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Issues in benefit-cost analysis of agricultural research projects†

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Use of benefit-cost analysis for economic comparison of agricultural research projects remains confounded, *inter alia*, by lack of rigour in specifying the without-project scenario and how benefits from an innovation endure after its adoption declines. Failure to account for the without-project scenario favours projects to the extent that more benefits are foregone than costs avoided. Moreover, it is unreasonable to assume generally that aggregate benefits from an innovation continue at the peak level until the end of a 30–40 year planning horizon. A general BCA model for agricultural research projects is presented to enable flexible handling of these issues.

1. Introduction

Consistent with Randall's (1999, p. 38) observation of recent 'enthusiasm in some circles for an expanded public role for BCA [benefit-cost analysis]', there has been a growing demand for BCA of agricultural research at the project level in the last decade. This demand has come from research organisations, and researchers themselves, who want to use the technique to more reliably identify the projects that will maximise research benefits under tightening budgets (Lack 1996).

Although 'standard justifications that economists give for systematic consideration of benefits and costs in public policy are not entirely convincing to philosophers or the general public' (Randall 1999, p. 38), economists have been more concerned that procedures for evaluating agricultural research may have systematically over-estimated the rates of return (e.g., Alston, Norton and Pardey 1995, chapter 6). This is particularly a concern because the preponderance of high estimated rates of return has led many agricultural economists and agricultural scientists to conclude in

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the past that there has been under-investment in agricultural research and development (Mullen and Cox 1995; Alston *et al.* 2000).

Nevertheless this article was motivated more directly by some economists expressing reservations regarding how rigorously BCA has been applied to provide economic *comparisons* of agricultural research projects (e.g., Fisher *et al.* 1996; Pannell 1996). A particular concern has been that information asymmetry often provides scope for project proponents to strategically distort the information provided to BCA analysts (Alston *et al.* 1995; Pannell 1996; Kingwell 1999). Honest oversights are another source of inaccuracy in BCA of agricultural research projects. One reason for these oversights is that some of those applying BCA inadequately understand core economic concepts like opportunity cost and marginal analysis.

Aiming to address these latter concerns, the purpose of this article is to help analysts to think through two issues among those that Fisher *et al.* (1996) identified as compromising the rigour with which BCA has been used to provide economic rankings of agricultural research projects. These issues concern specification of: (a) the without-project scenario; and (b) how declining adoption of an innovation affects the ongoing stream of benefits from its development. It should be noted that the term *research project* as used here includes research and development, extension, and adaptation of innovations developed elsewhere. It encompasses informal projects (e.g., through farmers 'learning by doing') as well as projects by professional scientists.

The nature of benefits from agricultural research projects is discussed next. Then, the two focus issues are considered and a general BCA model for *ex ante* BCA of agricultural research projects is presented and illustrated. Finally, a conclusion is provided.

2. The nature of benefits from an agricultural research project

In this section the benefits from an agricultural research project are considered, particularly distinguishing the advances in knowledge that are targeted in most individual projects from the innovations that the advances are intended ultimately to contribute toward.

2.1 Innovations

For economists generally, the term *innovation* refers to the first introduction of any new product, process or system into the economy (Freeman 1985). Referring specifically to innovations from agricultural research, Johnston *et al.* (1992) regard an innovation as a new technology that confers benefits by increasing productivity or improving product quality compared with that achieved using existing technologies.

The benefit from an agricultural innovation is measured by the increase in economic surplus resulting from its adoption (Johnston *et al.* 1992). A common method of approximating the increase in economic surplus is, first, to estimate the unit benefit from adopting the innovation (e.g., per tonne, per head, etc.) and, second, to multiply this figure by the total number of units (e.g., tonnes, head of livestock) over which the innovation is adopted. Alston *et al.* (1995, p. 311) concluded that this method generally provides reasonable approximations of total industry benefits from innovations although estimates of changes in equilibrium prices and quantities are required to identify how producers and consumers share these benefits.

2.2 Advances

Each research project seeks to advance knowledge, but only occasionally is knowledge advanced far enough by the bundle of resources devoted to a single project that an innovation results directly. An innovation typically arises only after there has been a sufficient accumulation of advances in knowledge (hereafter termed 'advances') over a series of research projects. This is obviously true for research projects aimed at strategic-basic knowledge (Pannell 1999), but often is the case for applied research projects as well. Follow-up research is often required to develop the advances from a research project into an innovation.

