Review of the returns to ACIAR's bilateral R & D investments

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REVIEW OF THE RETURNS TO ACIAR'S BILATERAL R&D INVESTMENTS

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The Australian Centre for International Agricultural Research (ACIAR) operates as part of Australia's international development cooperation program, with a mission to achieve more-productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

▶▶▶▶ ACIAR seeks to ensure that the outputs of its funded research are adopted by farmers, policy makers, quarantine officers and other intended beneficiaries.

▶▶▶▶ In order to monitor the effects of its projects, ACIAR commissions independent assessments of selected projects. This series reports the results of these independent studies.

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Foreword

Both public and private funders and managers of agricultural research have an ongoing interest in measurement of the economic (and wider) benefits from investment in agricultural research and development (R&D). Research evaluation is not a new activity in Australia and has been undertaken in the Australian Centre for International Agricultural Research (ACIAR) for more than 16 years. During this time the methodologies and efficacy of R&D evaluation have improved and ACIAR has moved accordingly to enhance the range and applicability of its research impact assessment program.

In this context ex-post and ex-ante evaluations of nominated completed projects to demonstrate the level and range of returns from investing in research are an increasingly active component of ACIAR's research operations and culture. Such assessments have a variety of purposes since they serve to enhance public accountability; measure economic (and other) benefits from agricultural research; provide insights into research management and selection practices; and give guidance into ACIAR's future research direction and priorities.

The range of assessments currently utilised by ACIAR includes:

- Project reviews undertaken before or close to the end of the project by independent experts to assess project performance against objectives.
- Adoption studies undertaken three years after the completion of larger projects for which there were no follow-on projects. These studies are designed to highlight the level of uptake of project results.
- Economic impact assessments undertaken once project results have been taken up by end users. Assessments measure returns on investments with added attention to poverty alleviation results and community benefits.
- Thematic studies and stocktakes to examine returns on ACIAR's investment in specific thematic research areas and the returns to ACIAR's overall investment in partner countries and Australia. The information obtained assists in shaping future investment patterns.

The use of stocktaking techniques to review previous quantitative research assessment results is a relatively new endeavour for ACIAR. As such, this report is an initial step in the use of such techniques to examine aggregate returns to ACIAR's research outlays based on impact assessments undertaken since 1998. ACIAR and the authors recognise that this exposition is a preliminary but instructive result which can be further refined to more accurately measure cross sectional benefits as ACIAR continually improves its assessment processes and project information base.

The approach used in this analysis involved:

- Reviewing previous ACIAR economic impact assessments
- Appraising the methods used for plausibility, transparency and analytical rigour
- Aggregating the benefits from the range of impact assessments categorised into three groups on the basis of plausibility of benefit estimates

These benefit results were subsequently measured alongside ACIAR's total research investment expenditure to present collective minimum benefit ratios.

The current study provides a useful systematic overview and aggregation of results across 29 earlier impact assessment studies covering 50 individual research projects. As such it provides a helpful insight into the overall effectiveness of interventions in recent years. The division of results by research area; geographic composition of benefits and the poverty relevance of assessed primary benefits have provided useful indications to research managers of the key characteristics of successful research to achieve ACIAR's mission and objectives. These characterisations of research effects also facilitate more cross-learning in terms of both spatial and discipline based lessons in ACIAR's program mix and impact assessment procedures.

Importantly this initial evaluation of the overall efficacy of ACIAR's bilateral investments concludes that such investments have been well justified by economic benefits quantified to date across a spectrum of research projects. The study shows that benefits from a limited assortment of studies completely justifies the entire ACIAR bilateral investment to date. This result applies to all scenarios when the summation of future benefits are included (recognising that research uptake and outcomes are generally incremental over time).

While the benefit-cost ratios presented in this study provide a clear vindication of ACIAR's agricultural research portfolio, it is acknowledged that the metrics are a substantial under estimate of the actual benefits attributable to ACIAR's full research program. This 'conservative' approach has been deliberately adopted to avoid misleading or exaggerated assessments. The explanation for this is fivefold:

- The projects selected for impact assessment may not be representative of the wider ACIAR project population.
- A range of likely benefits which are not readily estimated with rigour have been excluded to ensure reliable benefit valuation and credibility but all research related costs have been included as a more identifiable number. This gives a downward bias to the final ratios.

- Project impact assessments have been broadly categorised into three categories (i.e. potential benefits, plausible benefits and substantially demonstrated benefits) to address the variability in approach in the previous impact studies and the degrees of certainty in estimates. More consistent methodology and measurement across project evaluations will help in the future.
- The current study is inevitably constrained by the limited scope of some earlier assessments in terms of measuring spillover benefits and assessments against wider ACIAR goals (each of which is now being more fully analysed in current impact assessments). Some impact pathways were also not amenable to impact assessment due to attribution difficulties and were excluded.
- Although information is improving, there has been a lack of empirical data on both positive and negative social and environmental impacts which has also contributed to a cautious approach in this study, even though, intuitively, a range of social and environmental benefits are very likely to have been achieved in earlier research projects.

The above limitations will be progressively addressed as ACIAR improves on its generic impact measurement systems drawing on the experience of this exercise which has calculated minimum benefit-cost ratios.

Current limitations will also decline as a number of forward assessments are validated over time with enhanced adoption and dissemination giving greater credibility to output measurement. ACIAR's improved databases and up to date impact assessment processes will also assist future generic analyses to more accurately evaluate benefits and avoid understatements based on conservative assumptions.

The above contextual observations do not detract from the inherent advantages that this review has delivered by focusing on the direction and magnitudes of effects across projects. The very positive conclusions of the analysis of previous studies provide a sound basis for ACIAR to assess its future strategies and directions as we develop and finalise the next 2006–2010 Corporate Plan.

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Executive summary

Since establishment of the Australian Centre for International Agricultural Research in 1982, A$1.1 billion[1] has been invested in the Centre's bilateral research support programs. While the worth of this investment has been widely documented in qualitative terms, and the economic impacts of a number of individual research projects have been assessed, no single prior study has sought to determine whether the aggregate investment has been economically justified. The present analysis aggregates available estimates of ACIAR-attributable economic benefits, and sets these aggregates against total investment in bilateral activities to date, so as to determine whether documented impacts justify total costs under three scenarios of benefit aggregation. This is a highly conservative approach to derive minimum measures of overall investment efficiency, because benefits are derived from only a small share of ACIAR's activities whereas agency costs are all-inclusive.

ACIAR has a long tradition of economic impact assessment. The Centre's 29 economic assessments published to date within its Impact Assessment Series comprise the principal product of these efforts. However, as these assessments have been commissioned by individual external experts, there is some degree of variability in methods applied and the certainty of estimates made. This heterogeneity is compounded by differences in the types of research outcomes being evaluated, a factor that has further necessitated a diverse array of assessment methodologies.

In the context of this methodological variability, the present study identifies those results that could be aggregated with confidence to provide highly conservative estimates of total benefits. Hence, it is important to determine the certainty with which the findings of individual studies can be used. To that end, each individual impact assessment study was subjected to a critical review process so as to evaluate the confidence that can be placed in the reported estimates of benefits.

The review process is based on a framework of principles, criteria, and indicators for study credibility, which is derived from a selective review of the methodological literature. Two overarching principles underpin this review framework—'transparency' and 'analytical rigour'. Transparency embeds three criteria: 1. clearly derived and explained key assumptions; 2. comprehensive description of data sources; and 3. full explanation of data treatment. Analytical rigour includes: 1. representative data set utilised; 2. appropriate data treatment; 3. plausible counterfactual scenario developed; 4. adequate consideration of mission-relevance of economic benefits; and 5. plausible institutional attribution.

[1] All values are in real 2004 Australian dollars (A$).

On the basis of the assessment of individual impact studies against these criteria, three basic scenarios of benefit aggregation are constructed. First, a scenario of 'potential' benefits includes all ACIAR-attributable benefits estimated within the 29 economic impact assessments of the Impact Assessment Series. Second, a scenario of 'plausible' benefits includes only findings from studies based on empirical evidence of adoption of R&D outputs, and which receive moderate ratings for 'transparency' and minimal ratings for 'analytical rigour'. A third scenario of 'substantially demonstrated' benefits utilises only the studies with highly certain benefit levels, based on somewhat higher scores for 'analytical rigour' to explore whether the ACIAR investment is justified solely on the basis of the most robustly estimated benefits. Benefits realised to date (i.e. through 2004), and benefits inclusive of future projections are aggregated for each of the three scenarios.

When future benefits are included, the benefits for all scenarios are well in excess of aggregate ACIAR investment to date, and benefits generated to date exceed total costs for all but the most restrictive scenario. Under a real discount rate of 5%, all 'potential' benefits sum to 3.06 times total costs, while 'plausible' benefits result in a benefit–cost ratio of 1.62, and 'substantially demonstrated benefits' produce a benefit–cost ratio of 1.31. If only benefits to date are considered, the ratios are 1.33, 1.00 and 0.84, respectively.

It is clear from the benefit–cost ratios reported here that ACIAR's support for bilateral R&D activities has been an exceptionally efficient means of investment in development assistance. This is an impressive achievement, as to date no large bilateral development assistance agency has comprehensively shown that its overall investment has been justified.

Furthermore, it is likely that these measures understate actual returns on investment, as, depending on scenario, these substantial benefit levels are generated by only 3.0–7.8% of ACIAR's total investment in bilateral activities. Most of the outputs generated by the types of research that the Centre supports face severe attribution difficulties, and many important intended impacts face severe valuation problems. Impact assessment from the position of a funding and facilitating body further compounds these constraints. As a result, economic impact assessment has been applied to only a small portion of ACIAR's potential impact pathways. This means that many important benefits almost certainly have evaded assessment, and even the highest benefit–cost ratio reported here is likely to be conservative.

1 Introduction

The Australian Centre for International Agricultural Research (ACIAR) was established in 1982 to support collaborative research towards innovative solutions to the constraints afflicting agriculture in the developing world and Australia. The Centre was founded on the premise that both developing countries and Australia had much to gain from fostering partnerships between leading Australian and developing-country agricultural scientists. These research collaborations have been intended to result in productivity-enhancing technologies for the semi-arid and tropical conditions shared by Australia and many developing regions.

Since the establishment of ACIAR, nearly A$1.1 billion (real 2004 dollars) has been invested in bilateral research support and capacity-building initiatives of the Centre. Given that the creation of the Centre was explicitly premised on prior observations of high returns from agricultural research investments (ACIAR 1983), it is relevant to ask: 'Do the aggregate documented economic benefits resulting from bilateral ACIAR investments in collaborative research justify total funding for the Centre to date?' The present analysis is the first systematic attempt to answer this question.

Documentation of economic impacts has a long tradition at ACIAR, and the product of this tradition has been a series of economic impact assessments of investments in selected individual research undertakings. As a matter of policy, the primary investments that were selected for impact assessment were those that, with the benefit of hindsight, were regarded as 'success stories' that could easily be attributed to ACIAR's research investment (D. Templeton, Manager, ACIAR Impact Assessment Unit, 3 February 2005, pers. comm.). Consequently, each of these impact assessment studies in isolation does not offer evidence that can justify the total investment, because each cannot be assumed to be representative of the entire ACIAR research portfolio. As research is a highly uncertain process, there often are many 'dry hole' research undertakings to offset against successes, and these may expend significant funds without directly attributable effects on outcomes of interest. This renders estimates of research benefit–cost ratios inaccurate if associated costs of research 'failures' are not embedded in analysis (Rank and Williams 1999).

To go beyond these potential problems of analysis at the project level, it is possible to aggregate credible documented economic impacts from individual research undertakings, and to set such against total investment by a research funding institution such as ACIAR. Under this conservative approach, all impacts that have not been rigorously documented in economic terms make no

contribution to the numerator of benefit–cost ratios, while all research and research-related costs are included in the denominator. Thereby, credible minimum benefit–cost ratios for the *entire* ACIAR bilateral investment may be calculated.

This approach is biased towards conservatism by the fact that the economic impacts included are inherently partial, whereas the costs included are total. The estimated impacts are incomplete due to the fact that economic impact assessment currently can be rigorously applied to only a small subset of possible impact pathways from research. Furthermore, due to resource limitations, impact assessment has been applied to only a portion of assessable impacts. Moreover, long lags between investment in research, and the realisation of benefits, mean that, given the wide scope of the ACIAR bilateral investment portfolio, it is virtually certain that already completed research projects will yield future benefits that have been neither realised nor anticipated. Consequently, if the economic benefits included have been rigorously determined, and it can be safely presumed that ACIAR has not produced research with serious social costs, this approach will ensure that the benefit–cost ratios produced are likely to understate actual returns.

Economic impact assessments conducted for ACIAR research have been externally commissioned from a diverse range of experts and institutions, and benefits have been calculated for a wide array of research outcomes. As a result, analytical methods, data quality and underlying assumptions vary from study to study. This variability is compounded by the fact that ACIAR economic impact assessments are often a hybrid between ex-post and ex-ante assessment, with evaluation conducted after research completion, but before many benefits have been realised. The degree to which analyses are ex ante versus ex post is also variable. This introduces another element of diversity to the impact assessment study findings, as the more ex ante is the analysis, the more assumption-laden are the findings.

Consequently, critical review is essential to ensure the credibility and comparability of benefit values to be aggregated in the numerator of overall benefit–cost ratios. To do so requires the establishment of a review framework for study rigour that can allow for studies to be classified and grouped according to the confidence with which results can be used.

The present study adapts the approach, and builds on the framework for critical review of a similar study (Raitzer 2003) recently undertaken for the Consultative Group on International Agricultural Research (CGIAR). The application of this framework allows for the construction of three scenarios of benefit levels. First, all reported economic impacts attributable to ACIAR bilateral investments will be aggregated to explore the potential levels of benefits, inclusive of some estimates that are contingent upon hypothesised future changes in production practices. Second, those studies that are based on documented evidence of

adoption, and which meet basic standards for credibility will be used to construct a scenario of more-certain benefits. Third, a very restricted pool of studies that clearly illustrate rigorous calculation of research investment returns will be used to determine if the investment is justified by only aggregate benefits that have been calculated on a highly rigorous basis.

1.1 Background

1.1.1 The Australian Centre for International Agricultural Research

A statutory authority of the Australian Government, subject to the Department of Foreign Affairs and Trade, ACIAR is a unique organisational solution to funding for development-oriented agricultural research. Throughout its 23-year lifespan the Centre has remained a relatively small agency with a core professional staff of recognised researchers who serve primarily as 'research program managers' for sectoral research investment portfolios.

The following objective of the Centre (ACIAR 1987) was first articulated in 1987, and has remained essentially unaltered since:

> ACIAR's goal is to build the capacity of developing countries through collaborative research in the agricultural sciences to improve the social, physical and economic well-being of the poor by increasing productivity, stability, and sustainability in the agricultural sector.

The Centre's programmatic coverage has remained relatively continuous over its history, as activities in most of these areas date from within a few years of establishment. By 1985, the present array of activities had essentially emerged, although the programmatic organisation has shifted slightly during the Centre's evolution. Thus, description of ACIAR's present portfolio of programs provides valuable insights into the bilateral research funding activities to date.

