Eddleman 1991; USA; Sorghum
	01. Ahmed 1995; Sudan; Sorghum	24. Mamaril 2006; Philippines, Vietnam; GMO Rice	50. Villacis 2012; El Salvador; Sorghum	
	46. Soufi 2001; Senegal; Peanut	27. Mishra 2007; S Asia, Philippines; GMO eggplant	40. Reyes 2016; C America; Beans	
	11. Diaz 2002; Cameroon; Cowpea		26. Mather 2003; Honduras; Beans	
	48. Sterns 1994; Cameroon; Sorghum & Cowpea		25. Mather 2001; Dominican Rep; Beans	
	30. Moyo 2007; Uganda; Peanuts		19. Gonzalez 2003; Mexico; Beans	
	15. Eddleman 2001; Mali; Sorghum, Millet		28. Mooney 2007; Ecuador; Beans	
	51. Zereyesus 2017; Sorghum & millet global synthesis			

(*Continued*)

Table 1. (*Continued*)

	Region			
Technology	Africa	Asia	Latin America	Europe & USA
Crop storage	04. Boyes 2007; Senegal; Cowpea			
	29. Moussa 2011; W & C Africa; Cowpea			
	22. Leavens 2021; Senegal; Maize			
Other	35. Norton 2012; Lesotho; Resource management	16. Engle undated; Thailand; Fish ponds	49. Valdivia 1999; Indonesia; Small ruminants	03. Bencheva 2008; Bulgaria; Peanut economics
	22. Leavens 2021; Senegal; Food safety	35. Norton 2012; Nepal; Resource management	09. Dasgupta 2000; Honduras; Shrimp	
			35. Norton 2012; Ecuador; Resource management	

Only first authors listed. See Appendix A for complete references.

post-harvest loss reduction, and 2% on livestock husbandry. Some of the grain legume research projects were evaluated both for on-farm productivity gains and post-harvest loss reduction. We have very little benefit-cost information on the impact of nutritional, human health, and livestock research and no information on the impacts of research on natural resource management, policy, and fisheries. However, the absence of evidence on impact of some parts of the research portfolio should not be interpreted as a lack of actual impact from this research, as there has been no systematic effort to measure impacts from all the research projects carried out by CRSP and FtFIL. In fact, the case studies included in this review represent 5% or less than that of all the projects funded by USAID through these programs over the 40-year study period. The 46 impact studies cataloged over this 40-year time horizon convert to an average of 1.2 assessments produced per year.

The lack of information across the entire portfolio limits our ability to inform research resource allocation based on efficiency criteria. The findings are restricted to an overall comparison of the total investment pattern to just a small subset of case studies with benefit calculations that are not representative of the portfolio of programs nor the scale of technology development.

A second dimension of this meta-analysis is to explore welfare implications of the economic impacts of CRSP-FtFIL research, especially, the extent to which this may have reduced poverty. The studies listed in Table 1 show a wide geographic distribution with impacts accruing over different periods of time. While a precise analysis of the welfare effects is not possible given the data available, we can draw some general conclusions by looking at the extent of poverty in the countries where significant economic impact was achieved and using this to estimate the likely share of total benefits accruing to poor households. We premise this approach on the assumption that the economic benefits from the projects listed in Table 1 are widely shared across income classes within a country. Technology adoption raises income of farm adopters and, through market-level effects, reduces prices paid by consumers for food. In almost all the case studies listed in Table 1, the commodities affected by new technologies are produced predominantly by smallholders, who tend to congregate on the lower end of the income scale. For consumers, income elasticities for these commodities (especially food staples) are likely to be positive but small, meaning that per capita levels of consumption do not vary much across income classes (and, as a percentage of total expenditure, are higher for poor households). Thus, it is reasonable to assume that benefits are roughly evenly distributed across the income strata of a country, and therefore, the share of benefits accruing to those below a poverty line will be correlated with the poverty headcount index for that country at the time these impacts occurred. This is consistent with recent studies that have found that in low-income countries, income gains from agricultural growth are much more evenly distributed across income strata than growth in sectors like natural resource extraction, industrial development, and urban-based services (Ivanic and Martin, 2018; Ligon and Sadoulet, 2018). Moreover, studies often find that for low-income countries, within the agriculture sector, growth in staple food crop and livestock have even stronger effects on poverty reduction than growth in non-staple commodities (e.g., Diao et al., 2005).

To assess welfare impacts across countries, we focus on mean estimates of the distribution of net present values (NPV) that study authors estimated and assume this represents the expected value of income benefits accruing to the country where technology adoption occurred. In the case studies, the NPV is given in US$ at official exchange rates. We convert the estimates into its purchasing power parity (PPP) equivalent to facilitate international comparisons of welfare (PPP$ compares the cost of a similar basket of consumer goods across countries) and World Bank poverty rates, which are defined in terms of PPP$ per capita. We apportion NPV by year over the lifespan of the project to get an annual stream of benefits.[3] To get an estimate of the

---

[3] Assigning an equal share of NPV to each year of the project will tend to overestimate benefits in the early stages of the project when diffusion is just beginning and understate benefits toward the end of the project. Summing up over time, however, these errors should be small. The purpose of estimating an annual benefit stream is to align the benefits with the poverty headcount index for the same period.

benefits accruing to poor households, we multiply annual benefits by the poverty head count index for a country in that time period and re-aggregate these poverty-weighted benefits. The total income benefits accruing to poor households are thus found from:

$$\text{Benefits to poor households} = \sum\nolimits_{t=1978}^{2020} \sum\nolimits_{c=1}^{C} \sum\nolimits_{i=1}^{I} \text{Pov}_{ct} * V_{ct,i} \tag{1}$$

where $V_{ct,\,i}$ is the net annual benefit from project i (measured in constant 2016 PPP$) in country c in year t and Pov_{ct} is the poverty headcount index for that country and time period. This, of course, is only an approximate measure of the share of economic impacts accruing to poor households and depends on the strong (though not unrealistic) assumption that productivity gains in food staples in low-income countries are widely shared across the population.

