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Returns to Food and Agricultural R&D Investments Worldwide, 1958-2011

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Zvi Griliches published the first formal economic estimate of 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, Chan-Kang and Dehmer 2014). With prices of basic agricultural commodities soaring in recent years and renewed concerns about the ability of global food supplies to meet projected demand growth, 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 question, 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 are being interrogated and reinterpreted amid renewed criticisms of key methodological conventions that pervade the literature.

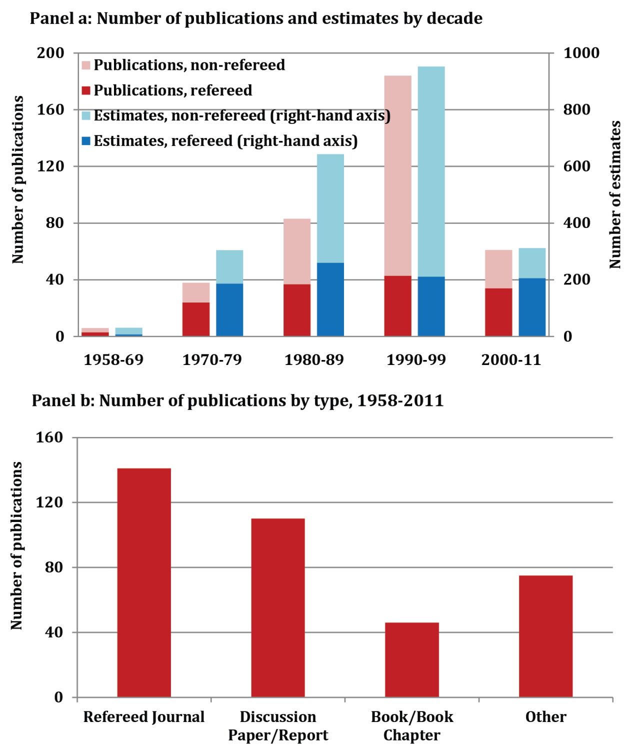
The purpose of this brief is to provide a descriptive global overview of this literature and its implications taken at face value. Other briefs in this series provide more regional overviews of the literature and a reinterpretation of the reported estimates by recasting them to circumvent previous methodological concerns. Conclusions emerging from this exercise are 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.

R&D EVALUATIONS CHARACTERIZED

We compiled 2,681 evaluation estimates from 372 separate studies published between 1958 and 2011 (Hurley, Rao and Pardey 2014a and b).[1] Nearly half of these studies (and 42 percent of the estimates) were published in the 1990s (Figure 1, Panel a).

Around 38 percent 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).

Figure 1: The published evidence



Source: Rao, Hurley and Pardey (2015) using data from InSTePP database.
Notes: "Other" includes graduate dissertations, conference papers and grey literature.

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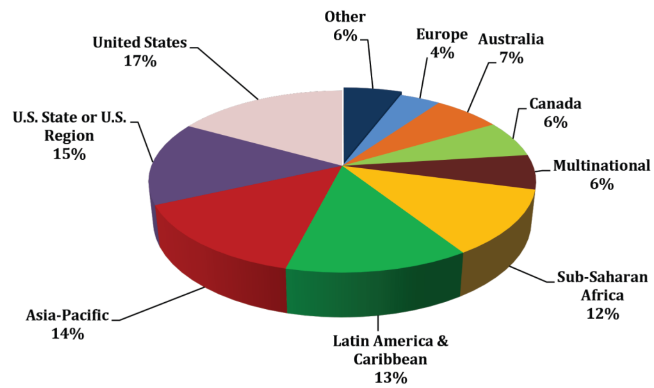
The preponderance (99 percent) of the evaluation evidence in the database pertains to research carried out by public agencies (including either state or national government or international organizations along with universities). Around one third of the reported estimates for publicly performed R&D involve research done jointly, say by a government agency in collaboration with a university, while universities are involved in 28 percent of the reported estimates. Around seven percent cover joint public and private research, while just one percent involves privately performed R&D. The CGIAR centers account for about 12 percent of the evaluation estimates (and around 18 percent of the studies).

Research performed in one location can affect agriculture in that location or elsewhere in the world. Figure 2 shows the geographic scope of where in the world the research was performed, with the caveat that the estimates 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 89 countries around the world. One-third of the evaluation estimates 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 14, 13 and 12 percent of the evaluation estimates respectively. More than 6 percent of the results are concerned with multinational research, and more than 40 percent of these multinational estimates deal with research carried out by the CGIAR.