The present ACIAR portfolio includes 11 bilateral research programs, in addition to multilateral and impact-assessment activities, as well as training of developing country scientists. Each bilateral research program contains 10–20 'projects' at any given time. These 'projects' comprise funding and coordination to partnerships between Australian and developing country researchers involved in research on a particular problem of mutual interest to Australia and developing country partners. The current array of research programs is as follows:

Agricultural Development Policy

This program, which largely consists of projects in the economics discipline, focuses on analysis of trade, rural development and natural resource management policies. Recommendations stemming from funded research projects in this

program are often oriented towards government audiences, and are intended to help target public-sector investments and policies, so as to maximise social benefits.

Agricultural Systems Economics and Management

As another program chiefly devoted to economics and social science research, projects in this area are distinguished by a primary focus on improving the relevance and effectiveness of productivity-enhancing research. Consequently, research funded in this program is typically oriented towards integration of socioeconomic considerations into other research and technology-transfer activities.

Animal Sciences

ACIAR actually has two programs in the livestock and poultry arena, and these collectively comprise one of the largest areas of emphasis of the Centre's bilateral portfolio. Within these programs, animal health, genetic improvement, postharvest issues, animal nutrition and the optimisation of complementarities with other farming components are principal focuses.

Crop Improvement and Management

Research projects funded within this program include crop improvement and crop management, so as to contribute to the enhancement of the productivity of crop production systems. In addition, complementary research on the conservation of germplasm is carried out to contribute to the maintenance of productivity gains.

Crop Protection

This ACIAR research program seeks to improve the methods by which major pests afflicting crop and fruit production are controlled. Areas of research funded include biological control, integrated pest management, biological pesticides, pest diagnosis techniques, and surveys of pest and disease distribution.

Fisheries

ACIAR's Fisheries Program includes research on a range of issues ranging from wild capture marine fisheries to freshwater aquaculture systems. Projects funded include research on the social implications of management practices, optimisation of management modalities, as well as the development of productivity-enhancing technologies for farm fisheries.

Forestry

The Forestry Program includes research that attempts to improve the sustainability and productivity of management practices in plantation and natural forest systems. Within this program, areas of research funded include tree genetic

improvement, disease management, plantation management, resource assessment, harvesting/processing technologies and management strategies for native forests.

Land and Water Resources

This program focuses on broad-scale management of land and water resources, so as to improve the environmental quality and productivity of agricultural production practices. Projects have been funded in the areas of methods for assessment and amelioration of agriculture-induced resource degradation, water resource management technologies, and land use planning practices.

Soil Management and Crop Nutrition

Projects within cropping systems and soil management at the field scale are the focus of this program. Most of the research projects funded in this program attempt to improve nutrient management practices, tillage management, or the modelling of cropping systems at the farm level, so as to raise overall productivity.

Postharvest Technology

This research program covers postharvest systems for food, fibre products and animal feeds. Funded research projects seek to improve the efficiency of processing and storage systems for these products, so as to reduce losses due to pests, and improve the quality of fibre and food products.

For fiscal year 2004–2005, the Centre has a total budget of $A52 million, of which $A40 million is comprised of bilateral activities. ACIAR's budget has been relatively stable since a few years after the Centre's inception, with fairly constant real (inflation-adjusted) funding levels.

The 2004–2005 distribution of bilateral expenditures by program is presented in Figure 1 (ACIAR 2004). From this figure, it is clear that, at present, the programs have relatively equal budgets, ranging from 6 to 12%. The primary areas of current emphasis include: crop productivity enhancement (21.2%), of which nearly half is devoted to crop protection; economics and policy research (16.2%); animal sciences (15.6%); fisheries (12.4%); and forestry (9.5%).

ACIAR places geographic emphasis on beneficiaries in the region surrounding Australia (Figure 2). Accordingly, Southeast Asia is presently a target of nearly half of ACIAR's bilateral expenditures, and Oceania follows with nearly a fifth (19.2%). North Asia and South Asia receive about a sixth (15.1% and 12.5%, respectively), while Africa is the intended beneficiary for a small share of funding (2.8%).

Figure 1. Breakdown of 2004–2005 ACIAR bilateral investments by research sector. Data from ACIAR (2004)

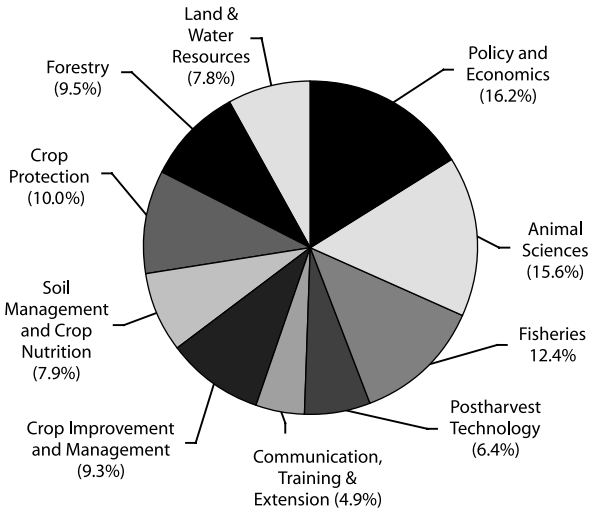
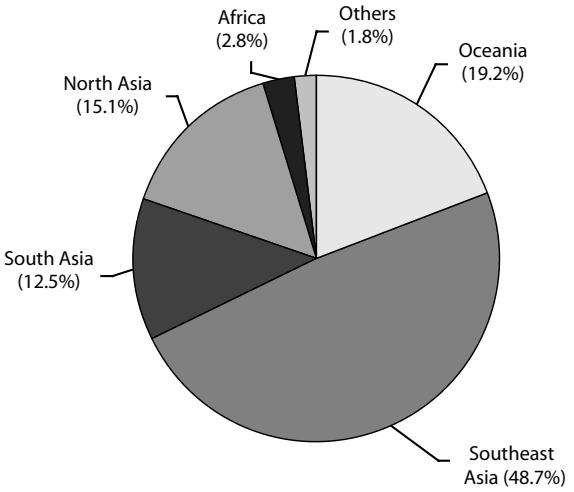


Figure 2. Breakdown of 2004–2005 ACIAR bilateral investments by targeted region. Data from ACIAR (2004)



1.1.2 Economic impact assessment at ACIAR

Economic impact has long been considered an important ultimate objective of ACIAR's activities, and was even cited as an early justification for the Centre's establishment (ACIAR 1983). The Centre pioneered the use of quantitative models for ex-ante assessment of the potential returns to different research endeavours, and arguably employed such models in a more comprehensive manner than did other agencies involved in international research (CGIAR 1991). Regular economic assessment of completed research activities was initiated in 1990 with the Centre's Economic Assessment Series, which includes 12 studies published through 1991. These studies were externally commissioned from economists with knowledge of the field in which the funded research was conducted, so as to embed impartiality. However, although the studies in this series were ex post of the funded research, they were essentially ex ante of achieved benefits.

In 1998, ACIAR initiated publication of the Impact Assessment Series. While publications in this series carried on the external authorship approach of the earlier economic assessments, the focus is slightly more ex post in many of the studies. However, these assessments are still not strictly ex post, but rather were conducted ex post of the research, with limited ex post assessment of benefits followed by longer ex ante projections based on preliminary impact trends. Studies conducted in this series are expected to meet a series of guidelines issued by ACIAR to ensure some continuity of methods and reporting.

The scope of the present analysis is restricted to the findings from the later Impact Assessment Series, and does not include the publications within the Economic Assessment Series, due to the speculative nature of the earlier ex ante approaches. As the current analysis seeks to derive credible lower-bound aggregate measures of documented impacts, analysis based on few observations regarding adoption and benefits in the field is not appropriate to include.

Not all publications in the Impact Assessment Series are economic analyses of ACIAR research investments. Of the 34 studies[2] published to date (May 2005), 29 fall into this category. These are listed in an appendix. The others comprise a poverty impact assessment framework, two poverty impact assessments, a research review, and a farm-level profitability assessment.

As the external authors of the impact assessment studies employed a variety of methodological approaches and assumptions, there is variation in the level of certainty of different assessments. Some assessments are largely rooted in ex-ante conjecture about possible future events, or make claims of impact without validating data sources or assumptions. Conversely, other assessments rigorously document benefits, so as to make conservative claims regarding impacts for which more empirical data are available.

1.2 Objectives

Overall objective: To calculate credible minimum aggregate benefit–cost ratios for total investment in ACIAR's bilateral research support activities to date

Sub-objectives:

1. To define a framework for evaluating the credibility of individual economic impact assessments of ACIAR-funded bilateral research activities

2. To evaluate ACIAR commissioned economic impact studies against the framework identified in sub-objective 1, so as to determine the credibility of individual estimates

3. To aggregate benefits from studies grouped by credibility, and set aggregates against total investment in bilateral activities to date, so as to derive overall benefit–cost ratios

4. To appraise the accuracy of aggregate benefit–cost measures, and analyse the characteristics of documented benefits.

[2] Copies of all studies in the Impact Assessment Series are available at <www.aciar.gov.au>.

2 Methods

As the present study is intended to assemble credible minimum figures for aggregate economic benefits resulting from ACIAR's bilateral activities, it is important that the basis for these figures is also credible and relatively certain. In the context of variable methods embedding different types of data sources, a critical review process is necessary to determine the confidence with which different findings may be used. Through such review, studies that are particularly credible may be isolated, so as to construct aggregate benefits estimates that embed minimum degrees of certainty.

2.1 Review framework

No widely accepted set of criteria for the rigour of economic impact assessment of agricultural research has yet been produced. Raitzer (2003) in an earlier, unrelated meta-analysis proposes one set of principles, criteria and indicators for study credibility, but these are oriented towards pure ex post approaches to analysis of research activities, rather than the actions of a funding body. The present study builds upon this, and elaborates a critical review framework for review based on synthesis of the existing methodological material available for economic assessment of investments in development-oriented agricultural research. Special considerations encountered from the perspective of a research funding agency are subsequently discussed.

2.1.1 Background on valuing the benefits of agricultural research

To provide some background for the methodology applied in the present review, it is useful to describe the general means by which the economic impacts of agricultural research are often estimated. Schultz (1964) was one of the primary economists to first argue that farmers operate on the production possibilities frontier, and actively utilise opportunities to increase agricultural productivity. This is a principal premise behind the benefits envisioned as a result of agricultural research, as the production frontier can be effectively raised through the generation of new technology. Consequently, farmers, as producers on the production possibilities frontier, can be expected to increase productivity levels. Thus, higher quantities of agricultural products will be supplied at any given price, and this increased supply will drive down prices. Producer income will be improved through higher productivity, while lower prices raise consumer purchasing power, which together underpin economy-wide growth. Agricultural development as a central driver of economic progress has now been accepted as a central tenet of modern development theory.

Generally, economic impact, as commonly assessed for agricultural research, is often a quantification of the value of productivity improvement or inputs saved. It is often taken as granted that such productivity increases will foster gains throughout the broader target economies, and thereby achieve ultimate goals of poverty alleviation. Thus, the values presented are, in most cases, quantifying intermediate indicators, rather than benefits to the poor.

Most economic impact assessments of agricultural research rely on implicit or explicit economic surplus techniques. In some cases, these are calculated through econometric methods or are subjected to multivariate sensitivity analysis through Monte Carlo simulation techniques. Economic surplus techniques build upon the approach first utilised by Griliches (1958) in a pioneering study on hybrid maize, in which adoption of a technological innovation fosters a downward shift in the supply curve, which is usually driven by reductions in the unit cost of production. Costs per unit of production may be lessened through reductions in losses due to pests or diseases, increased yield potential or increased efficiency of input use.

Benefits may be presented in an aggregate social form, including changes to producer as well as consumer surplus, or may be partitioned between producer and consumer groups through the use of price elasticities of demand and supply. Consumer benefits are transmitted through price reductions in 'closed economy' models. Open-economy models are also often used, and these do not base benefits on consumer price reduction, but assume that supply does not affect average prices. Under such assumptions, benefits are frequently measured through the value of increased production or inputs saved per unit of production, and are often implicitly assumed to be received by producers.

The scope of economic impact assessments is usually a single innovation or series of related technologies. Since research is an uncertain process characterised by many 'dry holes' producing little beneficial impact, and a few 'gushing wells' producing substantial benefits, benefit–cost analysis at the project level may not be representative of an aggregate research portfolio, unless the costs of associated unproductive investments are considered as well (Rank and Williams 1999).

2.2 Elements of good practice in economic impact assessment

To determine the 'with research' and 'counterfactual' levels of unit production costs, production levels and prices, several intermediate steps are required. First, linkages must be clearly established between research outputs and changes in productivity and production levels (Anderson 1997). To do so via the most commonly employed economic surplus techniques, the extent of use and uptake of the research output or new technology needs to be estimated (Maredia et al. 2000). For some types of research outputs, such as improved germplasm, this may

be a relatively simple task, as secondary data sources, such as seed sales estimates, can provide some simple indications of use. However, for research outputs without empirically observable indicators of adoption, such as policy research, there may be considerably more difficulty in determining the extent of use (Schuh and Tollini 1978). These difficulties may be compounded by the fact that the intensity of adoption for these outputs is often hard to discern. In these cases, to determine uptake, qualitative approaches are often necessary to query how research products are employed.

The dynamics of adoption can be difficult to predict and may be subject to stochastic influences (Ekboir 2003). Furthermore, preliminary measures of acceptance obtained in trial settings are often unrepresentative of broader conditions among the intended population of adopters (Dillon and Anderson 1990). As a result, there can often be little certainty in inferences about future adoption patterns based on promising research results or very preliminary evidence of use. This means that ex-ante assessment cannot offer much confidence about actual benefit levels that will be realised under field conditions. Documented evidence of growth in adoption rates is often necessary for predictions to be made with much certainty that adoption will follow specific diffusion curves.

For the collection of adoption data, it is important to use sampling procedures that are adequately representative of the range of conditions and resource endowments under which the innovation will be employed (Maredia et al. 2000). Ideally, the data-gathering process should encompass the concept of multiple-source-verification or triangulation, but this is often not possible for cases where adoption of the research output cannot be empirically observed (Masters et al. 1996). If expert opinions or secondary sources are cited for adoption estimates, it is essential that the basis of the estimates utilised be clear. Without a basis of solid adoption parameters, little confidence can be placed in the results of an economic assessment of research results. On the other hand, if adoption data robustly indicate widespread uptake, it is clear that benefits to the adopting population should be substantial, as producers have rationally chosen to adopt as a result of some benefits.

As mentioned previously, data on the productivity benefits and/or unit cost reductions attributable to the innovation are necessary for adoption estimates to be translated into economic parameters. These values should also be derived from estimates under field conditions, as trial sites often differ in resource endowments from those of the broader farming population. In addition, the heterogeneity of performance across agro-ecological conditions should be encompassed for estimates to be representative. If maintenance research is likely to be necessary to sustain research benefits, this should be incorporated in the estimated productivity trends.