Equation (1) can be thought of as a social welfare function which sums up the poverty-weighted incomes of each individual in the population, where the weight reflects the income shortfall of the poor. Foster, Greer, and Thorbecke (1984) postulate a class of such poverty weights as a function of societal aversion for poverty. Indifference to poverty gives everyone's income the same weight, while a strong aversion to poverty might give, for a specified poverty line, a weight of 1 to the income of poor households and 0 to the income of nonpoor households. An even stronger aversion to poverty might give an increasing weight to those individuals with incomes farther below the poverty line. Poverty data are from World Development Indicators and interpolated for missing years. The analysis is conducted for three poverty lines in PPP$/capita/day: $5.50, $3.20, and $1.90.

Results and Discussion

Cost-Benefit Analysis of University-Led Agricultural Research

Figure 3 presents the results of the Monte Carlo simulation analysis showing the median and distribution of aggregated benefits from the 46 case studies of economic impacts from university-led agricultural research. Impacts are expressed in both US$ and PPP$ at constant 2016 prices. The sample of studies documented a median estimate of US$2.94 billion in net benefits to farmers and consumers with a 95% confidence interval of US$2.4 billion to US$3.4 billion at official exchange rates. When the benefits are converted by each nation's PPP, the median estimate is PPP$8.43 billion, with a 95% confidence interval ranging from PPP$6.7 billion to PPP$10.0 billion. The distribution of net benefits is bimodal reflecting the combination of pessimistic and optimistic assumptions in each of the studies. Under the worst-case scenario, these studies generated a minimum of US$2.3 billion at official exchange rates (or PPP$6.4 billion) in net benefits for a multiplier of USAID research expenditures of 1.83 (or 5.17 at PPP), while under the most optimistic scenario, that ratio of net benefits to costs is approximately 2.87 (8.52 at PPP). At the median of the net benefit estimate, the benefit-cost ratio 2.36 (6.79 at PPP). Fifty-six percent of the benefits were found in IPM innovations, 31% in varietal improvement, 12% in crop storage, and 1% in livestock.

Figure 3 allows the comparison of the investment cost of the 40-year USAID investment in university-led agricultural research, across all programmatic areas, to the net benefits in developing countries from a non-representative sample of innovations from those investments. It does not include any spill-in benefits to the U.S. agricultural and food economy, which, as described in Glauber, Kraybill, and Mercier (2019), have in some cases been significant. For example, in southern Africa in the 1980s, plant breeding and genetics research by the INTSORMIL CRSP identified host plant resistance in sorghum against the sugarcane aphid, an endemic pest in Africa. When this pest began attacking U.S. sorghum production in 2013, it was partially controlled by incorporating this genetic material into U.S.-grown varieties (Peterson et al., 2018). Moreover, since each study presents the NPV to the technological innovation (i.e., local benefits of the innovation minus project costs incurred by U.S. government and partner-country

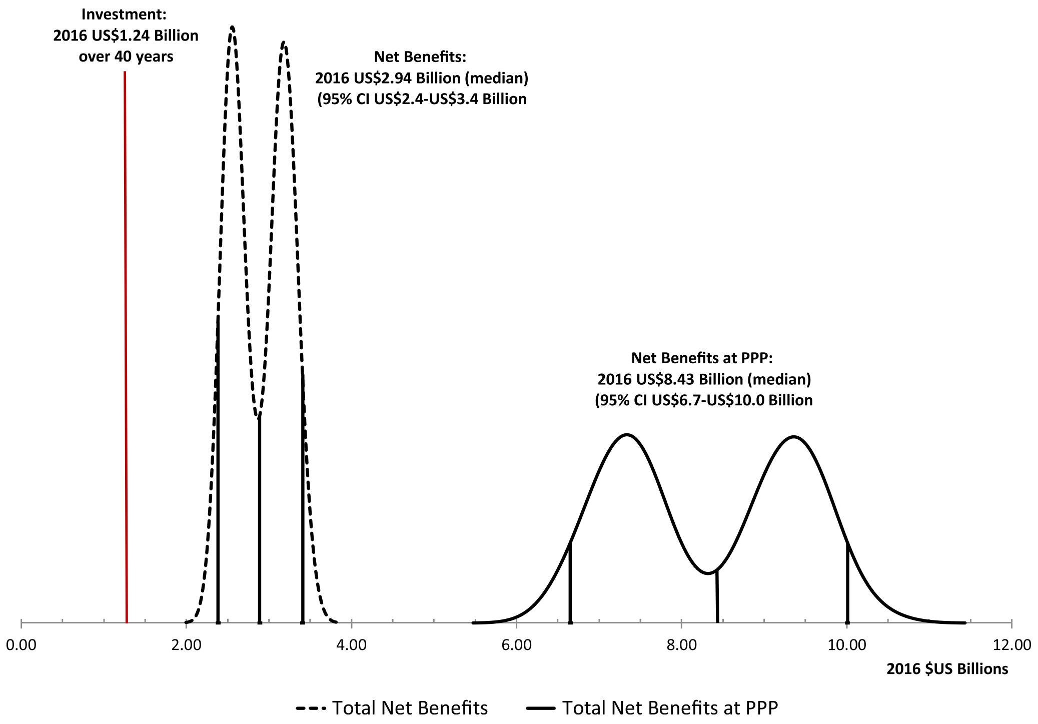

Figure 3. Estimated probability distribution of total net benefits from technologies developed through CRSP and FtFIL research in US$ and PPP$ (constant 2016 prices).

R&D investment), it cannot be considered as an accurate benefit-cost ratio but one that is biased downward since the project costs are counted twice.

