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BRIEF

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Returns to Food and Agricultural R&D Investments Worldwide, 1958-2015

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Zvi Griliches published the first formal economic estimate of the rates of return to food and agricultural R&D in the *Journal of Political Economy* more than half a century ago. Since then many economists have published a large number of similar estimates. The consensus that has emerged from this vast body of work is that these rates of return have been exceptionally high regardless of the type of research (e.g., basic or applied), research focus (e.g., maize, wheat, rice, horticultural crops, livestock, or natural resources), or who performed the research. Yet, even with such overwhelming evidence of high rates of return, growth in public R&D spending has slowed worldwide and especially in rich countries (Pardey et al. 2016). Although agricultural commodity prices have fallen from their 2010-12 peaks, there remains widespread concern about the ability of global food supplies to meet projected demand growth. Nonetheless, current trends in public R&D spending portend slower agricultural productivity growth that is particularly disconcerting.

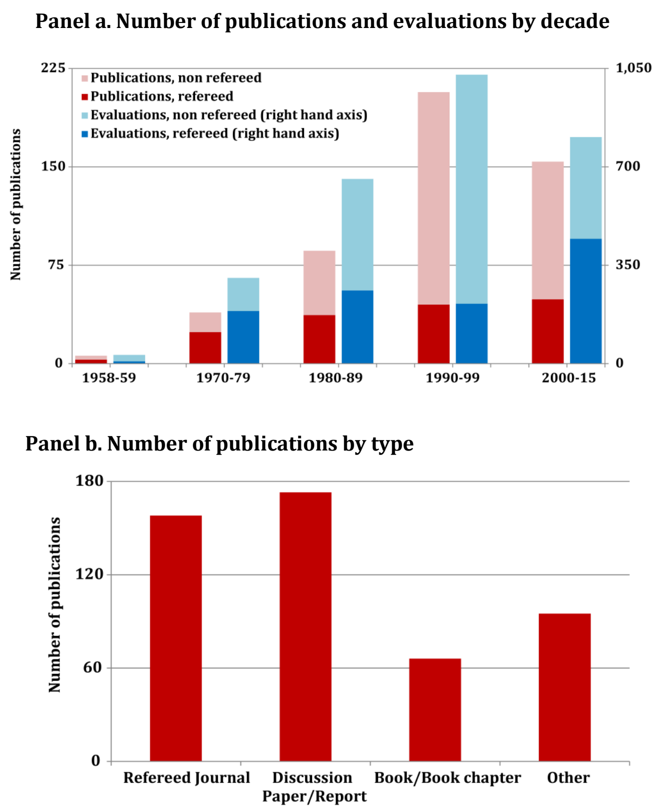
The apparent disconnect between the evidence of high rates of return and slowing growth in public R&D spending begs the simple, but important question: Why? To start to answer this and related questions, researchers with InSTePP at the University of Minnesota have compiled a comprehensive database of rate of return estimates from the worldwide literature on food and agricultural R&D. These estimates have recently been interrogated and reinterpreted amid renewed criticisms of key methodological conventions that pervade the research evaluation literature (Hurley et al. 2014a).

The purpose of this brief is to provide an up-to-date descriptive global overview of this literature and its implications taken at face value. Prior compilations of the returns-to-research evidence include Evenson et al. (1979) who reviewed 32 studies, Echeverria (1990) whose compilation included 124 studies (and about 256 evaluations), Alston et al. (2000), who analyzed 292 studies reporting 1,886 rates of return estimates, and Evenson (2001) who tabulated 260 studies and 566 estimates. This review and reassessment of the returns-to-research evidence leads to the conclusion that while most existing estimates misinterpret and likely overstate the payoffs to agricultural R&D, accounting for this upward bias still yields rates of return that are high enough to question the slowing growth in public food and agriculture R&D spending in many countries around the world.

R&D EVALUATIONS CHARACTERIZED

In version 3.0 of the InSTePP returns-to-research database summarized here, we have compiled 2,829 evaluations from 492 separate studies published between 1958 and 2015.[1] Nearly three quarters of these studies (and 65 percent of the evaluations) were published since 1990 (Figure 1, Panel a).

Figure 1: The published evidence



Source: InSTePP RtR Database ver.3.0, including all 2,829 evaluations.
Notes: "Other" includes graduate dissertations, conference papers and grey literature.

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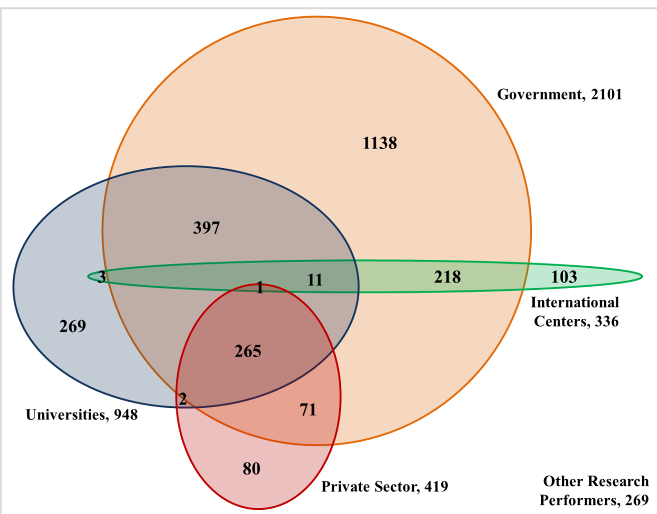
Around one third of the studies appear in refereed journals. The rest come from books, graduate dissertations, conference papers, and a good deal of grey literature, including reports published by various international and national agencies (Figure 1, Panel b).