Furthermore, increases in productivity must be relative to an appropriate 'counterfactual' level of technology. This cannot necessarily be assumed to be the level of technology applied before the research (CIE 1997). Agriculture is a dynamic sector, and there are many sources of innovation that may shift the productivity frontier, including spillover effects, the outputs of other research organisations and endogenous farmer experimentation (Alston and Pardey 2001). Thus, the baseline 'counterfactual' scenario for the calculation of shifts in production and productivity levels should attempt to reflect the level of progress achievable in the absence of the outputs of the assessed program (Salter and Martin 2001).

It is also possible that the counterfactual may represent a scenario of delayed technological availability, if it is likely that alternative research outputs would eventually substitute for the assessed technology. In this case, research benefits may actually be calculated on the basis of advancement of benefit flows (Ryan and Garrett 2003). In practice, this is often achieved by calculating the difference between the research benefits being realised at the observed/predicted rates, and a counterfactual scenario of lagged benefit flows. For such assumptions to be realistic, it is important that alternative sources of similar research outputs are adequately considered, and that the basis for estimated advancements in benefits be clear and robust. If no advancement in benefits is specifically assessed, there is an implicit assumption that no alternative source for similar technologies will emerge. It is important that potential alternative providers for technologies or innovations be considered before counterfactual conditions of technical change are specified.

However, the estimation of research benefits in isolation does not establish that assessed benefits are relevant to the organisation's goals. In the case of agencies concerned with 'research for development' (such as ACIAR), it is important that the assessed benefits contribute to poverty-alleviation goals, and do not primarily accrue to the wealthiest segments of society. In practical terms, this means that auxiliary analysis of producers' benefits is needed for sectors where the distribution of ownership and management of key resources is skewed towards a small number of individuals, and where price effects are unlikely to benefit poor consumers.

2.1.1 Special considerations in the case of a research funding body

The previous discussion relates primarily to analysis of the economic impact of a research executing agency. There are additional methodological difficulties in the analysis of the economic impact of the activities of a research funding agency, as the counterfactual in this case is not necessarily the same as a 'without research' scenario. For such a situation, the counterfactual cannot even necessarily be assumed to be a reduction in the research activities that received support from the funding agency, as illustrated below.

Most research agencies have two broad categories of funds—'core' funds, which are provided to fund the institution and certain research activities, and 'restricted' funds obtained through external grants. 'Core' funding, with few restrictions, can be easily shifted, and may be allocated so as to fill gaps in prioritised programs when 'restricted' funding is insufficient. Such behaviour may be particularly expected if the research institution has an established hierarchy of priorities with target allocation levels, as once a certain project funding level has been attained, priority may turn to ensuring that the next most prioritised project is adequately funded.

This means that funding may be 'fungible' if significant core resources are present. Thus, the addition of external funds to a research program may have a displacement effect and may result in a reallocation of core resources to another programmatic 'gap'. In this case, the overall effect of the funding contribution is not expansion of the funded research project, but rather the expansion of the project that receives the displaced core resources (Belli et al. 1998).

Alternatively, the addition of external funding may draw core resources to the funded project through requirements of matching contributions for funding eligibility. In this case, alternative internal project options that compete for core resources will suffer budget declines in favour of the externally funded project, and the funding will have fostered an 'agenda shift' in the recipient's portfolio. If the externally funded project produces more socially beneficial outcomes than do the competing projects that lose funding (or are never initiated), the proportion of benefits attributable to the external funding may be greater than the proportion of funding provided.

Finally, if the internal 'core' research funding is static, and additional external funding simply serves to expand the selected research activity, there are two likely effects on the research program. First, through the application of better research equipment, improved methods, expanded data collection and more comprehensive testing, it is possible that the research output is superior to that which could have resulted from the research conducted in the funding's absence. This technical superiority may lead to greater adoption levels, higher productivity levels and other contributions to benefits. Depending on whether there are increasing or declining returns to scale from research investment, this marginal improvement may yield a greater or lower return to the additional funds than to the counterfactual level of investment. Alternatively, it may be possible that the adoptable research output will ultimately require a minimum funding threshold. In this case, the addition of an external grant allows this threshold to be reached earlier. As a result, the output may not be enhanced, but it may be available sooner, and benefits may be enjoyed earlier, and potentially also for a longer time.

The consequence of these complexities is that the 'without ACIAR' scenario cannot simply be equated to a 'without research' scenario, as ACIAR is a funding and facilitating body. However, ACIAR does not merely contribute funding to the recipient research organisation. Rather it convenes and facilitates partnerships between Australian institutions and developing country research agencies. In so doing, the Centre catalyses capacity-building by exposing the funded researchers to new perspectives and novel techniques. As a result, the productivity and effectiveness of research may also be influenced. This may further compound potential 'agenda shifts' resulting from internal reallocation of resources. If the consequence of these alterations in research agendas and methods is to raise the rate of return to the overall research investment, the true impact attributable to ACIAR's actions may be much more than the proportion of research funding provided.

2.3 Framework for critical review

The previous observations lead to a number of principles, criteria and indicators for the accuracy and precision of assessments of the economic impact of research investments.

First, it is obvious that implementation of the enumerated 'elements of good practice' cannot be verified unless an assessment transparently describes how each of the factors has been handled. In the present review process, this means that transparency regarding each element is a necessary but insufficient condition for study rigour to be evident.

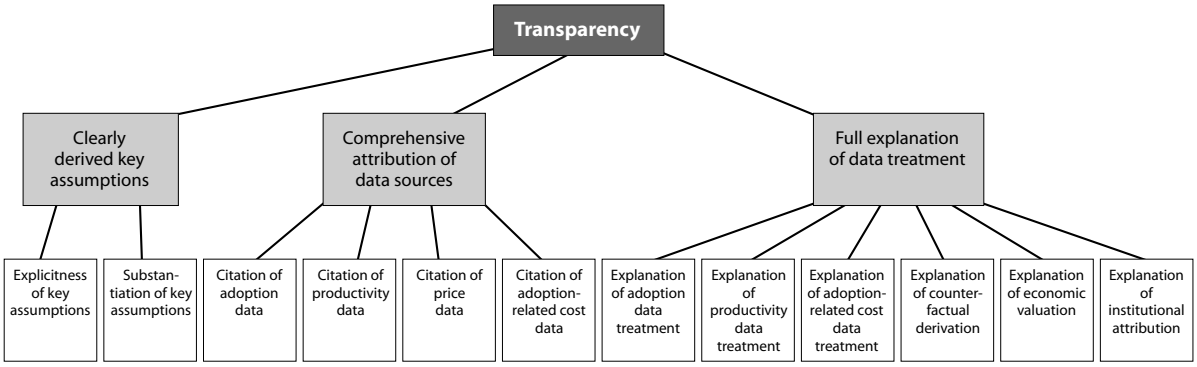
Second, a number of aspects regarding study methods are important for credibility, such as the quality of data utilised, the rigour with which data are treated, the plausibility of the 'without research' scenario developed, the assessment of the mission relevance of benefits estimated and the manner by which ACIAR's contributions have been identified. Generally, these all contribute to the rigour with which the research investment is attributed as an agent of desired mission-level changes. As a result, they can be grouped under the term 'analytical rigour'.

Thus, the two overarching principles for the review of assessments were;
1. transparency and 2. analytical rigour, with the former a necessary condition for the latter.

2.3.1 Transparency: criteria and indicators

Since the ability to understand the basis of estimates of benefits is a requisite condition for placing confidence in findings, it is imperative that credible studies be characterised by transparency (Baur et al. 2001). For the purposes of this study, transparency as a principle was represented by three broad criteria (Figure 3):

Figure 3. Hierarchical relationship of principles, criteria and indicators for assessing the transparency of reviewed studies



Clearly defined key assumptions

For the methods of a study to be clear, key assumptions that underpin the analysis should be apparent. This criterion was represented by two qualitatively assessed indicators—explicitness of key assumptions and substantiation of key assumptions. The explicitness indicator refers to how openly the study defines which aspects of the analysis have been derived from expert opinion or presumption by the author(s). Substantiation refers to whether a logical basis or citation has been provided to authenticate these untested assumptions.

Comprehensive description of data sources

Any economic analysis can only be as robust as the data employed therein and, as a result, the sources for such data should be clearly presented. Under this criterion, four indicators were enumerated, including description of data sources for extent of adoption (when relevant), productivity effects, costs associated with adoption and prices for valuing productivity changes. For each of these factors, it was noted whether all apparent sources of data were specifically cited.

Full explanation of data treatment

The methods applied to calculate benefit estimates from data collected should be described in detail for an analysis to be transparent. Six indicators were derived for this criterion, in a manner similar to those of the citation criterion. These include explanations of how estimates for adoption levels, productivity effects and adoption-related costs were inferred from available data. In addition, indicators represented the clarity with which derivation of the counterfactual, economic valuation, and institutional attribution methods were described. The ideal against which studies were evaluated was the provision of sufficient information to allow replication of the methodology used for processing each of these kinds of information.

2.3.2 Analytical rigour: criteria and indicators

There has been no framework defined in the literature to date for appraisal of an ex-post impact assessment's rigour. However, as previously noted, a number of methodological publications have been produced to provide guidance to impact assessment of research, and a number of papers have been written concerning common flaws in past approaches. It is possible to infer from these sources the necessary elements for best-practice rigorous assessment.

For a study to make a credible claim of impact, it is essential that a causal linkage be established between the assessed intervention and claimed effects (Ekboir 2003). Conceptually, the objective of ex-post impact assessment is the attribution of the effects of a particular research-derived intervention on the metrics of interest, relative to a myriad array of other potential causal factors. An essential part of this process is measurement and analysis of trends in metrics of interest over time. However, for these trends to be related to estimates of impact requires the construction of a 'counterfactual' (without the research-derived intervention) scenario that hypothesises plausible events in the absence of the research undertaking (Baker 2000). This counterfactual should take into account the relative role of alternative causes for changes observed and factors that may mitigate the effectiveness of the assessed output in the field.

To address the degree to which the reviewed studies demonstrated causality, five criteria were identified and developed through review of the methodological literature (Figure 4):

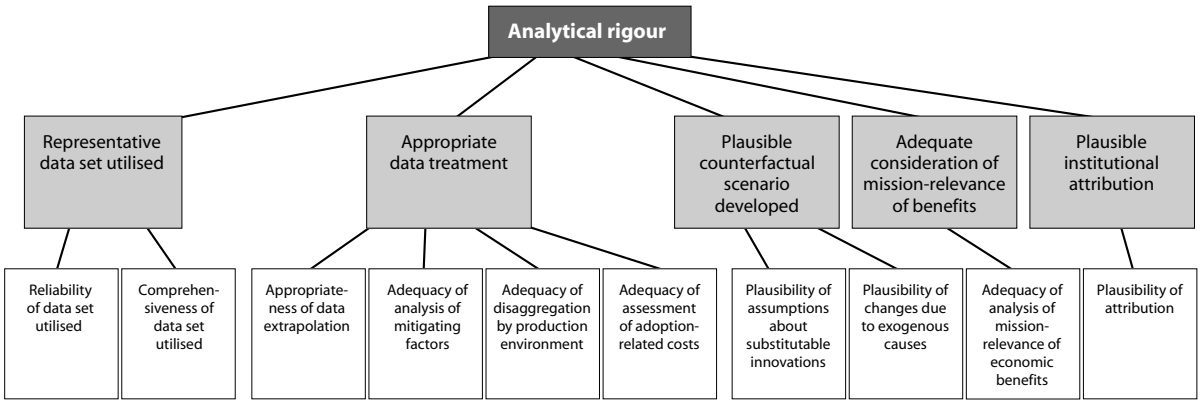
1. representative data-set utilised
2. appropriate data treatment
3. plausible counterfactual scenario developed
4. adequate consideration of mission-relevance of economic benefits
5. plausible institutional attribution.

Representative data-set utilised

For impact to be rigorously demonstrated through ex-post impact assessment, both measurement of metrics of interest and construction of the counterfactual must be rigorous. Measurement and monitoring of metrics of interest requires data from representative sites in enough quantity to perform comprehensive analysis at the scale over which trends will be extrapolated (Maredia et al. 2000). Such data typically include estimates of the area over which an innovation or new technology is applied or adopted, as well as data concerning the changes in productivity or inputs required per unit area of application that can be attributed to the innovation. A third important set of data concerns the appropriate prices for the shifted production or saved inputs.

This criterion was represented by two indicators—reliability of the data-set utilised and comprehensiveness of the data-set utilised.

Figure 4. Hierarchical relationship of principles, criteria and indicators for assessing the analytical rigour of reviewed studies



Appropriate data treatment

For an assessment to rigorously estimate research impacts, it is essential that robust methods be used to infer patterns of impact on productivity from data collected. Extrapolation of trends from available data on adoption and productivity in an appropriate and representative manner is an important element of this. In so doing, mitigating factors that may prevent expected patterns of benefits from being realised need to be assessed. Key parameters should be disaggregated in order to accompany spatial and temporal variance (Alston et al. 1995). Furthermore, additional costs necessary for the assessed benefits to be enjoyed, such as whether maintenance research investments are needed to sustain productivity gains, should be quantified and included in the analysis.

To assess the degree to which impact heterogeneity is considered in the reviewed studies, four indicators were used for evaluating the fulfilment of this criterion—appropriateness of data extrapolation, adequacy of analysis of mitigating factors, adequacy of disaggregation by production environment and adequacy of assessment of adoption-related costs.

Plausible counterfactual scenario developed

The counterfactual should represent the most realistic envisioned scenario in the absence of the assessed project. In the absence of a particular research program, it is likely that some sort of technological advancement would take place, and this must be captured in the counterfactual for an assessment to be accurate (Salter and Martin 2001; Baur et al. 2001). Ideally, such a counterfactual should be based on thorough analysis of the technical substitution possibilities and potential

alternative providers of similar research outputs. It is difficult for such counterfactual plausibility to be embedded if the counterfactual is not explicitly detailed.

Two indicators were used to assess the counterfactual scenarios developed in the reviewed studies—plausibility of assumptions about development of substitutable innovations from other research and plausibility of projected changes due to exogenous causes.

Adequate consideration of mission-relevance of economic benefits

Even if a high level of economic benefits can be attributed to ACIAR's bilateral activities, this does not, in isolation, illustrate that the organisation's mission is being achieved. As ACIAR's benefits are intended for the poor, some distributional analysis may be necessary. This is particularly the case when benefits accrue in the context of developing-country production sectors controlled by a small number of powerful interests, where benefits to labour or poor consumers are not evident. In sectors where there is a history of documented patterns of benefit distribution that have been shown to favour poorer populations, distributional analysis is less essential.

A single indicator, termed 'adequacy of analysis of mission-relevance of economic benefits' was used to assess whether there was sufficient attention in the study to the distribution of the assessed benefits among target populations.

Precise institutional attribution

For a rigorous analysis of the impact of investment in a specific institution to be made, an empirical basis should be used for attributing the effects of the institution's actions, as compared with that of its partners. However, it should be noted that it is almost always more accurate to consider complementary efforts as a single activity, as there is no accurate and accepted means by which credit can be partitioned among collaborating funding bodies (Maredia et al. 2000). Yet, for the purposes of the present analysis of ACIAR investment, impacts attributable to the Centre's involvement need to be estimated, and empirical attribution is therefore needed for rigorous analysis of ACIAR-derived benefits.

