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*Reassessing Research Returns: Attribution and Related Problems*

**INTRODUCTION**

It appears to be widely believed that, in general, public sector agricultural R&D has paid handsome dividends for society as a whole, but even those who hold that view may be sceptical about some of the very high reported estimates of rates of return to research.<sup>1</sup> An interest in the outcome might lead to biased estimates in some cases since rate-of-return estimates are often intended to be used to justify past investments and shore up support for future investments. Both implausibly high and unfavourable results are less likely to be acceptable for this purpose. Rates of return are also likely to involve errors even when the analyst is disinterested because it is inherently difficult to identify which research investment was responsible for a particular productivity improvement (or, conversely, which parts of the productivity benefits are attributable to a particular research investment).

Consider an ex post analysis of the contribution of agricultural R&D by the California Agricultural Experiment Station (CAES) to current productivity in California. For such an analysis we want to be able meaningfully to measure productivity growth and then attribute it among those investments by the CAES, other public R&D investments by the California state government and by other states and the United States Department of Agriculture (USDA), international R&D and private R&D investments. Moreover, we have to attribute the productivity growth not just between the CAES research and the other elements at a point in time, but among these elements over time, including the distant as well as the recent past. We want to be able to say which research, conducted (or paid for) by whom, and, in particular, when, was responsible for a particular productivity improvement. This *attribution* problem is difficult; it relates to the *appropriability* problem that underpins the in-principle argument for government involvement in research. Spillover effects of research, where research conducted by one firm (or state or country) yields benefits for free-riders, account for private sector underinvestment and the possibility of high social

\*Julian Alston, Department of Agricultural and Resource Economics, University of California at Davis, and a member of the Giannini Foundation of Agricultural Economics. Philip Pardey, International Food Policy Research Institute, Washington, DC, USA and Department of Applied Economics at the University of Minnesota. The authors thank Connie Chan-Kang, for valuable research assistance, and Ruben Echeverría, Will Masters and Michel Petit, for comments on an earlier version of the work.

rates of return. If it were easy to attribute benefits to particular investments, it should be possible to devise institutions to make the benefits appropriable. Thus the characteristics of research that gives rise to the potential for high rates of return also give rise to measurement problems.

In this paper we reassess the evidence on rates of return to research with an emphasis on the nature of the attribution problem and the likely implications of conventional evaluation methods. We suggest that the effects of attribution problems have not been neutral; on the whole, the rate-of-return estimates are likely to have been biased upwards.

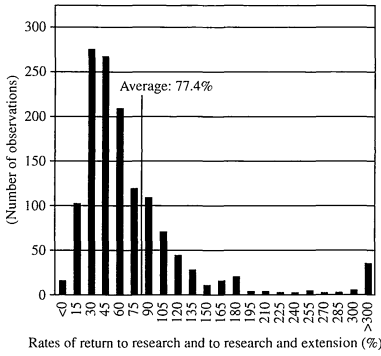
## OVERVIEW OF THE LITERATURE

Alston, Marra *et al.* (2000) and Alston, Chan-Kang *et al.* (2000) provide a comprehensive compilation, synthesis and quantitative meta-analysis of rate-of-return estimates that reveals interesting and useful patterns. A total of 292 benefit–cost studies of agricultural R&D (including extension) were compiled and these studies provide 1886 separate estimates of rates of return.<sup>2</sup> The estimates of rates of return to agricultural R&D range from small negative numbers to more than 700 000 per cent per annum. This large range reflects variation *within* groups (such as applied versus basic research, or research on natural resources versus commodities) more than *among* groups, and such large within-group variation makes it difficult to discern differences among groups. The estimated annual rates of return averaged 99.6 per cent for research only, 47.6 per cent for research and extension combined, and 84.6 per cent for extension only (Figure 1). Moreover, the distributions are generally positively skewed, with a significant number of exceptionally high rates of return.

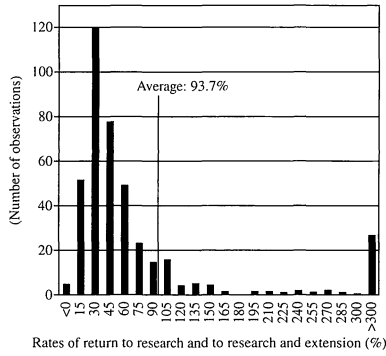
Table 1 shows the ranges of rates of return and the mean, standard deviation, mode and median rates of return according to the nature and commodity orientation of the research and the geographic location of the research performer. The preponderance of studies reported the returns to *all research* (mainly returns to aggregate investments in agricultural R&D), while just over half the observations pertained to *field crops* research and research performed in *developed countries*.