So the economic significance of an advance from an agricultural research project is as an input to the production of innovations. Benefits from an advance are thus appropriately derived from the demand for the innovations that eventually are produced from it. This can be accounted for in BCA in terms of the increase in the unit benefit arising from adoption of the innovation, and also through the effect of the higher quality of the innovation on its adoption pattern (e.g., on the rate of diffusion and the ceiling level of adoption). A lower-quality innovation might be developed without the advance, or else it may not be possible to develop an innovation at all unless the project goes ahead and the targeted advance is achieved.

The benefits from an advance do not accrue until producers begin to adopt the innovations resulting from it. Some idea of the typical lag between initiating an agricultural research project and the adoption of innovations therefrom has been provided by Cox *et al.* (1997). Their study suggested that productivity gains from Australian crop and livestock research lagged behind research expenditure by at least ten years. Given a positive discount rate, the present value of making an advance depends on how long it takes for the advance to be developed into an innovation and for adoption to subsequently begin. The challenge here is to estimate how long it will take to complete all the follow-up research activities required to arrive at an adoptable innovation. This clearly becomes more difficult the more activities that are involved and the more these activities are removed geographically and/or organisationally from the project being evaluated. The challenge might be met by including in the BCA process the people who would be involved in the follow-up activities.

The point of distinguishing advances from innovations for the purpose of BCA of research projects has been to highlight the importance of accounting for the benefits and costs of the same set of activities. The benefits of a project rarely arise directly from the advance it contributes but rather from the innovation the advance paves the way for. So the effects of a project relevant for BCA include, in addition to the effect on achieving an advance and on the costs of doing so, the effect on the subsequent activities required to develop the advance into an innovation. The profile of benefits from adoption of the desired innovation cannot sensibly be attributed to a project without accounting for the whole profile of costs of accomplishing the innovation, both during the project and afterwards in upgrading its advance into an innovation.

3. Defining the without-project scenario

The economic impact of a single research project can be measured by its effects on both the costs and benefits of what is usually a much broader research effort. The net impact of a proposed project on research costs is given by deducting research costs avoided from its own costs. Equivalently, the net impact of a project on research benefits is obtained by subtracting benefits foregone due to the project from the benefits added by the project.

These impacts may of course depend importantly on whose interests are of concern. If the client is a national research funding body, for instance, then all benefits that are added and foregone, and costs that are added and avoided, within the nation should be counted. If the comparison is for a research funding body concerned only with the welfare of a particular region, in contrast, then only the benefits that are added and foregone, and costs that are added and avoided, within that region are relevant. Similarly, the perspectives of industry and the community are different, which has important implications for the treatment of externalities. This suggests that BCA analysts should engage their clients in distinguishing which benefits and costs are relevant to their decision-making.

Research costs avoided and research benefits foregone due to initiating a research project cannot be determined without first clarifying what of relevance would occur without it; that is, without explicitly specifying a without-project scenario. As noted by Marshall and Brennan (1993) and Fisher *et al.* (1996), however, without-project scenarios for BCA of agricultural research projects often have been left unspecified. One of two assumptions are implicit in such analyses: either that there are no research benefits foregone nor research costs avoided due to the proposed project, or the costs avoided cancel out the benefits foregone. In these analyses the time profiles of net costs and net benefits of going ahead with the project are identical to those of the gross costs and gross benefits of the project itself, respectively. This approach is implicit in the approaches to BCA of agricultural research projects described by Page *et al.* (1991) and Johnston *et al.* (1992).

While this approach to handling the without-project scenario may be reasonable for some agricultural research projects, it is unacceptable when a proposed project is likely to result in significant costs avoided and/or benefits foregone, and when these are unlikely to cancel each other out. This is a common situation, as is argued below.

3.1 Research benefits foregone

There is likely to be interdependence between benefits from a proposed agricultural research project and benefits from other research projects. Some progress relevant to the research problem of concern can normally be expected to occur without the project proceeding. This commonly occurs through technological ‘spill-ins’ from other formal research projects and/or through informal research resulting in ‘farmer-generated’ or ‘spontaneously emerging’ knowledge. An illustration of the significance of technological spill-ins from formal research projects is the extent to which wheat cultivars grown in one state in Australia have been bred interstate. Such cultivars account for a large share (averaging 44 per cent between 1980 and 1994) of the area sown to wheat across all mainland states, despite the existence of breeding programs within each state (Brennan 1999).