Over half of the estimates refer to joint research and extension activities. Almost 40 percent evaluated broadly defined research investments that included both basic and applied research. Only a limited number of the evaluation estimates (less than one percent) focused solely on either basic research or extension.

Figure 2: Evaluation estimates by research performer



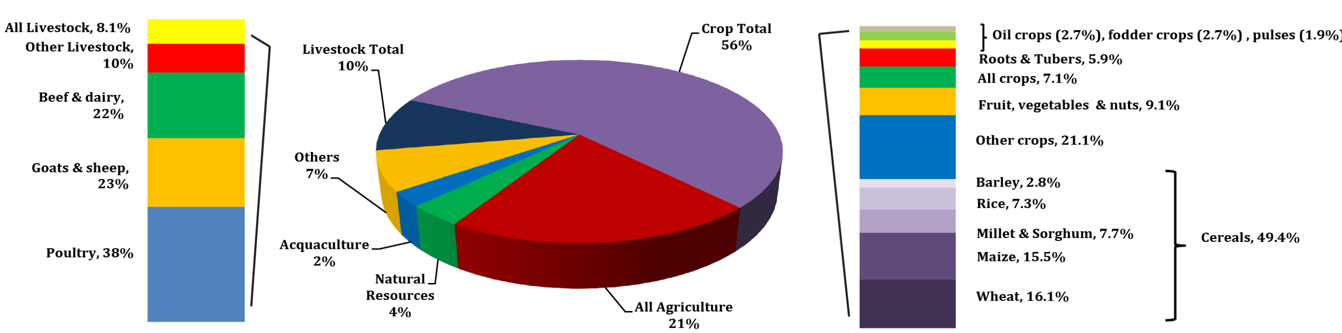
Source: InSTePP database.
Notes: Countries grouped according to FAO classification.

Cereal crop research makes up just over a quarter of the evaluation estimates, with maize and wheat research getting the most attention followed by sorghum and millet (Figure 3). Assessments of aggregate investment in "All agriculture" make up another fifth of the evaluations, followed by livestock which accounts for about one tenth 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

Figure 3: Evaluation estimates by commodity category



Source: InSTePP database.
Notes: Commodities are grouped into categories according to FAO classifications (see notes to table 1 for details). The stacked bars report commodity shares within the respective Livestock total and Crop Total categories.

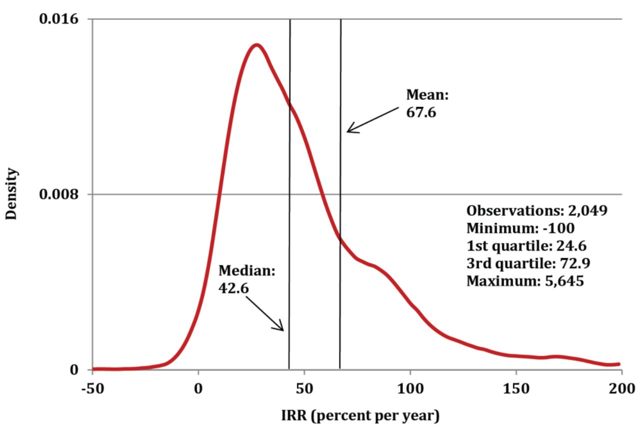
PRESENT VALUES

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.

BCR. This preference appears to have eluded many subsequent researchers: 93 percent of the compiled studies report IRRs, with only 28 percent reporting BCRs and only one in five reporting both. Given the predominance of the IRR in the literature, it is the focus of our descriptive overview in this brief.

Figure 4 shows the distribution of IRRs and other common descriptive statistics. The average IRR is 67.6 percent per year.

Figure 4: Distribution of internal rate of return estimates



Source: Hurley, Rao and Pardey (2014a).
Notes: Vertical axis represents relative frequency. For display purposes the plotted distribution was truncated at –50 and 200.

The distribution is right skewed, so the median of 42.6 percent per year provides a more robust measure of the centrality of the 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 24.6 percent per year, while a quarter exceed 72.9 percent per year.

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, the latter perhaps a more informative measure given the highly skewed nature of the distributions) 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, 47.0 percent per year, followed closely by joint research & extension investments, and investments in 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.[2] 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 38.4 percent per year, compared with 42 percent per year for all crops related R&D. For crops in general, estimates indicate that investments in pulses 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.