Likely poverty impacts from the 46 impact studies are shown in Table 2. In constant 2016 PPP$, net benefits from the CRSP and FtFIL projects in Africa, Asia, Latin America, and Eastern Europe through 2020 total PPP$8,064 million.[4] About 45% of these benefits accrued to countries in Asia, especially India. African countries received about 28% of benefits, Latin American countries (primarily in Central America) received about 23% and Eastern European countries about 4% of estimated benefits. Because poverty rates in these countries were high when these technologies generated economic impacts, our model assigns a high proportion of these impacts to the poor. Assuming that these benefits are widely shared amongst producers and consumers in the countries of impact, we find that households on the lower end of the income strata appeared to be the primary beneficiaries of these income gains. About 78% of the income benefits shown in Table 2 likely accrued to individuals living on less than $PPP 5.50/day, 57% to individuals spending less than $3.20/day, and 29% to those in extreme poverty with less than $1.90/day for subsistence. In Africa, our model assigns 46% of the benefits to those in extreme poverty earning less than $1.90/day and 28% of the benefits in Asia to this group.

---

[4] Total benefits from case studies are calculated through 2030 but the poverty alleviation benefits are truncated in 2020, when the latest available poverty estimates were calculated. Cumulative net benefits over 1978–2020 are PPP$8.06 billion compared with PPP$8.43 billion when benefits through 2030 are included (see Figure 3).

Table 2. Cumulative welfare impacts of technologies developed through CRSP and FtFIL research, 1978–2020

		Net Benefits Weighted by Poverty Headcount Index			Share of Total Net Benefits Earned by Poverty Class		
		<$5.50/day	<$3.20/day	<$1.90/day	<$5.50/day	<$3.20/day	<$1.90/day
Region	Total Net Benefits	(constant 2016 PPP$, millions)			(%)		
Africa	2,248	1,909	1,572	1,044	84.9	69.9	46.4
Asia	3,656	3,260	2,423	1,016	89.2	66.3	27.8
Latin America	1,877	1,028	604	297	54.8	32.2	15.8
Eastern Europe	283	111	27	3	39.3	9.5	1.0
Total	8,064	6,308	4,627	2,359	78.2	57.4	29.3

Other Impacts of University-Led Agricultural Research

The economic impacts from technological change described in the previous section are largely income gains to producing and consuming households, which are calculated using market prices to value the changes in quantities of goods produced and consumed. Beyond these direct income or economic impacts, new technologies can contribute to welfare changes in important ways that may be missed in market transactions. Changes to human health, environmental quality, and the risk of and ability to recover from economic shocks ("resilience") are additional ways as new technology may positively (or negatively) influence household and community well-being. There are also cases where university-led research may have made relatively small but nonetheless strategic contributions to advances in science and technology that, while not easily attributable to a particular institution, have resulted in significant social and economic impacts in developing countries. In this section, we briefly canvass some of the "non-market" or unattributed impacts of USAID-supported university research. Together, these additional dimensions of impact illustrate that purely economic measures of impact understate the overall value of this research investment.

Health and Environmental Benefits from Lower Pesticides Exposure

IPM has been a major theme of CRSP and FtFIL research. IPM aims both to increase farm productivity and create alternatives to pesticide use, especially where exposure to pesticides may have negative health and environmental effects. For example, in the 1990s research funded by the Rockefeller Foundation found that pesticide use in the Andes posed significant risks to human health and the environment but were also highly profitable because they enabled farmers to avoid crop losses (Crissman, Antle, and Capalbo, 1998). Subsequently, the IPM CRSP undertook research to develop IPM and piloted farmer field schools and other extension methods to enable farmers to reduce pesticide use on potatoes, focusing on the Carchi Province of Ecuador. Yaguana (2013) found that by 2011, most potato growers in Carchi had adopted at least some IPM methods, and that on average, adopters of IPM were able to lower their pesticide costs by around $500 per hectare, or by more than 60%, while maintaining potato yield. In addition to direct economic benefits from reduced pesticide costs (estimated by Yaguana, 2013 to be over $800,000 per year in Carchi), adoption presumably generated significant (though unmeasured) health and environmental benefits to local communities by reducing their exposure to pesticides.

Another CRSP IPM project on vegetable production in Central Luzon, Philippines, was found to have reduced pesticide use on onions by 25%–65% (Cuyno, Norton, and Rola, 2001). To derive an estimate of the perceived non-market value of lower pesticide use, the authors asked local residents about their "willingness to pay" for reduced risk to human and nonhuman species from lower pesticide exposure. The aggregate value of these environmental benefits in the five villages where the IPM program was centered was $150,000 for the 4,600 residents or about half the value of the direct economic benefits.

More recently, a USAID-supported project has developed insect-resistant varieties of eggplant using GM technology (*Bt* eggplant) in Bangladesh. A randomized control trial showed that adopters used 39% less pesticides (and 51% fewer sprays) and produced 42% higher yields on average than non-adopters (Ahmed et al., 2019). The study also found highly suggestive evidence that adoption improved the health of growers and their families: Individuals in adopting households were 10% points less likely to self-report health symptoms consistent with pesticide exposure compared with non-adopting households (Ahmed et al., 2019). The new eggplant varieties are proving popular due to their profitability and are being rapidly adopted in Bangladesh.

Nutritional Benefits from Dietary Quality and Diversification

Lack of balanced diet underlies the "triple burden of malnutrition": (1) undernutrition (caloric inadequacy), (2) micronutrient deficiencies, and (3) overnutrition (leading to obesity and associated non-communicable diseases). One means of improving dietary quality is through diversification, defined as the number of major food crops regularly consumed in one's diet (Ruel, 2003). Dietary diversity is enhanced when food becomes more affordable, either because household incomes rise or because the price of food declines. This is true even for food staples that often dominate the budgets of poor households because lower staple prices free up household expenditures to purchase other foods.

