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ON BENEFIT-COST EVALUATION OF RESEARCH PROJECTS

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ABSTRACT

There has been a growing demand for economic evaluation of agricultural research at the project level. In this paper the way in which benefit-cost analysis should be applied to research projects is reappraised. Specifically, attempts are made to reach a clearer understanding of the benefits and costs of undertaking a given research project at a particular time. In particular, the importance of recognising that a proposed project may not be the sole source of relevant technological advance is highlighted.

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1. INTRODUCTION

1.1 Background

Until recently, economic studies of agricultural research[1] largely concentrated on relatively broad issues such as the optimality of current investment in agricultural research or the distribution of benefits from agricultural research. Much of this work involved highly aggregated industry- or sector-level studies (Antony and Anderson 1991). In any case the studies have generally either examined aggregate effects of research across a sector (eg. Mullen *et al.* 1989) or used benefit-cost analysis of particular research areas to draw inferences for wider research areas (eg. Griliches 1958; Duncan 1973; Nagy and Furtan 1978).

There has been a growing demand, however, for economic evaluation of agricultural research at the project level. The demand is coming from research managers (in research institutions and in funding organisations) and from researchers themselves. The driving force is the recent contraction in the level of funds available for agricultural research and the consequent increase in competition for funding.

Research managers are increasingly recognising the advantages to be gained in attracting future funding from documenting the benefits of successful past projects or from being able to substantiate the benefits of projects for which funds are being sought. Research managers also have a brief to maximise the net benefits from their research programs. One of the main ways of achieving this is to undertake economic evaluations of each of the projects competing for the resources available to a program so as to be in a position to support those projects with the highest expected pay-offs.

However, economists have come to recognise that assisting research managers in making decisions about how to allocate available resources among possible research projects is a complex exercise. 'Conceptually, the decisions made by an administrator of research funds are among the most difficult economic decisions to make and to evaluate ... ' (Griliches 1958). The task remains daunting: 'Undertaking evaluations of this nature is harder than it first appears' (Johnston *et al.* 1992).

1.2 Recent Developments

Benefit-cost analysis (BCA) is a technique for aggregating the preferences of individuals in a society in order to be able to compare the benefits and costs of any action in monetary terms (Pearce 1983). Johnston (1990) argued that BCA is an appropriate technique for assisting research managers to evaluate projects. Issues concerning the value judgements underlying the technique, the basic elements of the BCA framework, the investment criteria and the difference between an ex ante and an ex post evaluation have been discussed at length elsewhere (eg, Johnston 1990) and are not discussed in this paper.

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[1] In this paper the term 'research' is used to encompass research and development, adaptation of an innovation developed elsewhere, extension, and adaptation of an innovation to producers' individual situations.

However, the skills required for BCA to be applied rigorously do not come cheaply. Identification and measurement of benefits from a specific research project is commonly a complex exercise. There has been a recent interest in simplifying application of BCA to research project evaluation and incorporating the simplified method into spreadsheets which can be readily used by research managers. The aim is to make BCA more widely understood by research managers, as well as to reduce the cost of applying it to a level at which it can be used as a routine decision-making tool.

Recent economic studies of this type include: evaluation of a selection of projects from the CSIRO Institute of Plant Production and Processing (Healy and I'Ons 1991, Johnston *et al.* 1992); evaluation of crop research projects by the Queensland Department of Primary Industries (Page and Walsh 1991, Page *et al.* 1991); and evaluation of projects funded by the Grains Research and Development Corporation (GRDC 1992). Table 2.1 of GRDC (1992) summarises recent economic evaluations of Australian agricultural research.

The 'cost reduction method' for simplifying application of BCA to research projects was used in a number of the above studies. Johnston *et al.* (1992) list and justify a number of assumptions underlying this method. Acceptance of a risk of approximation errors arising from simplifying assumptions can often be justified by their contribution to increasing the application of BCA by research managers. However, we are concerned that the method incorporates some implicit assumptions, particularly regarding the 'without-project' scenario, that have the potential to result in significant errors in advice concerning how resources should be allocated within a research portfolio.

1.3 Aim in this Paper

The aim in this paper is to reappraise the way in which BCA should be applied to research projects. In particular, the aim is to clarify the benefits and costs of undertaking a research project at a particular time.

2. BENEFITS OF TECHNOLOGICAL ADVANCES

2.1 Technological Advances as Intermediate Goods

The aim of a research project is to create new knowledge with which to solve a particular problem. New knowledge is variously called a 'technological advance' or a 'scientific breakthrough'. The benefits of a research project derive from the benefits of the technological advances expected to be achieved. BCA of a research project must therefore begin with a clear appreciation of the benefits from technological advances generated by the project[2].

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[2] The following discussion is intended to apply equally to ex ante and ex post applications of BCA. For the sake of clarity of expression, however, the use of tense will be that which is appropriate for discussing an ex ante application.

It is rare that technological advances accomplished in a research project immediately result in the commercial release of a completed innovation. Usually the outcome is incomplete in the sense that subsequent 'processing' is required prior to farmers being willing to adopt the innovation (or, alternatively, prior to an agency being willing to recommend its adoption). This processing may involve further development of the incomplete innovation, field testing and instigation of an extension effort. At least some of these processing tasks will usually be undertaken as parts of other projects or programs.

In general, therefore, a technological advance is an intermediate good. Realisation of benefits from a technological advance depends on subsequent processing successfully completing an innovation as well as on the level of demand for the innovation when it finally becomes available.

The need to recognise uncertainty regarding the success of research was discussed by GRDC (1992). Uncertainty as to whether a particular research project will meet its objectives applies also to subsequent projects required to progress the outcomes of the former project to the stage of a completed innovation. The probability of success at each step needs to be accounted for in predicting the expected gain from developing a technological advance. The gains from technological advances will increase in certainty the closer the technological advance is to completing an innovation, purely because there are fewer uncertain steps to be completed prior to release of the innovation and consequent realisation of benefits from all preceding technological advances. Some of these uncertain steps relate to whether subsequent research funding will be sufficient to allow completion of an innovation.