This criterion was represented by a single indicator, which attempted to capture the plausibility of the attributive basis for crediting the assessed project relative to other similar research endeavours. When a study did not attempt to attribute project benefits to joint research products, it received the lowest score. Such should not be interpreted as indicating that these studies are of low reliability, but it does reduce the reliability of any ACIAR attributable values derived thereof.

2.3.3 Rating of studies against the review framework

Each economic impact assessment study was reviewed against this framework, and a numerical score of 0 to 3 has been assigned for each indicator. Zero indicates that the indicator is unfulfilled or unconsidered, whereas 1 to 3 have been applied to rate partial to full fulfilment of the indicator. Irrelevant indicators for particular cases were not considered. Each indicator has been weighted equally. The ratings of individual indicators have been averaged for each principle.

2.4 Scenarios for benefit aggregation

Three basic scenarios have been constructed on the basis of the aggregate scores for the principles of 'transparency' and 'analytical rigour': 'potential', 'plausible', and 'substantially demonstrated' benefits. These scenarios are nested and progressively exclusive. As a result, the 'plausible' benefits scenario is inclusive of all 'substantially demonstrated' benefits, and the 'potential' benefits scenario is inclusive of all 'plausible' benefits.

2.4.1 Potential benefits

This scenario is unrestrictive and includes all estimated benefits from ACIAR's impact assessment series. While this scenario may give an idea of the possible returns that may have resulted from those ACIAR investments for which impact assessment studies have been conducted, some of the benefit estimates included have been based on very limited empirical data. In a few cases, projections of potential uptake and/or benefit levels have proven to be somewhat optimistic, and there can be little certainty that all of the benefits included have or will be realised. However, this scenario does help to illustrate the total value of benefits that ACIAR has documented as a result of all evaluated ACIAR activities, even if the documentation may be rudimentary.

This scenario is split into two sub scenarios—'benefits to date' and 'projected benefits'. 'Benefits to date' includes only estimates of benefits realised through 2004, while 'projected benefits' includes estimated benefits for the entire time period covered by the study. The latter period is typically 30 years from the initiation of the research, although a few studies have estimated a time frame that ranges 30 years from the initial diffusion of the research output.

2.4.2 Plausible benefits

This scenario is restrictive, and excludes those studies that have substantial methodological uncertainties, or which are purely ex ante. The initial criterion for inclusion in this scenario is that there is at least some empirical evidence that the research output has been adopted on a wide enough scale to justify the initial benefits estimated. This means that all studies included in this scenario must be at

least partially ex post, and must embed empirical evidence of adoption by farmers or research managers, in the case of technological innovations, or implementation of the recommendations in the case of policy enhancement.

Furthermore, these studies must rate reasonably well against the review framework. As it is impossible to determine the rigour of a study if the methodology is not evident, studies included in this scenario must receive at least moderate ratings for 'transparency' (an average score of 1.5 or more on the 0–3 scale for the indicators under this principle). In addition, studies in this scenario must have at least limited levels of rigour, with average scores of 1.0 or greater for the indicators under 'analytical rigour.' Estimates under this broad scenario are aggregated under sub-scenarios of 'benefits to date' and 'projected benefits'.

2.4.3 Substantially demonstrated benefits

This restrictive scenario is intended to isolate only those benefits that have been rigorously assessed, so as to calculate a 'lower bound' measure of economic impacts attributable to ACIAR's bilateral activities that has low potential for error. While this scenario may omit some likely benefits, the objective here is to assemble only those benefits that have served as a high-confidence core of the other two scenarios, and which are relatively unlikely to be very erroneous.

Studies included in this scenario are all already within the plausible pool, as this scenario is a subset of the plausible benefits. The additional criterion required for inclusion in this scenario was a higher rating for 'analytical rigour'. To be included in this scenario, studies must have at least an average of moderate ratings for this principle (1.5). As for the other two scenarios, sub-scenarios of 'benefits to date' and 'projected benefits' have been developed for the 'substantially demonstrated' scenario.

2.5 Adjustments and attribution

2.5.1 Adjustments

As noted previously, construction of the counterfactual is the conceptual core of an economic impact assessment. For the counterfactual to be plausible, it should encompass the possibility that, in the absence of the assessed project, other independently financed research might generate outputs that could substitute for those of the assessed intervention. A few of the reviewed studies that were otherwise robust did not appear to adequately incorporate potential substitutable research outputs, particularly from the private sector, in the specification of the counterfactual. Such studies primarily involved analysis of research activities where there are strong corporate actors with research capacities, coupled with rising incentives for private-sector investment in research similar to that assessed. To remedy this, for the plausible and substantially demonstrated scenarios, the

benefits reported in these studies were treated as an advancement of benefit flows rather than a benefit stream of 20–30 years.

This treatment was accomplished by defining an advancement period for the benefits attributable to the research. If analysis of a similar research intervention by ACIAR resulted in definition of an advancement value, this value was utilised for the adjustment. If no value had been defined, a default advancement of 5–8 years was specified on the basis of research investment trends. Benefits for these studies were then calculated as the annual differences between the assessed benefit profile and the same profile occurring after the specified lag. Negative differences for later periods in the benefit profile when annual benefits are calculated to decline over time have been omitted from this analysis, as advancement of research benefits should not lead to costs in later years. Rather, subsequent research should build upon the prior results by the time annual benefits are assessed to decline. For this reason, negative differences in the annual benefit profiles have been ignored.

2.5.2 Attribution

Most of the studies included did not attempt to partition out ACIAR-attributable benefits from those attributable to partner organisations. Rather, collective benefits from research conducted under ACIAR funding and the funding of others were estimated. Each study sets these benefits against total research costs, of which the ACIAR funding share is specified.

Generally, the consideration of total benefits against total research investments by all funding agencies is a robust and recommended approach, as there are few credible methods for attributing the effects of complementary research funding (Alston and Pardey 2001). Accordingly, ACIAR has discouraged such practices in individual impact studies (D. Templeton, Manager, ACIAR Impact Assessment Unit, 3 February 2005, pers. comm.). However, when the focus of the analysis is to derive credible aggregate impact values for investment in an entire organisation, attribution becomes a necessity, as without this step, the scope of the assessment becomes unwieldy and uninformative.

As discussed earlier, conceptually, the impacts of a funding body pose additional assessment challenges compared with assessment of a research output, as the counterfactual is dependent to some degree on assumptions about the funding recipient's internal allocation patterns. It is broadly recognised that ACIAR has been a leader in robust determination of research priorities, and that it has made strong contributions to research capacity in partner institutions. Consequently, it is plausible to expect that ACIAR's involvement has helped to allocate the research resources of recipient agencies in a more efficient and productive manner than would be the case in the Centre's absence. Following this conjecture, it is plausible

to assume that the benefits attributable to ACIAR's bilateral funding activities should be proportional to the share of the research budget provided by the Centre

Hence, the approach taken in the present analysis is to attribute ACIAR's work by dividing the share of estimated benefits by the proportion of funding provided by the Centre. This is analogous to the assumption that the returns to ACIAR's investment are the same as the returns to all other investors involved. At the project level, it is also similar to considering all complementary activities as indivisible, as the benefit–cost ratios are the same under this approach for ACIAR's investment as for the entire project.

2.6 Deflation and discounting

Conversion of nominal values to real 2004 Australian dollars was performed independently for each of the studies, as the studies used diverse base currency values. The Australian consumer price index was used to deflate/inflate nominal values so as to establish a common base-currency year of 2004 for all benefits included. Once adjusted for inflation, benefits from the included studies were aggregated to produce total annual benefit streams, and these total annual benefit streams were discounted using a 5% real social discount rate, with sensitivity analyses lowering the rate to 0% and raising it to 10%. This range of rates was chosen because it spans the recommended discount rate of 5% for ACIAR's individual assessments.

Although the estimated benefits included cover only a small sample of ACIAR's bilateral activities, they were set against comprehensive cost estimates for all bilateral investments, with the benefits from all other activities of ACIAR omitted. Costs were estimated from appropriation levels reported in ACIAR annual reports with multilateral program support subtracted.

To express the aggregation process algebraically:

$$TV_u = \sum_{t=s}^{n}\sum_{i=1}^{z} \frac{B_{it}a_{it}}{(1+r)^t} \qquad TC_u = \sum_{t=f}^{j}\sum_{c=1}^{q} \frac{K_{ct}}{(1+r)^t} \qquad BCR_u = \frac{\sum_{t=s}^{n}\sum_{i=1}^{z} \frac{B_{it}a_{it}}{(1+r)^t}}{\sum_{t=f}^{j}\sum_{c}^{q} \frac{K_{ct}}{(1+r)^t}}$$

where

TV = total value of benefits assessed
u = scenario under which estimate is generated
t = year (2004, the base year of the study, equals 0)
s = start year of benefit period
n = end year of benefit period

i = particular study included
z = total number of studies reporting benefits for year
B = benefit value reported in study (in 2004 Australian dollars)
a = attributive coefficient (if B is empirically attributed this equals 1, otherwise based on proportion of ACIAR funding)
r = real discount rate
TC = total costs of ACIAR bilateral investments
f = first year of ACIAR bilateral investment
j = most recent year of ACIAR investment
c = project receiving investment
q = number of projects receiving ACIAR bilateral investment
K = investments in project
BCR = benefit–cost ratio

2.7 Limitations

The accuracy of the present analysis depends upon a number of assumptions. Most importantly, it is assumed that ACIAR's bilateral research support activities have not resulted in any significant negative external effects. This may be a debatable premise, as it is possible that certain problems (such as exotic pest introductions) may be directly attributable to the research activities that the Centre has supported. Furthermore, certain negative social and environmental consequences of modern production practices may be indirectly attributed to the development of agricultural technologies (Alston et al. 2000). However, ACIAR has not made any systematic attempts to quantify the economic significance of these possible consequences of its research support, so the quantitative significance of such outcomes cannot be incorporated into the present analysis. It should also be noted that those studies that have attempted to investigate the significance of environmental costs attributable to agricultural technology development conclude that it is difficult to attribute research, or the generation of new knowledge, as the source of negative externalities (Maredia and Pingali 2001).

Although the present analysis can offer insight into the minimum level of economic impacts that have been documented as a result of ACIAR's support to bilateral research, this is not a conclusive indication of total impact achieved. At best, the aggregate impacts estimated comprise a very partial measure. As discussed later, only a small fraction of ACIAR's activities have been subject to impact assessment. Furthermore, most of ACIAR's bilateral portfolio has impact pathways that are not amenable to economic assessment with the analytical methods presently available, in part due to attribution difficulties. In addition, many important impacts, such as enhanced research capacity, face severe valuation problems even when reliably attributed. As a result, the incomplete measures of aggregate benefits reported in the present analysis are minimum values that exclude many likely important impacts.

While measured benefits are disaggregated both geographically and by category of research in the present study, these estimates should not be used in isolation to inform comparative judgments about the potential impact of present investment options. Existing methodologies for impact assessment differ substantially among research activities and impact pathways, as certain types of research outputs face greater problems of attribution and valuation than do others. As a result, estimated economic impacts cannot be directly compared across research areas. Furthermore, as research methods and adoption contexts are continually evolving, those areas that produced greatest impact in the past cannot be assumed to offer greatest potential for the future, even if impact could be consistently assessed across research topics.

Finally, there has been limited opportunity for interaction with the authors of analyses included in the present study. As a result, in some cases, assumptions had to be made from the evidence presented when the methodology of the analysis is not clear in the text of the assessment. These assumptions may over- or underestimate the transparency and/or rigour of certain analyses.

3 Results

3.1 The study pool

ACIAR's 29 economic impact assessments focus on 26 areas of research investment spread over 53 individual research projects. Aggregate ACIAR funding for these activities totals $A86.13 million[3], which equals 7.8% of total investment by the Centre in bilateral activities to date.

These studies have been relatively well distributed across a range of research emphases. Livestock/fisheries research has been assessed in the greatest number of studies, followed by postharvest research, crop/soil management and forestry (Figure 5). Thus, the distribution of studies is rather similar to the current budget allocation across these research areas.

The composition of assessment coverage by investment level is similar (Figure 6). Livestock/fisheries is also dominant, followed by forestry, postharvest research, and soil/crop management. The size of investments assessed is essentially similar across the research emphases.

All 29 studies have been conducted by external consultants. Of these, 21 have been done primarily by those working at consulting firms or as freelancers, five by experts in government agencies, and three by university professors.

[3] All values presented are in real 2004 Australian dollars (A$).

The dominant method applied in the studies was the economic surplus approach, complemented in two cases by Monte Carlo simulation techniques, which allow for the incorporation of uncertainty associated with key parameters. No studies used econometric techniques to assess research impacts, and most applied relatively simple methodologies. Twenty-three of the 29 studies did not empirically investigate the price effects of supply shifts, while only two of the studies assessed impacts across multiple markets.

Figure 5. Proportions of ACIAR economic impact studies by areas of research investment assessed

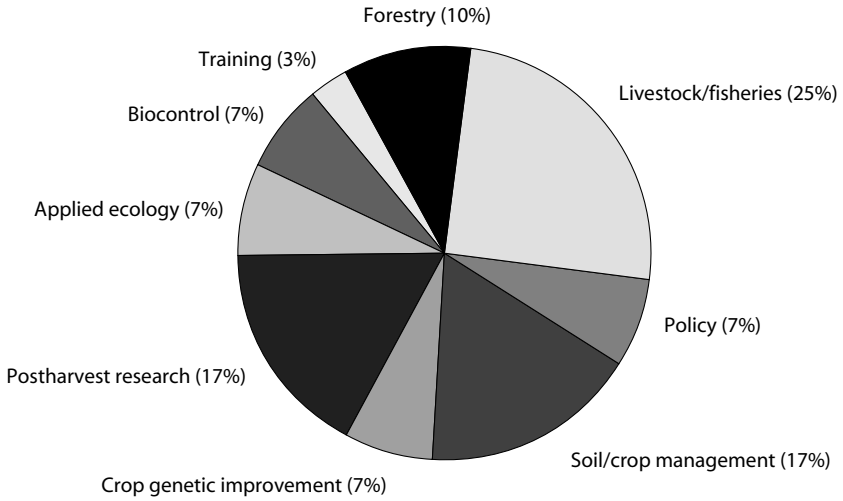
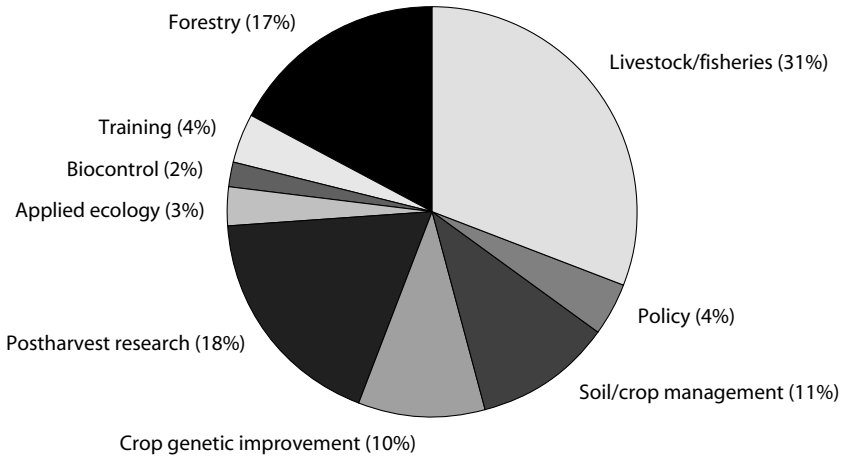