Most of the case studies of economic impact identified in this review likely contributed to dietary diversification through these income and price effects. Impacts that increased availability and affordability of foods that are rich in scarce micronutrients, such as Bt eggplant in Bangladesh and improved beans in Central America, may be particularly important to dietary quality. In West Africa, new early-maturing varieties of cowpea improved diets by making food more available to households during the hunger season prior to the traditional harvest months (Schwartz, Sterns, and Oehmke, 1993). None of the case studies in this review attempted to quantify specific nutritional impacts, although other meta-studies and econometric analysis have established clear and significant impacts from higher agricultural productivity on improved household nutrition in developing countries (see Pray, Masters, and Ayoub, 2017, for a concise review of recent evidence).

Impacts of Strategic Research that Addressed Significant Technical Bottlenecks

A 2012 Board for International Food and Agricultural Development review of the "CRSP model" identified two pathways through which U.S. university-led research contributes to agricultural development: (1) demand-driven research designed to achieve tangible development outputs to address local problems, and (2) strategic research which provides cutting-edge solutions to narrowly defined problems of global importance (USAID, 2012, pp. 32–34). All the case studies of impact identified in this review are examples of the first type—demand-driven research that produces tangible solutions to local problems. The impacts of strategic research, on the other hand, can be harder to identify and attribute to a single or few technology providers. Results of strategic research, for example, may provide component knowledge that enhances performance of applied R&D. Importantly, strategic research may help overcome technical bottlenecks and open new opportunities and approaches to seemingly intransigent problems.

One example of strategic research has been the extension of genomics-enabled plant breeding platforms to national agricultural research systems in low-income countries. Few of these countries have all the required expertise and infrastructure in phenomics, genetics, and bioinformatics to implement state-of-the-art breeding programs. Many suffer from small-country inefficiencies of size in research capacity that make these techniques cost prohibitive. FtFILs have allowed target nations to pursue activities where they hold a comparative advantage, for example in screening for resistance against persistent insects or disease and plant phenotyping, while U.S.-based scientists, often with degree-seeking students from the target nations, conduct genomic characterization and process bioinformatics to determine the genetic location of host plant resistance against these pests. Information and genetic markers are then fed back into host-country breeding programs to speed crop development, reduce yield damage, and increase crop production resiliency. Two recent examples include the discovery of the ARG1 gene that confers tolerance in sorghum against anthracnose, which is prevalent in humid lowlands of western Ethiopia, and the creation of genetic markers for the RMES1 SCA resistance locus that confers host plant resistance against the sugarcane aphid (SCA) in Haitian, and global, sorghum production (Lee et al., 2022; Muleta et al., 2022).

A second example of how US government-funded research provided narrowly defined but critical inputs to a problem of international significance is the development of thermo-stable vaccines against major livestock diseases (though this case also has dimensions of the first type of demand-driven research focused on tangible outputs). While a highly effective Rinderpest (cattle plague) vaccine had been developed in 1960 by the Scottish veterinarian Walter Plowright, its principal limitation was that it required refrigeration, a significant impediment to field vaccination in remote areas (Roeder, Mariner, and Kock, 2013). A 2-year research effort by Tufts University School of Veterinary Medicine and the United States Department of Agriculture successfully developed ThermoVax, a thermo-stable version of the Rinderpest vaccine, and by 1992 ThermoVax was commercially available in Africa. This innovation dramatically extended the reach of field vaccination programs. In 2011, the UN Food and Agriculture Organization and the World Health Organization declared that Rinderpest had been eradicated world-wide, only the second disease (after smallpox) to be so designated. That fact that U.S. universities appear to have unique capabilities for this type of technology development is revealed by the fact that USAID reenlisted Tufts and Florida universities to develop a thermo-stable vaccine against the *peste des petits ruminants*, a highly lethal virus that plagues goats and sheep in Africa.

Conclusions

Investing in R&D to raise agricultural productivity in developing nations is an important element of U.S. foreign technical assistance. Increasing agricultural productivity is valued not only for its contribution to ending hunger but also because it drives inclusive economic growth and transformation, promotes better health and nutrition, and conserves natural resources. USAID directs funding for agricultural R&D through national and international research institutions, including a major portion to U.S. universities. In this paper, we reviewed evidence on the economic impact of agricultural research supported by USAID and conducted by U.S. universities which is aimed at strengthening global food security. U.S. agricultural land-grant universities have been an integral part of the U.S. government's commitment to agricultural development for much of the past half-century and has been formally enshrined in USAID programs since the late 1970s. The two programs of most significance in this endeavor have been the Collaborative Research Support Program, which ran from 1978 to 2012 and its successor, the Feed the Future Innovation Labs, which have operated since 2012.

We identified nearly four dozen economic studies that quantified impacts of research projects undertaken by CRSP and FtFIL since 1978. Most of these studies used standard tools of benefit-cost analysis to appraise a project's NPV (i.e., the discounted present value of the annual stream of user benefits from higher agricultural productivity minus the costs of research and extension, including costs incurred by partner organizations). Since most studies lacked precise information on long-run benefits from technology adoption, they provided a range of NPV that considered uncertainty about the value of future benefits. Treating these estimates as random variables, we used a repeated sampling procedure to construct a probability distribution of the aggregate net benefits in developing countries from this sample of projects. In constant 2016 prices and at official exchange rates, their aggregate NPV had a median value of US$2.94 billion, with a 95% confidence interval ranging from US$2.4 billion to US$3.4 billion. This compares favorably against USAID's cumulative investment in the CRSP and FtFIL of US$1.24 billion over 1978–2018 despite the fact that the benefits are measured from only a small fraction of the total number of projects conducted under the CRSP and FtFIL mechanisms. Even if all other projects in the CRSP and FtFIL portfolios had zero gross benefits, granted as a very a heroic assumption, this program would still be considered highly successful. Our estimate could be considered as a minimum benefit calculation when evaluated at official exchange rates based on available information. Alternatively, we may have overestimated the attribution of these benefits to the USAID mechanism by not taking into consideration alternative projects or programs that complement the research intervention. For example, a development project may have been responsible for extending an innovation and thus deserves a portion of the impact attributed to their role in dissemination.