The estimates in Figure 1 and Table 1 predominantly refer to real (that is inflation-adjusted), marginal (that is, for incremental research expenditures), ex post (that is, for past investments), internal rates of return (IRRs). The implication when reporting an IRR is that the benefits from the research are being evaluated as though they can be reinvested, along with the original investment, at the same rate of return. Since the benefits are often accruing to farmers and consumers who typically do not have opportunities to invest at such high rates, it is worth dwelling briefly on what is implied by very high IRRs. A rate of return of 700 000 per cent is obviously implausible but more clearly so when we conduct a simple calculation; investing \$1 at an internal rate of return of 700 000 per cent per annum would generate \$7000 after one year, \$49 million after two years, \$343 billion after three years and

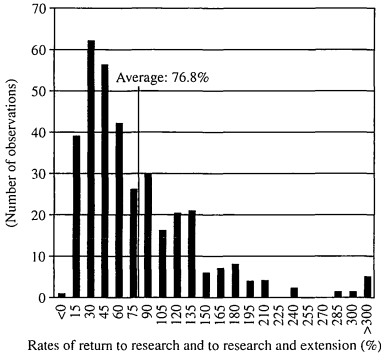
Ex-post studies (1367 observations)



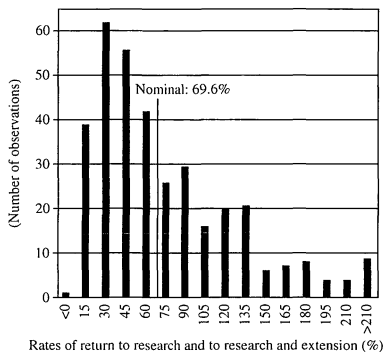
Ex-ante studies (405 observations)



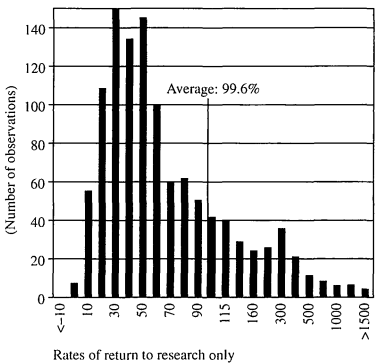
Real rates (1302 observations)



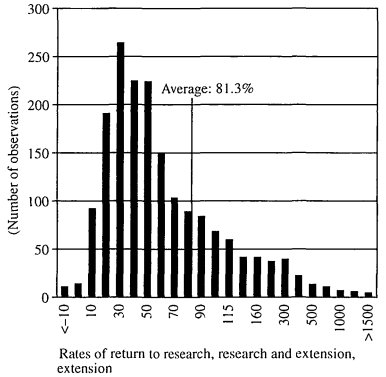
Nominal rates (351 observations)



(1144 observations)



(1852 observations)



Source: Alston et al. (2000).

FIGURE 1 Histogram of rates of return

**TABLE 1** *Rates of return*

	Number of estimates (count)	Rates of return (per cent per year)					
		Mean	Standard deviation	Mode	Median	Minimum	Maximum
<i>Nature of research</i>							
Basic	30	79.2	88.7	75	61.3	-1.3	457
Applied	192	163.5	557.0	38	46.0	6.0	5 645
All research	904	88.4	148.6	46	49.0	-7.4	1 720
Research & extension	643	46.8	43.4	28	36.0	-100.0	430
<i>Commodity orientation</i>							
Multi-commodity	436	80.3	110.7	58	47.1	-1.0	1 219
Field crops	916	74.3	139.4	40	43.6	-100.0	1 720
Livestock	233	120.7	481.1	14	53	2.5	5 645
Tree crops	108	87.6	216.4	20	33.3	1.4	1 736
Natural resources	78	37.6	65.0	7	16.5	0.0	457
<i>Geographic location</i>							
Developed countries	990	98.2	278.1	19	46	-14.9	5 645
Developing countries	683	60.1	84.1	46	43	-100.0	1 490
Multiregional	74	58.8	98.3	32	34	-47.5	677
IARC	62	77.8	188.6	26	40	9.9	1 490
<i>All studies</i>	1 772	81.2	216.1	46	44	-100.0	5 645

*Note:* Sample excludes two extreme outliers and includes only returns to research and combined research and extension, so that the overall sample size is 1772.

*Source:* Adapted from Alston, Chan-Kang *et al.* (2000, Tables 15 and 17).

\$2401 trillion the following year; that is, much more than the GDP of the world (\$26.2 trillion in 1997). Using a similar approach, we can also review the implications of a more typical estimate. If the investment of \$1.21 billion in 1980 in US public agricultural R&D had earned an internal rate of return of 48 per cent per annum, the mean for the US studies of agriculture in aggregate, the accumulated stream of benefits would be worth \$3 trillion (1980 dollars) by the year 2000, 4.5 months' worth of US total GDP, and more than 20 years' worth of US agricultural GDP. This is the implied benefit from the investment in 1980 alone. Such calculations might give rise to some doubts about whether the estimates rates of return really represent *internal* rates of return, or for that matter the true returns to research.<sup>3</sup>

### MEASUREMENT ISSUES AND PROBLEMS

Problems with data or measurement or misconceptions can result in an estimated rate of return that is higher or lower than the true value. One important problem is defining the relevant counterfactual alternative. In particular, to define what the world might be like in the absence of the particular research investment being evaluated, we have to take account of other things that might also be caused to change. Holding the right things constant is necessary to derive a stream of benefits that properly matches the stream of expenditures being evaluated.

