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Application of *ex ante* evaluation procedures to research

Some practical issues

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Three issues important in ex ante *evaluation of research are discussed. First, spillover benefits (within the research process) and external benefits and costs resulting from the environmental effects of applying research results are considered. Second, the use of supply elasticities in estimating aggregate benefits and the distribution of those benefits is considered. It is quite valid under some circumstances to use available supply elasticities to estimate producer gains from research. However, those circumstances are far from universal. Third, methods of handling risk and uncertainty and the importance of establishing a baseline from which to measure benefits are considered.*

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Introduction

Public and private sector funds for research and development activities are scarce resources. Managers of institutions that disburse public research funds, and of the research bodies that use those funds, are increasingly seen as being accountable for the efficiency of use of their resources. As a result, planning and priority setting have become important at all levels of decision making, to make sure that limited research resources are allocated to activities that are expected to generate the highest net 'payoff'. Thus, a systematic treatment of expected costs and benefits through an *ex ante* evaluation of research proposals is becoming an integral part of the planning process.

In applying benefit–cost methods to *ex ante* evaluation of research, a number of issues concerning cost and benefit measurement must be faced. In this paper, issues in three areas are considered. The first area is the scope of research benefits. External benefits from the research process itself and external costs and benefits from the application of research may be important in the total benefit–cost assessment. The second area is the estimation of benefits to producers. The third is uncertainties concerning the realisation of benefits more generally, with some observations on policy research.

The need for *ex ante* evaluation

The basic economic rationale for research evaluation is to improve efficiency in the allocation of research resources, through improvement in the standard and effectiveness of decision making. Economic theory suggests that to maximise the social value of output, resources should be allocated where their benefit is greatest at the margin of expenditure. At the same time, it would be useful for research managers to obtain feedback on what has been accomplished, to help them direct the course of future work. Research evaluation methods are available which can serve both these purposes in a systematic manner.

At the aggregate level, the use of research evaluation also provides a basis for optimising levels of investment in research. The question of how much to invest in research is important, because underinvestment in research will result in forgoing potential output and the associated welfare gains to the society, while overinvestment will result in sacrificed output and associated welfare losses due to the misuse of resources. Some writers, for example Evenson (1987), have argued that a major value of economic evaluation of past research in agriculture has been to demonstrate the exceptionally high returns to several agricultural research programs and the substantial underinvestment in agricultural research, both at national and international level.

Project evaluation procedures can be classified as *ex ante*, ongoing and *ex post*, depending on the point in the project cycle at which they are performed. Early research evaluation work concentrated on *ex post* analysis, with the aim of measuring and demonstrating the benefits of past research. More recently, however, the focus has shifted from evaluating past research to assessing prospective 'payoffs' from, and priorities in, future research.

Arguably the greatest potential contribution of *ex ante* research evaluation is in the area of planning and priority setting. It provides a basis for making a more efficient use of the resources allocated to research. Research managers can select those activities that offer the greatest expected net 'payoff', which can be defined so as to ensure that as far as possible limited time and research resources are used in the most productive way. The establishment of *ex ante* evaluation systems also provides the framework, and part of the data base, for effective monitoring of project progress.

The degree of methodological sophistication ranges from simple sorting and scoring models to complex mathematical programming models (Norton and Davis 1981), but in any case decisions must be made as to what costs and benefits will be counted. Funds for research in the Australian agricultural and resource sectors come from a mix of private sources, general taxation revenue and industry levies. Ultimately the source of funds used in any project should be influenced by the distribution of benefits expected if the research is successful. Both the source of funds and the distribution of benefits will dictate the scope of the benefit–cost framework to be employed. If the funds are being allocated from public sources, then a social benefit–cost framework is more appropriate. If the source is a private funding agency (such as an industry or an entrepreneur), only the private costs and benefits of the research are likely to be considered.

For example, in an evaluation from a private perspective, it would be unlikely that non-market benefits and consumer gains, or other social costs and benefits such as those arising from environmental impacts, would be included. This is because the purpose in such an evaluation would be limited to optimising the use of the resources of a producer. If the benefit of a new technology would accrue entirely to consumers, then there might be a strong argument for publicly funding the research on it.