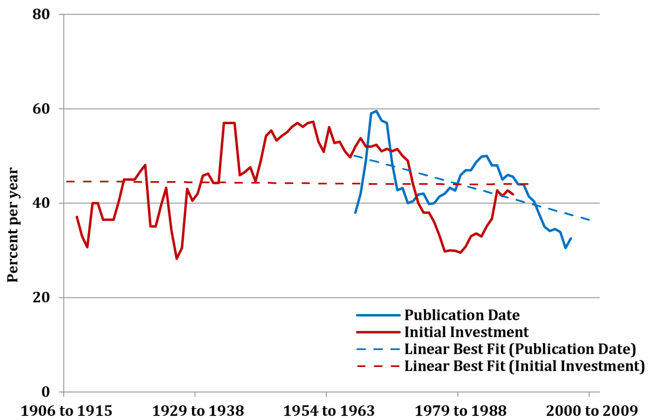
With growth in public R&D spending declining in recent years, the question that arises is whether or not these investments are becoming more or less productive overtime. Figure 5 provides two different perspectives

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

	Number of Obs	Number of Pubs.	Central Tendency			Range			
			Mean	Median	Standard Deviation	Minimum	Maximum	5th Percentile	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	6.0	5,645	17	321
Extension	17	9	77.0	47	85.2	1.3	350	1.3	350
Basic & Applied	752	140	50.3	40	45.7	-56.6	526	5	116
Res. & Ext.	1,045	175	66.2	44	83.3	-100	1,219	11.61	197.6
COMMODITY ORIENTATION									
Crop Total	1,177	207	56.2	42	72.3	-100	1,736	9	143
Cereals	589	116	52.7	39	47.8	-100	466	11	135
Maize	170	37	53.4	43.5	46.3	-100	291.4	4	135
Wheat	201	51	48.8	40	37.1	-47.5	290	14.2	110
Rice	87	30	75.1	60.1	72.4	0.0	466	17	215.8
Fruits, Veg. & Nuts	99	21	76.6	33.4	196.8	1.4	1,736	3.91	260
Livestock Total	211	41	129.3	56	504.7	2.5	5,645	10	158.5
Poultry	83	13	256.0	85.1	789.9	14	5,645	25.5	526
Other Livestock	128	33	47.2	38.4	32.2	2.5	143	6.8	111
Natural Resources	32	9	44.6	37.9	32.1	0.0	111.2	7	111.2
All Agriculture	468	72	64.5	37.9	101.8	-22.0	1,219	6.9	219.4
GEOGRAPHICAL ORIENTATION									
United States	644	72	82.8	41.3	298.0	-14.9	5,645	7.4	207.3
Other developed	388	69	75.0	50	132.6	-1.3	1,736	12	220
Asia & Pacific	314	54	76.9	52.8	83.0	-1	1,000	17	201
Latin America & Caribbean	273	55	47.9	41	30.0	-22	191	15.2	100
Sub-Saharan Africa	255	57	42.7	35	42.1	-100	350	-3.4	122.5
Multinational	133	43	47.7	32.4	72.1	-47.5	677	8.3	94.9
Global	30	11	34.5	33.6	19.5	9	84.2	9	79
ALL STUDIES	2,049	346	67.6	42.6	182.2	-100	5,645	9	166

Source: Author's estimates. Table excludes 632 BCR estimates.
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).

Figure 5: Moving median of reported IRRs over time



Source: Rao, Hurley and Pardey (2015).
Notes: The dotted lines represent lines of best fit.

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 5), reported median rates of return cycle around 44 percent per year, while trending significantly downward by 0.3 percent per year. The series starts in a trough just below 40 percent per year between 1959 and 1968, returns to this low between 1973 and 1982, and more recently reaches a new low of about 30 percent per year between 1999 and 2008. Notable spikes occur up to 60 percent per year 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 and Rao, Hurley and Pardey 2015). 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.[3]

Looking at the year of the initial investment in R&D (red line in Figure 5), the trend in the reported rates of returns is flat at around 44 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 growth in farm productivity. The trend exhibits a long period of time from about 1935 to 1975 with reported rates of return at or above 44 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 down to a low of just under 30 percent per year between 1976 and 1985. More recently they have trended upward toward 42 percent per year.

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 average (internal) rate of return of 67.6 percent, such an investment would be worth $0.67 sextillion ($0.67 x 10^{21}) in 2050 — a value that is more than 6 million times the projected size of the global gross domestic product in 2050 (Fouré et al. 2012). With such astronomical implications, it is not difficult to see how policy makers may question the credibility of such evidence.

High IRR values and their implausible implications are the result of two key assumptions used in the calculation. 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.

The IRR is the most common, but not the only way to measure the rate of return to food and agriculture R&D. Given the incredible implications of these IRR estimates and the clearly flawed assumptions they are based on, it seems prudent to seriously consider alternatives that utilize more appropriate assumptions and yield more sensible implications (see Alston et al. 2011 and Hurley, Rao and Pardey 2014a and b).