2.2 Benefits from Innovations

2.2.1 Types of innovation

Two types of innovation (process and product) can be distinguished (Johnston 1990). An innovation that lowers average production cost[3] is called a process innovation. Benefits arise from a rightward/downward shift of the product supply curve. An innovation that results in a product that better suits consumer needs is called a product innovation. In this case benefits arise from a rightward/upward shift of the product demand curve.

In this paper the discussion will largely refer to projects contributing to development of process innovations. However, the arguments are also applicable to projects contributing to development of product innovations.

2.2.2 Gains from adoption of innovations

According to welfare economics theory, the effect of an innovation should be valued by its influence on economic surplus, which should account for the effects the innovation has on all industries and not only the effects on the industry in which the innovation is applied. The cost reduction method (Johnston *et al.* 1992) provides an estimate of the increase in

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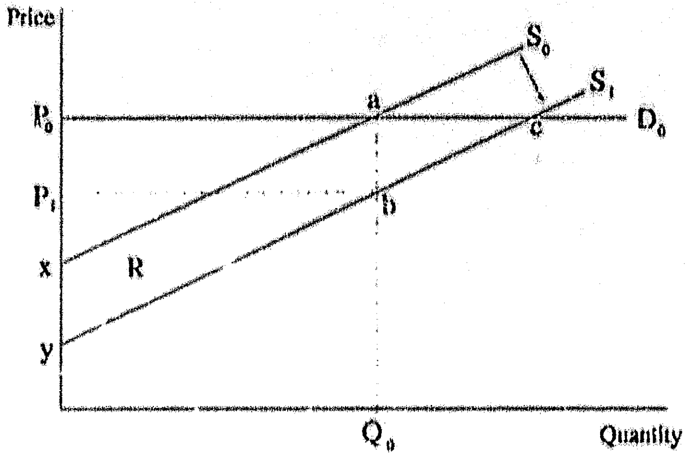
[3] That is, production cost per unit of output.

economic surplus attributable to a process innovation. The method is illustrated by Figure 1.

Figure 1: The cost reduction method for measuring benefits from an innovation.



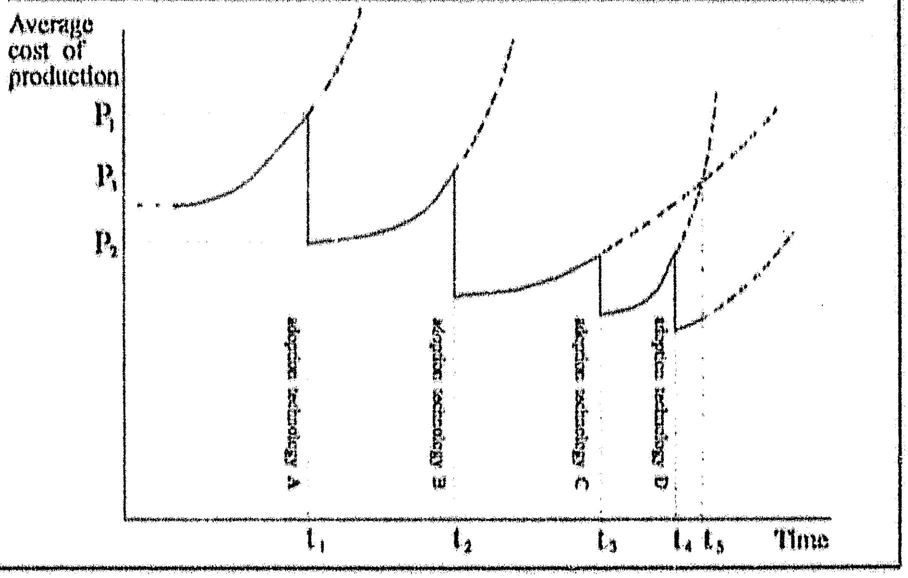
The initial demand and supply schedules for the industry of interest are denoted by D_0 and S_0 respectively. In line with a 'small country scenario', the demand schedule is represented as horizontal (following from an assumption of an infinite price elasticity of demand) and the supply schedule inclines upwardly to the right. Adoption of a process innovation is estimated to result in a lowering of the average cost of production by R. This cost reduction is assumed to apply to all intra-marginal production. Thus the effect of the innovation is represented by a parallel downward/rightward shift of the supply schedule to its new position denoted by S_1, where the size of the downward shift is equal to R. The 'pure cost reduction' is that which is realised at the existing level of production (represented by the area P_0P_1ab which is equal to the area xaby). It is only this value which is estimated when using the cost reduction method.

The possibility of measurement errors arising as a result of wrongly assuming a parallel supply shift has been discussed by Lindner and Jarrett (1978). Where the cost reducrion attributable to an innovation is likely to vary significantly within the target population, Marsden *et al.* (1980) propose that the population be disaggregated according to region or some other criterion into groups which are relatively homogenous in terms of the expected cost reduction.

Heim and Blakeslee (1986) observe that the impact of an agricultural innovation invariably depreciates over time as a result of obsolescence and biological decay. Obsolescence occurs when an incumbent technology is replaced by a newer one that produces superior results under the same conditions. An example is the replacement of a crop variety by a new higher-yielding one. Obsolescence can also occur due to release of an innovation that addresses the same problem in another way. For example, a disease-resistant cultivar could be made obsolete as a result of discovery of solutions such as a change of rotation or of a chemical treatment which lower the average cost of production relative to that resulting from using the cultivar. In other cases a technology can become obsolete because the original problem effectively disappears. For example, a dairy production technology specific to a district may become obsolete, but not because of release of a superior technology but rather because dairying in the district ceases due to the local dairy factory closing down.