Alston and Pardey (1996, ch. 6) suggested that the estimated rates of return to R&D in the literature have tended to be overoptimistic, relative to the corresponding true values, because the commonly used procedures understate the costs, overstate the benefits and often predetermine the research lag structure (that relates changes in productivity to past investments in research) in ways that lead to higher estimated rates of return. While some other common practices might lead to understatement of benefits, so that a particular estimated rate of return may be too high or too low, on balance we suspect that the tendency to overestimate has predominated.<sup>4</sup>

#### *Productivity measurement*

The ex post evaluation of public agricultural R&D investments often begins with a consideration of agricultural productivity. At a minimum, we want to avoid measurement problems associated with inappropriate aggregation or indexing procedures. Index number problems can account for some errors in measurement of productivity growth attributable to research, and aggregate productivity measures can be statistically sensitive to aggregation procedures (for example, Acquaye *et al.*, 2000).

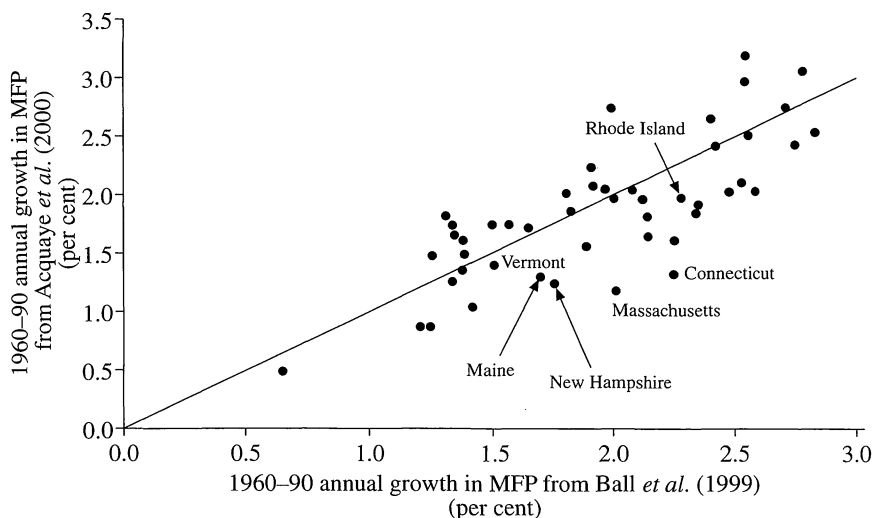
As pointed out by Schultz (1956), growth in the use of conventional inputs does not account for much of the growth in agricultural output. A part of the attribution problem is to remove the effects of various other (non-research) factors before attempting to attribute residual productivity growth to particular research investments. Understanding the sources of the growth not attributable

to conventional inputs is the first step to measuring the benefits from public R&D investments. Other factors, beyond conventional inputs, include such things as changes in input quality, output quality, improvements in infrastructure, economies of size and scale, and improvements in technology.<sup>5</sup>

Schultz (1956) and Griliches (1963) demonstrated the important role of changes in input quality in accounting for measured productivity growth in agriculture. Yet many subsequent studies of returns to public sector R&D have measured aggregate input quantities using index numbers that were not adjusted appropriately to account for changes in input quality. Such analysis overstates the productivity growth attributable to the public sector R&D by giving it credit for effects attributable either to schooling (from private or public investments in education unrelated to R&D) or to private R&D (in the case of embodied technological change).<sup>6</sup>

Craig and Pardey (1996, 2001) and Acquaye *et al.* (2000) among others have shown that correcting for changes in input quality can have major implications for understanding changes in input use and productivity in US agriculture. Adjusting for input quality change is likely to lead to a lower estimated rate of return to public sector R&D and a better appreciation of the different roles played by private and public sector R&D (in agriculture and elsewhere) and education.<sup>7</sup> Less is known about the quantitative effects of accounting for research-induced changes in output quality.

Acquaye *et al.* (2000) compared the estimates of US state-specific and national productivity growth for the 1960–90 period, as reported by Ball *et al.* (1999), and corresponding estimates based on their own calculations. In Figure 2, the annual rates of growth in these alternative indexes are plotted against



**FIGURE 2** Growth in productivity, 1960–90, Ball et al v. Acquaye et al.

each other, state by state. The national average annual growth rates are essentially indistinguishable (1.99 versus 2.00). The state-specific annual growth rates differ quite substantially in some cases, with positive or negative differences of up to 40 per cent of the estimates from Ball *et al.*, and little in the way of systematic patterns, apart from the Northeast region, where the Ball *et al.* estimates were generally substantially greater than those of Acquaye *et al.* Comparing the state-by-state estimates, by subtracting the latter estimate from that of Ball *et al.* (1999), the mean difference was small (0.07 per cent per annum) but some of the differences were quite large (the standard deviation of the differences was 0.37 per cent per annum). The simple correlation between the estimates was 0.78.

Possible explanations for these differences include differences in the raw data, and differences in the inputs and outputs included in the definition of agriculture, as well as differences in the treatments of the data. Preliminary analysis points to the importance of differences in the approaches taken to measure capital, and in the resulting measures of the stock of capital and service flows from it, and differences in the quantity indexes of land and labour arising from different quality adjustments, even though the two studies both adjusted their series for input quality changes. The point of this comparison was not to find fault with the estimates: both sets may be valid, but for different purposes. The key point is that two careful studies produced very different measures of productivity patterns, and they would imply contrasting estimates of benefits attributable to public research rather than, say, schooling reflected in labour quality, or investment in improvements reflected in land quality.