Spillovers from research

If accurate estimates are to be made of the likely value of research, the identification and measurement of the side effects of technical change may be necessary. There may be either positive or negative indirect effects, or both. In general it is difficult to combine the direct and indirect effects of technical change into a single-valued parameter. That is no reason, however, to ignore the indirect effects. Their inclusion not only improves the measurements of costs and benefits, but provides a basis for determining any complementary policies that are needed.

Spillovers which require further attention fall mainly into two categories: effects on the research process itself (intermediate effects), and environmental effects of technological change.

'Intermediate' effects

Spillover effects may occur within the research environment, as a result of the actual process of research. These spillover effects are known as 'intermediate' products (Horton 1990; Heisey and Mwangi 1992). For example, research programs invariably have a training or educational component — researchers acquire new skills and knowledge. This increase in human capital may have considerable value to society (for instance, in future research). Such benefits may need to be taken into account in assessing the productivity of the research effort, particularly if they differ greatly between avenues of research.

A principal intermediate effect of research is that on the institutional setup of the industry concerned — the effect of new research technology (such as measurement techniques) on the industry's capacity to devise and disseminate new production technology (Horton 1990). At present there is a large degree of uncertainty about the scale and value of these effects. This is because, so far, most of the work in research evaluation has been concerned primarily with issues of allocative efficiency (Israel 1987), with little consideration of institutional efficiency. Though the links between such intermediate impacts and ultimate economic benefits may be unclear, ignoring them is likely to result in underestimating the value of research.

Measures of the intermediate impact of agricultural research may include: changes over time in the number and composition of scientists working in national and international agricultural research programs; the proportion of agricultural revenue spent in research;

private sector expenditure on agricultural research; and extent of interdisciplinary involvement. However, the distinction between institutional impacts and production impacts should be seen not as a difference in kind, but as a distinction between direct and indirect effects. Institutional capacity should be assessed by the value of output, which in turn should be assessed (in the case of an applied research institution) in terms of effects on production. Nores (1988) concluded that 'the institutional impact cannot be dissociated from production impact. As they interlink, both types of impact need to be assessed as part of the same studies'.

One way to start to incorporate this effect of research into the evaluation framework would be for research agencies to at least consider the long and short term institutional benefits that are likely to arise through the implementation of new research technologies or procedures. In some cases, as for example in developing countries, the potential benefits from such intermediate products may be significant. While uncertainties about these benefits may not allow them to be calculated in dollar terms, it would be useful to list the expected changes in operational setup, to put these benefits into perspective.

Thus, when evaluating research, agencies must be aware that there is a need to systematically incorporate its institutional impact. Otherwise, it is likely that the benefits obtainable from any project will be underestimated.

Environmental consequences

Environmental side effects of the application of research results (not necessarily adverse) may occur in the form of direct impacts which affect the well-being of humans, such as some forms of pollution, or as indirect impacts such as change in the leisure value of particular locations or resources. Either way, these are 'non-market' effects, and they may be significant.

The adoption of modern agricultural technologies has often resulted in external benefits or costs. For instance, use of modern clearing methods to produce farmland from woodland has contributed to soil erosion and salinity problems. Some uses of fertilisers or pesticides may lead to surface and ground water contamination by toxic chemicals, with significant costs. On the other hand, the adoption of minimum tillage technology and herbicides by Australian farmers has probably had environmental benefits. Although the adoption of these methods has probably been largely driven by operating cost savings, it is likely to have significantly reduced the soil erosion, nutrient loss and consequently also the downstream costs from cropping. In another area, research that results in an increase in fish stocks may have considerable value to anglers.

It is important to include externalities in *ex ante* assessment of research for two reasons. First, to omit external costs and benefits from assessments of the worth of research projects could affect the accuracy of the estimates of their net value, perhaps resulting in a ranking of competing projects which does not reflect their relative potential net social benefits and could lead to inefficient resource use. Second, where externalities are positive and substantial (as may also be the case for some of the intermediate effects referred to above), the case for public funding of research may be strong, where private agencies have little incentive for funding it.