Technological spill-ins or farmer-generated knowledge would not normally be expected to generate advances to address a particular problem as promptly or effectively as a tailor-made research project. Even so, these alternative sources of advances are generated at a cost and would provide benefits to the target population of farmers (Antony and Anderson 1991). Where advances relevant to solving the problem targeted by a proposed project would arise from alternative sources, success in the project means that some or all of the benefits from these without-project advances would be foregone. This can happen because the advances from the project are superior to those from the other projects — even though the latter advances are still achieved, they therefore contribute less to an innovation than they would otherwise. It can happen also if the other projects are curtailed, postponed or cancelled in reaction to the project going ahead, and therefore the advances they would have targeted are not achieved.

To estimate the research benefits foregone requires a forecast of the advances toward the desired innovation which might be generated without the project, and the resulting time profile of benefits that would accrue once the desired innovation is developed via this alternative route. Clearly, in doing so it is important to account for the degree to which the prior advances to be developed further by the proposed project are also available to the other projects. Otherwise all the benefits from prior advances would incorrectly be included as benefits from proceeding with the proposed project.

Those best placed to predict the benefits and costs added as a result of proceeding with a given project, often the project proponents, will frequently differ from those best situated to predict the benefits from other projects that would be foregone and any costs that would be avoided. In many cases the latter task might be most appropriately performed, or at least overseen, by the organisation commissioning the suite of analyses.

One method of accounting for foregone benefits that might usefully be adapted to other circumstances was that applied by Marsden *et al.* (1980) and illustrated in figure 1. If a project proceeds then, as a result of the advance anticipated therefrom, an innovation is expected eventually to become available at t_1. Relevant advances are assumed to occur more slowly without the project, so that a similar innovation becomes available later than with the project, at t_2. The time profile of adoption is assumed to be the same in both cases, except that the with-project profile commences earlier than the without-project profile and the ceiling level of adoption is attained earlier, at t_3, with the project than at t_4 without it. The benefits from adopting the innovation that arises eventually without the project are displaced, and therefore foregone, by the benefits arriving earlier with the

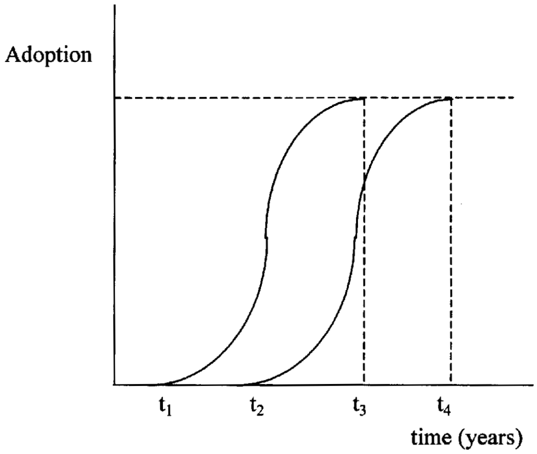

Figure 1 Impact of a research project on adoption

project. Hence the project's net benefit increases with the discount rate that is specified. The task of measuring the profile of net research benefits is thereby narrowed to estimating how much longer it would take for the similar innovation to arise from alternative sources, and choosing a discount rate. Predicting this delay obviously presents a challenge, which nevertheless can be reduced through close attention to historical trends regarding the variables (e.g., yield) that the innovation would influence.

There is considerable scope to adapt the method outlined above to a wide variety of research settings. For instance, it is not necessary to assume that the advances arising without the project would be as successful in solving the research problem of concern as would the advance from the proposed project. Thus the peak level of aggregate benefits need not be the same with and without the project. Flexibility to assume otherwise is afforded in the general model that is presented later.

3.2 Research costs avoided

Now consider the possibility of interdependence between the costs of a proposed agricultural research project and the costs of alternative research activities. Interdependence exists if proceeding with the proposed project results in curtailment, postponement or abandonment of other research activities. To the extent that this is the case, the net cost of the proposed project is less, by the value of the research costs avoided, than the cost of the resources utilised in the project itself.

The significance of the cost-avoidance effect of proceeding with a project varies according to the type of agricultural research setting being targeted. In cases where the without-project advances in relevant knowledge are likely to be incidental, such as from chance observations by farmers, the cost-avoidance effect is often minimal and safely disregarded. At the other extreme are cases where the resources available to solve a particular problem are already limiting, so that a new project can be resourced only by transferring resources from existing research activities.

The method of incorporating foregone benefits that was outlined above can be extended to account also for costs avoided. If any costs are avoided, after all, they would be those of achieving the benefits that are foregone. As for foregone benefits, the method needs to recognise that the advance generated by a project is unlikely in most cases to directly yield an innovation. Hence the method needs to account for added and avoided research costs not only in generating the targeted advance but also in the follow-up activities required to generate the desired innovation. In some cases these follow-up research activities include those of maintenance research. Maintenance research continues after an innovation is generated with the aim of protecting the research benefits achieved against biological decay, which occurs when changes in the production environment render an incumbent technology less productive (e.g., where a new strain of pathogen emerges after a disease-resistant crop cultivar is released) (Swallow *et al.* 1985).