#### *Matching benefits and costs: attribution among groups*

Multi-factor productivity is the measurable stream of output not accounted for by measured inputs. We can translate the productivity measures into measures of streams of research benefits using conventional procedures. The attribution of these benefits to particular inputs can be thought of as a two-step process. Having accounted for the contribution of factors other than R&D in the first step, a second step involves discerning the share of these residual benefits most appropriately attributed to research by a particular individual, programme, state, nation or other aggregate. This attribution problem can be thought of in terms of matching streams of research benefits to corresponding streams of costs.

*Understated costs* Understatement of public sector research costs arises in a number of ways. As pointed out by Fox (1985), a common source of understatement is not allowing for the full social cost of using government revenues for R&D. General taxation involves a social cost of more than one dollar per dollar raised, an excess burden (see Findlay and Jones, 1982; Fullerton, 1991; Ballard and Fullerton, 1992). Most studies have not adjusted for the effects of the excess burden of taxation on the measures of costs, an omission that will lead to a systematic understatement of the social costs and an overstatement of the social rate of return.



Occasionally, studies of particular programmes of research fail to attribute an appropriate portion of R&D overhead (including the costs of associated basic research and institutional overheads) to the particular projects being evaluated, or they omit components of the effort involved in the development and extension phases of a project. It is not easy to estimate costs attributable to total research (let alone research on a particular set of issues), but there seems to be a tendency to understate costs of individual research programmes, and research overall, through the tendency to omit or underestimate overhead costs.

Agricultural research consists of a continuum of activities, from basic science through to field extension work, that interact with and complement one another. To measure properly the contribution of one element of the whole, it is important to control for the effects of all of the others. Many previous studies have failed to take proper account of other elements and, as a result, they have tended to overestimate the gains in productivity attributable to a particular element of total expenditures on R&D. Equivalently, many studies have underestimated the total expenditure (that includes foreign and domestic, private and public, and basic and applied work and extension) required to achieve a particular productivity gain.

*Overstated benefits* Overstatement of benefits sometimes arises from not counting the effects of private-sector R&D or spillovers of technology from other places (states, countries or competing institutions) and, instead, attributing all of the gains in productivity to only a part of the total relevant R&D spending.<sup>8</sup> Private sector research is often omitted from the analysis, or its effects are considered but not properly taken into account. This is a problem in econometric studies, in particular, where the omission of relevant explanatory variables can lead to biased estimates of the effects of variables included in the analysis.<sup>9</sup> The same may also be true of synthetic (benefit–cost) approaches, where productivity gains are deduced or assumed rather than statistically estimated, depending upon how the growth in productivity attributable to public sector R&D is estimated. Similar concerns arise in relation to the treatment of extension, private or public sector research conducted elsewhere (for example, overseas or in sectors other than agriculture) that spills into agriculture, basic (or pre-technology) research that may underpin the applied research whose effects are being assessed, and development work that was necessary to allow the commercial adoption of the results.

R&D spillovers appear pervasive and confound the attribution of research benefits. Using firm-level data from the chemical industry, Mansfield (1977) reported that the returns to innovators (private rates of return) were significantly smaller than ‘social’ rates of return. More recently, Jaffe (1986) developed a patent-based metric of R&D ‘spillover pools’ to investigate firm-to-firm spillover effects. He found indirect but convincing econometric evidence of the existence of R&D spillovers, demonstrating that, on average, firms had higher returns to their own R&D (in terms of accounting profits or market value) if that research was conducted in areas where other firms do much research. Analogous firm-to-firm spillover effects are no doubt a feature of privately performed agricultural R&D.

Agricultural economists also have been giving attention to economies of size, scale and scope in agricultural R&D, and the related questions of spatial spillovers of public agricultural research benefits (and costs), especially in recent years (for example, see Johnson and Evenson, 1999; Byerlee and Traxler, 2001). Efforts to measure spatial spillovers of agricultural research results to date have tended to apply arbitrary assumptions based on geopolitical boundaries and geographic proximity rather than agroecological similarity (for example, Huffman and Evenson, 1993).<sup>10</sup> In our own work, still in progress, in which we have used measures of agroecological similarity to parameterize technological spillover potential, we have found very substantial spillover effects among US states. An implication is that the typical studies that do not allow for interstate or international spillovers, or that capture them crudely using arbitrary assumptions, will tend to overstate the own-state research responsibility for state-level productivity growth, and understate the benefits from technological spilling from other states or elsewhere. A tendency to overstate own-state responsibility for productivity growth means that state-specific rates of return to research will tend to be overstated.

*Ambiguous effects* Some other choices in an analysis may have important implications for the estimated rate of return, but often we cannot generalize about the size and direction of the bias. For instance, most studies have not attempted to correct for the commodity programmes or other distortions, an omission which Alston *et al.* (1988) showed might lead to over- or understatement of the benefits and the rate of return.<sup>11</sup> Similarly, selection bias can be a problem – projects may have been selected for analysis because they are known to be winners, without regard for the higher proportion of unsuccessful projects, which could be regarded as contributing to an overhead cost to be borne by the successful projects. On the other hand, this should not be a problem with studies based on analyses of aggregate data, and more aggregative studies do report lower rates of return (Alston, Chan-Kang *et al.*, 2000; Alston, Marra *et al.*, 2000).