There are only a few studies that incorporate the environmental consequences of agricultural decisions into calculations of the social benefits from agricultural research (Carlson 1989; Capalbo and Antle 1989). Just and Antle (1990) developed a conceptual framework in which farmers' production decisions are represented as generating a joint distribution of output, input and environmental effects. In most such studies the less direct environmental effects, whether adverse or positive, have been assumed to be minor or have effectively been ignored.

In principle, there is no reason why the assessment of research projects cannot include the analysis of environmental impacts (Rose and Anandajayasekeram 1992). An approach potentially relevant to the evaluation of research impacts is outlined by Dixon, Carpenter, Fallon, Sherman and Manopimoke (1988). Essentially that approach involves an attempt to value environmental aspects of project impacts on the same basis as is used for other goods, in a benefit–cost framework. Capalbo and Antle (1989) argue that the economic welfare methods that have been developed for valuing non-market goods (such as contingent valuation and travel cost methods) can readily be adapted to the valuation of environmental externalities which arise from the implementation of research results.

Any economic assessment of environmental impacts of research applications must be based on an understanding of physical and biological effects. In this connection, environmental impact assessment procedures may be useful, since they are designed to identify and predict the impact of an action on the bio-geographical environment and on human health and well-being (see Worner and Prestin 1973; Munn 1979).

A full environmental impact assessment requires a determination of the initial, reference state of the environment, an estimate of the future state if the proposed action is not taken, and an estimate of the future state if it is. For every proposed action an environmental assessment should include:

- prediction of the nature and magnitude of environmental effects (both positive and negative);
- a listing of impact indicators (whereby effects could be monitored);
- the identification of human concerns regarding environmental changes;
- a statement as to whether the externalities could be incorporated into a market framework and their values elicited.

The level of detail necessary in an environmental impact analysis will depend on the sensitivity of the affected environment, the scale of the proposed technology and the types of effect it could have. Also important will be the social value, at both a national and local scale, of preserving and possibly enhancing the relevant environmental quality, the resources and scientific expertise of the country and the time available for assessment (Munn 1979). Clearly, the cost of impact assessment, relative to likely environmental values, will also be a primary consideration.

There are techniques for the estimation of non-market values. However, it should be noted that there are serious doubts as to their usefulness in many cases. For example, see the discussion in ABARE (1991) of the limitations of contingent valuation methods.

The full assessment of environmental quality issues requires complex analyses of physical, biological, social and economic processes. Such a breadth of analysis is likely to be beyond the scope of most research assessment activities. Nevertheless some assessment of environmental impact is necessary when evaluating research and development, especially where the environmental impact of the application of the research is likely to be significant. In the absence of the data required for a thorough analysis, it may still be possible to identify the nature of the social costs and benefits, together with the gainers and losers.

Ultimately, a long term commitment to the relevant areas of cross-disciplinary research will be required if a full picture of the social costs and benefits of any proposed resource technology is to be gained. Meanwhile, some assessment should be made of the environmental consequences of the proposed technologies, based on the limited available information and methods. The prediction of negative environmental side effects does not necessarily mean that the new technology should not be used. The net benefits may be sufficiently large to provide compensation to those who are harmed and still leave a net surplus to the society. (Whether to do so then becomes a question of policy.)

Supply responses and the dynamics of research adoption

The development and use of 'economic surplus' measures has been essential to much of the work on both *ex ante* and *ex post* research evaluation. Attempts to estimate the returns to agricultural research on the basis of some type of economic surplus framework date at least from the seminal work of Griliches (1958). Norton and Davis (1981) provide a review of the wide range of techniques used to obtain both *ex ante* and *ex post* estimates of research payoffs. However, all approaches are based on some explicit or implicit idea of consumer and producer benefits. Besides the calculation of such 'economic surplus' from simple supply/demand models, direct estimation from programming models and from production function estimates have been used.

