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Estimating *ex post* Impacts and Rates of Return to International Agricultural Research for Development

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1. Introduction

How to reconcile the challenges of rigorously assessing the impacts of international agricultural research on development outcomes with the well-documented and widely-cited high estimates of rates of return to investment in agricultural research? This question was raised during the SPIA session at ISPC17 and this note provides an initial response. It first summarizes updated estimates of rates of return to agricultural research, funded in part by SPIA, but then describes key challenges to applying rates of return to estimate *ex post* impacts of research investments and identifies key elements of an alternative approach to thinking about and measuring the impacts of CGIAR research.

As many of the outputs of international agricultural research are global public goods (non-rival and non-excludable), there exists a strong theoretical motivation for the international community to jointly invest public funds in such research. Private markets would be expected to "underprovide" such research since firms or individual investors responsible for developing a new agricultural technology may not be able to capture all, or even any, of the benefits accruing from their investments. This has long been the rationale for funding of CGIAR research. And as Pardey, Chan-Kang, Dehmer, & Beddow (2016) highlight, Sub-Saharan Africa is now lagging further behind the rest of the world in terms of per-capita investment in agricultural research and development than was the case in 1980, suggesting that there is still a strong economic development argument for investment by donor countries. While the conceptual motivation for investment in research is clear, the empirical questions of how much to invest and in which areas of research remain.

2. Estimates of rates of return to investment in agricultural research are still high

Starting with Griliches (1958), many empirical studies of the past several decades have attempted to complement this theoretical rationale for public investment in research with attempts to quantify the actual rates of return to such investments. Griliches observed the rate of adoption of hybrid maize varieties in different states of the United States and created a simple model for linking the economic benefits from higher maize yields back to investments in research. These studies were meant not to ask whether such investments were a good use of public funds, but instead attempted to provide empirical estimates of how much of the achieved benefits could plausibly be linked back to public and private investments in agricultural research. The rate of return is a summary measure of the relationship between investments (costs) and a stream of possible future benefits that takes into account time lags and other uncertainties related to whether research will lead to a "marketable" innovation and whether that innovation will contribute to economic benefits. Specifically, the "internal rate of return" (IRR) is the discount rate (the rate at which delayed future benefits are valued lower than today) that makes a Net Present Value (benefits minus costs, all in today's dollars) equal to zero.

Some have argued that the rates of return to research have declined over time, and yet whenever the literature – comprising many hundreds of individual studies on the rates of return to investment in agricultural research – has been systematically reviewed, no declining trend in the estimates over time can be found (Alston et al, 2001; Hurley et al, 2016). However, while there may not be evidence of a decline over time, there is a debate on whether the way IRR is calculated has resulted in a systematic and significant overestimate of returns. First, the calculations assume that the beneficiaries of the investments (e.g., farmers and consumers) can reinvest their benefits at the same high rate of return. Second, the cost of the investment over time is discounted at the same high rate of return. These two assumptions inflate the reported rate of return on the investment when compared with historically more reasonable reinvestment and discount rates.

To correct for these two assumptions, Rao, Hurley, & Pardey (2016) propose using the modified internal rate of return (MIRR)[1]. Examining more than 2,829 evaluations in the database of the International Science and Technology Practice and Policy (INSTEPP, v3.0) program, they find that the mean IRR is an implausible 59.6 percent whereas the recalibrated MIRR is 14.3 percent —still high, suggesting that aid investments in agricultural research pay off handsomely, but at a more realistic order of magnitude. As Rao, Hurley & Pardey (2016) argue, it is the MIRR that people are usually thinking about when they consider a rate of return as it is, by construction, a compounding rate of return equivalent to a mortgage rate or annualized return on a pension portfolio. Thus, MIRR benefits from greater salience and is a more appropriate measure for summarizing and *communicating* the costs and benefits associated with research.