#### *Research and adoption lags: attribution over time*

Investing in research is like investing in physical capital in some respects: current productivity depends on the flow from the *stock* of usable knowledge, derived from the history of past investments, not simply the current rate of investment. Hence investment decisions taken in one period have consequences that last into the future. Indeed, the lags and dynamics in agricultural R&D are, perhaps, of greater duration and importance than those for most other types of capital investments. There are lags of several years, typically, between when an expenditure is made on research and when the resulting innovation or increment to knowledge begins to be adopted and to affect production and productivity.

The effects of a particular investment today can persist over many future production periods, perhaps forever. The effects of other R&D investments may be short-lived or non-existent. Estimating the parameters that characterize

this overall dynamic research–development–adoption–‘disadoption’ process is the most challenging empirical problem in evaluating R&D. In the evaluation of individual process innovations (for example, Griliches, 1957; Schmitz and Seckler, 1970) it is sometimes possible to obtain good information on the timing of events. More often, however, and inevitably in the case of aggregative analysis across programmes and commodities, the information is not directly accessible and must be either estimated as a part of the analysis, or imposed on it.

Even the more data-rich studies of aggregate national research systems typically use only 40 or 50 years of annual observations on research (and, perhaps, extension) expenditures to attempt to explain 20 or 30 years of variation in production or productivity. Such data are not sufficient to estimate the research lag profile accurately. Indeed, to obtain estimates at all, it has been found necessary to impose a lot of structure on the lag relationship – including presumptions about its length, smoothness and general shape – and these generally untested (or inadequately tested) restrictions have affected the answers obtained. These presumptions may have been devised arbitrarily, with a view to convenience of estimation as much as anything, rather than empirically. For example, studies have typically imposed a finite lag structure linking R&D spending to changes in productivity over less than 20 years. But some types of research have effects that persist indefinitely (for example, we still use electricity), while others have effects that are finite, as the innovation loses effect (for example, pest resistance is eroded) or is replaced by other innovations and becomes obsolete (for example, new and better agricultural chemicals or plant varieties supersede the old); some are very short-lived (for example, specific computer chips). Hence a flexible, infinite lag with some allowance for research obsolescence may be appropriate for econometric work, especially work that aims to estimate the returns to aggregate R&D.

In principle, given sufficient data, a flexible infinite lag model could be implemented using modern time-series econometric approaches. In practice, given data (and other) constraints, the infinite lag structure might be better approximated by the use of a longer finite lag structure than most studies have used (although the potential for bias might still arise). The few studies that have attempted to estimate econometrically lag lengths for aggregate agricultural R&D in the United States and the United Kingdom have found that lag lengths of *at least* 30 years may be necessary (for example, Pardey and Craig, 1989; Chavas and Cox, 1992; Huffman and Evenson, 1992, 1993; Schimmelpenninck and Thirtle, 1994; Alston *et al.* 1998). This suggests that the typical study has used a truncated lag structure that is too short.

In a synthetic study, where the research-induced shifts are given, the truncation of the lag amounts to leaving out benefits, which would, holding other things constant, bias the rate of return downwards. In an econometric study, however, truncation of the lag amounts to omitting relevant explanatory variables, which 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 the 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 has biased rates of return upwards. This view is supported by the meta-analysis of Alston, Chan-Kang *et al.* (2000) and Alston, Marra *et al.* (2000), and by the econometric analysis of Alston *et al.* (1998).

## ILLUSTRATIVE EXAMPLES OF ATTRIBUTION PROBLEMS

To illustrate the nature and importance of the attribution problems underlying estimates of rates of return to research, two examples are used. First, there is an assessment of the US benefits from wheat variety improvement R&D conducted by the Consultative Group on International Agricultural Research (CGIAR). Second, evidence on the effects of different treatments of the research lag structure on the evaluation of rates of return to agricultural R&D is considered.

### *Attribution among investors: US benefits from the CGIAR*

Pardey *et al.* (1996) investigated the impacts in the USA of varietal improvement research performed at the international agricultural research centres funded by the CGIAR. This investigation focused on two cases: the wheat-breeding work carried out at the International Wheat and Maize Improvement Centre (CIMMYT) in Mexico (and its antecedent agencies) and the rice-breeding programme of the International Rice Research Institute (IRRI) in the Philippines. Both of these programmes are very well known: they have been at the centre of efforts to develop the high-yielding grain varieties whose use in developing countries has contributed to large increases in worldwide food supplies – increases commonly referred to as the ‘Green Revolution’.

The contributions of these new varieties to farm technology in the USA have been important secondary outcomes of the CGIAR varietal improvement efforts. The objective of the work by Pardey *et al.* (1996) was to evaluate these contributions and compare the US benefits with the US contributions to the CIMMYT and IRRI wheat- and rice-breeding programmes. A review of that study illustrates the point that substantial attribution problems can arise even when the details of the technology and the timing of events are well documented and understood.