Because USAID-funded agricultural research is heavily oriented toward raising productivity of smallholder farmers, and especially for food crops, it should come as no surprise that the primary beneficiaries are likely to be low-income households in developing countries. When adjusted for PPP in the countries where technology adoption occurred, the aggregate economic impact from the set of project rises to over PPP$ 8.43 billion (median value, again at 2016 prices). Under the most optimistic scenario, these studies document benefits that are 8.5 times greater than the total cost of the entire CRSP-FtFIL program. Under the strong assumption that these benefits were evenly shared amongst the population in the countries where economic impacts occurred, we estimate that about four-fifths of these economic benefits accrued to individuals with incomes under $5.50/day, and about 29% to those in extreme poverty subsisting on less than $1.90/day. Or, alternatively, we could say that the majority of CRSP-IL impacts accrued in countries where poverty rates were exceptionally high and to commodities of particular importance to lower income strata of the populations within these countries. Moreover, as this estimate only considers a subset of CRSP and FtFIL projects undertaken over these years, and only considers one dimension of outcomes (income benefits), it represents an underestimation or minimum bound of the full impacts achieved by the USAID-University partnership to date.

Nearly all the impact studies identified in our review focused on crop improvement research, namely, integrated management of crop pests and diseases, breeding of new crop varieties, and improved crop storage. This is not a balanced representation of the CRSP and FtFIL research portfolio, however, and major parts of the USAID investment—in natural resource management, livestock and fish, human nutrition, and policy—have received scant attention for their economic and social impacts. But the lack of formal studies on impact cannot be interpreted as a lack of impact of research in these areas. Rather, it likely reflects both the initiative of certain CRSP and FtFIL programs in sponsoring impact studies as well as the ease of undertaking such assessments. More assessments on a broader range of programs would provide an objective basis for evaluating the relative performance of FtFIL investments. Given the history and uneven attention to impact assessment studies, USAID could consider incentivizing this process, such as by reserving some project funds for impact assessment.

Often, CRSP and FtFIL research is directed toward upstream, strategic research that contributes basic or targeted knowledge to larger efforts (involving many partners, in both research and implementation) to address pressing challenges. In addition, many CRSP and FtFIL projects have been oriented toward achieving impacts that are hard to quantify in a money metric. Several of the case studies included in this synthesis described (but rarely were able to monetize) significant benefits above the income gains they documented, such as improvements to farm family health through more judicious use of chemical pesticides, greater dietary diversity of nutritious foods, and greater stability of agricultural yields. Comparing these secondary benefits to those produced by FtFIL labs targeting nutrition, or crop and resource management for example, may show that the secondary benefits outweigh those produced by direct investment.

Getting a fuller account of impacts of USAID-funded research remains important for improving the design of research projects and the allocation of budgetary resources across the program portfolio. Program areas within USAID's R&D portfolio where evidence of impact is especially needed include crop and natural resource management, policy, livestock, and nutrition. A more systematic commitment to *ex post* and *ex ante* analysis to assess benefits relative to costs of agricultural R&D can help to focus investments on the most impactful areas and help to justify further Congressional funding for agricultural R&D in foreign aid. Given the multiple policy objectives this aid aims to achieve, a broader set of impact measures should be considered. It is becoming increasingly possible, through integrated models, to consider not only economic impacts but also on impacts on nutrition and health, climate and environmental change, and resilience to shocks. And, important for the long-run graduation of foreign countries from the need for technical and food assistance, the impact of U.S. investments on human and institutional capacities in agricultural science and technology could also receive attention.

Acknowledgements. The authors acknowledge the important research assistance of Maria Alejandra Ramirez Lopez and Wyatt Pracht. This study is made possible by the support of the American People provided to the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet through the United States Agency for International Development (USAID) and by the United States Department of Agriculture (USDA). The contents are the sole responsibility of the authors and do not necessarily reflect the views of USAID, USDA, or the United States Government. Program activities are funded by the United States Agency for International Development (USAID) under Cooperative Agreement No. AID-OAA-A-13-00047.

Author contributions. Conceptualization, TJD, KF; Methodology, TJD, KF; Formal Analysis, TJD, KF; Data Curation, TJD, KF; Writing—Original Draft, TJD, KF, Writing—Review and Editing, TJD, KF; Supervision, TJD; Funding Acquisition, TJD.

Competing interests. TJD and KF declare none.

Data availability statement. Data are available from cited references or the authors.

References

Ahmed, A., J. Hoddinott, K. Islam, A.S.M. Khan, N. Abedin, and N. Hossain. "Impacts of BT Brinjal (Eggplant) Technology in Bangladesh." *IFPRI Bangladesh Policy Research & Strategy Support Program*. Washington, DC: International Food Policy Research Institute, 2019.

Alston, J.M., M.C. Marra, P.G. Pardey, and T.J. Wyatt. "A Meta Analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem." *IFPRI Research Report No 113*. Washington, DC: International Food Policy Research Institute, 2000.

Alston, J.M., M.C. Marra, P.G. Pardey, and T.J. Wyatt. "Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D." *Australian Journal of Agricultural and Resource Economics* **44**,2(2002):185–215.

Crissman, C., J. Antle, and S. Capalbo, eds. *Economic, Environmental, and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production*. Dordrecht: Kluwer Academic Publishers, 1998.

Cuyno, L.C.M., G.W. Norton, and A. Rola. "Economic Analysis of Environmental Benefits of Integrated Pest Management: A Philippine Case Study." *Agricultural Economics* **25**(2001):227–33.