The data presented in table 1 shows the imputed MIRR estimates the authors generated in relation to the originally reported IRR for a set of 2,208 studies[2] on the returns to investment in agricultural research, broken down by research area and geography. This table is reproduced from Rao, Hurley and Pardey (2017). Their calculations of MIRR are based on a 30-year time horizon for the evaluation of costs and benefits, and a discount rate of 10%. Aside from the striking deflation of estimates that is apparent when using the MIRR, the other notable feature of the figures presented in the table is the consistency across geographies and areas of research. All estimates for the mean and median fall in the range 15 – 20%.

Table 1: Reported IRRs and imputed MIRR for 2,208 studies on returns to investment in agricultural research in the INSTEPP database. Figures are based on assumption of a 30-year evaluation period for costs and benefits, and a discount rate of 10%. (Source: Rao, Hurley and Pardey, 2017, p. 23).

	N	MIRR (imputed) Mean	s.d.	IRR (calculated) Mean	s.d.
All studies	2,208	17.8	5.3	63.2	175.6
Crops	1,086	17.8	3.9	57.2	73.4
Livestock	205	19.6	8.0	132.1	511.8
All agriculture	747	16.7	5.1	48.9	82.5
Natural resources	29	16.5	2.8	45.3	31.2
US	842	17.5	6.6	67.4	261.7
Other developed country	356	18.6	5.1	75.8	137.6
Asia & Pacific	249	19.6	4.3	83.3	91.6
Latin America and Caribbean	367	17.0	3.0	46.3	27.9
Sub-Saharan Africa	259	17.0	4.1	45.1	37.3
Multinational	101	17.4	3.8	50.6	78.4
Global	13	17.1	2.2	44.0	23.2

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[1] Specifically, the IRR finds the discount rate at which the present value (ie. at year zero) at which the streams of costs and benefits from research are equal to each other. By contrast, the benefit-cost ratio is simply the ratio of the two. To convert a benefit-cost ratio to a modified rate of return, a transformation is carried out that gives us the annualized rate of return for an investment of the present value of research costs at the initiation of a project. As noted in the legend for table 1 here, assumptions are needed regarding the discount rate to apply to cost and benefit streams and the period of time over which these are evaluated. It should be noted that the choice of IRR or MIRR continues to be a point of debate in the literature – see Hurley, Rao and Pardey (2014), Oehmke (2017) and Hurley, Rao and Pardey (2017) for a detailed exchange.

[2] Representing a subset of the 2,829 INSTEPP evaluations for which sufficient information is available to allow MIRR to be imputed

3. Critiques of rates of return literature applied to agricultural research for development

While it is intuitively appealing, especially for comparing economic returns to alternative investment options, there are many conceptual and empirical concerns associated with rates of return other than simply which of the summary measures (IRR or MIRR) to use to communicate the results. This is particularly true for agricultural research for development (AR4D) investments whose expected outcomes are social and environmental as well as economic. These concerns are related to both the benefits and the costs:

Estimating and valuing the benefits

It is very challenging to generate a credible estimate of the size of the benefit that will accrue in the future (*ex ante*) or has accrued in the past (*ex post*), from investments in agricultural research. Even if one starts from the viewpoint that contributions to science and to capacity from the research process itself will be excluded, the challenges associated with estimating benefits from a research-based technology or other innovation are enormous. Ignoring most of these challenges, the IRR literature still follows the simple methods for estimating the flow of benefits from investments in agricultural research sketched out by Zvi Griliches more than half a century ago. While the IRR methodology was specifically developed to quantify benefits of yield enhancements, there is growing recognition of the challenges to accurately estimate the contribution of improved varieties to increased production *ex post* (See Box 1).