Consider the case of wheat. New varieties have been introduced into the USA at an increasing rate during the past few decades, and have made a substantial contribution to the maintenance and growth of per acre yields. Between 1900 and 1970, an average of five varieties were released in the USA every year; since 1970, over 21 wheat varieties per year have appeared. Even in the absence of increases in biological potential, there is a continuing demand for new varieties, so that host plant resistance can evolve to respond to the evolution of plant diseases and pests.

Pardey *et al.* (1996) obtained detailed data on experimental yields of the many wheat varieties at multiple locations in each of the different wheat-growing states. Comparison of experimental plot yields of new varieties with those in production in 1970 indicates that, in the absence of the new varieties, overall wheat yields would have been 33 per cent lower in 1993. The authors estimated that, over 1970–93, gains in yield generated economic benefits with a present value in 1993 of about \$43 billion (1993 dollars); that is, approximately one-ninth of the total value of wheat production over the period is attributed to increases in yields resulting from the introduction of new varieties. These are the *gross* benefits to producers and consumers as a result of the US *adoption* of the new varieties. One important aspect of the attribution problem here involves determining who deserves the credit for these gains. In particular, what is the fraction of the total benefit that can be attributed to the work done at CIMMYT?

Pardey *et al.* (1996) had complete information on the genetic (and breeding) history of each important variety grown in the USA, for each wheat-growing state, along with an extensive data set on experimental yields by variety for multiple experimental sites (within states). Unfortunately, even such uncommonly detailed information is not enough to solve the attribution problem; genotype does not translate simply into yield gains or other phenotypic characteristics such as seed size and colour as well as protein and fibre content that translate into tangible economic value. How much of the credit for the improvement in US wheat yields associated with semi-dwarfing should go to Norman Borlaug (who led the effort at CIMMYT, and earlier at the Rockefeller Foundation-sponsored research programme in Mexico that began in 1943) compared with the breeders at Washington State University (who previously made the first US cross with the *Norin 10* variety from Japan)? How much credit for the excellence of today's variety should go to the breeder who bred it, compared with the breeders and farmers who bred or selected its parents, grandparents, and so on? It is not easy to identify the separate marginal product of any particular breeder in the chain. Consequently, economists studying this type of issue have ended up using mechanistic rules to apportion the total benefits across steps in the history of development of a new variety.

Pardey *et al.* (1996) examined the effects of using a variety of subjective rules to accommodate differing perceptions of the relative importance of earlier and later breeding steps, to compute and attribute the benefits from wheat breeding. In general, they found that the US benefits from the CIMMYT wheat-breeding programme were very large. Even using their most conservative attribution rule (giving the greatest credit to the more recent, US-based innovations, and the least credit to the earlier CIMMYT-based innovations), the additional wheat produced in the USA as a consequence of the CIMMYT programme was worth \$3.6 billion dollars from 1970 to 1993. US government support of the wheat-breeding programme at CIMMYT since 1960 was about \$68 million (in present value terms as of the end of 1993). Counting only the benefits from the yield gains in the USA, the benefit–cost ratio of US support was greater than 49 to 1. This is the most conservative estimate. Using alternative attribution rules, the benefit–cost ratio could have been as high as 199 to 1.

Recall that this is the benefit from US *adoption* of varieties containing CIMMYT-derived germ plasm, which is a gross rather than net measure of the benefits to the USA from CIMMYT's wheat variety improvement programme. It does not account for the costs to the USA as a net exporter, which arise when the rest of the world adopts new CIMMYT-based wheat varieties and this leads to a reduction in the demand and price for US wheat. To evaluate this effect is a much larger undertaking; it involves measuring the effect of CIMMYT's wheat-breeding programme on the entire world. This is yet another form of attribution problem, one which generally has not been recognized in previous studies of the country-specific benefits from international agricultural research (one exception is Brennan and Bantilan, 1999).

*Attribution over time: specifying and estimating lag relationships*

In empirical work on models of effects of research on aggregate agricultural productivity, the number of lags and the shape of the lag structure are usually chosen arbitrarily; rarely is either the lag length or the lag form tested formally. Common types of lag structures include the de Leeuw or inverted-V (for example, Evenson, 1967), polynomial (for example, Davis, 1980; Leiby and Adams, 1991; Thirtle and Bottomley, 1988) and trapezoidal (for example, Huffman and Evenson, 1989, 1992, 1993; Evenson 1996). A small number of studies have used free-form lags (for example, Ravenscraft and Scherer, 1982; Pardey and Craig, 1989; Chavas and Cox, 1992), but most have restricted the lag distribution to be represented by a small number of parameters, because the time span of the data set is usually not much longer than the assumed maximum lag length.