A simple extension to the method outlined above is to assume that the time profile of undiscounted research costs is identical with and without the project, and that the lag associated with the without-project profile of costs is the same as that associated with the without-project profile of benefits. The first assumption may be considered reasonable given the method's prior assumption that the innovations emerging with and without the project will be similar. However, the second assumption is valid only when it is reasonable to expect that the without-project research activities would be abandoned if the proposed project were to proceed.

This method assumes that benefits are foregone, and the costs of achieving them are avoided, as a consequence of proceeding with a project. As observed above, however, it is possible for a project to displace the benefits from other projects without those projects being curtailed or postponed in any way. In such cases benefits are foregone without avoiding any costs. Flexibility to account for this possibility is provided in the general BCA model presented.

3.3 A default method of accounting for the without-project scenario

The method sketched above might usefully be regarded as a default method of accounting for the without-project scenario in BCA of agricultural research projects. A more detailed listing of the assumptions involved in this method follows:

1. If the proposed project does not proceed, 'substitute' research activities similar to those proposed in the project will commence L years after the scheduled commencement of project activities. The time profile of undiscounted costs for the substitute activities will therefore be identical to that for the project, except lagged by L years.
2. The advance without the project will be the same quality as that arising from the project, except it will become available L years later.
3. The time profile of follow-up and maintenance research activities (and therefore their undiscounted costs) with and without the project will be identical, except the latter time profile will lag by L years.
4. The innovation arising without the project will be the same quality as that eventually following the project. The undiscounted time profile of benefits will therefore be identical in both cases, except that the without-project profile will lag the with-project profile by L years.

Under this default method the economic impact of each research project depends on the values of L and the discount rate, as well as on the profiles of benefits and costs for the with-project scenario. Compared with a method of overlooking the without-project scenario for all the projects to be compared, the effect of this method on the economic ranking of projects will thus depend only on how L is assumed to differ across the various project evaluations (given the same discount rate for all evaluations). The key to this method is to estimate L thoughtfully *for each separate project*, bearing in mind the rate at which technological spill-ins and farmer-generated knowledge *relevant to each project* are likely to arise.

One or more of the assumptions of the default method will be unreasonable for many agricultural research projects that are proposed, however, and should be replaced by those that are more apt. In these cases we believe that the default assumptions nevertheless serve a valuable role by requiring analysts to explicitly justify departures from them. For instance, assumption 3 implies that achieving an advance earlier by L years as a result of proceeding with a project will bring forward all the required follow-up activities, and thus first adoption of the desired innovation, by L years. This assumption may be unreasonable when one or more of the follow-up activities cannot commence until complementary advances are achieved in other projects (e.g., when follow-up research depends on development of a new laboratory technique which is unlikely to become available until some years after the proposed project achieves its advance).

Failure to account for the without-project scenario means that the benefits that are foregone, and the costs that are avoided, by proceeding with a project are left unaccounted for. Consequently, any economic ranking of projects based on BCA will be systematically biased in favour of particular projects to the extent that they forego more benefits than they avoid costs.

4. Benefits from an innovation after its adoption declines

The second key issue addressed in this article concerns whether, and to what extent, benefits from an innovation decline once adoption begins to decline from its peak. As observed by Alston *et al.* (1996), it has been common in past economic evaluations of research to assume that the effects on production of new knowledge from a particular research effort eventually diminish. For instance, Page *et al.* (1991) implied that benefits from a technology cease to accrue as soon as producers replace it by adopting another technology. Nevertheless in some recent Australian discussions of how BCA should be applied to research project evaluation, including Johnston *et al.* (1992) and GRDC (1992a), it has been suggested that benefits from a technology more often than not continue indefinitely, irrespective of whether its adoption declines and ultimately ceases.

It helps in considering this issue to think about technologies in terms of the knowledge embedded in them. Since an innovation arises from new knowledge, we are then interested in the extent to which benefits continue to flow from this addition to knowledge once adoption of the innovation starts to decline. If, as claimed by Alston *et al.* (1996, p. 335), 'knowledge itself does not depreciate', then the persistence of benefits from an addition to knowledge beyond 'disadoption' of the innovation to which it first contributed depends on how much and for how long that knowledge increment contributes to subsequent innovations, as well as on the adoption of those innovations.