The preponderance (88 percent) of the evaluation evidence in the database pertains to research carried out by public agencies, including either state or national government or international organizations along with universities (Figure 2). Nearly 40 percent of the reported evaluations for publicly performed R&D involve research done jointly, say by a government agency in collaboration with a university, a private company, or an international agency, while universities are involved in 34 percent of the reported evaluations. Around 12 percent cover joint public and private research, while 15 percent involves privately performed R&D. The CGIAR centers account for about 10 percent of the evaluations (and around 18 percent of the studies).[2]

Figure 2: Evaluations by research performer



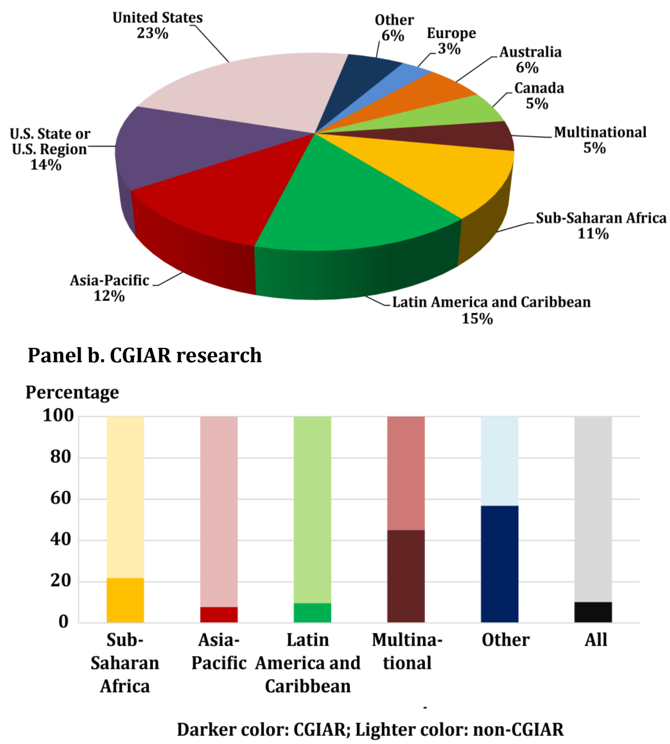
Source: InSTePP RtR Database ver.3.0.
Notes: Elliptical overlaps indicate jointly performed R&D. For example, 948 evaluations pertain to university research of which 269 involved no partners, 3 involved joint research with international centers and 397 were joint with government agencies.

Research performed in one location can affect agriculture in that location or elsewhere in the world. Figure 3, Panel a shows the geographic scope of where in the world the research was performed, with the caveat that the evaluations tagged "multinational" report studies of research with a multinational (more than one country) orientation, irrespective of the geographic location of the agency(ies) carrying out the research. The database includes studies of the impact of agricultural R&D for 85 countries around the world. Around 38 percent of the evaluations refer to research performed by federal or state agencies (including land grant universities) in the United States. Institutions from Asia-Pacific, Latin America & Caribbean, and sub-Saharan Africa account for 12, 15 and 11 percent of the evaluations respectively.

Figure 3, Panel b identifies the share of regionally performed R&D evaluations (from Figure 3, Panel a) that refer to research conducted by centers that constitute the CGIAR (CG for short), which accounts for 286 (10 percent) of the overall evaluations. A large share (45 percent) of the 140 evaluations designated multinational report on CG center research. Much of the CG's research is focused on sub-Saharan Africa, so it is of little surprise that 22 percent of the evaluations for that region pertain to research carried out by the CG.

Figure 3: Evaluations by research performer

Panel a. Region-specific evaluations



Source: InSTePP RtR Database ver.3.0, including all 2,829 evaluations.
Notes: Countries are grouped according to FAO regional classifications (FAO 2016). "Other" includes evaluations for 'other developed' countries, West Asia & North Africa and 'global' studies. "Multinational" includes observations that span multiple countries and, perhaps, multiple regions.

Over half of the evaluations (60 percent) refer to joint research and extension activities. Almost 30 percent evaluated broadly defined research investments that included both basic and applied research. Only a limited number of the evaluations (around one percent) focused solely on either basic research or extension.