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ENDNOTES

1. After correcting some errors (and dropping several studies that reported only producer or consumer surplus estimates) in the compilation developed for Alston et al. (2000), we added 77 new studies published during the period 1999-2011 which reported 510 additional IRRs or BCRs. 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—that are extreme outliers (with IRR values in excess of a half-million percent per year). Of these 2,681 estimates, 2,049 are IRRs and 632 are BCRs.

2. 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.

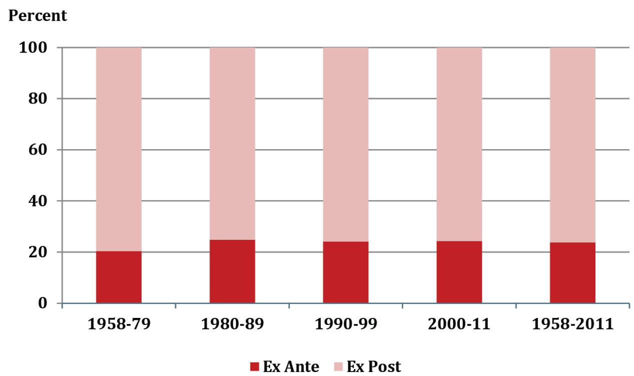
3. As Alston and Pardey (2001, p.147) describe "In a synthetic [e.g., a typical economic surplus] study, where the research-induced shifts are given, the truncation of the lag amounts to leaving out benefits, which would …[other things held constant] … bias the rate of return down. In an econometric 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."

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.

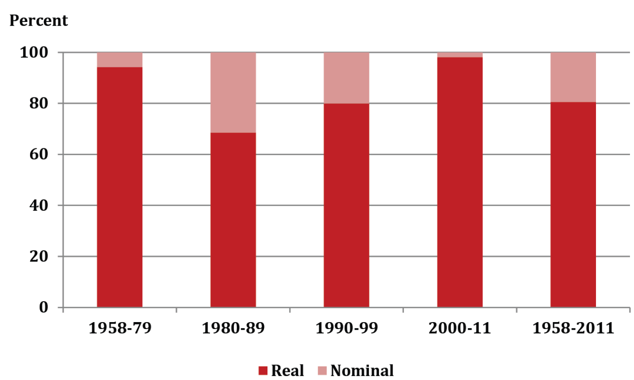
EX ANTE vs. *EX POST*

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



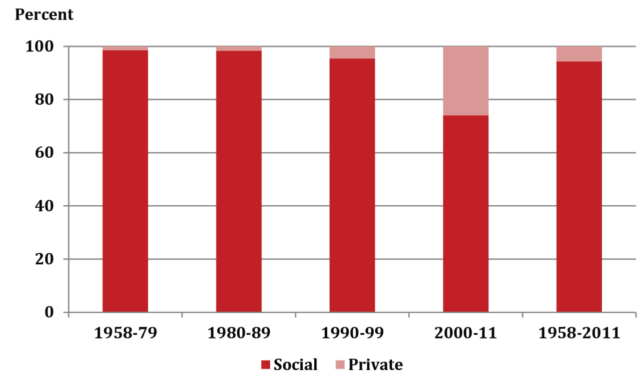
REAL vs. NOMINAL

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.



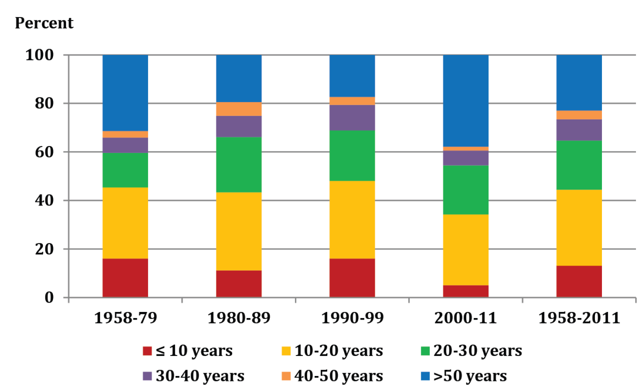
SOCIAL vs. PRIVATE

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 estimates from 2000 to 2011.



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. The length of time benefits are evaluated has increased dramatically over time. Between 1958 and 1979 most evaluations (29.3 percent) assumed benefits accrued for only 10 to 20 years. Between 1980 and 1999, most (21.6 percent) assumed benefits accrued for 20 to 30 years. Between 2000 and 2011, most (almost 40 percent) assumed benefits accrued for half a century or more.



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