The cycle of incumbent technologies becoming obsolete and being replaced by lower cost innovations is portrayed in Figure 2. The figure represents the case of a single producer. At time t_2 when technology A is made obsolete by technology B (due to the lower average cost associated with technology B) the average costs resulting from the technologies are P_1 and P_2 respectively. The gain at that time from adoption is therefore equal to P_1 minus P_2.

Figure 2: The cycle of technology adoption and replacement.



Biological decay occurs when changes in the production environment render an incumbent technology less productive (Swallow *et al.* 1985). All else being equal, the faster the rate of biological decay of a technology, the quicker can it be expected to become obsolete. An example of biological decay is the emergence of a virulent strain of disease pathogen some years after the release of a new crop cultivar.

In some cases the incidence of biological decay may be broader than the industry into which the technology is introduced. For instance, the incorporation of leguminous pastures into rotations to build soil fertility has experienced biological decay in many areas due to its effect of raising the rate of soil acidification. The average cost not only of growing pastures but also of crops grown in rotation has thus been increased over time relative to what it would otherwise have been. However, biological decay is not a problem of all technologies. For example, a new shearing technology is unlikely to be affected by biological decay. In such cases the replacement of the technology is purely due to another technology making it obsolete.

The effect of biological decay on the average cost resulting from using a technology is also illustrated in Figure 2. The average cost associated with technology A is shown as beginning to increase from the time of its adoption (t_1). Increases in the producer's average cost cease when technology A is made obsolete for this producer by adoption of technology B at time t_2. Adoption of technology B results in a sudden lowering of average cost at that time. The figure also illustrates the processes of technologies B and C being replaced at times t_3 and t_4 respectively.

The benchmark from which the gain accruing from a process innovation at a point in time is measured is the average production cost associated with the incumbent technology at that time. As illustrated above, this benchmark can be expected to increase over time if the incumbent technology is susceptible to biological decay. The average cost associated with the innovation can also be expected to increase over time if the innovation is also prone to biological decay.

It has typically been assumed in evaluations of research projects (eg, Johnston *et al.* 1992) that the cost reduction enabled by adopting an innovation remains constant over time. It is apparent that this assumption is implicitly based on a further assumption of equal rates of biological decay for the old and new technology (i.e., that both are equally susceptible to biological decay). The economic significance of differences between the rates of biological decay of an incumbent technology and an innovation has thus usually been ignored in the majority of previous analyses of agricultural research projects.

Figure 2 can be used to illustrate this discussion. The average costs associated with technologies A and B in the diagram increase at the same rate. Thus they have the same rate of biological decay. Thus the size of the cost saving attributable to release of technology B remains constant over time. The rate of biological decay for technology B is greater than that of C with which it is replaced. In this case, the cost saving from replacing technology B with C increases over time. Conversely, the rate of biological decay of technology D exceeds that of C, so the cost saving from replacing D with C decreases over time. In fact, technology C would be readopted in preference to D at time t_5 unless a technology resulting in an average cost lower than c_3 is released by that time.

A further important point relevant to measuring gains from an innovation is that assumed gains must be realistic under commercial circumstances. Caution needs to be exercised in assuming that farmers on average will realise the same gains as recorded in experiments (Davidson and Martin 1965). GRDC (1992) reported the results of a survey of agricultural consultants from the main grain producing areas of Australia. Among other findings, on-farm yield increases from adopting a new variety were estimated to be between -20 and 120 per cent of yield increases achieved in research trials[4]. Murphy (1988) found that

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[4] No-one from the public sector, where most of the advisory effort is concentrated, was included in the survey.

yield increases from on-farm research trials were translated into equivalent commercial yield increases on the same farms, but found no robust relationship between improvements in on-station trials and farm yields. As GRDC (1992) argued, further empirical evidence of the transferability of agricultural research outcomes to commercial situations is required.

2.2.3 Innovations from maintenance research

The benefit of some innovations derives entirely from maintaining productivity increases generated at the outset by earlier innovations. For instance, release of a new cultivar may allow a return to the yield achieved when the existing cultivar was first released. Research contributing to such innovations is called maintenance research (Swallow *et al.* 1985).

The benefits of productivity-maintaining innovations are in essence calculated no differently than benefits of productivity-increasing innovations. The benefit still comes from lowering the unit cost of production relative to what it would have been otherwise at that time. However, in this case the lowering of costs derives from ameliorating continued increases in production costs as a result of ongoing depreciation of the existing technology.

The difference between a productivity-increasing and a productivity-maintaining innovation can be explored using Figure 2. The average cost resulting from use of technology B when it is first adopted (t_2) is lower than for technology A when it was first adopted (t_1). Thus technology B is a productivity-increasing innovation (even though a significant proportion of the cost reduction achieved at time t_2 actually compensates for earlier cost increases caused by biological decay of technology A). The average cost resulting from use of technology C when it is first adopted (t_3) is the same as for technology B when first adopted. Thus technology C is a productivity-maintaining innovation. Technology D is also a productivity-maintaining innovation.

2.2.4 Benefits from industry expansion

In many cases an innovation affects the productivity of a single industry. That is, it has no external effects on the productivity of any other industry. This type of impact can be represented within a partial equilibrium framework as a downward/rightward shift of the industry supply curve[5]. The increase in economic surplus resulting from this single shift represents the benefit accruing from an innovation.

There are further benefits from the innovation due to the effect of the cost reduction on expanding the size of the industry. These further benefits are represented by the welfare triangle shown in Figure 1 as abc. The cost-reduction method does not include the value of this welfare triangle in estimating the benefit from an innovation, nor does it account for the benefits from industry expansion being partially offset by concurrent declines in

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[5] This assumes that the innovation is not transferred to producers in other countries. Otherwise the resulting supply shifts in those countries would also have to be accounted for, as in Edwards and Freebairn (1984).

the sizes of other industries competing for the same resources.