Cereal crop research makes up almost one quarter of the evaluations, with maize and wheat research getting the most attention followed by sorghum and millet (Figure 4). Assessments of aggregate investment in "All

PRESENT VALUES

Perhaps the majority of investments, and especially investments in food and agricultural R&D, involve benefits and costs that are spread out over long periods of time. Therefore, it is important to consider how $1 of today's costs or benefits compare with $1 of costs or benefits realized one, two, ten or fifty years in the future. To make this comparison, one needs to know what can be done with $1 today, instead of waiting for the future. For example, if $100 of research benefits were realized today and deposited in a bank account that paid an interest rate of ten percent per year, that $100 would be worth $110 in one, $121 in two, $259.37 in ten, and $11,739.09 in fifty year(s). Alternatively, to accrue $100 in one, two, ten or fifty years from now would only require realizing research benefits of $90.91, $82.64, $38.55, or $0.85 today if those benefits could then be invested at an interest rate of ten percent per year. These are known as present values because they show how much must be deposited presently to earn $100 at some point in the future. Present values vary depending on the amount received in the future, how long in the future this amount is received, and the interest rate, which is also often referred to as the discount rate.

agriculture" account for nearly one third of the evaluations, followed by livestock which constitutes only nine percent of the studies. A small though non-trivial number of assessments of natural resources, forestry, and joint crop and livestock research are also represented in our database.

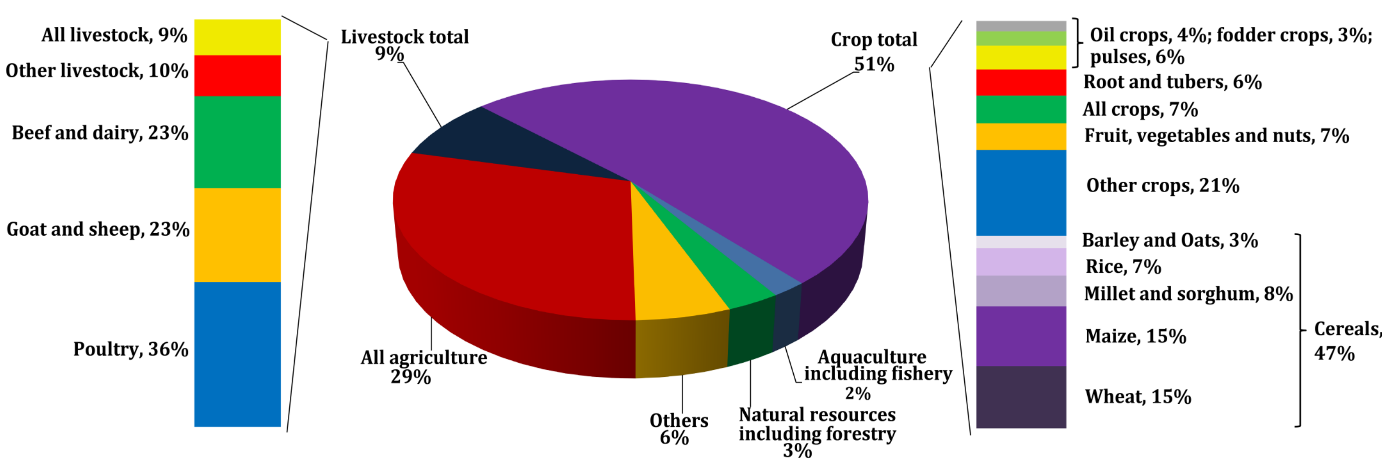
RATES OF RETURN AT FACE VALUE

Nearly all studies of the rates of return to food and agricultural R&D report an internal rate of return (IRR) or a benefit-cost ratio (BCR). The IRR is the interest rate that equates the present value of an investment's benefits to the present value of its costs. The benefit-cost ratio (BCR) is the ratio of the present value of an investment's benefits to the present value of its costs. Griliches' seminal 1958 study reported both the IRR and BCR, though Griliches expressed a preference for the BCR. This preference appears to have eluded many subsequent researchers: 94 percent of the compiled studies report IRRs, with only 34 percent reporting BCRs and one in four reporting both. Given the predominance of the IRR in the literature, it is the focus of our descriptive overview in this brief.

Figure 5, Panel a shows the distribution of IRRs and other common descriptive statistics for the full sample and a decomposition into two subsamples: one that consists of 388 evaluations drawn from three recent U.S. studies (i.e., Alston et al. 2011; Plastina and Fulginiti 2012; and Wang et al. 2012) and one that consists of the remaining evaluations. The average IRR for the full sample (red plot, Figure 5, Panel a) is 59.6 percent per year, which lies between the average of 24.5 percent per year for the recent U.S. evaluations (blue dashed plot, Figure 5, Panel a) and 65.7 percent per year for the remaining evaluations (blue solid plot, Figure 5, Panel a). A Kolmogorov-Smirnov test rejects the hypothesis that the two subsamples are drawn from the same distribution.