Until quite recently, it was common to restrict the lag length to less than 20 years. In the first studies, available time series were short and lag lengths were very short. The more recent studies have tended to use more flexible, and longer, lags. Pardey and Craig (1989) used a free-form lag structure to model the relationship between agricultural productivity and public sector agricultural research, and found 'strong evidence that the impact of research expenditures on agricultural output may persist for as long as thirty years' (p.9) and that 'long lags – at least thirty years – may be necessary to capture all of the impact of research on agricultural output' (p.18). Using a non-parametric approach, Chavas and Cox (1992, p.590) confirmed Pardey and Craig's result, finding that 'at least 30 years of lags are necessary to capture the effects of public research'. Several subsequent studies have followed this advice. However, none of these studies, including Pardey and Craig (1989) and Chavas and Cox (1992), tested how much longer than 30 years or so the lag should be. In contrast, Alston *et al.* (1998) argued for representing an infinite lag between research investments and productivity with a finite lag between research investments and *changes in* the stock of knowledge.<sup>12</sup>

Alston *et al.* (1998) laid out a model in which current aggregate production depends on the utilization of a stock of useful knowledge, which is itself a function of the entire history of relevant investments in R&D – potentially an infinite lag between past investments in research and the effects on production.

They noted that the stereotypical study of returns to agricultural research has used a comparatively short, finite, lag structure (typically with fewer than 30 years and often fewer than 15 years of past research investments used to explain current productivity). A short, finite lag may reasonably represent the link between investments in research and increments to the stock of useful knowledge, but it would be a significant conceptual error to use the same lag to represent the relation between investments in research and production, since production depends on flows from the entire stock of useful knowledge, not just the latest increment to it. Moreover, an inappropriate truncation of the research lag would be likely to lead to an upward bias in the estimated rate of return to research, since truncating the lags amounts to introducing an omitted-variables problem, which will bias upwards the coefficients on the remaining, shorter lags (as argued by Alston and Pardey, 1996).

Table 2 summarizes the results from past econometric studies of returns to agricultural research across countries, classified according to the length and form of the research lag, and it can be seen that the results are consistent with expectations. Most studies have used short lags (and other restrictions on the form of the lag) and shorter lags tend to coincide with larger estimated rates of return.

To illustrate their ideas and implement the arguments, Alston *et al.* (1998) assumed a linear model of agricultural productivity of the form:

$$MFP_t = \alpha + \beta K_t + \gamma Z_t + u_t$$

where  $MFP_t$  is multi-factor productivity in year  $t$ ,  $K_t$  is the knowledge stock in year  $t$ ,  $Z_t$  is a weather-related variable in year  $t$ , and  $u_t$  is a random residual in year  $t$ . They assumed the knowledge stock grows according to:

$$K_t = (1 - \delta)K_{t-1} + I_t$$

where  $\delta$  is a proportional (declining balance) knowledge depreciation rate and  $I_t$  is the increment to knowledge as a result of (recent) research. Taking innovations to be given by a finite lag (of length  $L_R$ ) of past logarithms of research investments ( $R_{t-s}$ ) they defined:

$$I_t = \sum_{s=0}^{L_R} b_s \ln R_{t-s}$$

Combining these elements, they obtained an empirically useful model,

$$MFP_t = \alpha\delta + \beta \sum_{s=0}^{L_R} b_s \ln R_{t-s} + \gamma(Z_t - (1 - \delta)Z_{t-1}) + (1 - \delta)MFP_{t-1} + v_t$$

This model nests the primary alternatives in the literature: (a) the stock of useful knowledge never depreciates ( $\delta=0$ ), (b) the stock of useful knowledge vanishes in finite time ( $\delta=1$ ), which is implied by the archetypical model which uses a finite lag between research investments and production, and (c)

**TABLE 2** *Lag structure and estimated rates of return to research from econometric models*

Lag structure	Mean lag (years)	Number of estimates (count)	Rate of return (per cent per year)				
			Mean	Mode	Median	Minimum	Maximum
<i>Form</i>							
Polynomial	13.2	285	79.9	58	58	4.5	729.7
Trapezoidal	32.7	55	97.7	95	67	11.0	384.4
Free form	28.0 <sup>a</sup>	6	26.5	6	30	6.0	45.0
Inverted 'V'	12.0	33	134.5	30	72	23.0	562.0
Other	13.3 <sup>a</sup>	304	75.6	46	48	-1.0	1 219.0
No structure	26.6	79	45.8	54	51	0.3	185.0
No lag	0	36	48.0	46	44.4	20.9	111.0
All forms	16.3 <sup>a</sup>	762	77.9	58	53	-1.0	1 219.0
<i>Length</i>							
0	0	36	48.0	46	44.4	20.9	111.0
>0 and <15	9.9	408	95.2	58	60.7	0.0	1 219.0
15 to 30	22.3	174	58.1	46	49.9	4.5	260.0
>30	38.0 <sup>a</sup>	144	60.1	40	41.6	-1.0	384.4
Unspecified		100	60	27	41.2	8.9	337.0

*Notes:* The figures in this table encompass studies reporting econometrically estimated rates of return to agricultural research only, and to research & extension reported in Alston, Chan-Kang *et al.* (2000; Table 16).

<sup>a</sup>represents the mean length of the R&D lags for rate of return estimates based on finite lag structures. One of the 6 *free form* estimates is based on an infinite lag structure, as are 43 of the 304 *other* estimates, 44 of the 762 *all forms* estimates and 44 of the 144 >30 years estimates.



an intermediate case in which knowledge decays, but only gradually (that is,  $0 < \delta < 1$ ). This structure can be used to evaluate the typical assumptions about the shape of the research lag, as well as the implicit assumptions about knowledge depreciation associated with explicit assumptions about the research lag length.