This approach is unlikely to lead to significant miscalculation of benefits where an innovation applies to a sizeable industry, because any approximation error can be usually expected to be small relative to the size of the pure cost reduction. Johnston (1990) cites Marsden *et al.* (1980) as evidence for this. For example, a higher yielding wheat variety may lead to wheat displacing barley from some of its existing area. The net effect on economic surplus of the marginal changes to crop areas would be very small compared with the effect of the reduction in the average cost of wheat production.

This will not be the case, however, where an innovation applies to a small (or newly formed) industry. In such a case the pure cost reduction may be relatively small (or nil if, for example, an innovation solely allows adaptation of a crop to new regions), with the major impact coming through the expansion of the industry. The net effect on economic surplus of growth of the industry and any compensatory declines in other industries then become critical to assessing the benefit accruing from the innovation.

In such cases, an approximate method of estimating the net benefit from marginal changes to sizes of industries is to estimate the net increase in economic surplus from each added hectare of an industry as being equal to the sum by which the post-innovation gross margin (per hectare) in the industry exceeds the gross margin in the partially displaced industry. However, this estimate accounts for only the short term effects on producer surplus since it ignores any longer term effects on farm overhead costs that may arise from farmers shifting between industries. It also fails to account for any effects on consumer surplus.

In cases where an innovation affects not only the productivity of the industry to which it is directly applied but also indirectly the productivity of another industry that shares resources with the former industry, more care is needed. The indirect effect of an innovation applied to one crop on the subsequent quality of land for pastures and other crops grown in rotation is a typical example in agriculture. Apart from the benefit of an innovation in terms of the industry to which it is directly applied, significant productivity benefits can flow on to the entire farming system of which that industry is a part.

For instance, an innovation that leads to an increased use of wheat growing land for growing broadleaf crops (eg, a new canola variety) can be expected to raise the productivity of the land for wheat growing, because broadleaf crops are a `break-crop' for wheat. Planting a broadleaf crop often improves weed control in subsequent wheat crops (by allowing depreciation of the seed bank for weeds affecting wheat and enabling use of grass-targeting herbicides) and allows decay of the stock of grass-dependent soil pathogens (eg, take-all) which lower wheat yields. Leguminous broadleaf crops may have the added effect of improving soil nitrogen fertility for wheat growing (or avoiding the cost of achieving a similar result by applying a fertiliser).

In these cases, the increase in the size of one industry directly attributable to an innovation (eg, an expanded area of canola due to release of a new variety) signifies a substantial change of farming system on the land onto which the industry expands. The important effect that the increase in the size of one industry has on the productivity of other industries represented in the modified farming system means that each of these productivity changes must be accounted for when measuring the benefits from an innovation.

A method for approximating the increase in economic surplus from this type of innovation is provided by Johnston *et al.* (1992). The method involves, firstly, estimating the increase in the average gross margin per hectare from changing the farming system to incorporate the industry benefiting directly from the innovation. The next, and final, step is to multiply this estimated change in average gross margin per hectare by the number of hectares on which the new farming system is expected to be adopted.

2.2.5 Pattern of gains from an innovation over time

An innovation generally experiences increasing levels of adoption for some time, followed by decreasing levels as it is replaced by a superior innovation. Johnston *et al.* (1992) argue that subsequent innovations can be expected to build upon the gains of the original innovation and that, therefore, the benefits outlast the original adoption cycle. It is asserted that benefits therefore continue at the peak level for as long as development of subsequent innovations continues to utilise the additional research capital (eg, knowledge) accumulated in developing the original innovation. Page *et al.* (1991) assume instead that benefits only accrue from an innovation until it becomes obsolete. The differences of approach are likely to lead to considerable divergence of estimates of benefits from the same innovation.

The nature of the problem being solved is important in determining which approach is likely to be appropriate. At one extreme, it may be reasonable in some cases to anticipate that the current 'genus' of solutions to a problem will, with continuing innovation, remain economically superior in the foreseeable future. If it is reasonable to expect that diesel-fuelled tractor use in modern agriculture will continue indefinitely, for instance, then it is reasonable to follow the approach of Johnston *et al.* (1992) when estimating the benefit from an innovation increasing the fuel efficiency of diesel-fuelled tractors. This is because it is likely that the innovation will be incorporated, probably with further refinement, in all future 'species' of tractor design.

At the other extreme, the current genus of solutions to a problem may be expected to be rendered extinct by imminent progress within another genus of solutions. For instance, the benefits from a proposed innovation involving insecticide protection of a certain crop may be expected to cease once the insecticide is made obsolete by release of a genetically-engineered cultivar with natural insect resistance. This may be the case if the type of additional knowledge accumulated in developing the proposed insecticide is unlikely to contribute to the evolution of solutions in any other genus of innovations (eg, development of an insecticide for another crop). Unless there is some other use for the knowledge, the approach of Page *et al.* (1991) is appropriate.

The situation for the majority of innovations can be expected to lie somewhere between these extremes. In general it is reasonable to expect that the additional knowledge accumulated in developing an innovative solution to a problem will form a foundation from which a series of further solutions of the same genus will evolve.

In many cases it can also be expected that the series from the same genus will, for an unknown duration, continue to be preferred by an industry. However, the broader process of technological evolution occurring across an economy is likely to periodically result in a preferred solution arising in another genus. At such times the knowledge accumulated during evolution of solutions within the former genus may be expected to cease generating benefits unless the knowledge is likely to contribute to other fields of technological evolution[6]. In some cases it is also possible that evolution within the former genus during its hiatus will eventually result in the genus once again containing a series of preferred solutions. Hence benefits once again begin to accrue from the knowledge accumulated during the earlier 'reign' of the genus.