Given the skewedness of these distributions, the median (37.5 percent per year) provides a more robust measure of the centrality of the full sample estimates. The minimum is a dismal -100 percent per year, while the maximum is an incredible 5,645 percent per year. Seventy-five percent of these IRRs exceed 22.5 percent per year, while a quarter exceed 62.4 percent per year. The BCR estimates plotted in Figure 5, Panel b are also

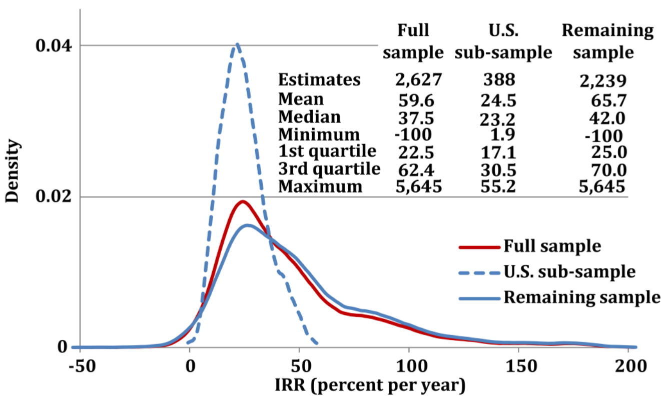
Figure 4: Evaluations by commodity category



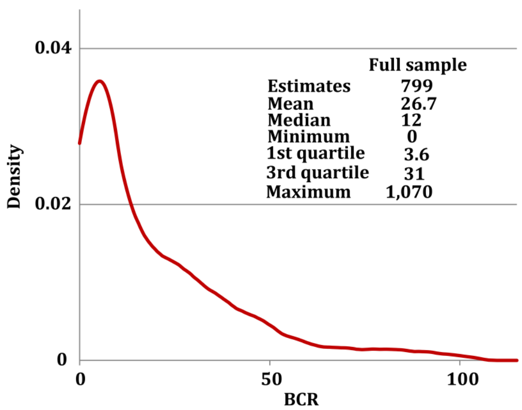
Source: InSTePP RtR Database ver.3.0, including all 2,829 evaluations.
Notes: Commodities are grouped into categories according to FAO classifications (FAO 2015) (see notes to Table 1 for details).
The stacked bars report commodity shares within the respective Livestock total and Crop Total categories.

Figure 5: Distribution of internal rate of return estimates

Panel a. Internal-rate-of-return distributions



Panel b. Benefit-cost-ratio distribution



Source: InSTePP RtR Database ver.3.0.
Notes: Vertical axis represents relative frequency. Panel a truncates the plotted distribution at –50 and 200 for display purposes. Descriptive statistics are reported for both the "full sample" of 2,630 IRR evaluations, a "U.S. subsample" that contains the 388 U.S. estimates reported by Alston et al. (2011), Plastina and Fulginiti (2012), and Wang et al. (2012), and a "remaining sub-sample" that is the full sample net of the U.S. sample. Panel b truncates the plotted distribution at 0 and 100, again for display purposes only.

positively skewed—with a mean of 26.7 and a median value of 12—, although the preponderance (75 percent) of the reported BCRs are less than 31 (and 62 percent are equal or less than 20).

Table 1 provides summary measures that characterize the distribution of the reported IRRs, including measures of the central tendency of these distributions (specifically their mean and median values) and indications of the dispersion of the estimates (specifically their standard deviation and the 5th and 95th percentiles) stratified by the type and commodity focus of the R&D. Investments in extension received the highest median return, 46.0 percent per year, followed closely by applied R&D investments, and investments in basic and applied types of R&D. Basic research shows the lowest return on investment. If such relatively low rates of return for basic research are truly the case, then fewer investments of this type would be expected, which could explain why so few evaluations of basic research (less than one percent) have been performed. A more plausible explanation however is that the difficulties in measuring and attributing the benefits to broadly conceived basic R&D are likely to bias estimates downward and lead to fewer attempts by researchers to evaluate such work.

Estimates of the returns to R&D also vary depending on the focus of the research.[3] According to this evidence, livestock R&D has tended to be more profitable, on average, than crop R&D, with poultry R&D tending to be the most profitable, but also the most variable, of the livestock estimates. Setting aside poultry research, the median IRR for the remaining livestock research is 38 percent per year, compared with 40.8 percent per year for all crops related R&D. For crops in general, estimates indicate that investments in roots and tubers have been the most profitable. Rice investments have been the most profitable for the cereal crops, though these estimates of returns are highly variable like the poultry estimates. Research focusing on natural resources (including forestry) has reportedly received much lower rates of return than other investment options. This may be an indication of the problems with trying to properly measure both the private and public benefits from this type of research (especially if a large proportion of these are non-market benefits). Alternatively, it may be an indication that the returns are indeed lower, either because of longer than average lags between R&D spending and the realization of the resulting benefits, or because the market consequences are muted by lower than average rates of adoption.

Figure 6, Panel a gives a mapped representation of the number of IRR evaluations by country and the corresponding median IRR by country. The evaluations are evenly split between more- and less-developed countries, although among the less developed countries just eight account for more than two-fifths of the evaluations. For Greece, Denmark, France, South Korea, Chad, Israel and Indonesia, the median IRR exceeds 100 percent per year, but these medians are not necessarily representative of the central tendency of the returns to research for these countries. In most instances they are based on less than two evaluations, with the exception of Indonesia where we have 40 evaluations, however 31 of them come from two studies written by the same lead author.