This reasoning underlies GRDC's argument that: 'even if technology A is displaced by technology B, the benefits of the technology B will be measured in relation to A. Thus, it can be argued that the benefits from A will still continue, *insofar as A was a stepping stone to technology B*' (1992a, p. 22, emphasis added). Those who assume that benefits from an innovation continue indefinitely are thus making the judgement, often perhaps implicitly, that the knowledge increment responsible for the innovation will contribute to an endless succession of increasingly superior innovations.

Since the caveat italicised above is critical to understanding the issue of concern here, it may be useful to provide a simple illustration. Assume that all innovations relevant to the research problem of interest are productivity-increasing and the technologies of concern are immune from biological decay. Suppose that technology *X*, allowing production of grain at a cost of $300 per tonne, is superseded by technology *Y*, allowing the cost of production to be reduced to $200 per tonne. Technology *Y* was built on the stepping stone of the knowledge increment responsible for innovating technology *X*. Technology *Z*, with a production cost of $100 per tonne, is subsequently released. Development of this technology in no way utilised the knowledge increments responsible for innovating technologies *X* or *Y*. The unit benefit from technology *Y* at any time is given by the amount by which the unit cost associated with this technology is lower than that associated with the lowest-cost technology otherwise available at that time. The unit cost associated with technology *X* is initially the relevant benchmark, and therefore the unit benefit from developing technology *Y* is initially $100 (i.e., $300 minus $200) per tonne. However, the unit cost associated with technology *Z* becomes the relevant benchmark once this technology becomes available. Thus, there is no further benefit from technology *Y* once it is replaced by technology *Z*.

GRDC (1992a, p. 19) proposed that 'the maximum time horizon for the estimation of benefits and any ongoing costs [of an agricultural research project] should be set at 40 years from the first year of the project' and

Johnston *et al.* (1992) also used this length of planning horizon. Thus benefits from an innovation continue at the peak level, once this is achieved, for the remainder of the 40 years only if: (a) adoption of the innovation does not decline from the maximum over this period, or (b) any adoption decline is offset by adoption of newer innovations building upon the knowledge increment responsible for the 'original' innovation. In contrast, the benefits from an innovation decline immediately as its own adoption declines only if the knowledge increment responsible for this innovation does not contribute to newer innovations that replace it.

Usually it is reasonable to expect that the knowledge increment responsible for an agricultural innovation will be used for some years subsequently to help develop innovations that replace it. This is consistent with the findings by Pardey and Craig (1989), Chavas and Cox (1992) and Cox *et al.* (1997) that the effects of research expenditures on agricultural output seem to persist for at least 30 years, given that adoption of agricultural innovations rarely continues for this long. Hence the position of Page *et al.* (1991), as outlined above, is likely to be reasonable for only few innovations of concern to this article. Nevertheless at some stage it is likely that this path of building upon the 'original' knowledge increment will be side-lined at least partly by another path of research that is not built upon this knowledge increment. For instance, a knowledge increment responsible for insecticide protection of a crop may be made obsolete if a cultivar genetically engineered so as to have 'natural' insect resistance is released subsequently, and if the knowledge embedded in the insecticide is unlikely to be of use elsewhere (e.g., in developing an insecticide for another crop). Alternatively, it is possible that the problem motivating an innovation can disappear. For example, an innovation targeted for a particular industry in a particular district may become obsolete if the industry disappears from the district due to changes in production, prices or government policy.

Given recent rates of technological progress and structural change within agriculture, it seems unreasonable therefore to assume generally that the benefits from a knowledge increment responsible for an agricultural innovation will remain undiminished for 40, or even 30, years. Econometric evidence for this proposition is limited, however, since 'there is little agreement in the literature about either the length or the shape of the lag profiles' (Mullen and Cox 1995, p. 113). Nevertheless some econometric support for the proposition based on Australian data has been provided by Cox *et al.* (1997) whose analysis suggested that the productivity impact of research for both crop and livestock industries peaked 20 years later.

For many agricultural research projects, therefore, it will be reasonable to assume that benefits from developing an innovation will decline at some stage during a 30–40 year planning horizon. Often the benefits are unlikely to decline to zero within this period, but rather to a lower level that depends on the degree to which it is anticipated that alternative paths of innovation will emerge, or that structural change reducing the economic significance of the research problem will occur. Flexibility in accounting for this kind of scenario is provided in the general model for BCA of agricultural research projects presented later.