Figure 6. Proportions of investment in different research areas covered within ACIAR's economic impact assessments



Just over half of the studies (15/29) contain an explicit counterfactual or 'without research' scenario. The remainder implicitly claim that production methods would remain static in the absence of the assessed research output. Of those studies that did derive an explicit counterfactual, 11 did so based on delayed

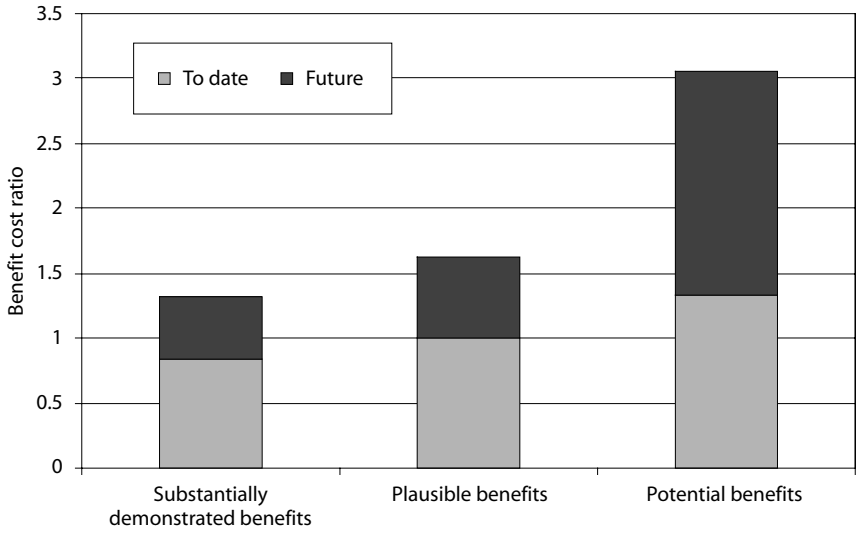
availability of the technology produced, and four applied modelling techniques to estimate the likely evolution of production levels if the research assessed had not been undertaken.

3.2 Potential benefits

While the benefits estimated in this scenario give the most complete picture of potential benefits that may have accrued to the ACIAR investment to date, these benefits include estimates that are highly uncertain. Twelve of the studies that report estimates included here are essentially ex ante with few empirical observations upon which key parameters are based, and the remainder include substantial ex-ante extrapolations. Thus, it is quite possible that some of the assessed benefits included in these aggregate estimates may turn out to deviate substantially from future predictions.

In aggregate, the benefits reported in the 29 assessments which, as already noted, comprise just 7.8% of ACIAR's total bilateral investment to date, well justify the entire ACIAR $A1119 million investment in bilateral activities, as the benefit–cost ratio is 3.06, when the real alternative rate of return to capital is considered to be 5% (Figure 7). The investment is also justified on the basis of benefits produced to date, as this benefit–cost ratio is 1.33. Raising the discount rate to 10% reduces these ratios to 1.82 and 0.97, respectively, while a discount rate of zero results in ratios of 5.31 and 1.75. The internal rate of return is 16.22% for all of the benefits in this scenario including future projections, while if only benefits to date are considered, the rate of return is 10.48% (Table 1; Figure 13).

Figure 7. Aggregate benefit–cost ratios inclusive of benefits to date and ex-ante projections under three scenarios of aggregation of economic impact estimates



Total benefits estimated in this scenario reach A$3424 million (Figure 10). Annual benefits are estimated to begin in 1987, peak in 2006 at A$272 million, and continue through 2030 (Table 2).

Table 1. Internal rates of return (%) produced under three scenarios of benefit aggregation.

	Potential benefits (includes 29 assessments)	**Plausible benefits** (includes 12 assessments)	**Substantially demonstrated benefits** (includes 7 assessments)
Total	16.22	10.98	8.25
To date	10.48	5.71	2.37

Nearly three-quarters (70.9%) of these benefits stem from five research areas assessed in seven studies. These include: the development of improved short-rotation *Eucalyptus* and *Acacia* lines and hybrids in China (21.3%); conservation tillage and controlled traffic research for Australia and China (14.8%); biocontrol of the banana skipper (an insect pest of bananas) in Papua New Guinea (13.8%); the development of vaccines for Newcastle disease in Africa and Asia (11.0%); and pig breeding and feeding research in Vietnam (10.0%).

Partitioned by research sector, crop/soil sciences (27.5%), livestock/fisheries (25.6%), and forestry (25.3%) each produce just over a quarter of the benefits, followed by biocontrol with nearly a sixth (13.9%), and postharvest research with slightly less than a tenth (8.6%). The remaining research areas collectively comprise only 4.9% of the benefits (Figure 8).

Figure 8. Proportions of 'potential' benefits derived from ACIAR bilateral investment in different areas of research

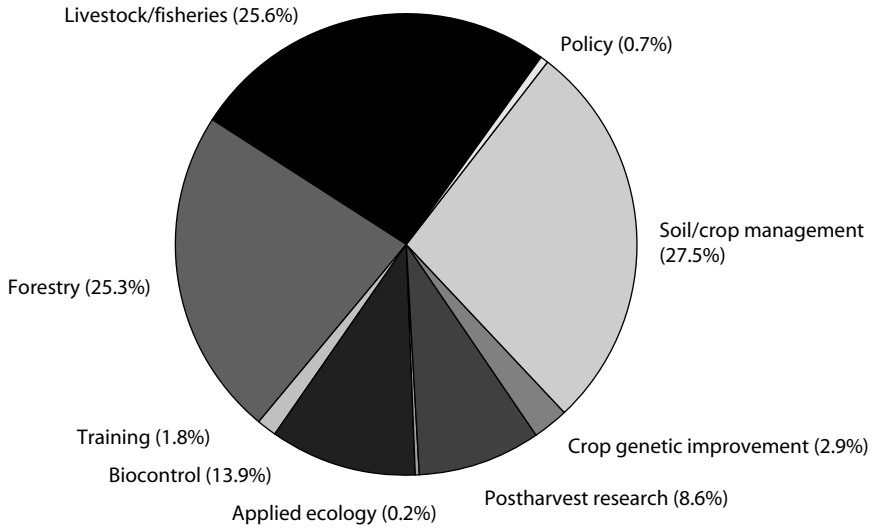


Table 2. Annual benefit and cost estimates for ACIAR bilateral research support under different scenarios of study selection and real discount rates (millions of 2004 A$)

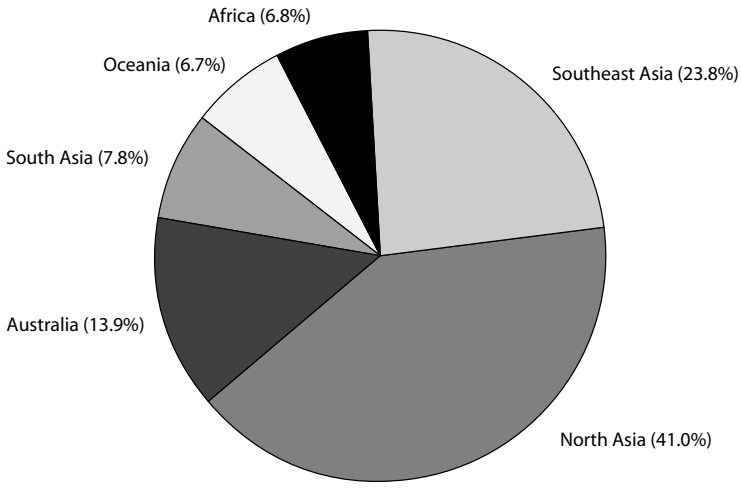
Year	Substantially demonstrated benets			Plausible benets			Potential benets			ACIAR bilateral investment		
	5% discount rate	0% discount rate	10% discount rate	5% discount rate	0% discount rate	10% discount rate	5% discount rate	0% discount rate	10% discount rate	5% discount rate	0% discount rate	10% discount rate
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47	0.50	4.01
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.21	8.69	64.30
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.86	15.40	103.61
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	54.69	21.64	132.35
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	53.29	22.14	123.12
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.07	0.39	57.10	24.91	125.92
1988	0.00	0.00	0.00	0.57	0.26	1.22	0.90	0.40	1.93	57.23	26.22	120.48
1989	0.49	0.23	1.00	1.17	0.55	2.37	3.32	1.57	6.78	52.93	25.46	106.35
1990	1.99	1.42	2.82	9.46	5.13	17.41	13.33	7.05	24.95	49.34	24.92	94.64
1991	8.24	6.00	11.44	20.75	12.56	34.62	26.14	15.36	44.62	43.96	23.31	80.48
1992	23.97	18.35	31.20	36.46	25.21	53.29	41.32	27.88	61.89	45.82	25.52	80.08
1993	20.49	15.69	26.61	34.67	23.88	50.58	41.81	27.99	62.63	49.23	28.79	82.13
1994	23.79	18.15	31.02	37.68	26.56	53.44	43.65	30.18	63.02	55.09	33.82	87.72
1995	42.73	32.65	55.49	56.56	41.45	76.80	72.46	51.61	101.11	76.61	49.39	116.45
1996	91.96	70.45	118.88	104.51	78.87	137.26	119.89	89.14	159.83	43.64	29.54	63.31
1997	85.99	65.71	111.28	98.73	74.68	129.08	122.95	91.68	162.99	66.53	47.28	92.14
1998	52.48	39.84	68.23	60.22	46.07	77.54	93.33	69.97	122.77	51.87	38.71	68.57
1999	39.97	30.90	51.00	46.37	36.47	58.06	82.46	63.80	105.16	66.74	52.29	84.21
2000	42.93	34.48	52.86	50.02	40.94	60.33	83.82	67.78	102.52	49.54	40.75	59.67
2001	117.94	99.45	139.24	124.70	106.20	145.66	172.73	147.04	201.90	49.61	42.85	57.04
2002	120.20	106.19	135.82	131.87	117.80	147.24	168.30	149.73	188.64	44.16	40.06	48.47
2003	143.01	132.84	154.34	160.32	149.52	172.09	201.50	188.57	215.32	44.21	42.11	46.32
2004	121.18	117.50	125.59	145.30	142.06	149.28	204.27	200.74	208.51	40.65	40.65	40.65
2005	116.02	117.71	115.38	144.34	147.99	141.92	220.94	228.04	215.34			
2006	108.37	114.95	103.55	135.20	145.07	127.56	271.84	295.33	252.37			
2007	86.49	95.20	80.17	122.06	137.19	110.47	244.16	278.17	216.95			
2008	84.77	97.78	75.36	112.42	132.07	97.85	248.51	297.13	211.08			
2009	29.38	33.27	27.24	51.81	62.47	44.65	184.38	231.33	149.93			
2010	23.60	27.01	21.98	28.21	33.28	25.42	163.39	214.16	127.84			
2011	10.72	10.21	11.96	15.29	16.73	15.21	114.92	156.72	87.26			
2012	12.75	13.72	13.02	16.68	19.59	15.69	105.82	151.01	77.22			
2013	7.31	5.84	9.14	10.98	11.60	11.52	63.98	93.62	46.48			
2014	7.20	5.77	9.00	10.17	10.65	10.83	52.95	80.13	37.78			
2015	13.74	17.16	12.77	14.94	19.26	13.47	60.38	96.92	40.74			
2016	8.79	9.20	9.52	9.48	10.46	9.91	37.96	61.63	26.21			
2017	6.42	5.17	8.01	6.57	5.45	8.09	43.15	74.45	28.08			
2018	10.21	12.80	9.90	10.27	12.93	9.93	29.22	50.48	19.82			
2019	6.09	4.93	7.59	6.15	5.05	7.62	30.08	54.81	19.53			
2020	0.12	0.25	0.06	0.17	0.37	0.08	15.29	33.39	7.27			
2021	0.12	0.26	0.05	0.17	0.37	0.08	19.03	43.68	8.62			
2022	0.00	0.00	0.00	0.04	0.11	0.02	7.48	18.05	3.23			
2023	0.00	0.00	0.00	0.04	0.10	0.02	4.37	11.10	1.80			
2024	0.00	0.00	0.00	0.04	0.10	0.01	3.93	10.49	1.54			
2025	0.00	0.00	0.00	0.03	0.01	0.01	3.58	10.04	1.34			
2026	0.00	0.00	0.00	0.03	0.09	0.01	3.30	9.70	1.18			
2027	0.00	0.00	0.00	0.03	0.09	0.01	3.06	9.44	1.04			
2028	0.00	0.00	0.00	0.03	0.09	0.01	0.38	1.22	0.12			
2029	0.00	0.00	0.00	0.03	0.09	0.01	0.03	0.09	0.01			
2030	0.00	0.00	0.00	0.02	0.08	0.01	0.02	0.08	0.01			

Table 3. Ratings for five studies reporting, against the review framework, the largest values in the 'plausible' benefits scenario