Much of the literature on rates of return to investments in agricultural research focuses on estimating an increase in Total Factor Productivity (TFP) or “k-shift” in the production function for a single crop or commodity (using yield as a proxy for TFP). By contrast, following decades of research we understand that the potential benefits to producers are much more complex, and may involve the reallocation of economic activity across the entire household enterprise. The benefits to consumers are similarly derived from more complex channels than simply the quantity increase in supply. For instance, consumer benefits may come in the form of nutritional enhancement or improved quality and again, the benefits may cut across crops. Thus, shorter duration rice may in fact reduce the aggregate supply of rice but may offer the opportunity for producers to grow chickpeas in the off-season. This, in turn, could shift the aggregate supply of chickpeas. Alternatively, rice producers may shift their rice harvest earlier, reducing the length of the hungry season that in some parts of the world can follow the depletion of the previous season’s stocks. Capturing these benefits require slightly different methods from the standard approaches, although they are not inconsistent with that framework.

Box 1. Challenges to estimating the ex post contribution of improved crop varieties to increased productivity at scale

Summary of the methods used for IRR calculations

The first step is to determine whether improved varieties (or other research-derived technologies) have been adopted at a large scale (i.e. adoption survey). If so, then the impact of widely adopted varieties on aggregate agricultural productivity is modeled as an exogenous "shock" to a market that is assumed to be in partial equilibrium (i.e. prices have adjusted until supply equals demand). The supply curve is assumed to shift down (representing a unit cost reduction for a given level of output). The magnitude of this supply shift requires an estimation of this change in the unit cost of production *with* vs. *without* agricultural research and development investments. Alston, Norton, & Pardey (1995) is the canonical text outlining how to link estimated changes in yield with vs. without a specific technology (for example, as calculated in on-station research trials), to changes in the unit cost of production. However, there are a great many different data sources that have been used to estimate the parameters that either directly (when shifts in a supply function are estimated) or indirectly (when a production, profit or cost function is estimated with the research as an argument) represent the supply shift induced by the adoption of research-derived technologies. Such sources include experimental data, industry data and subjective data arising from structured interrogation of the agricultural researchers who developed and trialed the technologies.

All else being equal, the economic surplus generated by this improvement in productivity is assumed to be shared between producers and consumers according to a series of conditions that approximate the context. Thus, the partial equilibrium model gives economists a way of estimating a "stream" of benefits that are assumed to flow from the adoption of new varieties over time, measured in dollars.

Challenges

There are numerous first-order problems with the assumptions underlying this approach and the way in which it has been operationalized by CGIAR economists over the past decades. First, data on adoption of improved varieties are scarce and, where available at large scale (i.e. across multiple geographies to allow for comparisons), are based on "expert opinion" estimation (e.g. the recent Diffusion and Impact of Improved Varieties in Africa project that SPIA managed – see Walker and Alwang, 2016). While it may have been realistic in the past to expect experts to have a comprehensive, objective view of which varieties are being adopted for a given crop across the total area grown of that crop, this is increasingly unlikely as the number of varieties expands and the ability to visually distinguish them declines (Stevenson et al, 2018). Nationally representative survey data are to be preferred, but self-reported use of improved varieties also suffer from measurement error. Indeed, several case-studies using DNA fingerprinting show that farmers can often not reliably identify the varieties they are cultivating.

Second, as de Janvry, Dustan and Sadoulet (2011) outlined in their SPIA report on methodology, adoption is a choice and thus there is a process of self-selection into adoption among any population of farmers. The characteristics of the adopting farmers (typically adopters are wealthier, more educated, and more willing to take productive risks than non-adopters) confound comparison of the productivity of adopters and non-adopters. Therefore, using estimates of the marginal contribution to increased productivity of the technology from the agricultural station and multiplying those with aggregate adoption numbers is unlikely to give a reasonable approximation of actual benefits.

Incorporating benefits related to the broader CGIAR system-level outcomes, many of which are part of long, complex causal chains unrelated to yield improvement, is arguably an even greater challenge. These benefits (and disbenefits in the form of negative ecological impacts) are not straightforward to estimate, let alone value—in monetary terms – or to discount (based on the assumption that benefits in the future are worth less than benefits today). The green accounting / environmental economics literature offers a way forward for the CGIAR to help bring these pathways for impact into the cost-benefit calculus. However, establishing the biophysical basis (i.e. the environmental production function) associated with specific interventions or technologies is often a formidable problem, one that has confounded efforts to more fully understand the impacts of NRM research for many years.