It is clear that the extent to which benefits of an innovation are likely to persist over time needs to be determined as realistically as possible for each innovation being evaluated. Consistent application of a uniform rule across all innovations does simplify BCA evaluations considerably. However it can be expected to result in calculation of misleading benefit-cost ratios, both for assessing any single innovation and for choosing among opportunities to develop various possible innovations.

3. BENEFITS AND COSTS OF A RESEARCH PROJECT

Evaluation of whether to undertake a research project at a particular time requires that the benefits and costs of undertaking the project at that time be distinguished from those of the technological advances it generates. The reason for this is that it often the case that there are alternative possible sources of a solution to a particular problem, even if the technological advances arising from alternative sources are not identical to those targeted in the project being evaluated.

Previous studies have recognised the likelihood of relevant technological advances becoming available in the absence of a proposed project (eg., Marsden *et al.* 1980, Gross *et al.* 1991 and Morris *et al.* 1992). GRDC (1992) recognised that the comparability of the benefit-cost ratios it reported for the various projects evaluated was limited due to inconsistency among analysts in defining without-project scenarios.

It is therefore necessary to recognise in benefit-cost evaluation that relevant technological advances can become available without the project and that the benefits and costs of technological advances arising from the project will then be marginal to those arising from alternative sources. Only if it is unlikely that relevant technological advances will arise from alternative sources is it appropriate to measure the benefits and costs of the project using the existing technology as a benchmark.

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[6] Solutions arising within the former genus may in some cases continue to be preferred by a minority of producers due to their unique circumstances. In these cases the knowledge accumulated during developing a particular solution may continue to generate benefits, but at a much lower level than attained at peak adoption.

3.1 The 'With-Project' and 'Without-Project' Scenarios

The research funding decision involves a choice between funding a proposed project during a specific period (i.e. the 'with-project' scenario) and not funding it during that period (i.e. the 'without-project' scenario). Careful specification of the without-project scenario is important because it provides the benchmark from which the impact of a proposed project is measured.

There are many examples of farmer-generated (or 'spontaneously emerging') knowledge or technology arising in the absence of formal research projects. For example, Morris *et al.* (1992) reported Nepalese farmers growing Indian wheat varieties which had never been officially released in Nepal. Marsden *et al.* (1980) reported how adoption of Zebu cattle in Australia began without preceding formal research into the tick-resistance benefits of these breeds, and how subsequent research by the CSIRO Division of Entomology into this issue increased the rate of adoption.

Technological spillover from other local research or from other areas ('spill-in') may also be a significant alternative source of technological progress for the target area of a research project. For example, Table 1 demonstrates that wheat cultivars bred interstate have at times accounted for a major share of the area sown to wheat in each mainland State despite breeding programs within each State. On average, 48 per cent of Australian wheat area in the 1980s was sown to cultivars developed outside the State in which they were grown.

Table 1: Use by States of Wheat Cultivars Developed in Other States, 1980-81 to 1989-90

Year	NSW	VIC	QLD	SA	WA	Total
	(% of area sown to interstate cultivars)					
1980-81	8.9	70.7	34.9	55.9	79.6	50.8
1981-82	16.0	62.2	29.1	52.6	80.3	51.1
1982-83	32.8	53.7	27.2	51.5	80.3	57.7
1983-84	49.7	46.2	21.7	39.5	79.1	56.6
1984-85	53.4	38.4	19.2	43.3	73.0	55.1
1985-86	45.6	43.8	20.1	36.8	58.6	46.8
1986-87	42.5	55.5	27.4	26.3	51.9	44.3
1987-88	31.8	52.9	28.2	20.5	56.2	40.9
1988-89	26.0	44.8	27.4	15.1	49.3	34.9
1989-90	25.4	42.8	28.2	10.1	53.5	35.3
Mean	34.2	51.2	26.0	34.1	67.4	48.1

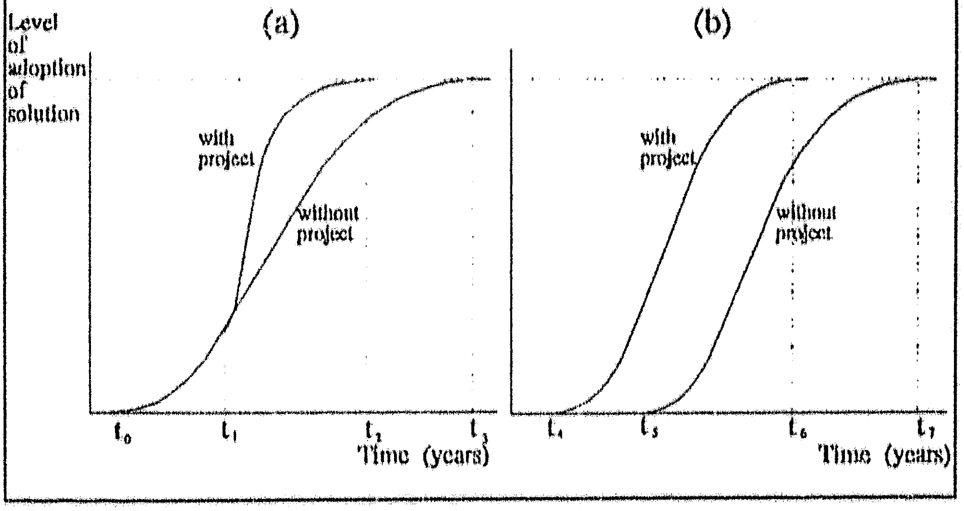
Farmer-generated or spill-in technological advances will not necessarily be as effective in addressing a problem in a target area as those expected to arise from a proposed research project, but they would provide benefits and involve costs all the same (Antony and Anderson 1991). A decision whether to fund a project to solve a particular problem therefore requires judgements regarding:

(i) the rate at which technological progress relevant to solving the problem would become available from an alternative source if the project were not to proceed during the proposed period; and

(ii) the cost of acquiring and adapting technological progress from alternative sources for use in the target area.