				Low rating (0)	High rating (3)	Economic benefits to PNG and Australia from biological control of banana skipper	Breeding and feeding pigs in Australia and Vietnam	Controlling *Phalaris minor* in the Indian Rice-Wheat Belt	Acacia hybrids in Vietnam	Eucalypt tree improvement in China
TRANSPARENCY	**1. Clearly derived key assumptions**	Explicitness of key assumptions		major assumptions underlying analysis are not defined	all major assumptions explicitly stated	3	3	2	2	2
		Substantiation of key assumptions		explicit assumptions have no clear basis	explicit assumptions have logical justification and/or citation	2	2	1	2	1
	2. Comprehensive attribution of data sources	Citation of adoption data		unclear basis of adoption estimates	adoption estimates cited and/or data collection described	NA	2	0	1	1
		Citation of productivity data		unclear basis for productivity claims	productivity claims based on cited references or clear methods	2	2	2	1	1
		Citation of adoption-related costs data		unclear empirical basis for deriving costs of adoption	estimates of adoption-related costs cited or given logical justification	1	1	1	1	1
		Citation of price sources		unexplained basis of commodity prices	cited basis for commodity prices	3	2	2	2	2
	3. Full explanation of data treatment	Explanation of scaling up adoption estimates		no basis provided for adoption estimates	gathering process for adoption estimates defined	1	2	1	1	1
		Explanation of scaling up productivity estimates		unclear extrapolation from limited productivity impact data	clearly defined methodology for scaling-up estimates from specific sites	3	3	2	1	2
		Explanation of scaling up adoption-related costs		incorporation of costs associated with adoption unclear	costs considered (or not considered) in an explicit manner	1	2	1	2	2
		Explanation of economic valuation		commodity prices used, discounting and deflating unclear	commodity prices used, discounting and deflating clearly presented	3	3	2	2	1
		Explanation of counterfactual derivation		no 'without scenario' presented	without scenario comprehensively developed	3	0	2	3	2
		Explanation of institutional attribution		unclear basis by which benefit claims are partitioned	clearly defined method for attributing benefits to specific agencies involved	NA	NA	2	3	2
DEMONSTRATION OF CAUSALITY	**1. Representative data set utilised**	Reliability of data set utilised		data sourced from uncorroborated expert opinion or assumption	empirical data for key parameters validated through triangulation	3	2	2	2	1
		Comprehensiveness of data set utilised		data sourced from single location or trial	large number of sample sites representing range of relevant conditions	2	2	1	2	2
	2. Appropriate data treatment	Appropriateness of data extrapolation		limited data or assumptions extrapolated over large spatial/temporal scales	data extrapolated only over populations represented	2	2	2	2	2
		Adequacy of analysis of mitigating factors		no mitigating factors considered	consideration of major relevant alternative causal factors	2	1	1	1	1
		Adequacy of disaggregation by production environment		only 'average' conditions considered	heterogeneity in impacts appropriately captured	1	1	1	1	1
		Adequacy of assessment of adoption-related costs		adoption-related costs unconsidered	comprehensive empirical assessment of all additional costs necessary for benefits	1	1	1	1	1
	3. Plausible counterfactual scenario developed	Plausibility of assumptions about development of substitutable innovations		no other research agencies or sources of spillovers are considered	alternative sources of substitutable research outputs analysed to derive counterfactual conditions	1	1	0	3	2
		Plausibility of projected changes due to exogenous causes		counterfactual assumes unrealistic stagnancy in production practices	counterfactual represents realistic and substantiated path of events	2	2	1	2	2
	4. Adequate consideration of mission-relevance of economic benefits	Adequacy of analysis of mission-relevance of economic benefits		the relevance of benefit pathways that have not been previously documented to be pro-poor are unconsidered	distributional implications of estimated benefits are thoroughly analysed	2	2	1	1	1
	5. Plausible institutional attribution	Plausibility of institutional attribution		no attribution attempted	empirically-based attribution	1	1	2	2	2
				Average tranparency score		2.20	2.00	1.50	1.75	1.50
				Average score for demonstration of causality		1.70	1.50	1.20	1.70	1.50
						Substantially demonstrated	Substantially demonstrated	Plausible	Substantially demonstrated	Substantially demonstrated

Research benefits are calculated to accrue primarily in China (41.0%), Vietnam (17.1%), Australia (13.9%), India (7.4%) and Papua New Guinea (6.4%). On a regional basis, this means that North Asia receives the largest benefit share (41.0%), followed by Southeast Asia (23.8%), Australia (13.9%), South Asia (7.8%), Africa (6.8%) and Oceania (6.7%) (Figure 9).

Figure 9. Distribution of 'potential' benefits derived from ACIAR's bilateral research investments by geographic region



3.3 Plausible benefits

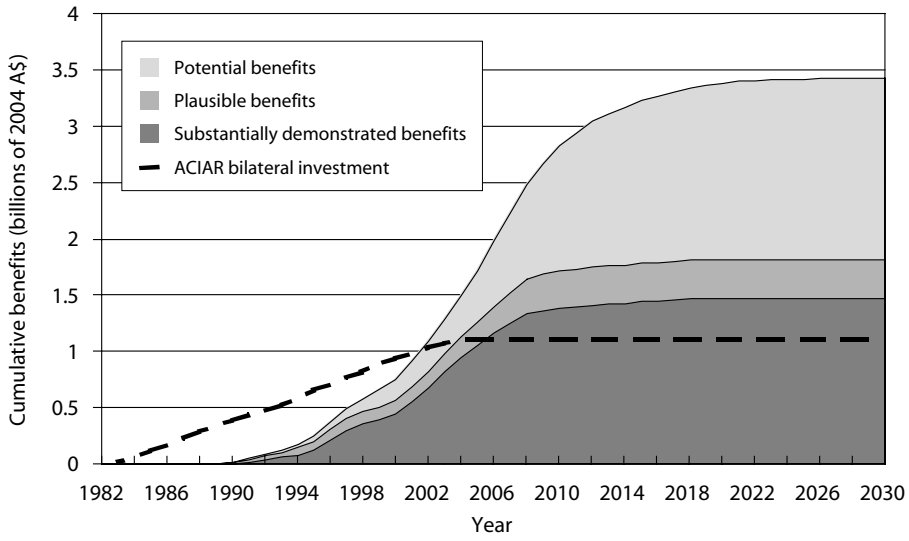
The scenario of 'plausible' aggregate benefits contains estimates that are of higher certainty than those in the 'potential' scenario. Each of these estimates is for cases where widespread utilisation of a research output has been well documented. This greatly reduces the risk that benefit evolution will diverge widely from predictions, as the relevance of the output to the adoption context has been at least partially validated empirically. Of course, there is still some uncertainty about the ex-ante extrapolations embedded in the projected future benefits, even if the uncertainty is somewhat less than for pure ex-ante conjecture. The criterion that some empirical estimates of adoption must underpin the claimed patterns of research output application eliminates 12 of the 29 studies from the review pool.

In addition, application of the critical review framework enumerated in the methodological section ensures that the benefits aggregated in this scenario have been calculated with at least a moderate degree of rigour. As a result, of the 17 remaining studies, 5 more are eliminated, due primarily to unclear or limited data sources for key parameters, such as adoption and productivity changes. This more limited assortment of 12 studies covers only 3.4% of the aggregate ACIAR bilateral research budget to date. Details about how the studies producing the five largest benefit levels in this scenario have been rated against the review framework can be found in Table 3.

Even so, this more limited set of plausible estimates still justifies the entire ACIAR bilateral investment to date. The aggregate benefit–cost ratio is 1.62, inclusive of future benefit projections, under a discount rate of 5% (Figure 7). If only benefits to date are considered, the investment remains justified with a benefit–cost ratio of 1.00. With the discount rate raised to 10%, the total benefit–cost ratio falls from 1.62 to 1.07, while benefits to date are 0.73 times costs. Under no real discounting, the overall benefit–cost ratios are 2.41 and 1.32, respectively. The internal rate of return is 10.98%, inclusive of future benefits, and 5.71% inclusive of only those benefits realised through 2004 (Table 1; Figure 13).

Total benefits estimated in this scenario reach A$1622 million through 2030 (Figure 10). Annual benefits are estimated to begin in 1988 and peak in 2003 at A$160 million.

Figure 10. Cumulative benefits and costs of ACIAR's bilateral activities under three scenarios of aggregation of economic impact study results



Three-quarters (74.8%) of these benefits are produced by just three research areas assessed in four studies. These benefits are dominated by those of *Eucalyptus* and *Acacia* improvement in China (34.6%), banana skipper biocontrol in Papua New Guinea (26.0%), and pig genetic improvement in Vietnam (14.2%).

When split by research area, forestry dominates the benefits (42.9%), followed by biocontrol (26.2%), livestock/fisheries research (15.0%) and soil/crop management (10.6%). The remainder comprise 5.3% of the research benefit sources (Figure 11).

Chinese beneficiaries receive the largest share of the benefits (36.6%), followed by those in Vietnam (22.5%), India (14.0%), Australia (14.0%) and Papua New

Guinea (12.2%). As these countries collectively comprise 99.3% of the benefits, and most of these countries are alone in their respective regions, the regional distribution of benefits is essentially similar (Figure 12).

Figure 11. Proportions of 'plausible' benefits derived from ACIAR bilateral investment in different areas of research

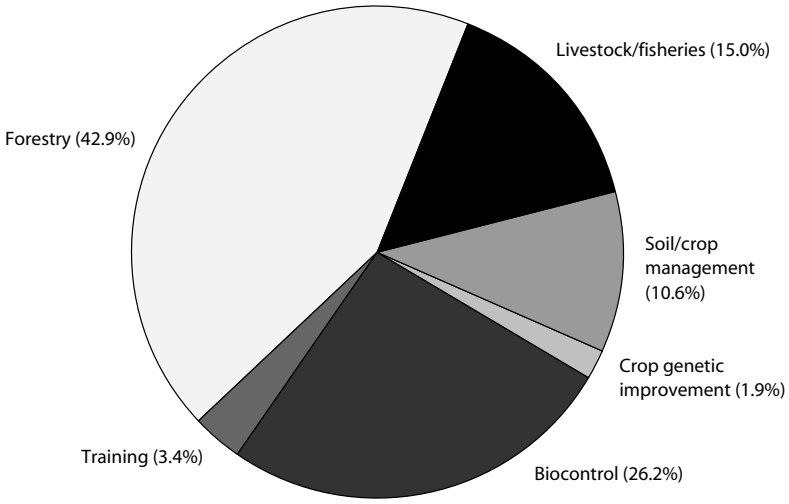
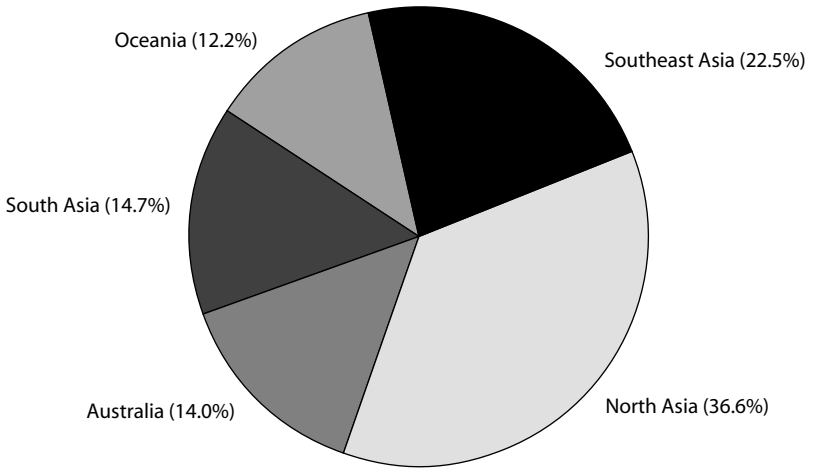


Figure 12. Distribution of 'plausible' benefits derived from ACIAR's bilateral research investments by geographic region



3.4 Substantially demonstrated benefits

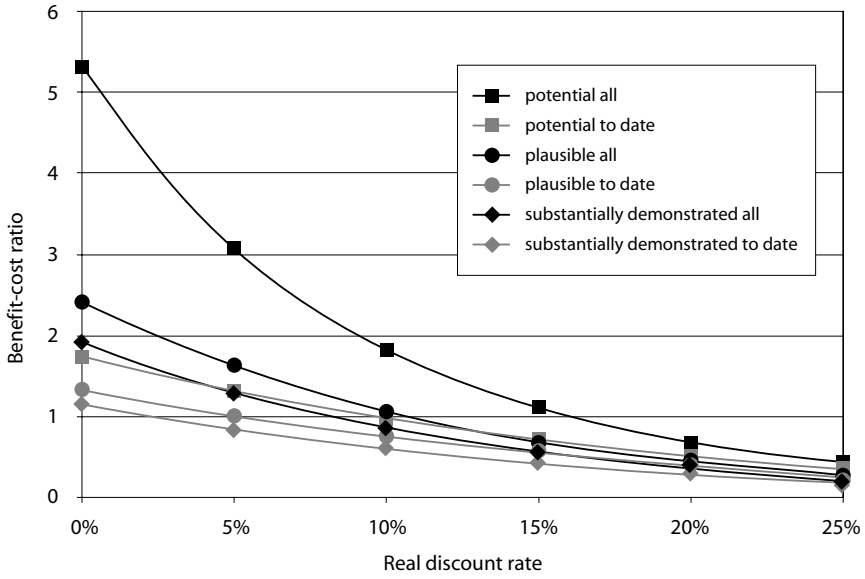
The scenario of 'substantially demonstrated' benefits is intended to test whether aggregation of only those benefits that are calculated with exceptional rigour will justify the total ACIAR investment. While the benefits in this scenario are all highly robust, it should be recognised that many benefits that can be reasonably expected to accrue are omitted. Thus, the benefit–cost ratios produced here are

very likely to be underestimates, although there is relatively little risk that these benefits will not be realised.

Application of the review framework so as to include only benefits that have been calculated with high 'analytical rigour' reduces the number of studies to seven. The primary reasons for exclusion of the five studies from the 'plausible' scenario relate to data limitations and limited assessment of potential threats to assessment validity. Collectively, the aggregate costs of the research assessed in the seven studies in this scenario comprise 3.0% of total investment in ACIAR's bilateral research support.

However, even this highly limited assortment of seven robust and rigorous studies justifies the aggregate ACIAR investment. Benefits inclusive of future projections are 1.31 times costs with a discount rate of 5%, and the benefit–cost ratio is 0.84 to date (Figure 7). If the real discount rate is raised to 10%, these ratios become 0.87 and 0.59, respectively, whereas with a discount rate of zero, the ratios are 1.93 and 1.12. The internal rate of return is 8.25% inclusive of future projections, and 2.37% for benefits to date (Table 1; Figure 13).

Figure 13. Effect of real discount rate on aggregate benefit–cost ratios under three scenarios of study selection



Aggregate benefits inclusive of future projections total A$1470 million in this scenario (Figure 11). The period of annual benefits is estimated to begin in 1989, peak in 2003 at A$143 million, and continue through 2021 (Table 2).

The vast majority (86.4%) of these benefits comes from just three research areas. These benefits primarily result from *Eucalyptus* improvement in China (36.7%),

banana skipper biocontrol in Papua New Guinea (32.1%), and pig genetic improvement in Vietnam (17.5%).

On the basis of research sector, forestry results in nearly half the benefits (47.0%), followed by biocontrol with a third (32.1%) and livestock/fisheries (18.5%). Crop genetic improvement produces the remaining 2.4% (Figure 14).

China receives the largest share (36.7%) of the estimated benefits. Vietnam receives slightly over a quarter (27.8%), while Australia (17.2%), Papua New Guinea (14.9%) and India (3.0%) follow. As these comprise almost all of the benefits, the regional distribution is essentially similar (Figure 15).