Estimating the costs (investments)

How to define the research investment that contributed to a stream of benefits? If we accept that current research builds on past research (from inside and outside the CGIAR), and that the research expenditure is just one part of the total investment needed to produce an outcome or impact, especially once we are in the realm of long-term societal goals as codified in the Sustainable Development Goals (SDGs), this apparently simple question becomes rather hard to pin down. As CGIAR research funding has become more project-oriented, even tracking and apportioning investments to areas of research and to specific outputs has become extremely difficult (Elven & Krishnan, 2018).

4. Comparison to rates of return calculations in other fields

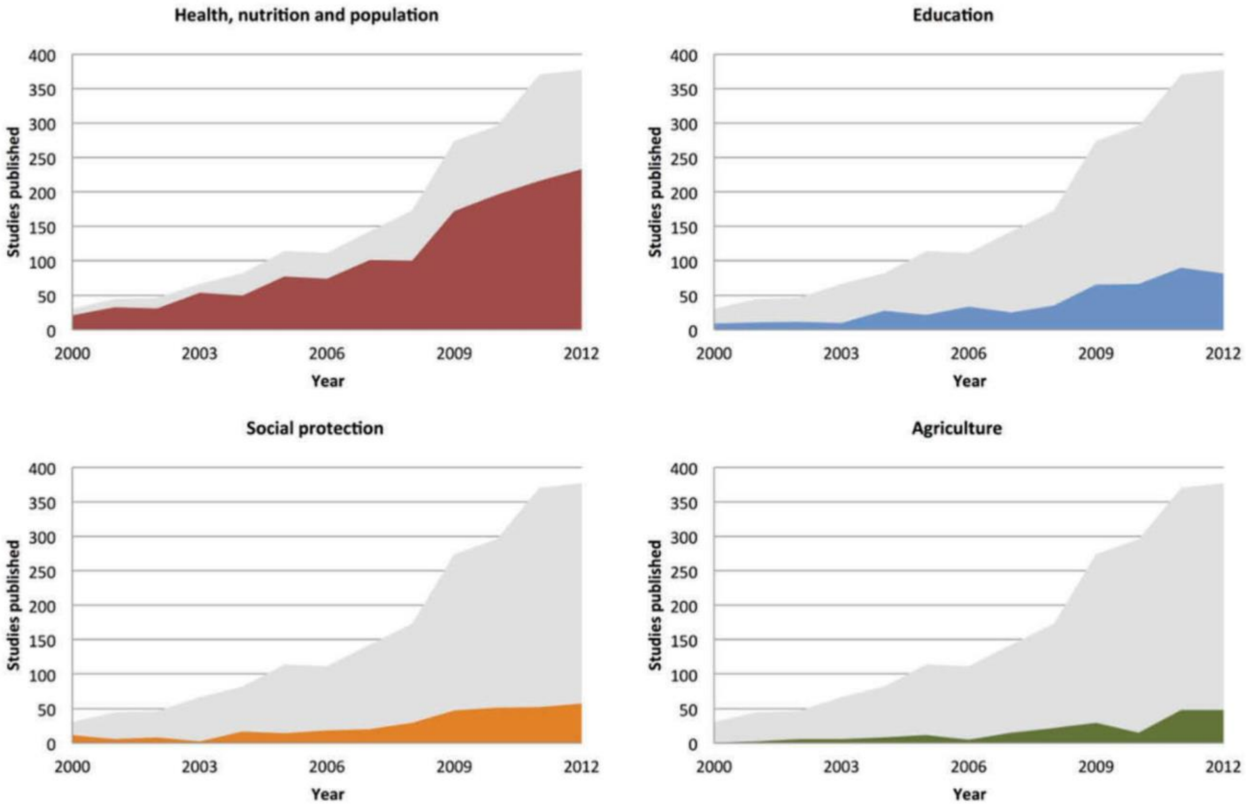
The appeal of the rate of return is the apparent simplicity it brings to inherently fraught comparisons that investors need to make about where to invest scarce resources. Agricultural research is in competition with investments in health, education, infrastructure, humanitarian emergency relief, etc. However the use of rates of return calculations is heavily skewed towards agricultural research when compared with other fields of research and/or development, and even more so when weighted by the total value of investments. In an article in Nature in which he reflects on the challenges to doing credible estimates of the rates of return to investment in research, Macilwain's (2010) example highlights how much the literature on rates of return to investments in research is dominated by agriculture (Table 2).