The discussion of this section, it should be noted in closing, has assumed implicitly that the rate of biological decay in the innovation is the same as for the without-project technology (i.e., that both are immune from biological decay, or else their benefits both decay at the same rate), so that the unit benefit from the innovation remains unchanged over time. Otherwise, unit benefits from the innovation would increase (decrease) over time if biological decay of the innovation were slower (faster) than for the without-project technologies. An example is research developing a crop cultivar with more durable disease resistance than current cultivars. Nevertheless the general assumption is probably defensible in most cases. However, the following recommendation by GRDC implies that biological decay of an innovation always reduces the unit benefits gained from it:

> Where it is suspected that a technology will not be available indefinitely because of its decreasing applicability (e.g., a new variety may eventually no longer be disease resistant), then benefits should be curtailed or gradually reduced in accordance with the expected life of the technology. (1992b, p. 22)

This recommendation is mistaken because it fails to recognise that without-project technologies are usually also susceptible to biological decay.

5. A general model for BCA of agricultural research projects

5.1 The model

We propose a general, but operationally simple, model to assist BCA practitioners make their assumptions explicit when dealing with the issues raised above. The model accounts for the following features of both the with- and without-project scenarios:

1. Added and avoided research costs associated with the with- and without-project scenarios, respectively. Separate variables are included for annual costs of the project (i.e., cost of achieving the targeted advance under each scenario), follow-up research activities and maintenance research activities.
2. Added and foregone research benefits associated with the with- and without-project scenarios, respectively.

The model as presented offers considerable flexibility for defining the profile of benefits. The classical representation of a cumulative adoption profile is an S-shaped or logistic function (Marsh *et al.* 2000). To simplify modelling, the form of the model presented here approximates this profile linearly, and also includes a 'disadoption' phase, by using a trapezoidal adoption profile (although other functional forms, S-shaped or otherwise, could also be used). Consistent with the discussion above, the model allows the profile of benefits to extend beyond the adoption profile. This flexibility is provided by an opportunity to modify the trapezoidal adoption profile in order to allow some or all of the benefits of developing an innovation to outlast its adoption. While some econometric studies have assumed a trapezoidal profile of lagged benefits from research (e.g., Huffman and Evenson 1992; Mullen and Cox 1995), this choice has been based less on empirical evidence than on pragmatic reasons.

It is also assumed in the model presented here that the innovation exhibits the same rate of biological decay as the one it supersedes and, therefore, that a constant unit benefit accrues from the desired innovation over time. Although it was suggested above that this assumption is probably reasonable for most agricultural innovations, it will be necessary to modify the model (i.e., by allowing unit benefits to increase or decrease over time) when the assumption is inappropriate.

The with-project framework is illustrated in figure 2, where the benefits and costs are in undiscounted real values. Project costs of C_1 per year are incurred from the commencement of the project until t_1. Added follow-up research expenditure, C_2, is incurred from that time until a subsequent period

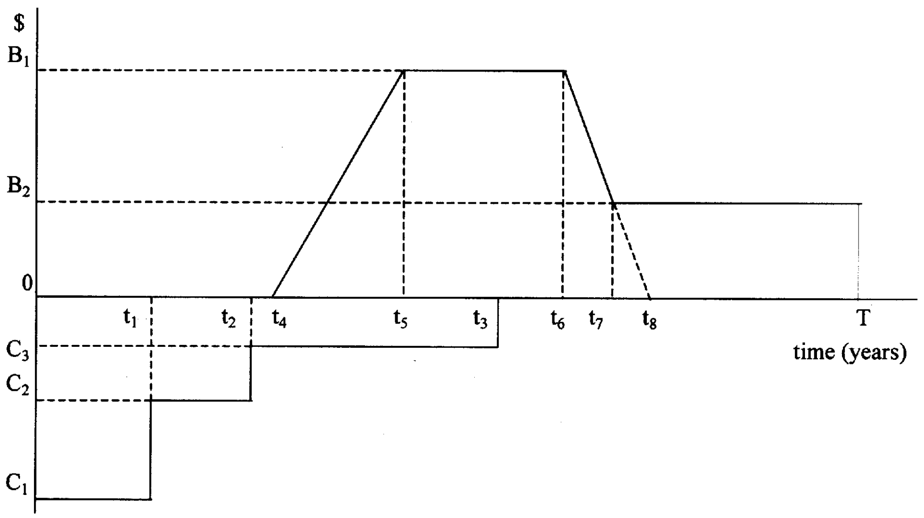

Figure 2 Illustration of the with-project scenario

t_2. The amount of C_2 required could be greater or less than C_1. Subsequently, added maintenance research expenditure, C_3, expected to be lower than C_1 or C_2, continues until period t_3. Specification of an equivalent series of cost and time parameters is required also for the without-project scenario, where the cost parameters refer to avoided costs.