Two of the possible types of impact of a research project are illustrated in Figure 3. Figure 3(a) illustrates a situation in which a solution is already available (adoption commenced at time t_0) and the impact of a technological advance from a research project is to increase the rate of adoption of the solution from time t_1. In this example the ceiling level of adoption is the same under both scenarios and it is attained at time t_2 with the project and at time t_3 without the project[7]. Marsden *et al.* (1980) evaluated the above-mentioned CSIRO research into tick resistance of Zebu cattle using this type of model.

Figure 3: Impact of a Research Project.



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[7] In some cases it may be more realistic to assume that the ceiling level of adoption of technologies from alternative sources will be lower than that likely from a proposed research project or, alternatively, that attainment of the same ceiling level of adoption would only be possible if there was significant expenditure on adapting technological advances from alternative sources to increase their effectiveness for the target area.

The authors applied this type of model in evaluating the benefits of a crop variety trials project in the central west of NSW, in particular for measuring the benefits of increasing the rate of adoption of relatively new crop types such as faba beans and chick peas (GRDC 1992). The area sown to new crop types was assumed to increase by 5 per cent per year with the project until the adoption ceiling was reached, and by 2.5 per cent per year without the project.

Figure 3(b) illustrates a situation in which a solution to a problem is yet to become available. The technological advance generated by proceeding with the project is expected to result in release of a solution at time t_4. Without the project, a solution is expected to become available at time t_5. The rate of subsequent adoption is the same in both cases. Once again the ceiling level of adoption is the same under both scenarios and it is attained at time t_6 with the project and at time t_7 without the project. This type of model was also used by the authors in evaluating the benefits of the crop variety trials project discussed above, in particular for measuring the benefits of enabling earlier commencement of adoption of new varieties of traditionally-grown crops such as wheat and barley. Adoption of new varieties of these crops was assumed to begin two years earlier with the project than would be the case without the project.

3.2 Measuring the Marginal Impacts of a Research Project

Earlier resolution of a problem as a result of undertaking a proposed project can reasonably be expected to allow a whole chain of succeeding activities to be addressed sooner than they would otherwise have been. For example, earlier development of a technological advance as a result of proceeding with a project can be expected to bring forward projects[8] required to process the advance into a completed innovation. A maintenance research project designed to protect the gains achieved by the advance is also likely to commence earlier, as are various other projects designed to capitalise on the knowledge gains achieved in the project.

Hence a project can reasonably be expected to result not only in earlier commencement of benefits and costs of solving the target problem but also, by a similar degree, earlier commencement of benefits and costs of undertaking the chain of succeeding activities. This type of situation can be analysed by adapting the 'change framework' developed by Gross *et al.* (1991) to account for a project resulting in earlier commencement of benefits and costs of solving a particular problem. The adaptation accounts for the additional impacts of enabling earlier commencement of a chain of succeeding activities. The version of the framework illustrated in Figure 4 relates to the situation represented in Figure 3(b)[9]. The benefits and costs are in real values but have not been discounted to reflect the time value of money.

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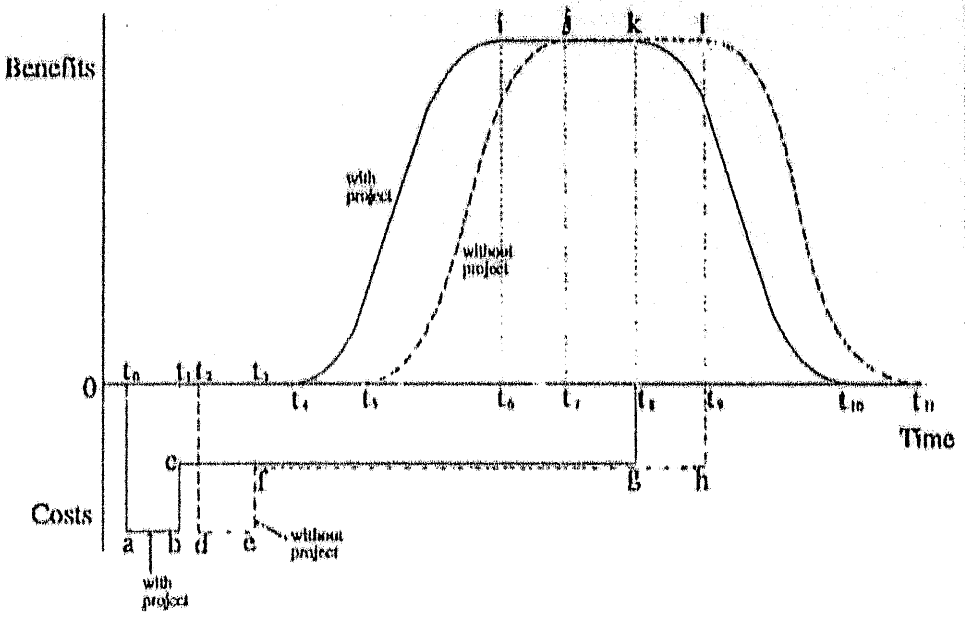
[8] Regardless of whether undertaken by research institutions or by farmers.

[9] This is only one of a wide range of possible situations that could be analysed using other versions of the framework.

Figure 4: Measuring benefits and costs of a research project.



The costs of the proposed project commence at t_0 and continue at the same rate until the project is completed at t_1. Thereafter there are continuing costs associated with the chain of activities dependent upon completion of the project. The total of these annual costs is assumed here to remain constant until t_8 at a level lower than for the proposed project, which is appropriate for cases where subsequent activities primarily involve refinements of a well-developed ('mature') technology. In cases of 'immature' technologies, however, a series of major activities may be expected to follow on from completion of a proposed project (eg., in the case of a project aiming to establish the feasibility of developing a particular type of solution), so that the total annual costs of the succeeding chain of activities may be higher than that of the proposed project.