Figure 14. Proportions of 'substantially demonstrated' benefits derived from ACIAR bilateral investment in different areas of research

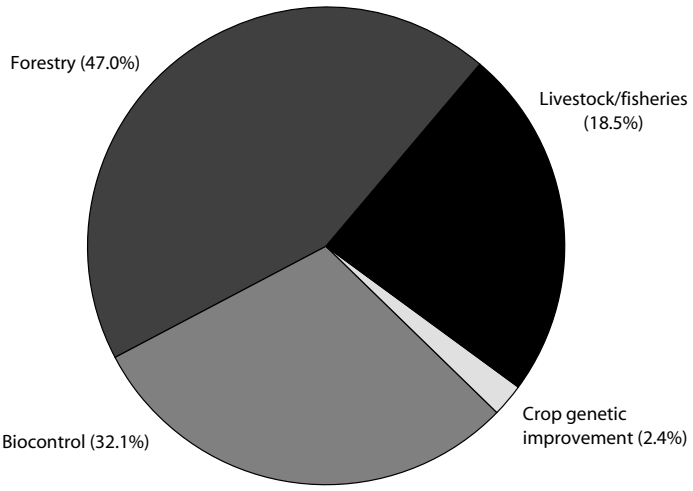
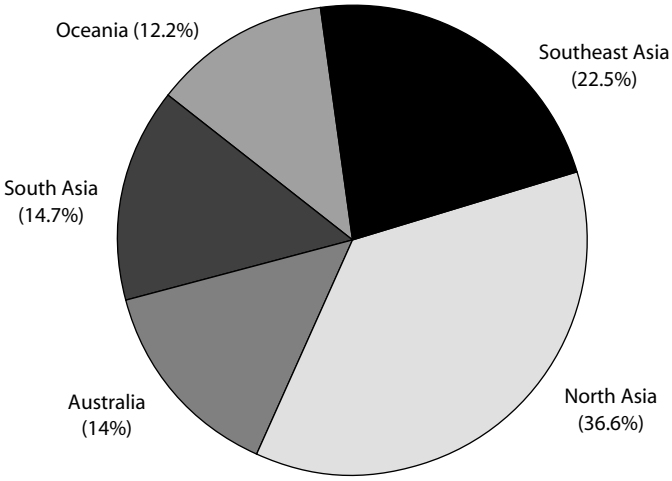


Figure 15. Distribution of 'substantially demonstrated' benefits derived from ACIAR's bilateral research investments by geographic region



4 Discussion

4.1 Significance of findings

The overall benefit–cost ratios reported here all justify the ACIAR investment in bilateral activities when the alternative rate of return to capital is considered, and two of three scenarios justify the investment on the basis of benefits to date. Sensitivity analyses, using 10% and zero real discount rates, after deflation/inflation to real 2004 Australian dollars, also maintain this result for the potential and plausible benefits scenarios. Consequently, the investment is shown to be economically justified.

This is an impressive achievement, as very few aggregate government programs have comprehensively illustrated the economic worth of funds received. This is particularly the case for the development-assistance sector, where no large bilateral agency has yet shown that overall investment has been justified. Furthermore, these aggregate benefit levels are only partial, as the sources of these benefits collectively comprise less than 7.8% of the total costs of ACIAR bilateral programs, yet they produce benefits well in excess of total investment.

This is particularly impressive when it is considered that these ratios were all calculated under the assumption that the real discount rate is 5%. Such a rate of return cannot necessarily be expected over long time frames, and lower real discount rates may be more realistic. For example, the United States Government currently recommends a 3.1% discount rate for analysis of long-term investments (US Office of Management and Budget 2005). Use of such a lower rate would make the ratios obtained here even higher.

4.2 Accuracy of aggregate benefit estimates

The range of benefit–cost ratios produced in the present analysis is fairly wide, from about one to more than three. In considering this range, one encounters a trade-off between accuracy and precision. Many analyses have relied upon assumptions or expert opinion, in lieu of available data on adoption or unit productivity. While these benefits may indeed be realised, there can be little confidence in the precision of these estimates. Exclusion of these assessed benefits, so as to only retain estimates made with greater precision, increases the certainty that estimated benefit levels have been realised. However, by excluding likely benefits, this enhanced precision comes at the cost of accuracy. Thus, the more comprehensive and extrapolative scenarios encompass more of the likely benefits but do so with less reliability than the most restrictive scenarios.

Furthermore, the research projects that result in the assessed benefits represent a small share of ACIAR's overall bilateral research portfolio. Even with overhead costs considered, the specific projects for which impact assessment has been performed constitute only 7.8% of ACIAR's bilateral investment to date. Thus, if the economic returns of these projects are representative of ACIAR's broader investment portfolio, overall benefit–cost ratios may be more than 40. Yet, for the reasons noted in the introduction, this is unlikely, as the assessed projects are probably not representative. However, if all projects were assessed, the benefits would indeed almost certainly be much higher than the levels estimated in this analysis.

The current state of impact-assessment methods renders it impossible to comprehensively assess ACIAR's entire research funding portfolio. While methods are relatively well developed for adaptive research that produces 'finished' technologies, other research outputs are less readily assessable. Basic research that improves fundamental understanding of issues that underpin applied research is much more difficult to value, as is research that confirms the previous state of knowledge. Adoption in contexts of multiple information sources, indirect information flows and incremental adoption decisions is difficult to trace. These problems affect most of ACIAR's bilateral portfolio, particularly investments in the policy and natural resource management arena, where research often results in recommendations, rather than new technological packages.

In fact, only a small proportion of ACIAR's bilateral activities have focused upon those areas (such as crop germplasm improvement) that are most readily assessable with commonly accepted economic valuation techniques. A substantial portion of the Centre's bilateral portfolio, such as farming systems research, crop nutrition, soils research and crop protection, has been in the 'natural resources management' research arena, which presents particular valuation difficulties (Kelley and Gregersen 2003). Furthermore, no adequate economic means have yet been developed to value enhanced capacity, an outcome at the core of ACIAR's mode of operating.

As a result, it is not practical to expect that all of the economic benefits resulting from ACIAR's bilateral activities to date have or could be captured in its series of economic impact assessments. Even if impact assessment coverage were to be greatly expanded, many benefits are simply not amenable to economic assessment with techniques presently available. This renders the estimates made here inherently conservative.

Furthermore, even for those projects that have been assessed, it is likely that only a portion of benefits has been captured. Research creates impacts through a multitude of pathways, and only a small number of these are captured in any impact assessment. Longer-term effects, in terms of unpredicted use of research

outputs, catalysis of subsequent research and enhanced research capacity are seldom encompassed. When this fact is coupled with the limited share of research activities assessed, it is apparent that only a tiny proportion of total benefits stemming from ACIAR's bilateral activities is represented in the numerator of the present analysis. If all benefits stemming from these investments could be comprehensively assessed, it is likely that aggregate benefit–cost ratios would be much higher.

The assessed levels of impact are all the more remarkable when it is considered that ACIAR is a relatively young organisation, compared with typical gestation periods for research impact. Research is an indirect and stochastic driver of development processes, in which critical masses of knowledge need to accrue before technological and policy innovations are possible. In the process, many intermediate developments and adaptations are required to ensure that new techniques and approaches are relevant to contexts for adoption. As a result, there are substantial lag periods between research investments and the development of an adoptable research output. Furthermore, diffusion and adoption of new technologies at the farm level is a gradual process, creating adoption lags.

Consequently, the lags between research investments and development outcomes are long and unpredictable, and may be decades or more. In fact, some (e.g. Alston et al. 1998) argue that these lags are nearly infinite, as new research continually builds upon stocks of existing knowledge, and would be impossible without prior efforts. The practical implication of this is that impact may not be assessable until long after development investments. As a result, given ACIAR's relatively short history, most of the Centre's impact may not yet be evident. This fact renders the benefit–cost ratios obtained here inherently conservative.

4.3 Patterns of documented impact

4.3.1 Patterns of impact by research area

The array of benefit sources is rather unusual in the present analysis, as forestry research investments produce the highest levels of economic returns in two out of three scenarios. This is somewhat unexpected, as prior studies have generally found lower returns to forestry research investments than to crop productivity-enhancing research, due to greater methodological difficulties in assessment, and long rotation times that lengthen adoption lags (Alston et al. 2000). However, the forestry research that has resulted in the assessed benefits is actually genetic improvement, and many would consider short-rotation *Eucalyptus* and *Acacia* cultivation as more similar to crop production than to traditional forestry. Thus, these benefits are amenable to assessment with current techniques similar to those employed in assessment of crop genetic improvement.

Soil/crop management research is the primary source of potential benefits, and is the second major source of plausible benefit estimates. This is a somewhat unusual finding, as other research entities have had a poor record of documenting impacts from this research area (Lele 2003). Measurement problems often arise for research in this category, due to the multiplicity of potential causes for shifts in management practices. These difficulties might explain why this research area is not a major source of substantially demonstrated benefits. Nevertheless, it is impressive to see that ACIAR has effectively illustrated large levels of benefits from such research undertakings.

Livestock research has a mixed track record of documented economic impact (Alston et al. 2000), and few innovations in this sector have widespread adoption documented among developing country producers. This may be due to the fact that social and cultural factors are of greater importance for livestock husbandry than for crop production (Riethmuller 2003). However, in this analysis it is a primary source of benefits in all scenarios. This is also a notable departure from the patterns found in previous analyses.

Biocontrol is the third primary source of research benefits assessed. These findings repeat previous observations of exceptional returns to biocontrol research activities, such as billions of dollars of benefits attributed to cassava-mealybug biocontrol (Zeddies et al. 2001). Biocontrol benefits are also particularly amenable to assessment, as averted productivity losses can be estimated with reasonable precision, and establishment of control is somewhat easy to verify.

However, unexpectedly absent from the major sources of benefits is crop genetic improvement, which traditionally has been the source of the most repeatedly quantified large-scale agricultural research impacts (Alston et al. 2000; Raitzer 2003). Although crop genetic improvement comprises a relatively small share of ACIAR's portfolio, the benefits stemming from this research area present relatively few difficulties for economic assessment. It is consequently somewhat puzzling that fewer impact assessments have been conducted for ACIAR's bilateral activities in this area. However, it might also be noted that the crops that have received emphasis in ACIAR's crop improvement activities, which primarily include food legumes and oilseeds, have fewer documented examples of impact attributable to genetic improvement than do cereals (Alston et al. 2000).

4.3.2 Geographic composition of benefits

A large proportion of the benefits assessed in all scenarios accrues to beneficiaries in China. Given the rapid evolution of the Chinese economy, as well as ACIAR's focus on the country, this may not be surprising. However, this does not reduce the relevance of these benefits. Although China has benefited from strong economic

growth over the past two decades, and poverty has been sharply reduced, the country remains poor by international standards. With a per capita GDP of US$1100, there is no doubt that China remains a developing country, and will be so for some time. Yet, it must also be recognised that the country's world-renowned success in combating rural poverty can be attributed in part to agricultural and natural resource management research (Fan et al. 2002). ACIAR's contributions in this regard have been shown in the reviewed assessments to be important.

Vietnam is the second major beneficiary of the benefits estimated in the Impact Assessment Series. Like China, Vietnam has also experienced rapid economic growth over the past two decades, and there has been an accordant sharp decline in rural poverty rates. It seems reasonable to expect that agricultural research, such as ACIAR has supported, has played a similar role as has been documented in China in this achievement.

The fact that Australia receives nearly half of its investment in ACIAR's activities back under the scenario of potential benefits underscores its effectiveness as a source of technologies and innovations that are mutually beneficial. It should be noted that these benefits are strictly productivity-related, and indirect benefits, such as enhanced international standing and improved international knowledge flows, are omitted.

India and Papua New Guinea also receive substantial benefit shares. As Papua New Guinea is one of the world's most poverty-plagued countries, and is a primary intended beneficiary of ACIAR's activities, benefits to this country are particularly mission-relevant. Although an epicentre of the green revolution, India still has a high prevalence of malnutrition, which makes continued agricultural productivity enhancements, such as assessed in the reviewed impact studies, particularly needed.

4.4 Poverty relevance of primary assessed benefits

In the 'plausible' and 'substantially demonstrated' scenarios, three research investments account for the vast majority of estimated benefits: 1. *Eucalyptus* and *Acacia* improvement in China, 2. pig breeding and feed research in Vietnam, and 3. banana skipper biocontrol in Papua New Guinea. In the scenario of 'potential' benefits, ex-ante projections add conservation tillage research in China, as well as Newcastle disease vaccine research oriented towards several Asian and African studies. The present section discusses the poverty relevance of the first three benefit sources. As the latter two are premised largely on future adoption patterns, insufficient data are currently available for social implications to be clear.

4.4.1 *Improved* Eucalyptus *and* Acacia *lines and hybrids*

As noted previously, a large percentage of the assessed benefits is derived from the development of short-rotation *Eucalyptus* and *Acacia* tree species for Chinese plantations. It may be noted that the development of these 'fast-wood' plantation systems is not without controversy. Certain environmental groups claim that such plantations are often established at significant social cost, and with severe resource degradation. For example, critics point to recent experiences in Indonesia, where corruption and mismanagement have led to millions of hectares of illegal plantation development, and allege that fast-wood plantations are often established at the expense of existing natural forests (Barr 2001). Claims are also often made that fast-wood species mine the soil of nutrients, waste high volumes of water and are highly susceptible to disturbances, including pests and stochastic events (Cossalter and Pye-Smith 2003).

Many of these claims do not withstand closer scrutiny. In China, it appears that the Indonesian experience has not been mirrored. Without the establishment of high-yielding plantations of improved lines and hybrids, it is unlikely that plantation output could keep pace with the strong growth in demand for stock to feed China's pulp mills. According to a recent analysis (Katsigris et al. 2004), for these mills to remain profitable, large stocks of fibre would need to be imported from Southeast Asia, if plantation production were not to expand rapidly. The analysis further concludes that such strong demand would be likely to catalyse illegal harvesting in the region, due to rising fibre prices and weak regulatory enforcement in the region. If the development of domestic fibre supplies from fast-wood plantations helps to satisfy this demand, potential logging of natural forests may be abated.

The nutrient requirements of short-rotation eucalypts are indeed higher than traditional species with longer rotation times, but these requirements pale in comparison with agricultural crops. As a result, fertilisation is required for optimal returns, but there is little evidence that cultivation of these species destroys soil fertility. Acacias are leguminous, so cultivation of hybrids within this genus helps to enhance soil nitrogen levels. While fast-wood species do utilise more water in the latter period of rotations, shorter rotation times, with a higher frequency of establishment periods, balance out this brief period of increased demand. As a result, overall increases in water usage are often minimal (Cossalter and Pye-Smith 2003).

Furthermore, susceptibility to pest damage thus far has been documented to be lower in exotic *Eucalyptus* plantations than in native stands (Nair 2001). So, despite the potential vulnerability created by genetic uniformity, the absence of co-evolved pests and enemies still renders this risk reduced in most cases.

However, while there is little evidence to support claims of deleterious environmental consequences of fast-wood development, there is also little evidence by which the poverty-relevance of increased returns in this sector can be established, particularly in the Chinese context. None of the three studies of these research impacts attempts to quantify the proportion of benefits accruing to target poor populations, while adoption is documented to occur primarily in corporate plantations and state-owned forest enterprises. As *Eucalyptus* and *Acacia* pulp are primarily utilised for high-quality printer and copier paper, it is not clear that consumer price effects attributable to productivity increases would reach the poorer segments of society.

In terms of producer benefits filtering down to the poor, previous studies offer few findings to concretely establish that productivity increases in these plantation systems will translate into exceptionally high demands for labour. Rather, employment intensities for establishment, management and harvesting operations reported by major commercial forestry enterprises range from 1–3 people per hectare per year (Cossalter and Pye-Smith 2003). Whether such employment levels represent increased opportunities for unskilled labourers is a function of the likely pattern of land use under counterfactual conditions. Relative to agricultural employment, these levels are low, but if land would otherwise be barren or under longer-rotation species (as is claimed in the impact assessments reviewed), these levels illustrate increased local employment opportunities. Additional job opportunities will also be afforded through processing operations, and the level of employment offered will depend on whether logs are processed for pulp or value-added timber products. As the lines and hybrids developed are primarily utilised for the former, secondary employment effects may be somewhat limited.

Thus, it is likely that a substantial number of jobs has been created through the availability of these shorter rotation *Eucalyptus* lines and hybrids. However, it remains unclear what proportion of the benefits has been passed down these pathways. This is clearly an area for future research, if ACIAR is to establish the mission-relevance of the bulk of the benefits generated to date by its bilateral activities.