Alston *et al.* (1998) applied this type of model to data on US aggregate agricultural productivity for the period 1949–91, making use of annual data on total agricultural R&D (including extension) expenditures by the federal government and 48 state governments, for the period 1890–91. The agricultural input data were adjusted for quality change over time, which will account for certain types of private R&D expenditures and human capital improvements, and so on, but there may still be an omitted-variables bias from the exclusion of private R&D and spillover effects. The details of the data, estimation procedures and so on, can be found in Alston *et al.* (1998).

The primary conclusion was to reinforce the view that agricultural research affects productivity much longer than most previous studies have allowed, possibly forever. A model consistent with infinite lags was statistically preferred over a more conventional model with finite lags. The results also suggest that many previous studies may have unduly restricted the shape of the research lag profile – often basing the entire distribution of lag coefficients on a single estimated parameter. The implications for reported rates of return were quite dramatic. The statistically preferred model indicated a much lower real, marginal internal rate of return to public agricultural research in the USA than was implied by a more typical model, using a trapezoidal lag structure with shorter lags.

## CONCLUSION

Studies of returns to agricultural research have yielded results suggesting that the investment has been enormously socially profitable. Many of the estimates are likely to have been biased upwards, however, as a result of attribution problems. The challenge is to determine what productivity growth would have been in the absence of a particular research investment. The typical approaches understate the period over which research affects productivity and, in econometric studies using time-series data, this means they overstate the shorter-term impacts, leading to overstated rates of return. Typical approaches also fail to take into account the effects of work done by others in the research–development–extension continuum, and this gives too much credit to the particular investor being evaluated. Corresponding work remains to be done to establish the empirical importance of incomplete correction for locational spillovers of research results in biasing estimated returns of return to research.

## NOTES

<sup>1</sup>Contrary views are the exception (for example, Pasour and Johnson, 1982; Kealey, 1996).

<sup>2</sup>Partial periodic tabulations and narrative reviews can be found in Evenson *et al.* (1979), Echeverría (1990), Alston and Pardey (1996) and Fuglie *et al.* (1996).

<sup>3</sup>Of course, even though there is a unique true rate of return to any particular set of past investments, there is no such thing as *the* rate of return to agricultural research. In a typical agricultural research portfolio, some (perhaps most) investments yield no benefits whatsoever, whereas others in the same portfolio yield very high returns, sufficient to make the portfolio as a whole profitable. Even though very high rates of return are not implausible in every context, they are much less plausible for the more aggregative investments that represent extensive portfolios.

<sup>4</sup>In particular, the conventional estimates may exclude benefits from 'maintenance' research, benefits from disease prevention, food safety R&D, or social science research related to agriculture (some of which may not show up clearly in commodity markets and some of which are not captured in conventional productivity measures) and the spillover benefits from agricultural R&D into non-agricultural applications.

<sup>5</sup>In addition, conventional productivity measures do not account for the consumption of unpriced natural resource stocks in the process of production. Rate-of-return studies that use conventional productivity indexes will tend to overstate the social value of technological changes that involve a faster rate of consumption of natural resource stocks, and will understate the benefits from technologies that involve greater environmental amenities or resource stock savings (for example, see Alston, Anderson and Pardey, 1994; Perrin and Fulginiti, 1996).

<sup>6</sup>Some studies have included additional explanatory variables to represent the effects of factors such as 'education', 'infrastructure' or 'private R&D' in a model of productivity. Clearly, the appropriate adjustments of the dependent variable can be different, depending upon the explanatory variables other than public R&D that are to be included in the model to account for the effects of input and output quality, and so on.

<sup>7</sup>It is tricky to isolate the effects of schooling from the benefits of training in the context of research programmes, a benefit that should be attributed to R&D.

<sup>8</sup>Griliches (1992) discussed the problems of accounting for R&D spillovers. Building on Griliches (1974), Pray and Neumeier (1990) discuss the role of private sector R&D.

<sup>9</sup>Private R&D expenditures ( $R^P$ ) are likely to be positively correlated with public R&D expenditures ( $R^G$ ) and, as a result, the omission of  $R^P$  from a productivity model would be expected to lead to an upwards bias in the coefficient on  $R^G$ . The confounding of effects extends beyond overstating the rate of return to  $R^G$  when we go beyond the consequences of statistical correlation and consider causal connections between the two types of expenditure and, perhaps, complementary or substitution interactions between  $R^P$  and  $R^G$  in affecting productivity.

<sup>10</sup>The pattern of geographical spillovers is largely conditioned by agroecological factors, although economic and policy factors play important roles too. For example, Pardey and Wright (2000) discuss the intellectual property protection aspects that affect the international flows of germ plasm and related biotechnologies.

<sup>11</sup>Exceptions include Oehmke (1988), Zachariah *et al.* (1989) and Huang and Sexton (1996).

<sup>12</sup>Some other recent studies, beginning from an examination of the time-series structure of the data, rather than reflection about the structural relationships, have been tending in a similar direction (for example, Akgüingör *et al.*, 1996; Makki *et al.*, 1996; Myers and Jayne, 1996). They have used time-series methods involving data transformations, such as first differences, and they have found smaller estimated rates of return as a result.

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