The box-whiskers plots in Figure 6, Panel b provide more detail on the nature of the dispersion in IRR estimates among different regions of the world. The horizontal bar within each box indicates the median IRR, the upper and lower portions of the box the 75th and 25th quartile range respectively, and the upper and lower values of the whiskers represent the 90th and 10th percentile in each region. For the more-developed countries the plots reveal relatively high IRRs for Europe, while for the less developed countries the IRRs in the Asia-Pacific region are relatively high. However, the interquartile range in

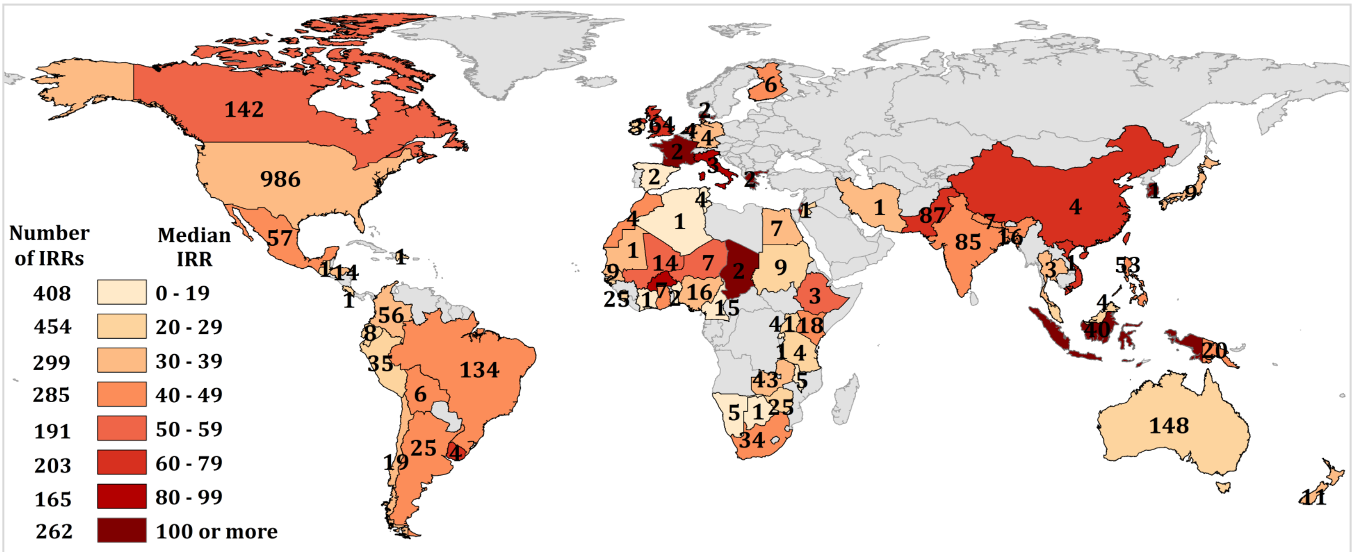
Table 1: Attributes of the Reported Internal Rate of Return Estimates

	Number of Obs.	Number of Pubs.	Central Tendency: Mean	Central Tendency: Median	Central Tendency: Standard Deviation	Range: Minimum	Range: Maximum	Range: 5th Percentile	Range: 95th Percentile
	(count)		*(percent per year)*			*(percent per year)*			
R&D ORIENTATION									
Basic	16	8	42.9	29.8	34.1	-1.3	110	-1.3	110
Applied	208	51	139.5	43.5	528.1	6	5,645	17	321
Extension	20	10	72.2	46	79.1	1.3	350	4.2	252.5
Basic & Applied	752	140	50.3	40	45.7	-56.6	526	5	116
Research and Extension	1,616	288	53.8	35	70.1	-100	1,219	10.8	161
COMMODITY ORIENTATION									
Crop Total	1,375	303	54.1	40.8	68	-100	1,736	9	135
Cereals	656	150	51.3	38.9	46.1	-100	466	11.1	130
Maize	189	47	51	41	44.6	-100	291.4	9	130
Wheat	221	65	47.4	39	36.2	-47.5	290	14	110
Rice	93	36	74.3	53.2	70.8	0	466	17	215.8
Fruits, Veg. & Nuts	94	27	82.6	39.2	200.9	1.4	1,736	5.7	260
Livestock Total	230	51	121.7	53.4	484	-2	5,645	9.3	156
Poultry	85	14	250.1	84.6	781.4	-2	5,645	18	526
Other Livestock	23	9	70.3	64	33.1	9.3	143	22.3	132
Natural Resources	36	11	43.9	38.7	30.6	0	111.2	7	111.2
All Agriculture	825	82	47.5	28.1	79.4	-22	1,219	9	138.7
GEOGRAPHICAL ORIENTATION									
United States	986	80	63	31.8	242.4	-14.9	5,645	8.9	156.7
Other developed	409	81	72.5	49	129.7	-1.3	1,736	10.5	210
Asia & Pacific	331	60	76.7	52	82	-1	1,000	17	201
Latin America & Caribbean	407	120	45.2	39.3	27.8	-22	191	15.8	96
Sub-Saharan Africa	299	82	41.9	35	40.9	-100	350	-2	119
Multinational	136	42	46.4	34.1	69.7	-47.5	677	10	88.4
Global	59	19	34.5	30.3	18.9	7	84.2	9	79
ALL STUDIES	2,627	461	59.6	37.5	161.9	-100	5,645	9.3	146