4.4.2 Pig breeding and feed research

Increased livestock productivity is the second major source of benefits stemming from ACIAR's bilateral activities. This impact pathway arguably imparts less controversy than does fast-wood forestry, as individual farmers are the primary adopters for the technologies that resulted from these activities. Furthermore, consumer price reductions resulting from productivity enhancement are more likely to benefit poorer populations, due to lower expenditure elasticities for basic meat than for office paper products.

The primary source of livestock research benefits attributable to ACIAR is increased pork productivity and leanness in Vietnam. It is likely that the income elasticity of pork meat, although lower than many non-food products, may be higher than many basic staples, such as rice. This means that the distributional consequences of declines in pork prices are difficult to predict with the data available in the present analysis. This is especially the case for the leaner pork meat that resulted from the genetic improvement component of this research project.

The information provided in this study is also insufficient to establish the distributional implications of producer benefits. Although pork production is dominated by smallholders in Vietnam, the proportion of intensive large-scale production is rising. Although cross-breeds are common in both large-scale and smallholder production (Nin et al. 2003), it is not clear whether adoption of the improved breeds developed under ACIAR funding is primarily among the latter or the former from the impact analysis conducted.

4.4.3 Banana skipper biocontrol

In contrast, the poverty-relevance of the third major source of research benefits, support to biocontrol research for control of the banana skipper in Papua New Guinea, has been investigated empirically. In an assessment of the impact of this research on poverty, Bauer et al. (2003) claim that this research has lifted 43,000 people above the poverty line through averted income losses and cost increases. In addition, they find an income increase of 0.9% to 2.2% for 700,000 subsistence banana producers. If these figures are accurate, they appear to indicate that the total annual research benefits of A$13.4 million for the year of analysis are relatively pro-poor.

Given that banana is a subsistence staple crop primarily cultivated by smallholders in Papua New Guinea, it is almost self-evident that benefits should primarily accrue to the poor. The expenditure elasticity for bananas is low, which means that the poor spend proportionally much more of their income on bananas than do the better off. Thus, price reductions accrue primarily to the poor. Furthermore, as production is clearly dominated by subsistence smallholders, producer returns will also primarily accrue to this population.

4.4.4 Overall benefit distribution

The proportion of the major sources of ACIAR-attributable benefits that accrues to target poor populations cannot at this point be discerned with certainty. While it is clear that the biocontrol proportion of research benefits accrues largely to populations of greater impoverishment, assessed benefits stemming from the other two major sector sources are less clear in their poverty-relevance. For more in-depth analysis of the proportion of benefits that reach target poor populations

to be possible, greater analysis of the characteristics of adopters and the adoption process will need to be pursued. In addition, the beneficiaries of consumer price effects will need to be more robustly identified. However, this is not to say that these benefits have not been pro-poor. Rather, there merely remains uncertainty about precisely what portions of benefits have reached poor populations.

4.5 Economic impact assessment methods and approaches

The impact assessments reviewed are, for the most part, reasonably transparent and methodologically sound. The primary limitations encountered related more to the frequent assumptions that underpinned parameters, than to the analytical methods employed to calculate estimates of impact from these parameters. These assumptions are often necessitated by the ex-ante nature of the studies conducted, as assessment had been conducted in many cases before impacts were evident at wide scale. Indeed, application of the basic criterion that at least some empirical estimates underpinned adoption parameters employed in the assessment eliminated 12 studies, or a third of the Impact Assessment Series publications, from the review pool.

Attribution of economic benefits to research investments is rarely a simple task, as there is a confluence of factors that help to drive desired outcomes. In the context of agricultural research conducted for the benefit of those in the developing world, these difficulties are often exacerbated by a paucity of reliable statistics on productivity and production levels. In the absence of this information, robust calculations of economic impact pose strong methodological challenges.

Furthermore, ACIAR, as a funding rather than research body, faces a number of important additional limitations in the pursuit of economic-impact assessment estimates, and these strongly affect how the studies have been rated in the present analysis. Impact assessors situated within research organisations have relatively direct access to data collected during the research process. Furthermore, they are often actively involved in analysis of farmer responses to new technologies generated, as well as assessment of the scale and progress of adoption. Since they are often located within the same facility as the researchers, they also are likely to receive significant secondary informal information about research progress, and are more likely to be intimately familiar with the outputs produced. Impact assessment is often also conducted within these organisations after a considerable amount of data about adoption has been collected.

This is not the case with impact assessment produced by a funding body. Information about research outcomes and the adoption context must be obtained from the research body by the impact assessor, often at considerable effort.

Informal feedback loops that help to provide knowledge about where impact has become most widespread and assessable are often considerably fewer between the funding and research organisations than within a single research body or network. Furthermore, past patterns of impact may be considered implicitly linked to future funding possibilities. As a result there may be incentives for bias in information provided from the funding recipients to assessors who work on behalf of the funding organisation.

As a result, impact assessors commissioned by a research funding organisation, such as ACIAR, have a much smaller pool of reliable information from which to begin their efforts. Often, few empirical data regarding adoption are available without conducting field surveys to directly collect such data. Estimates based on discussions with the staff of the research organisation about how the technology has evolved, and what impact pathways are most important, are frequently the only source of readily available information. As a result, with limited funds available for impact assessment, assumptions based on the best available evidence are often the only practical option.

These problems are in some ways compounded by the use of external consultants for impact assessment conduct. While the externality of these assessors may help to ostensibly engender some degree of objectivity, and the incentives for biased reporting to an external agent may be lower than to a direct representative of the funding organisation, other difficulties are created. External consultants are often less familiar with the research investment to be assessed than are employees of the funding body, which means that even more background information must be obtained. Such consultants also may be less familiar with the adoption context than are those who have more regularly performed assessment in these areas, and this may limit the ability to assess the veracity of information obtained. With high consultancy rates and short contract durations, these external consultants have particularly limited opportunities for primary data collection.

It appears that these constraints, rather than the quality of analysis per se, may be the principal reasons for which a number of studies were not included in the more selective scenarios. In the context of these limitations, the impressive benefit–cost ratios achieved under the 'plausible' and 'substantially demonstrated' scenarios constitute an admirable achievement.

5 Conclusion

This analysis has illustrated that investment in bilateral research support by the Australian Centre for International Agricultural Research has been well-justified by economic benefits quantified to date. Despite a research portfolio subject to attribution difficulties, the Centre has successfully managed to demonstrate high levels of returns for a remarkable array of research undertakings. This is to be commended, as it is very likely that most benefits arising from the Centre's support can never be fully captured in quantitative terms. In this context, the fact that the sum of those few benefits that can be estimated clearly exceed normal standards of investment efficacy (benefit–cost ratios are greater than one) is rather impressive.

ACIAR is still a rather young organisation in the time frames of lags encountered between the generation of new knowledge and the development of economic impacts from improvements in the state of knowledge. As a result, a number of its assessments have been heavily ex ante. As time passes, the Centre eventually should be able to validate many of the assumptions needed to underpin these projections, and the case for the economic worth of its bilateral activities should become even more convincing. More importantly, it is almost certain that many new and often unanticipated benefits from past investments by ACIAR will become evident only with the passage of more time.

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Appendix. ACIAR Economic Impact Assessments included in review

Notes:

* = substantially demonstrated benefits.

** = plausible benefits.

All impact assessments were included as having potential benefits.

No. 1 Centre for International Economics. 1998. Control of Newcastle disease in village chickens.

No. 2 George, P.S. 1998. Increased efficiency of straw utilisation by cattle and buffalo (*) (**)

No. 3 Centre for International Economics 1998. Establishment of a protected area in Vanuatu

No. 4 Watson, A.S. 1998. Raw wool production and marketing in China: ACIAR project 8811

No. 5 Collins, D.J. and Collins, B.A. 1998. Fruit fly in Malaysia and Thailand 1985–1993

No. 6 Ryan, J.G. 1998. Pigeonpea improvement (*) (**)

No. 7 Centre for International Economics 1998. Reducing fish losses due to epizootic ulcerative syndrome

No. 8 McKenney, D.W. 1998. Australian tree species selection in China (**)

No. 9 ACIL Consulting 1998. Sulphur test KCl-40 and growth of the Australian canola industry

No. 10 AACM International Pty Ltd 1998. Conservation tillage and controlled traffic

No. 11 Chudleigh, P. 1998. Postharvest R&D concerning tropical fruits

No. 12 Waterhouse, D., Dillon, B. and Vincent, D. 1999. Economic benefits to Papua New Guinea and Australia from the biological control of banana skipper (*Erionota thrax*) (*) (**)

No. 13 Chudleigh, P. 1999. Breeding and quality analysis of rapeseed

No. 14 McLeod, R. 1999. Improved drying of high moisture grains

No. 15 Chudleigh, P. 1999. Use of management of grain protectants in China and Australia

No. 16 McLeod, R. 2001. Control of footrot in small ruminants of Nepal (*) (**)

No. 17 Tisdell, C. and Wilson, C. 2001. Breeding and feeding pigs in Australia and Vietnam (*) (**)

No. 18 Vincent, D. and Quirke, D. 2002. Controlling phalaris minor in the Indian rice–wheat belt (**)

No. 21 McLeod, R. 2003. Improving methods in diagnosis, epidemiology, and information management of foot and mouth disease in Southeast Asia

No. 23 McLeod, R. 2003. Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China

No. 25 Brennan, J.P. and Quade, K.J. 2004. Genetics of and breeding for rust resistance in wheat in India and Pakistan (**)

No. 26 Mullen, J.D. 2004. Impact assessment of ACIAR-funded projects on grain-market reform in China

No. 27 van Bueren, M. 2004. Acacia hybrids in Vietnam (*) (**)

No. 28 Harris, D. 2004. Water and nitrogen management in wheat–maize production on the North China Plain (**)

No. 29 Lindner, B. 2004. Impact assessment of research on the biology and management of coconut crabs on Vanuatu

No. 30 van Bueren, M. 2004. Eucalypt tree improvement in China (*) (**)

No. 32 Jiang, T. and D. Pearce. 2005. Shelf-life extension of leafy vegetables: evaluating the impacts

No. 33 Vere, D. 2005. Research into conservation tillage for dryland cropping in Australia and China

No. 34 Pearce, D. 2005. Identifying the sex pheromone of the sugarcane borer moth (**)

IMPACT ASSESSMENT SERIES

No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics (1998)	Control of Newcastle disease in village chickens	8334, 8717 and 93/222
2	George, P.S. (1998)	Increased efficiency of straw utilisation by cattle and buffalo	8203, 8601 and 8817
3	Centre for International Economics (1998)	Establishment of a protected area in Vanuatu	9020
4	Watson, A.S. (1998)	Raw wool production and marketing in China	8811
5	Collins, D.J. and Collins, B.A. (1998)	Fruit fly in Malaysia and Thailand 1985–1993	8343 and 8919
6	Ryan, J.G. (1998)	Pigeon pea improvement	8201 and 8567
7	Centre for International Economics (1998)	Reducing fish losses due to epizootic ulcerative syndrome—an ex ante evaluation	9130
8	McKenney, D.W. (1998)	Australian tree species selection in China	8457 and 8848
9	ACIL Consulting (1998)	Sulfur test KCL–40 and growth of the Australian canola industry	8328 and 8804
10	AACM International (1998)	Conservation tillage and controlled traffic	9209
11	Chudleigh, P. (1998)	Post-harvest R&D concerning tropical fruits	8356 and 8844
12	Waterhouse, D., Dillon, B. and Vincent, D. (1999)	Biological control of the banana skipper in Papua New Guinea	8802-C
13	Chudleigh, P. (1999)	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039
14	McLeod, R., Isvilanonda, S. and Wattanutchariya, S. (1999)	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008 and PHT/1990/008
15	Chudleigh, P. (1999)	Use and management of grain protectants in China and Australia	PHT/1990/035
16	McLeod, R. (2001)	Control of footrot in small ruminants of Nepal	AS2/1991/017 and AS2/1996/021
17	Tisdell, C. and Wilson, C. (2001)	Breeding and feeding pigs in Australia and Vietnam	AS2/1994/023
18	Vincent, D. and Quirke, D. (2002)	Controlling *Phalaris minor* in the Indian rice–wheat belt	CS1/1996/013
19	Pearce, D. (2002)	Measuring the poverty impact of ACIAR projects—a broad framework	
20	Warner, R. and Bauer, M. (2002)	*Mama Lus Frut* scheme: an assessment of poverty reduction	ASEM/1999/084
21	McLeod, R. (2003)	Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in Southeast Asia	AS1/1983/067, AS1/1988/035, AS1/1992/004 and AS1/1994/038
22	Bauer, M., Pearce, D. and Vincent, D. (2003)	Saving a staple crop: impact of biological control of the banana skipper on poverty reduction in Papua New Guinea	CS2/1988/002-C
23	McLeod, R. (2003)	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011 and AS2/1993/001

IMPACT ASSESSMENT SERIES

No.	Author(s) and year of publication	Title	ACIAR project numbers
24	Palis, F.G., Sumalde, Z.M. and Hossain, M. (2004)	Assessment of the rodent control projects in Vietnam funded by ACIAR and AUSAID: adoption and impact	AS1/1998/036
25	Brennan, J.P. and Quade, K.J. (2004)	Genetics of and breeding for rust resistance in wheat in India and Pakistan	CS1/1983/037 and CS1/1988/014
26	Mullen, J.D. (2004)	Impact assessment of ACIAR-funded projects on grain-market reform in China	ANRE1/1992/028 and ADP/1997/021
27	van Bueren, M. (2004)	Acacia hybrids in Vietnam	FST/1986/030
28	Harris, D. (2004)	Water and nitrogen management in wheat–maize production on the North China Plain	LWR1/1996/164
29	Lindner, B. (2004)	Impact assessment of research on the biology and management of coconut crabs on Vanuatu	FIS/1983/081
30	van Bueren, M. (2004)	Eucalypt tree improvement in China	FST/1990/044, FST/1994/025, FST/1984/057, FST/1988/048, FST/1987/036, FST/1996/125 and FST/1997/077
31	Pearce, D.	Review of ACIAR's research on agricultural policy	
32	Tingsong Jiang and Pearce, D.	Shelf-life extension of leafy vegetables—evaluating the impacts	PHT/1994/016
33	Vere, D.	Research into conservation tillage for dryland cropping in Australia and China	LWR2/1992/009, LWR2/1996/143
34	Pearce, D.	Identifying the sex pheromone of the sugarcane borer moth	CS2/1991/680

ECONOMIC ASSESSMENT SERIES (DISCONTINUED)

No.	Author and year of publication	Title	ACIAR project numbers
1	Doeleman, J.A. (1990)	Biological control of salvinia	8340
2	Tobin, J. (1990)	Fruit fly control	8343
3	Fleming, E. (1991)	Improving the feed value of straw fed to cattle and buffalo	8203 and 8601
4	Doeleman, J.A. (1990)	Benefits and costs of entomopathogenic nematodes: two biological control applications in China	8451 and 8929
5	Chudleigh, P.D. (1991)	Tick-borne disease control in cattle	8321
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