The concern here is with techniques involving the use of estimated demand and supply curves to provide measures of changes (resulting from a research application) in consumer surplus and in some equivalent producer-side measure. Specifically, the problems considered here relate to the supply side of such methods. The use of changes in the area above a supply curve as a measure of producer benefits, in most circumstances, involves some perils. In the conventional model of a competitive industry, it is assumed that all firms operate at minimum average cost in the long run, and that this minimum is the same for all. The mechanism for change in industry size is entry and exit of identical firms. There are only normal profits earned. The long run supply curve is horizontal, and adoption of any cost reducing technology will result in a downward shift in that curve, to the benefit only of consumers.

In some industries this model is not strictly valid because there is some inelasticity of supply in the long run. However, Mishan (1968) points out that even in these cases above-normal profit may not exist. The upward slope of the supply curve represents a rise in industry average costs due to increasing scarcity of some combination of factors of production. Rents to these factors increase; profits do not. Only by analysing the factor markets, therefore, is it generally possible to assess the full implications of a market change. In general, no valid measures of factor rents can be derived from product supply curves. Mishan mentions two exceptions to this generalisation. First, if the upward slope in a long run industry supply curve is caused by the fixity of a single factor, such as land in agriculture, a meaningful measure of producer gains (that is, gains to landowners) can be derived from the product supply curve. The second case is that where a short run inelasticity of product supply is due to capital fixity, in which case the area above the supply curve is a measure of quasi-rent to the capital concerned. In both cases it is valid to take the area between the supply curve and the price line as a measure of factor rent, because the supply curve is a representation of industry marginal costs, excluding factor rent.

The general use of areas above the supply curve, regarded as quasi-rents, in studies of agricultural research benefits has been based on the presumption that the measure can be taken as an indication of rent to land (see, for example, the discussion of underlying assumptions in Edwards and Freebairn 1981, 1984). However, the measure is strictly valid only in the Ricardian case of land with a single agricultural use. Most land has alternative uses. The supply price for a given quantity of one farm commodity will, therefore, include the opportunity cost of excluding the land from its next best use. As Rose (1980) points out, while this does not necessarily invalidate the use of shifts in supply curves to estimate changes in rent, it does complicate the measurement problem.

In addition, there is little certainty in available measurements of agricultural supply elasticities, and little consistency in their treatment or the meaning imputed to them. In many studies where supply elasticity is used to measure surplus, the underlying assumption that the use of supply elasticity in welfare measurement depends on fixity of agricultural land is carefully observed (see, for example, Edwards and Freebairn 1981 and 1984; Freebairn, Davis and Edwards 1982; and Johnston, Tulpulé, Foster and Gilmour 1992). In other cases, little attention is paid to the assumptions constraining valid application of the model. Alston (1991, p. 24), for example, refers to an analysis by Harberger (1991) to make a fairly naive general interpretation that 'the standard surplus measures may be used as measures of welfare change'. He appears to mean, by 'the standard surplus measures', that the area between price and a supply curve can be taken as measuring quasi-rent to some factor, no matter what the industry or circumstances. Freebairn et al. (1982) and Alston and Scobie (1983) use as an example of a base agricultural industry, in their models of multi-sector systems, the US pork industry. There seems to be an implicit assumption that, because the pork industry is regarded as an agricultural industry, the welfare measurement techniques generally applied in agriculture must be valid. However, as Lemieux and Wohlgenant (1989) point out, there is no ultimate land or other resource constraint on the pork industry. It is just another competitive industry with a presumably near infinite long run supply elasticity.

Lemieux and Wohlgenant (1989) provide a carefully reasoned application of research evaluation techniques to a pork industry development. They use surplus measures derived from econometric estimates of short and medium term supply elasticities. They argue that in the long run there is unlikely to be significant inelasticity of supply in any of the pork production, processing and distribution sectors. There are therefore, they infer, significant benefits to producers from research only in the short to medium term. Consumers will capture the bulk of longer term benefits. Similar conditions are likely to apply to most intensive agricultural production activities, such as poultry and lot-fed beef production. Most are capital and technology intensive, and are therefore likely to require significant periods of adjustment to any innovation. For that reason, there may be substantial quasi-rents accruing to the initial industry participants. However, in the long run, there are no real constraints to industry expansion and thus there is no reason to believe that there are continuing producer rents.