As a result of the proposed project, an innovation is produced that yields a stream of benefits to those who adopt it. Those benefits begin to flow at time t_4, and reach the maximum adoption level, where benefits are B_1 at time t_5. Benefits in the years between t_4 and t_5 are obtained by linear interpolation. Benefits continue at the peak level until time t_6, when the adoption of the innovation begins to decline. If there are no enduring benefits from this innovation, then benefits cease at time period t_8. If there are enduring benefits (B_2, where $B_2 \leq B_1$), then they continue from t_7 to T, the end of the planning horizon. Benefits in the years between t_6 and t_7, and between t_7 and t_8 if there are no enduring benefits, are obtained by linear interpolation. Specification of an equivalent series of benefit and time parameters is required also for the without-project scenario, where the benefit parameters refer to foregone benefits in this case.

The adoption ceiling, and therefore peak aggregate benefits, would be the same in each scenario in the special case where the 'quality' of the resulting innovation is the same. However, the adoption ceiling frequently would be lower without the project than with it, since the resulting innovation in the former case often is less well tailored to the specific problem targeted by the project. For similar reasons, without-project enduring benefits would often be expected to be lower than those from the with-project research.

The time profiles of research benefits and costs for the with- and without-project scenarios can be contrasted graphically as in figure 3. The

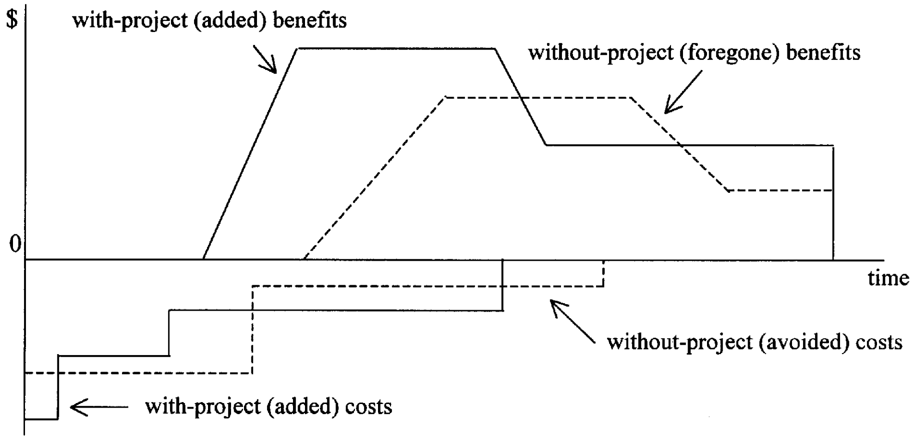

Figure 3 Illustration of the with- and without-project scenarios

Table 1 Empirical illustration of the general BCA model

	With project	Without project scenario					
		A	B	C	D	E	F
Project cost ($000/yr)	200	0	200	0	200	0	200
Follow-up research cost ($000/yr)	100	0	100	0	100	0	100
Maintenance research cost ($000/yr)	40	0	40	0	40	0	40
Peak benefits ($000/yr)	500	0	500	500	300	0	300
Enduring benefits after adoption ends ($000/yr)	0 [a]	0	0	0	0	0 [b]	150 [c]
Delay in without-project research (yrs)	n.a.	0	3	3	3	0	3
No. of years of research	3	0	3	3	3	0	3
No. of years of follow-up research	2	0	2	2	2	0	2
No. of years from initial adoption to peak	5	0	5	5	5	0	5
No. of years peak adoption persists	7	0	7	7	7	0	7
No. of years of declining adoption	4	0	4	4	4	0	4
Results:							
Net present value		1458	268	−517	1058	2996	1516

Notes: n.a. Not applicable
[a] This applies only to research settings A, B and C (see notes [b] and [c]).
[b] With-project scenario has enduring benefits of $500 000.
[c] With-project scenario has enduring benefits of $250 000.

model requires these benefits and costs to be estimated on an annual basis. Once the flow of annual costs and benefits in each case has been estimated, standard BCA measures such as the Net Present Value (NPV) and Benefit-Cost Ratio (BCR) can be calculated.