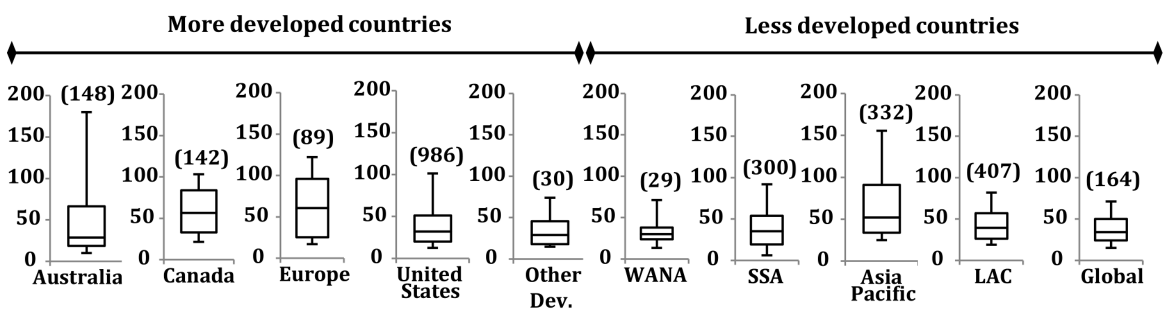
Source: Author's estimates based on InSTePP RtR Database ver.3.0. Table reports only IRR evaluations, excluding 632 BCR evaluations. Notes: Studies grouped according to FAO commodity classification standards at www.fao.org/waicent/faoinfo/economic/faodef/faodefe.htm; Cereals include barley, maize, millet, rice, sorghum, sorghum/millet and wheat; Fruit, Vegetables & Nuts include apple, banana, beans, cashew nuts, chilies, citrus, cole crops, cucurbit, fruit/nut, guava, leafy vegetables, mango, melon, onion, pineapple, plantain, stone fruits, and tomato; Poultry include poultry; Other Livestock include beef, dairy, dairy and beef, goat, sheep, sheep/goats, buffalo, cattle, other livestock, pork and swine; Natural Resources include forestry and natural resources; All Agriculture include all agriculture; Multinational includes evaluations of investments that span several countries; and Global includes evaluations that encompass a large number of countries (typically spanning multiple continents). Descriptive statistics are reported for the full sample of 2,630 IRR evaluations, including 388 US estimates reported by just three studies, Alston et al. (2011), Plastina and Fulginiti (2012), and Wang et al. (2012).

Figure 6: Geographical perspectives on the IRR evidence

Panel a. Number and median IRR by country



Panel b. Dispersion of IRRs by region



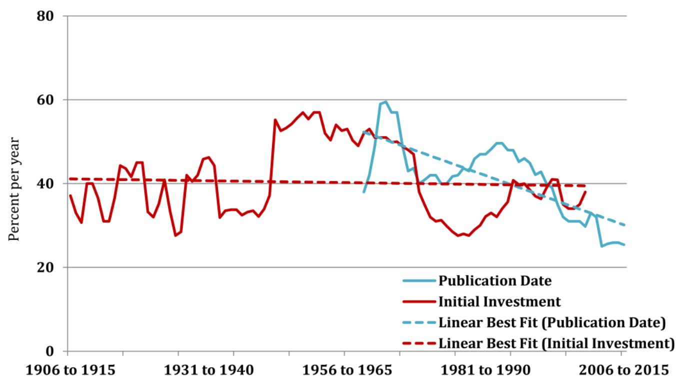
Source: InSTePP RtR Database ver.3.0.
Notes: Panel a displays the number of IRR estimates per country for the period 1958-2015. The shading indicates the range within which the median IRR for each country falls. The horizontal bar within the box and whiskers plots in Panel b indicates the median, the lower and upper ends of the box the 25th and 75th percentile respectively, with the lower and upper ends of the whiskers being the 10th and 90th percentile respectively. The bracketed number is the number of evaluations in each grouping.

these two regions is also wider indicating greater dispersion relative to elsewhere.

With the rate of growth in public R&D spending declining in many, especially rich-country jurisdictions in recent years, the question that arises is whether or not these investments are becoming more or less productive overtime. Figure 7 provides two different perspectives on the answer to this question by looking at the ten year moving median rate of return based on the year the study was published and the year of the initial R&D investment.