A substantial literature exists on the farm level impact of research affecting various stages of agricultural producing, processing and marketing systems. The principle findings are reviewed by Alston (1991). Most of that work (for example, Freebairn et al. 1982; Alston and Scobie 1983; Johnston, Tulpulé, Foster and Gilmour 1992) is based on the explicit assumption that long run supply elasticities are infinite in all but the agricultural producing sector, so that rents accrue only to owners of agricultural land.

However, as a result of developments in intensive livestock industries and, to some extent, plant industries, there are many traditionally agricultural industries that are becoming less land dependent. This is because changes in technology, both within and outside agriculture, tend to allow substitution of other factors for the constraining land characteristics. For example (using 'land' in its most general sense), the development of prawn and salmon aquaculture has substantially reduced dependence on extensive natural fisheries resources. Developments in hydroponic production of vegetables may have a similar effect on the constraints once placed on horticulture by limited availability of particular types of land.

In any case, econometrically estimated supply curves for agricultural products seldom reflect the true long run conditions. Most are likely to incorporate the effects of some degree of medium term stickiness in other physical capital as well as land constraints. Part of the short term inelasticity of supply of any one commodity from multi-enterprise farms is likely to be due to quasi-rents from alternative enterprises. In a closed economy that will make little difference to the total benefits from a research based innovation, but it will substantially affect the distribution of those gains. If long term supply is in reality reasonably elastic, much more of the benefit may accrue to consumers than appears from the available data. For an exporting industry that has some influence on world prices, a highly elastic long term industry supply will mean a transfer of benefit in the long term to overseas consumers and consequently a lesser aggregate benefit to the domestic economy.

Even in industries dependent on fixed natural resources, there can be no presumption that valid measures of rent can be made. Estimated supply curves for some such industries may not be marginal cost curves. For example, consider the case of an open access fishery. Both economic theory and empirical observation suggests that there will be no persistent rents in a such an industry. Provided short terms profits appear to be available, participants in the fishery can be expected to continue to increase effort until total industry costs equal revenue. Thus, the industry supply curve is the average cost curve. Any rise in fish prices will give existing industry participants and potential entrants incentive to expend more effort. So there will be a conventional, upward sloping, supply curve. Yet this supply curve is an average cost curve, so its use to provide estimates of rents would be quite misleading. There will be no rents.

It should be clear from the arguments given above that there is an inconsistency between the use of fairly short run measured supply elasticities in a comparative static framework and the long term perspective. If the long run supply curve is (near) horizontal, but an upward sloping supply curve is assumed when estimating benefit, producer shares of gains from research will be overestimated. For some traded goods, this may result in a substantial overestimate of the total benefits to the economy. This risk should be considered in *ex ante* resource allocation as well as in *ex post* research evaluation. If, in fact, the long run supply curve is (near) horizontal, then almost all the benefits arising from research will accrue to consumers. This would lead to a strong argument for publicly funding research initiatives, provided that the benefit to domestic consumers alone is sufficient to justify the cost. On the other hand, if the choice to be made is between alternative research proposals to address the same problem, the adoption of an incorrectly shaped curve will make little difference in the eventual choice of proposal, irrespective of the shape of the supply curve, since the choice will then be made on the basis of the costs of alternative means of obtaining similar benefits.

These comments do not necessarily imply that the 'economic surplus' approach to benefit estimation is generally invalid. Rather, they mean that a good deal of care is needed when thinking through both the conceptual and practical phases of any application of that approach, as they have direct bearing on resource allocation based on *ex ante* evaluation. Agencies would therefore need to consider the degree of dependence of the industries concerned on fixed resources, and the relevance of marginal costs to their industry supply schedules, before they evaluate research benefits using 'economic surpluses'.

The evaluation of expected benefits

Whereas *ex post* analyses of research can be based on empirical observations, *ex ante* evaluations will remain complicated by lack of information on basic parameters. In some cases there may be uncertainty about underlying physical and economic relationships. In other cases, there will be knowledge of those relationships with some degree of reliability. Estimates of costs and benefits may be only order of magnitude figures based on the informed judgment of the researchers. However, even then something useful may be said about the probability distribution of possible outcomes and, therefore, about expected outcomes and risks. The usefulness of the evaluation procedure depends heavily on the ease and rigour with which issues of risk and uncertainty can be handled.