5.2 Illustrative applications

Consider a project with the features shown in the with-project column of table 1. Details of the assessment of the project under six alternative sets of assumptions regarding research settings are provided in table 1 (assuming a planning horizon of 40 years and a real discount rate of 7 per cent per year). These research settings differ in terms of the without-project scenario assumed and, in the case of settings E and F, also in terms of with-project assumptions regarding enduring benefits. In summary, the alternative research settings are:

A Without-project scenario is not accounted for. Benefits from the innovation are assumed to endure no longer than its adoption.

B Without-project scenario consists of one or more research activities which, in aggregate, have the same time profile of undiscounted benefits and undiscounted costs as the proposed project, but lagged three years. The without-project research activities would not proceed if the proposed project were to proceed, so all the benefits of these activities are foregone and all their costs are avoided.

C As for scenario B, except that the without-project costs are zero.

D As for scenario B, except that the without-project innovation is less well adapted than the with-project innovation (thus without-project peak benefits are lower).

E As for scenario A, except that with-project benefits are assumed to endure at the peak level until the end of the planning horizon.

F As for scenario D, except that with-project and without-project benefits both endure beyond adoption of the innovation, at 50 per cent of their respective peak levels.

The two key issues addressed in this article are highlighted in the comparisons made in table 1. First, the impact of accounting for a without-project scenario is shown by a comparison of settings A and B. If the true situation is as reflected in setting B but the analysis ignores benefits foregone and costs avoided (as in setting A) then, in this case, the NPV of the project is overestimated by more than five times. The effect of the without-project innovation being less successful at solving a problem than the innovation sought from a proposed project is illustrated by the NPV under setting B (where with- and without-project peak benefits are equivalent) being only 25 per cent of that under setting D (where without-project peak benefits are 60 per cent of those with the project).

Significantly, the manner in which the without-project scenario is defined is shown to be important by the marked differences between the NPVs calculated under settings B and C. Under setting B both costs avoided and benefits foregone by proceeding with the proposed project are accounted for. In contrast, setting C accounts for benefits foregone but not for any costs avoided. As a consequence the NPV calculated under setting C is lower than under setting B. In this case the setting chosen in fact makes a critical difference to whether the project should proceed on economic efficiency grounds, since its NPV is positive given setting B but negative given setting C.

Second, the impact of including enduring benefits from the project beyond the life of the project is shown by comparing setting A with setting E (the NPV with setting E is about twice as high), and setting D with setting F (the NPV with setting F is 43 per cent higher). Hence the NPV of the project can be altered significantly by the inclusion of enduring benefits, even if only at a lower level than the peak benefits.

These illustrative results highlight how important realistic accounting for the without-project scenario and enduring benefits can be for satisfactory application of BCA to a single research project. It follows that if BCA is to be used to compare the economic performance of different research projects, and if the projects vary in terms of their without-project scenarios and levels of enduring benefits, then it will be important to pay close attention to defining these features for each project if BCA is not to provide a biased economic ranking of the projects.

6. Conclusion

Two issues confounding attempts to use BCA to make economic comparisons of different agricultural research projects were addressed with the aim of helping analysts to think through these issues more systematically when specifying their models. Nevertheless it should be clear from the discussion that there is no easy recipe for dealing with these issues, and that some element of subjectivity will inevitably remain in such exercises.

With regard to defining the without-project scenario, the first of the issues covered, we concluded that assuming there are neither benefits foregone nor costs avoided when proceeding with an agricultural research project is usually unreasonable. The effect of such an assumption is to systematically favour particular projects to the extent that they involve more foregone benefits than avoided costs.

In order to encourage analysts to give due consideration to the without-project scenario, a default method of accounting for benefits foregone and costs avoided was presented. Although not all the details of the default specification will be reasonable for all projects, we believe this specification usefully highlights many of the key parameters that need to be considered if without-project scenarios are to be represented adequately on a project-by-project basis. The general BCA model for agricultural research projects presented above offers considerable flexibility in this regard.

In relation to the second of the issues addressed, we found that it is unreasonable to assume generally that the benefits from an innovation will persist at the peak level until the end of a 30–40 year planning horizon. It will often be more realistic to assume that benefits from an innovation will decline from the peak level before the end of this period. Again, the general BCA model presented earlier offers considerable flexibility for handling this issue.

Clearly, sometimes BCA models can be simplified consistently across projects without biasing the economic ranking of the projects. Where each project would add equally to research overhead costs, for instance, this effect can safely be ignored across all projects. However, given that projects generally differ in terms of their without-project scenarios, and also in relation to how persistently the benefits from their respective downstream innovations accrue, simplifications that ignore these inter-project differences weaken BCA as a reliable guide for improving the efficiency of allocating resources between agricultural research projects.

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