In terms of the publication date (blue line in Figure 7), the reported median rates of return cycle around an average of 49.5 percent per year from 1959 to 1972, thereafter trending down by 1.9 percent per year to a low of 25.4 percent between 2006-2015. The pace of decline over more recent decades is faster than the overall trend rate of decline since 1959, which averaged 0.9 percent per year. Notable spikes of up to 60 percent per year occur between 1963 and 1972, and 50 percent per year between 1984 and 1993. One possible reason for the recent declining trend is that more recent studies may have evaluated more recent investments that have been yielding lower rates of return. However, there have also been shifts in the predominant methodological conventions used in the literature that could help explain the results. For example, the length of time that an investment's benefits are evaluated has increased markedly over time (see Appendix). Typical benefit profiles initially increase, peak, and then decline over time. With such profiles, extending the length of time that benefits are evaluated means adding years with lower than average benefits, which will push the reported rate of return downward.[4]

Figure 7: Moving median of reported IRRs over time



Source: InSTePP RtR Database ver.3.0.
Notes: The dotted lines represent lines of best fit. The solid lines represent ten-year moving averages of the reported IRRs, with end points truncated when the number of IRR evaluations fell below 20.

Looking at the year of the initial investment in R&D (red line in Figure 7), the trend in the reported rates of returns is almost flat, hovering around a long-run average of 40.3 percent per year, though there is substantial and irregular variation around this trend. The reported returns to research initiated in the first half of the 20th Century trended upwards. Much of this evidence pertains to research conducted in the United States, during a period of an initial take up of a whole slew of agricultural (e.g. crop varietal, chemical, mechanical and irrigation) technologies which spurred a surge in farm productivity (Alston et al. 2015). The trend exhibits a long period of time from about 1943 to 1977 with reported rates of return at or above 40.3 percent per year. This period includes World War II and the economic expansions that followed. It ends around the time of the 1973 OPEC Oil Embargo, which was followed by the highly inflationary 1980s in the United States. During this period of high inflation, rate of return estimates dipped to a low of just under 30 percent per year between 1974 and 1985. Thereafter they trended upward toward the long-run average, around which they have fluctuated in recent years.

CONCLUSION

The wide dispersion in the reported rates of return makes it difficult to discern meaningful patterns in the evidence. Nonetheless, the mean and median values of the reported rates of return to food and agricultural R&D based on the IRR are high regardless of the type of research, commodity focus, performer, or time period of the research. Despite this evidence of high potential payoffs, growth in public spending on food and agricultural R&D has languished in many (especially high-income) countries in recent decades.

Recent research however has begun to question whether this IRR evidence should be taken at face value. Agricultural R&D spending by the United States Department of Agriculture and state agricultural experiment stations was $4.1 billion in 2000. With an annual rate of return equal to the average internal rate of return of 59.5 percent, such an investment would be worth $56.3 quintillion ($56.3 x 1018) in 2050—a value that is more than 2.3 million times the projected size of the global gross domestic product in 2050 (Foure et al. 2012). Using the median internal rate of return (37.3 percent per year), the implied 2050 value of a year 2000 R&D investment of $4.1 billion is $31.4 quadrillion, or 1,300 times the projected 2050 size of the world economy. In both cases these are astronomical implications, and it is not difficult to see how policy makers may question the credibility of such evidence.

As shown by Hurley et al. (2014a and b), the IRR exceeds and diverges from an annualized rate of return as research investments become more profitable. Furthermore Hurley et al. (2016) clarify that the IRR is an equilibrating discount rate that is not comparable to the annualized rate of return that is familiar to investors and borrowers. Thus is seems prudent to seriously consider alternative ways of summarizing the economic costs and benefits of R&D that are less prone to misinterpretation and yield more sensible empirical implications (see Alston et al. 2011 and Hurley et al. 2014a, b and 2016).

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ENDNOTES

1. After correcting some errors (and dropping several studies that reported only producer or consumer surplus estimates) in the compilations developed for Alston et al. (2000) and Hurley et al. (2014a), we added 122 new studies published during the period 1973-2015 which reported 588 additional evaluations. The study and evaluation totals we note here and describe and discuss below exclude two observations, both from a 1986 study of U.S. poultry and eggs R&D (Martinez and Norton 1986) that are extreme outliers (with IRR values in excess of a half-million percent per year). This leaves 2,827 evaluations or 3,426 estimates (consisting 2,627 IRRs and 799 BCRs). A single evaluation (of a particular technology) in a given study may report multiple IRRs or BCRs or both.

2. Prior compilations that reviewed the returns-to-research evidence on CGIAR-related research include Raitzer (2003), Raitzer and Kelly (2008), Renkow and Byerlee (2010) and McClintock and Griffith (2010).

3. These judgments of relative profitability are based on rankings of reported IRR. Caution is in order here when using IRR to rank projects as certain projects with lower IRRs may have higher net present values.

4. As Alston and Pardey (2001, p.147) describe "In a synthetic [e.g., a typical economic surplus] study, where the research-induced shifts are given, the truncation of the lag amounts to leaving out benefits, which would …[other things held constant] … bias the rate of return down. In an econometric study, however, truncation of the lag amounts to omitting relevant explanatory variables. This will lead to biased parameter estimates, with too much econometric weight (yielding larger values for the parameters) on the more recent lags. By itself, the omission of long lags here, as with the synthetic approach, amounts to understating total benefits: but unlike the synthetic studies the present value of the benefits associated with the shorter lags is now greater. In a discounting context, given typically high rates of return, the latter effect is likely to dominate (since the benefits associated with the long-past research expenditures are heavily discounted), so that truncation of the lag will tend to bias rates of return up."