Sources of uncertainty

Often, many of the parameters that affect the size of potential research benefits are unknown, or are highly uncertain. For example, in the case of a fishery, there may be only limited information about the size of the current fish stock and the biological relationships that determine the maximum sustainable yield. As a result, it is likely to be difficult to accurately predict the consequences for commercial fishing of research based innovations that would affect these factors. Any assessment of benefits of research applicable to the fishery would therefore involve some risk.

Other factors that affect the size of research benefits but which are likely to be known only roughly include how industry cost functions and output would change as a result of adoption of the research results. (This can also be true even in *ex post* evaluations.) For example, in assessing research into new chickpea varieties, Johnston, Healy, Pons and McGregor (1992) estimated benefits for Queensland only. Even though the new variety has now been adopted in other states, lack of information about cost savings achieved there precluded benefit estimation for those states.

In *ex ante* assessment, prior information will be limited not only about factors that influence the size of benefits in any one year, but also about the probability of research success and, in the event of success, the spread of benefits over time.

Clearly, a major problem in the *ex ante* evaluation of research will be uncertainty about whether the research will be successful. This uncertainty may be reduced, and the accuracy of the evaluation accordingly increased, to the extent that the research builds on previous or current knowledge. However, such dependence on earlier or current research projects may complicate the evaluation of research proposals, since any benefits would then be attributable to more than one project. Decision makers would then be left with the onerous task of identifying what proportion of research benefits are attributable to the individual past and future projects. One way of dealing with this problem might be to evaluate whole research programs rather than individual research projects.

Another means has been to draw upon evaluations of past research in which similar problems were faced. However, this approach may be difficult to use if there is only limited information about the performance of similar earlier research.

In addition, there are further complicating issues. First, the realisation of benefits from successful technical research may be policy dependent. Second, there may be uncertainties about the baseline from which the benefits should be measured.

Dependence of benefits on policy decisions is illustrated by much fisheries research, where the realisation of research benefits will depend on the current and future fishery management systems. For example, many of Australia's fisheries are characterised by the absence of effective property rights to fish resources. Research that could in principle increase profitability for operators in a fishery would then result in an increased amount of fishing activity as competition for the apparently greater profits increases. Without effective property rights (or a management system that effectively provides them), more effort than is economically desirable would be likely. Rents that could have been realised from application of the research would then be eroded, and operators would achieve only normal profits, as before. Since management systems may change in the future, the benefits realised from fisheries research are therefore uncertain. As a result, any *ex ante* evaluation of fisheries research must include some explicit assessment of the prevailing and expected property rights regimes in the fishery concerned, and must be explicitly conditional on the regimes assumed.

An associated problem is that of the establishment of a 'baseline' for assessment of the research benefits. For a cost reducing innovation, the baseline would appear to be the current industry cost structure. However, the baseline may also depend partly on external events. For example, research might be proposed into technology that appears likely to reduce costs sufficiently for Australian producers to compete in markets that were formerly inaccessible. One essential question in evaluating this research would be 'What would happen without the research?' It is possible that Australian producers would ultimately be able to enter the market even without the research, perhaps as a result of a worldwide shortage of supply or improved marketing of the Australian product. Thus, *ex ante*, it is difficult to predict whether even technically successful research would be of any benefit, and if so, by how much. Clearly, agencies need to explicitly consider what could happen without a given research program before they can estimate its net expected benefits.

This difficulty of identifying the baseline from which benefits should be measured is particularly important in relation to policy research: that is, research which is intended to provide new information to policy makers, as distinct from new technologies. The value of such research depends primarily on what policy decision would be taken in its absence.

There is a further complication in relation to policy research. The basic economic framework for research assessment has been designed with scientific or technical research in mind. With policy research, where the output is advice to policy makers about settings of rules that define property rights and other regulations, there is an extra dimension of uncertainty. Pilot scale testing is rarely possible. Broad adoption of a technical innovation that is counterproductive is likely to be a rare event. However, with policy research, testing is through implementation. The risk that advice will be misleading is a risk to be taken seriously in the evaluation of policy research.