Diao, X., A. Nin-Pratt, M. Gautam, J. Keough, J. Chamberlin, L. Hou, D. Puetz, D. Resnick, and B. Yu. "Growth Options and Poverty Reduction in Ethiopia: A Spatial, Economy-Wide Model Analysis for 2004-2015." DSGD Discussion Paper. Washington, DC: International Food Policy Research Institute, 2005.

Foster, J., J. Greer, and E. Thorbecke. "A Class of Decomposable Poverty Measures." *Econometrica* **52**,3(1984):761–6.

Glauber, J., D. Kraybill, and S. Mercier. *How the United States Benefits from Agricultural and Food Security Investments in Developing Countries*. Washington, DC: International Food Policy Research Institute, 2019.

Hayami, Y., and V.W. Ruttan. *Agricultural Development: An International Perspective*. Baltimore, MD: Johns Hopkins University Press, 1985.

Ivanic, M., and W. Martin. "Sectoral Productivity Growth and Poverty Reduction: National and Global Impacts." *World Development* **109**(2018):429–39.

Lee, S., F. Fu, C. Liao, D.B. Mewa, A. Adejanju, G. Ejeta, D. Lisch, and T. Mengiste. "Broad-Spectrum Fungal Resistance in Sorghum Is Conferred Through the Complex Regulation of an Immune Receptor Gene Embedded in a Natural Antisense Transcript." *The Plant Cell* **34**,5(2022):1641–65.

Ligon, E., and E. Sadoulet. "Estimating the Relative Benefits of Agricultural Growth on the Distribution of Expenditures." *World Development* **109**,2(2018):417–28.

Maredia, M.K., and D.A. Raitzer. "Estimating Overall Returns to International Agricultural Research in Africa through Benefit-Cost Analysis: A 'Best Evidence' Approach." *Agricultural Economics* **41**,1(2010):81–100.

Mellor, J. *Agricultural Development and Economic Transformation*. Ithaca, NY: Cornell University Press, 2017.

Muleta, K.T., T. Felderhoff, N. Winans, R. Walstead, J. Rigaud Charles, J.S. Armstrong, S. Mamidi, et al. "The Recent Evolutionary Rescue of a Staple Crop Depended on Over Half a Century of Global Germplasm Exchange." *Science Advances* **8**(2022):1–11.

Peterson, G.C., J.S. Armstrong, B.B. Pendleton, M. Stetler, and M.J. Brewer. "Registration of RTx3410 Through RTx3428 Sorghum Germplasm Resistant to Sugarcane Aphid [*Melanaphis saccari* (Zehntner)]." *Journal of Plant Registrations* **12**(2018):391–8.

Pray, C.E., W.A. Masters, and S. Ayoub. *Impacts of Agricultural Research on Poverty, Malnutrition, and Resilience*. Washington, DC: United States Agency for International Development, 2017.

Raitzer, D.A., and T.G. Kelley. "Benefit-Cost Meta-Analysis of Investment in the International Agricultural Research Centers of the CGIAR." *Agricultural Systems* **96**(2008):108–23.

Rao, X., T.M. Hurley, and P.G. Pardey. "Are Agricultural R&D Returns Declining and Development Dependent?" *World Development* **122**(2019):27–37.

Roeder, P., J. Mariner, and R. Kock. "Rinderpest: The Veterinary Perspective on Eradication." *Philosophical Transactions of the Royal Society B* **368**(2013):20120139.

Ruel, M. "Operationalizing Dietary Diversity: A Review of Measurement Issues and Research Priorities." *Journal of Nutrition* **133**,11(2003):3911S–26S.

Schwartz, L.A., J.A. Sterns, and J.F. Oehmke. "Economic Returns to Cowpea Research, Extension, and Input Distribution in Senegal." *Agricultural Economics* **8**,2(1993):161–71.

Stanley, T.D., H. Doucouliagos, M. Giles, J.H. Heckemeyer, R.J. Johnston, P. Laroche, J.P. Nelson, et al. "Meta-Analysis of Economics Research Reporting Guidelines." *Journal of Economic Surveys* **2**(2013):390–4.

USAID. *BIFAD Review of the Collaborative Research Support Program (CRSP) Model. A Report Commissioned by the Board for International Food and Agricultural Development (BIFAD) at the Request of USAID*. Washington, DC: United States Agency for International Development (USAID), 2012.

Yaguana, V.D.R.C. "Adoption Analysis and Impact Evaluation of Potato IPM in Ecuador." M.S. thesis, Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2013.

Zereyesus, Y.A., and T.J. Dalton. "Rates of Return to Sorghum and Millet Research Investments: A Meta-Analysis." *PLoS ONE* **12**,7(2017):e0180414. DOI 10.1371/journal.pone.0180414.