After the technological advances generated in the project are processed into a solution, adoption of the solution commences at t_4. Adoption (and therefore total benefit from adoption[10]) increases until the ceiling level of adoption is attained at t_6. Total benefit from the solution would soon after begin to decline as it enters its decreasing adoption

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[10] Total benefit may, however, increase at a slower rate than adoption if the solution experiences biological decay.

phase as a result of newer technologies making it obsolete. However, the benefits of the project continue at this peak level until t_8 despite benefits from the solution having declined. This reflects an allowance for newer solutions (including those from maintenance research) building upon the knowledge gains achieved in the project. Total benefits from the project subsequently decline once this genus of solutions is made obsolete by those of a another genus, until benefits cease when adoption from this genus ends at t_{10}. The costs of the chain of activities dependent upon a development of a solution to the target problem are assumed to cease at t_8[11].

An alternative project addressing the same problem is expected to commence at t_2 and be completed at t_3, after which there are continuing costs associated with the subsequent chain of activities. The length of the alternative project, the level of its annual costs and the level of continuing costs are all assumed to be the same as for the proposed project.

The solution resulting from the technological advances of the alternative project becomes available at t_5 after which its adoption (and therefore total benefits from adoption) increases until the ceiling level of adoption is attained at t_7. The benefits of the alternative project continue at this peak level until t_9 as a result of newer solutions building upon the knowledge gains achieved in the alternative project. Total benefits from the alternative project subsequently decline once this genus of solutions is made obsolete by those of another genus, until benefits cease when adoption from the earlier genus ends at t_{11}. The costs of the chain of activities dependent upon a development of a solution to the target problem are assumed to cease at t_9.

Subject to these assumptions the cost effect of proceeding with the project results purely from shifting a given pattern of costs so that it is incurred closer to the present. The (undiscounted) total value of the costs with the proposed project (measured by the area $t_0$abcgt_8) is the same as the (undiscounted) total value of costs of not proceeding with the project (measured by the area $t_2$defht_9). The cost impact of undertaking the proposed project therefore arises only as a result of the discount rate incorporated in standard BCA methodology to account for the marginal rate of time preference.

Similarly, the effect on benefits from proceeding with the project results purely from shifting a given pattern of benefits so that it accrues closer to the present. The (undiscounted) total value of the benefits from the proposed project (measured by the area $t_4$ikt_{10}) is the same as the (undiscounted) total value of benefits from not proceeding with the project (measured by the area $t_5$jlt_{11}). The impact on benefits of undertaking the proposed project therefore also arises only due to the marginal rate of time preference.

The marginal rate of time preference can normally be expected to be positive (i.e., a given real benefit increases in value the earlier it is received, as does a given real cost). According to the above framework, therefore, undertaking a proposed project increases the present value of benefits as well as increases the present value of costs. The project satisfies the criterion of economic efficiency if its marginal benefit exceeds its marginal

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[11] It is assumed that research resources would be reallocated to the new genus of solutions at this point.

cost. In that case the benefit–cost ratio (BCR) of the proposed project exceeds, as is required to justify the project, the break-even value of one.

A significant feature of the change framework is that it does not require the benefits of a technological advance to be explicitly deduced from its expected contribution to developing a solution to a target problem[12]. In the change framework judgements about this relationship are implicitly incorporated in assumptions regarding the extent to which the project increases the rate of adoption of a solution and/or brings forward the commencement of its adoption.

3.3 Empirical Significance of the Change Framework

Page *et al.* (1991) and Johnston *et al.* (1992) implicitly assumed that the research projects they evaluated were the only sources of solutions to the problems being addressed. In this formulation the marginal benefit and marginal cost of a research project are equivalent, respectively, to the benefit and cost of the technological advances arising from the project.

We contend that a 'static' without–project scenario such as this is not appropriate for most agricultural research projects. In order to explore the importance of this issue we recalculated the original BCA of the crop variety trials project evaluated for GRDC (1992) using, firstly, a 'static' without–project scenario (i.e. no adoption of new varieties of traditional crops and no expansion of the area of new crop types) and, secondly, the original 'dynamic' without–project scenario (i.e. adoption of new varieties of traditional crops delayed by two years relative to the with–project scenario and expansion of the area of new crop types at a lower rate than in the with–project scenario). To be otherwise consistent with the Johnston *et al.* (1992) framework, the original BCA has been recalculated assuming that the peak level of benefits from innovations (i.e., released varieties) resulting from the project continues until 40 years after its completion.

The difference between the two approaches is illustrated in Figure 5 in relation to measuring the benefits from that part of the project evaluating new wheat varieties.

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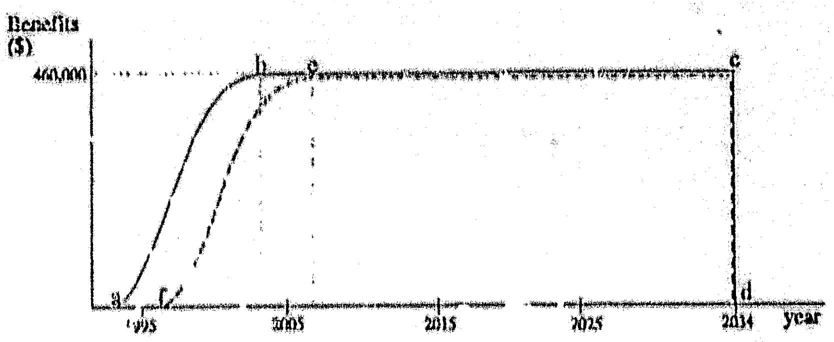
[12] In accounting for the benefits of research projects, Page *et al.* (1991) and Johnston *et al.* (1992) focussed on the benefits of solutions (i.e., completed innovations) eventually arising from the technological advances generated by a project. For consistency it is then necessary, as argued by Johnston *et al.* (1992), to account for the costs of processing the technological advances into solutions in addition to the costs of generating the technological advances.