Ways of handling uncertainty

There are many ways of making conditional predictions based on limited information. One extreme would be to assume that the worst scenarios imagined will eventuate: that is, to assume that adverse resource use changes result from the research (resulting from the research costs, forgone benefits and implementation costs), or that the benefits of application of the research are nullified as a result of unforeseen events (such as the loss of improved crops by sudden weather changes). The net gains or losses from alternative projects estimated in this way can be compared, *ex ante*, and the projects with the highest positive, or least negative, expected worst outcomes selected for funding. This 'minimax' approach can provide practical information when choosing between research proposals, and has been applied to agricultural research (for example, CIMMYT 1988).

In addition, this approach has application in the *ex post* evaluation of research, when there is a high probability of variability in the production process, such as where climatic factors are unreliable. For example, the full benefits of research to improve the preservation quality of fruit (for example, Horticultural Research and Development Corporation 1992) are obtained only if the crops do not fail as a result of unforeseen weather changes or pollution, which is clearly a danger. Subjective judgment based on historical data may allow for some estimation of the size and probability of realisation of research benefits. However, the minimax approach to research appraisal would be useful for estimating likely minimum benefits.

Clearly, however, using the minimax approach the benefits obtained most of the time are likely to be underestimated in such a case. The method seems most applicable when there is uncertainty about the nature or form of physical or economic relationships which influence the research output or its use. Where some information exists on the probabilities of alternative outcomes, the use of stochastic techniques offers greater promise. An example of this approach in research evaluation is given by Johnston, Tulpulé, Foster and Gilmour (1992). Monte Carlo procedures are used to estimate probability distributions of net returns. A simple application requires estimates only of upper and lower bounds and most likely values for each uncertain parameter.

This approach offers two potential benefits. First, it provides simple summary measures of the moments of the distribution of overall expected returns. Second, it provides measures of the sensitivity of expected net returns to variations in the assumed probability distributions of individual parameters (see Pagan and Shannon 1984). Those assumed probabilities are likely to depend on the state of knowledge about physical and economic relationships (as well as on the actual relationships) and on the amount of effort put into project planning by the researchers. Sensitivity analysis may serve to identify particularly important areas of deficiency in information or project planning. It may, therefore, enable the efficiency of project planning to be increased, in addition to its contribution in the *ex ante* evaluation and selection of research proposals.

Conclusions

Budget procedures in most institutions will no longer permit the allocation of funds without some analysis of the 'payoffs' from alternative projects. Thus, *ex ante* evaluation of research activities is becoming increasingly important in planning and priority setting. The *ex ante* evaluation of natural resource research activities presents analysts with an array of alternatives and challenges. There is a need for judgment on a wide range of issues: the mechanical implementation of a given procedure or procedures could be more dangerous than productive. Nevertheless, there is a need to improve the rigour with which *ex ante* evaluation techniques are applied.

Private costs of and returns from research may substantially diverge from full social costs and returns. Current policy trends in Australia and elsewhere are such that there is likely to be increasing pressure to adequately incorporate the social costs and benefits (especially environmental implications) into any evaluation. The intermediate products of research activities (as distinct from side effects of the applications) are also important. Since decisions are based on expectations of future events, risk and uncertainty are important considerations, here as in other areas of investment analysis. In performing *ex ante* risk analysis, all possible scenarios should be considered. However, given the lack of information regarding so many of the parameters affecting an *ex ante* evaluation, assessments of research will often contain a subjective component warranting some sensitivity analysis. One important area for judgment is what would happen in the absence of a given research effort.

Although formal research evaluation methods may improve the efficiency with which resources are used, care must be taken not to overemphasise the use of quantitative estimates alone in decision making. The allocation of resources based on estimated costs and benefits could lead to a bias toward those research activities whose potential results are most obvious and easily understood and measured (World Bank 1979).

However, all factors that affect the scale of research costs and benefits need to be considered explicitly, even if they cannot be valued numerically. It must be stressed that while benefit–cost analysis is likely to be a useful tool in the *ex ante* assessment of research, the existence of unresolved uncertainties means that the subjective judgement of informed researchers and funding agents remains crucial.

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