Appendix A. List of Economic Impact Studies Identified through Literature Search

1. Ahmed, Mohamed M., William A. Masters, and John H. Sanders. 1995. Returns from Research in Economies with Policy Distortions: Hybrid Sorghum in Sudan. Agricultural Economics 12: 183–192.
2. Baez, Carolina. 2004. Potential Economic Benefits from Plantain Integrated Pest Management Adoption: The Case of Coastal Rural Households in Ecuador. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
3. Bencheva, Nelly, Carel Ligeon, Stanko Delikostadinov, Naveen Puppala, and Curtis Jolly. 2008. Economic and Financial Analysis of Peanut Production in Bulgaria. Journal of Central European Agriculture 9(2): 273-282.
4. Boys, K., M. Faye, J. Fulton, and J. Lowenberg-DeBoer. 2007. The Economic Impact of Cowpea Research in Senegal: An Ex-Post Analysis with Disadoption. Agricultural Economics 36: 363-375.
5. Boys, Kathryn, Joan Fulton, Mbene Faye, and J. Lowenberg-DeBoer. 2004. Adoption and the Economic Impact Implications of Storage Technology and Improved Cowpea Varieties in the North Central Peanut Basin of Senegal. Staff Paper, USAID Bean/Cowpea CRSP, Purdue University, West Lafayette, Indiana.
6. Cole, Donald C., Stephen Sherwood, Charles Crissman, Victor Barrera, and Patrico Espinosa. 2002. Pesticides and Health in Highland Ecuadorian Potato Production: Assessing Impacts and Developing Responses. International Journal of Occupational and Environmental Health 8: 182–190.
7. Cuyno, Leah C.M., George W. Norton, and Agnes Rola. 2001. Economic Analysis of Environmental Benefits of Integrated Pest Management: A Philippine Case Study. Agricultural Economics 25: 227-233.
8. Daku, Lefter S. 2002. Assessing Farm-level and Aggregate Economic Impacts of Olive Integrated Pest Management Programs in Albania: An Ex-Ante Analysis. PhD Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
9. Dasgupta, Siddhartha, and Carole Engle. 2000. Nonparametric Estimation of Returns to Investment in Honduras Shrimp Research. In, PD/A CRSP 17th Annual Technical Report. USAID Aquaculture CRSP, Oregon State University, Corvallis, OR.
10. Debass, T. 2000. Economic Impact Assessment of IPM CRSP Activities in Bangladesh and Uganda: A GIS Application. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
11. Diaz-Harmelo, F., A. Langyintuo, and J. Lowenberg-DeBoer. 2002. Impact of Cowpea Breeding and Storage Research in Cameroon. In, Challenges and Opportunities for Enhancing Sustainable Cowpea Production (C.A. Fatokun, S.A. Tarawali, B.B. Singh, P.M. Kormawa and M. Tamo, eds.). International Institute for Tropical Agriculture: Ibadan, Nigeria, p. 407-423.
12. Diaz-Harmelo, F., and J. Lowenberg-DeBoer. 1999. Estimating Research Benefits with Both Producing and Postharvest Technology: The Case of Cowpeas in Cameroon. West Africa Regional Social Science Report No. 2, USAID Bean Cowpea CRSP, Michigan State University, East Lancing, MI.
13. Eddleman, B.R., C.C. Chang and B.A. McCarl. (undated). Economic Benefits from Grain Sorghum Variety Improvement in the United States. Unpublished mimeo, Texas Agricultural Research Center, Corpus Christi, Texas.
14. Eddleman, B.R., C.C. Chang and B.A. McCarl. 1991. Economic Benefits from INTSORMIL Grain Sorghum Variety Improvement in the United States. Report to USAID INTSORMIL under TAMRF No. 9045, University of Nebraska, Lincoln, NB.
15. Eddleman, Bobby, R., Alpha O. Kergna, Jeffrey Vitale, Bruce A. McCarl, C. Chen, and Paul Dyke. 2001. Economic and Environmental Impact of Improved Sorghum and Millet Technology in Mali. Paper presented to the SANREM Research Scientific Synthesis Conference, November 28-30, 2001, Athens, GA.
16. Engle, Carole R., and Michael Skladany. (undated). The Economic Benefit of Chicken Manure Utilization in Fish Production in Thailand. Unpublished mimeo. University of Arkansas at Pine Bluff, Pine Bluff, Arkansas.
17. Francisco, S.R., and G.W. Norton. 2002. Economic Impact of Alternative Fruit and Shoot Boer (*L. orbonalis*) Control in Eggplant. Report to USAID IPM CRSP, Virginia Polytechnic Institute and State University, Blacksburg, VA.
18. Gomez, Gabriel Garcia. 2012. The Economic Impact of the New Insensitive Sorghum Cultivars in the Dairy Market of Nicaragua. MS Thesis. Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.
19. Gonzalez-Ramirez, Horacio. 2003. Economic Evaluation of Bean-Research Investment in Mexico. PHD Thesis. Department of Agricultural Economics, Michigan State University, East Lancing, MI.

(*Continued*)

Appendix A. (*Continued*)