Table 2: Rates of return calculations for investments in public research (Source: Macilwain, 2010, p. 683). *Data from "Rising Above the Gathering Storm" (National Academies, 2006); Scott, G. et al. "The Economic Returns of Basic Research and the Benefits of University–Industry Relationships Science and Technology Policy Research (Univ. Sussex, 2001).*

Year of study	Subject	Annual rate of return % (IRR)
1958	Hybrid corn	20 – 40
1967	Poultry	21 – 45
1979	Tomato harvester	37 – 46
1968	Agricultural research	35 – 40
1968	Agricultural research	28 – 47
1979	Agricultural research	37
1979	Agricultural research	45
1981	Agricultural research	37
1991	All academic science research	28
1993	Agricultural research	43 – 67
2000	Pharmaceuticals	30+

This does not mean, however that evidence in other fields overall is more limited. Rather, the type of evidence and the way it is aggregated are different. The evidence base for the effectiveness of different specific health interventions (the products of health research) from rigorous impact evaluations is vast (see Figure 1 for a breakdown just for impact evaluations within the context of international development), and a strong tradition of systematic reviews aggregates evidence across single studies to derive more generalizable lessons. Moreover, key health research success stories (such as the development of the polio vaccines, or more recently of antiretroviral therapy) go a long way towards motivating many other health research investments.

Figure 1: Number of new impact evaluation publications by sector, 2000–2012. *Source: Cameron, Mishra, & Brown (2016), p.8. Note: Grey segment shows annual total of impact evaluations in international development across all four sectors, with color band in each figure showing the relative contributions from each sector.*



This illustrates that credible estimates of the impacts of specific research outputs can justify overall investment in a broader research portfolio. Such an approach also, implicitly but importantly, avoids conflating the uncertainty of research itself with the complexity of AR4D impact pathways. Not all research investments will pay off but the (small) share that does can justify the whole portfolio. Increasing the share that pays off—and thus the overall return to the portfolio—will come through strengthening the quality of research for development, which includes developing plausible impact pathways and theories of change informed by evidence from rigorous impact assessment.

5. If not (M)IRR, then what?

The length and complexity of the causal chain linking agricultural research to poverty make it very hard to document such impacts (Gollin, Probst and Brower, 2018). The same can be said for many other welfare indicators. In such cases, multiple pieces of evidence, often from studies using different methods - micro and macro, quantitative and qualitative - may be needed to piece together a convincing *ex post* case for a contribution from research.

The case is strongest when each study is of high quality, and SPIA has identified three main areas where rigor in impact assessment could be enhanced: accuracy in measurement of outcomes and impacts as well as costs; much more stringent requirements for establishing causal inference between the use of research and the outcomes generated by that use; and more careful sampling to ensure representativity and enable accurate modeling impacts at large spatial scale (Stevenson, Macours and Gollin, 2018).

This approach to impact evaluation, when done right, can provide much more credible and rigorous evidence on impacts and cost-effectiveness (even if it is piecemeal), than a rate of return simulation which has always relied heavily on guestimates and a limited methodological toolkit. It can also provide valuable information to inform future R&D efforts. The onus is on the user of evidence to know what set of studies makes a convincing case and whether the studies themselves are good. SPIA sees an important role in supporting these kinds of deliberations for the case of investment in AR4D by providing advice about quality standards (for users of evidence) and research designs (for researchers of prospective new studies).

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