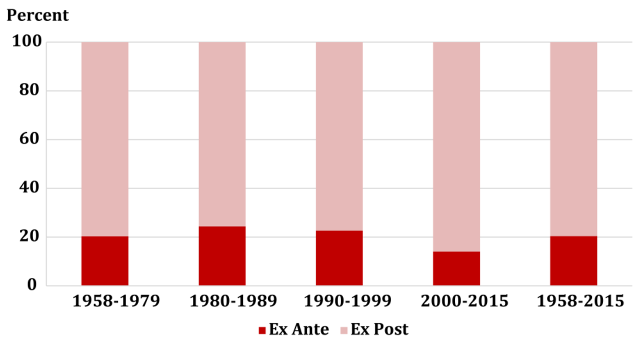
5. These data exclude the 401 evaluations that assumed benefits accrued over an infinite time horizon.

APPENDIX: METHODOLOGICAL VARIATIONS

Researchers estimating the returns to R&D have a variety of methodological choices to make. The choices made have varied over time and can influence rate of return estimates.

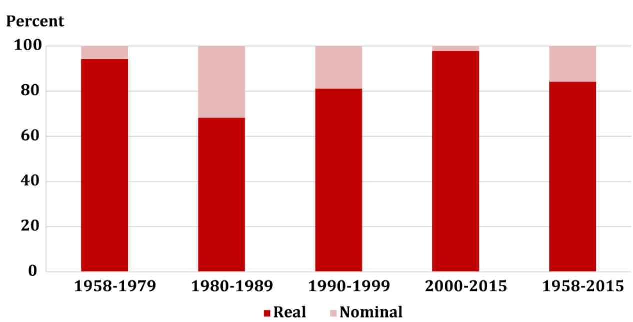
EX ANTE vs. *EX POST*

Ex Ante evaluations assess proposed investments in R&D, while *ex post* evaluations look at past R&D investments. Most evaluations reported in the literature (four out of five) were *ex post* rather than *ex ante*, and this share has remained fairly steady over time.



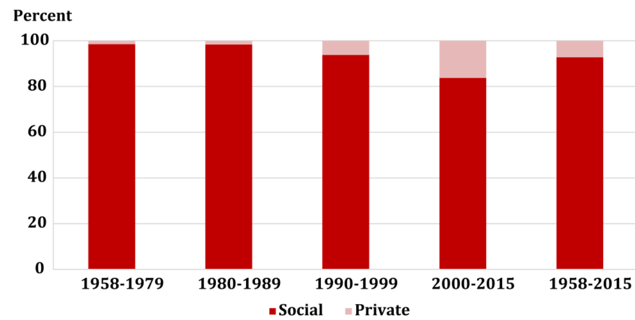
REAL vs. NOMINAL

While some studies evaluated the nominal costs and benefits of an investment, the majority have taken into account inflation by evaluating real costs and real benefits. Between 1980 and 1999 studies using nominal values were more common than prior to 1980 or after 1999. This is likely attributable to the highly inflationary period of the 1980s and the difficulty in choosing appropriate deflators to estimate the real costs and benefits of research.



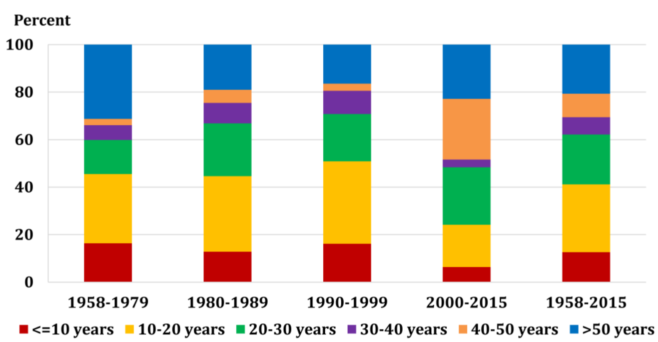
SOCIAL vs. PRIVATE

Social R&D evaluations attempt to evaluate the costs and benefits of an investment accruing to all members of society, while private evaluations focus only on the costs and benefits accruing to a particular societal group. Prior to 2000, more than 95 percent of evaluations looked at the social costs and benefits. More recently, the number of private evaluations has increased markedly representing about one in four evaluations from 2000 to 2015.



LENGTH OF BENEFITS

Agricultural R&D often produces long-lasting benefits and the length of time these benefits are evaluated can influence the estimated rate of return. Between 1958 and 1979 most evaluations (33.9 percent) assumed benefits accrued for 40 years or more, although almost 46 percent of the evaluations included benefit streams of 20 years less (and over 16 percent had streams of 10 years or less).[5] Between 2000 and 2015, once again a substantial share (over 48 percent) assumed benefits accrued for more than 40 years, while the evaluations with benefit streams of 20 years or less had shrunk to just 24 percent (with only 6 percent of the evaluations having streams 10 years or less). Thus the average length of time benefits are evaluated increased dramatically in recent years. For each of the three plotted periods beginning in 1958, the average length of the benefit stream fluctuated between 20-22 years, jumping to an average of 32 years for the period 2000-2015.



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