Figure 5: Research project benefits under static and dynamic without-project scenarios.



Benefits from the wheat varieties to be evaluated in the project were predicted to commence in 1995 with the project, with the peak level of total benefits from these varieties of $460,000 per year being realised by 2003. This peak level of total benefits from the varieties is assumed to continue until 2034 (i.e., 40 years after completion of the project). If a static without-project scenario is assumed, the (undiscounted) total benefits of the project are therefore given by the area in Figure 5 denoted by abcd.

If the dynamic without-project scenario outlined above is assumed, however, benefits from these new varieties would commence in 1997, with the $460,000 peak annual benefits realised by 2005. In this case the (undiscounted) total benefits of the project are denoted by the area abef. This level of project benefits is much lower than that obtained assuming a static without-project scenario.

This discrepancy is reflected in the considerable differences between the benefit-cost ratios calculated using the alternative without-project scenarios. With a 5 per cent discount rate applied, the benefit-cost ratio for the project was found to be 31:1 with a static without-project scenario compared with 6:1 with a dynamic without-project scenario. With a 10 per cent discount rate applied, the corresponding benefit-cost ratios were 15:1 and 4:1. It is apparent that inappropriate use of a static without-project scenario can result in serious over-estimation of the benefit-cost ratio of a research project.

Use of a static without-project scenario for the project BCA in line with most (if not all) of the BCAs of other projects would therefore be expected to have significantly improved the BCR ranking of the project within the 21 GRDC projects evaluated (see Table 4.1 of GRDC 1992), and to have increased the average benefit-cost ratio of all the projects evaluated.

GRDC (1992) argues that the major role of BCA in research project evaluation is to provide information to managers to assist them to efficiently allocate resources among a portfolio of prospective projects. GRDC reasons that in this task consistency in the approach to applying BCA across projects is more critical than accuracy in estimation of parameters. However, the distinction between consistency of approach and uniformity of assumptions, particularly regarding the without-project scenario, is crucial. The without-project scenario of each project can be expected to be unique. Thus an assumption that the without-project scenarios of all projects are the same is likely to distort conclusions to the same extent that would occur if the with-project scenarios of all projects were assumed to be the same.

3.4 Evaluating Extensions of Ongoing Programs

It is common for certain types of research to proceed within ongoing programs (for instance, varietal assessment or crop breeding for disease resistance). In such programs, the same type of research activity is likely to be repeated periodically as circumstances change. In a program of breeding for disease resistance, for example, continuing evolution of pathogens requires that the entire process of developing a disease-resistant variety be ongoing. Hence an ongoing program at any time comprises an array of similar projects, each of which has reached a different point in a relatively standard `project cycle'. However, in practice, these projects are strongly interlinked by sharing a common pool of staff and other resources.

In a wheat breeding project, for example, new lines of genetic material are continually being tested. These tests lead to the identification of a number of superior breeding lines and, with skill and fortune, to a released wheat cultivar. Brennan (1988) estimates that the expected time taken from first crosses to cultivar release is 13 years. The range of breeding activities to be performed if a wheat breeding project were to be extended by three years would be spread along a continuum. At one end of the continuum, crosses for a prospective cultivar to be released perhaps 13 years later may be carried out. At the other end, final field evaluations for a cultivar expected to be released in the second year of the extension may be performed.

In this situation the funding decision will almost invariably relate to extension of a program rather than to whether a new project should be initiated within the program. The extension of a program may involve initiating one or more projects, but it will also involve progressing an array of projects initiated during previous funding rounds. Evaluating whether an ongoing program should be extended therefore effectively involves applying BCA to each of the projects to be progressed during the extension and then aggregating to determine the overall benefit-cost ratio. This procedure will need to ensure that the without-project scenario of each project adequately takes into account the expected with-project outcomes of the remainder of the program.

4. DISCUSSION AND CONCLUSIONS

The aim of a research project is to generate new knowledge (technological advances) to help solve a particular problem. In general, benefits will arise from the project only to the extent that a completed innovation is the eventual outcome and the innovation is adopted. This generally requires the original technological advances to be progressed in further projects. These projects must first be resourced and successfully completed. Since technological advances generated by a research project are intermediate goods, evaluation of their benefits requires an understanding of the nature of the benefits of a completed innovation.

However, the marginal benefit from a research project will not in general equal the sum of benefits from the technological advances it generates, since technological advances relevant to the problem being addressed can usually be expected to arise from other sources if the project does not proceed. A realistic estimate of the marginal benefit from a research project must account for that likelihood. Equally, realistic estimation of the marginal cost of a research project will account for any effect that proceeding with the project has on saving resources that would otherwise eventually have been devoted to solving the same problem. Since the without-project scenario of each research project is unique, care in its specification is critical if BCA is to be validly used as a tool for assisting research managers to allocate scarce funds among a portfolio of research projects.

To explore the empirical significance of inappropriately defining the without-project scenario, a research project was alternately evaluated using, firstly (as per the original analysis), a 'dynamic' without-project scenario (wherein relevant technological advances were assumed to arise without the project) and a 'static' without-project scenario (wherein the proposed project was assumed to be the sole source of relevant technological advances) It was found that inappropriate use of the 'static' without-project scenario would result in the benefit-cost ratio of the project being seriously over-estimated.

If economic analysis is to improve decision-making by research managers, it is therefore critical that without-project scenarios are realistically accounted for in all cases. The gains in reliability of advice achieved by requiring of consistency of BCA assumptions across projects should not be confused with the gains in simplicity achieved by imposing uniformity of assumptions. Consistency requires that the unique circumstances of each project be as accurately as possible reflected by unique assumptions. Griliches (1958) and Johnston *et al.* (1992) were right: economic evaluation of research is difficult. There is a real danger that recent attempts encouraging research managers to believe otherwise will lead to disenchantment of research managers and economists alike.

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