20. Hristovska, Tatjana. 2009. Economic Impacts of Integrated Pest Management in Developing Countries: Evidence from the IPM CRSP. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
21. Jaen Celada, Jaeljattin R. 2011. Estimating the Potential Returns to Research and Development from Sorghum Value Added Products in El Salvador and Nicaragua. MS Thesis. Department of Agricultural Economics, Kansas State University, Manhattan, KS.
22. Leavens, Laura, Jonathan Bauchet, and Jacob Ricker-Gilbert. 2021. After the Project is Over: Measuring Longer-term Impacts of a Food Safety Intervention in Senegal. World Development 141: 105414.
23. Magen, Benjamin B. 2012. An Ex-Post Economic Impact Assessment of Bean/Cowpea CRSP's Investment on Varietal Development in Senegal. MS Thesis. Department of Agricultural, Food and Resource Economics, Michigan State University, East Lancing, MI.
24. Mamaril, Cezar Brian C. 2006. Transgenic Pest-resistant Rice: An Ex-ante Economic Evaluation of an Adoption Impact Pathway in the Philippines and Vietnam for Bt Rice. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
25. Mather, D.L. 2001. Economic Assessment of Bean Research in the Dominican Republic. MS Thesis. Department of Agricultural Economics, Michigan State University, East Lancing, MI.
26. Mather, D.L., R. Bernsten, J.C. Rosas, A. Viana Ruano, and D. Escoto. 2003. The Economic Impact of Bean Disease Resistance Research in Honduras. Agricultural Economics 29: 343-352.
27. Mishra. Sanjiv. 2003. An Ex-Ante Economic Impact Assessment of Bt Eggplant in Bangladesh, the Philippines and India. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
28. Mooney, Daniel F. 2007. The Economic Impact of Disease-Resistant Bean Breeding Research in Northern Ecuador. MS Thesis. Department of Agricultural Economics, Michigan State University, East Lancing, MI.
29. Moussa, B., J. Lowenberg-DeBoer, J. Fulton, and K. Boys. 2011. The Economic impact of Cowpea Research in West and Central Africa: A Regional Impact Assessment of Improved Cowpea Storage Technologies. Journal of Stored Products Research 47: 147-156.
30. Moyo, Sibusio, George W. Norton, Jeffrey Alwang, Ingrid Rhinehart and C. Michael Deom. 2007. Peanut Research and Poverty Reduction: Impacts of Variety Improvement to Control Peanut Viruses in Uganda. American Journal of Agricultural Economics 89(2): 448-460.
31. Moyo, Sibusiso. 2004. The Economic Impact of Peanut Research on the Poor: The Case of Resistance Strategies to Control Peanut Viruses in Uganda. MS Thesis. Department of Agricultural, Food and Resource Economics, Michigan State University, East Lancing, MI.
32. Mutoc, M. 2003. Increase in Calorie Intake Due to Eggplant Grafting in the Philippines. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
33. Myrick, Stephanie, George W. Norton, K.N. Selvaraj, and Kiruthika Natarajan. 2014. Economic Impact of Classical Biological Control of Papaya Mealybug in India. Crop Protection 56:82-86.
34. Natarajan, Kiruthika. 2013. Economic Impact Assessment of Integrated Pest Management (IPM) on Onion in Tamil Nadu. PhD Thesis, Tamil Nadu Agricultural University, Coimbatore, India.
35. Norton, George W., and Abigail Nguema. 2012. CCRA-6 Economic Analysis and Impact. Presentation at the SANREM CRSP Annual Meeting, Cincinnati, Ohio, October 20, 2012.
36. Norton, George W., Jeffrey Alwang, and Majdeddin Sayed Issa. 2016. Impacts of IPM on Vegetable Production in the Tropics. In, R. Muniappan and E.A. Heinricks (eds.), Integrated Pest Management of Tropical Vegetable Crops. Springer.
37. Nouhoheflin, Theodore. 2010. Assessing the Economic Impacts of Tomato Integrated Pest Management in Mali and Senegal. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
38. Rakshit, Atanu, A.N.M. Rezaul Karim, Tatjana Hristovska, and George W. Norton. 2011. Impact Assessment of Pheromone Traps to Manage Fruit Fly on Sweet Gourd Cultivation. Bangladesh Journal of Agricultural Research: 36(2): 197–203.
39. Reyes, Bryon. 2012. The Economic Impact of Improved Bean Varieties and Determinants of Market Participation: Evidence from Latin America and Angola. PhD Thesis. Department of Agricultural, Food and Resource Economics, Michigan State University, East Lancing, MI.

(*Continued*)

Appendix A. (*Continued*)

40. Reyes, Byron A., Mywish K. Maredia, Richard H. Bernsten, and Juan Carlos Rosas. 2016. Opportunities Seized, Opportunities Missed: Differences in the Economic Impact of Bean Research in Five Latin American Countries. MSU International Development Working Paper No. 151, Department of Agricultural, Food and Resource Economics, Michigan State University, East Lancing, MI.
41. Reyes, Byron, Mywish K. Maredia, and Richard H. Bersten. 2012. Improved Bean Varieties in Central America and Ecuador Generate Economic Benefits to Farmers. Impact Assessment Research Brief, USAID Dry Grain Pulses CRSP, Michigan State University, East Lancing, MI.
42. Reyes, Byron, Mywish K. Maredia, Malick Ba, Clementine Dabire, and Barry Pittendrigh. 2013. Economic Impacts of Bio-control Research to Manage Field Insect Pests of Cowpea in Burkina Faso: Baseline Survey Report. Staff Paper 13-04, Department of Agricultural, Food and Resource Economics, Michigan State University, East Lancing, MI.
43. Reyes, Byron, Richard H. Bersten, Mywish K. Maredia, Eric Crawford, Jim Kelly, and Juan Carlos Rosas. 2012. New Bean Varieties and their Economic Impacts: Evidence from Latin America. Poster. USAID Pulse CRSP, Michigan State University, East Lancing, MI.
44. Schwartz, Lisa A., James A. Sterns, and James F. Oehmke. 1993. Economic Returns to Cowpea Research, Extension, and Input Distribution in Senegal. Agricultural Economics 8: 161-171.
45. Secour, William Glen. 2012. Two Essays on Evaluation Challenges in Integrated Pest Management: An Evaluation Design for the Onion IPM PIPE and Identifying Women's Crops and Agricultural Technologies. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
46. Soufi, Widad. 2001. Economic Evaluation of the Adoption of New Varieties of Peanuts in Senegal. MS Thesis. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA.
47. Sparger, J. Adam, Jeffrey Alwang, George W. Norton, Mauricio Rivera, and Donald Breazeale. 2011. Designing an IPM Research Strategy to Benefit Poor Producers and Consumers in Honduras. Journal of Integrated Pest Management 2(3): 1-9.
48. Sterns, James A., and Richard H. Bernsten. 1994. Assessing the Impact of Cowpea and Sorghum Research and Extension in Northern Cameroon. MSU International Development Working Paper No. 43. Department of Agricultural Economics, Michigan State University, East Lancing, MI.
49. Valdivia, Corinne. 1999. Returns to investments in small ruminant research in Indonesia: The Small Ruminant Collaborative Research Support Program (SR-CRSP) in West Java. Agricultural Economics 21: 41-51.
50. Villacis, Aveiga Alexis Homero. 2012. Returns to the Introduction of New Sorghum Cultivars into the Dairy Industry of El Salvador. MS Thesis. Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.
51. Zereyesus, Yacob A., and Timothy J. Dalton. 2017. Rates of Return to Sorghum and Millet Research Investments: A Meta-Analysis. PLoS ONE 12(7): e0180414.

Cite this article: Dalton, T.J. and K. Fuglie (2022). "Costs, Benefits, and Welfare Implications of USAID Investment in Agricultural Research through U.S. Universities." *Journal of Agricultural and Applied Economics* **54**, 461–479. https://doi.org/10.1017/aae.2022.18