Benefits to Australia from ACIAR-funded research

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Australian Government
Australian Centre for International Agricultural Research

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

The Australian Centre for International Agricultural Research (ACIAR), part of Australia's official development assistance program, has a primary role and mission to help developing countries to reduce poverty and achieve sustainable development.

ACIAR is unique, however, in that it achieves this mission by supporting collaborative research and development (R&D) between Australian scientists and scientists in developing-country partners on mutual problems in agriculture, forestry and fisheries. If successful, the impact of this research occurs in both countries and is usually sustainable for long periods after the funding is completed.

The study reported here was commissioned to look in more detail at the mutual benefits flowing from ACIAR's activities. It found that ACIAR does indeed occupy a unique position, interfacing with Australia's overseas development program and its domestic innovation system. The study draws on the results of all previous independent impact assessment studies to examine benefits more closely.

The analysis shows that, as well as returns to partner countries from R&D being very high, the Australian benefits from the research are also substantial. For all the impact studies undertaken so far, the present value (PV) of the Australian benefits has been estimated to be $748 million from 35 projects, compared with a total PV of costs to ACIAR for these projects of $60 million. The study highlights that these Australian benefits come from different categories of impacts: direct production improvements (44%), indirect (35%) and direct (12%) protection from pests and diseases, and increased trade (9%). The study emphasises the importance of ACIAR's collaborative mode of operation and, in consequence, that care needs to be taken in attributing the benefits. The strong partnership focus of ACIAR's modality means others also contribute funds to the research and therefore can claim a proportion of the benefits.

The study cautions against extrapolating these findings to all ACIAR projects, because only 8% of projects have been evaluated so far, a sample too small to make inferences from. However, its authors were able to draw several important conclusions, including that there does not seem to be a trade-off between Australian benefits and total project benefits in the collaborative projects selected.

This report is an important companion to the earlier study 'Review of returns to ACIAR's bilateral R&D investments' (IAS No. 35), which focused on all benefits from ACIAR's R&D and the reliability of the independent impact assessments.

Peter Core
Director, ACIAR

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Acknowledgments

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Summary

ACIAR generates benefits to Australia in a number of ways

- Figure S1 illustrates the variety of ways in which ACIAR generates benefits to Australia, both in the context of Australia's aid program in general, and specifically to Australian agriculture.

Effectively delivering international aid

- From the evaluations undertaken to date, it is estimated that ACIAR-funded projects have delivered a total of $6.4 billion[1] to developing country partners for the expenditure of $250 million on those projects (expressed in constant 2004 dollars).

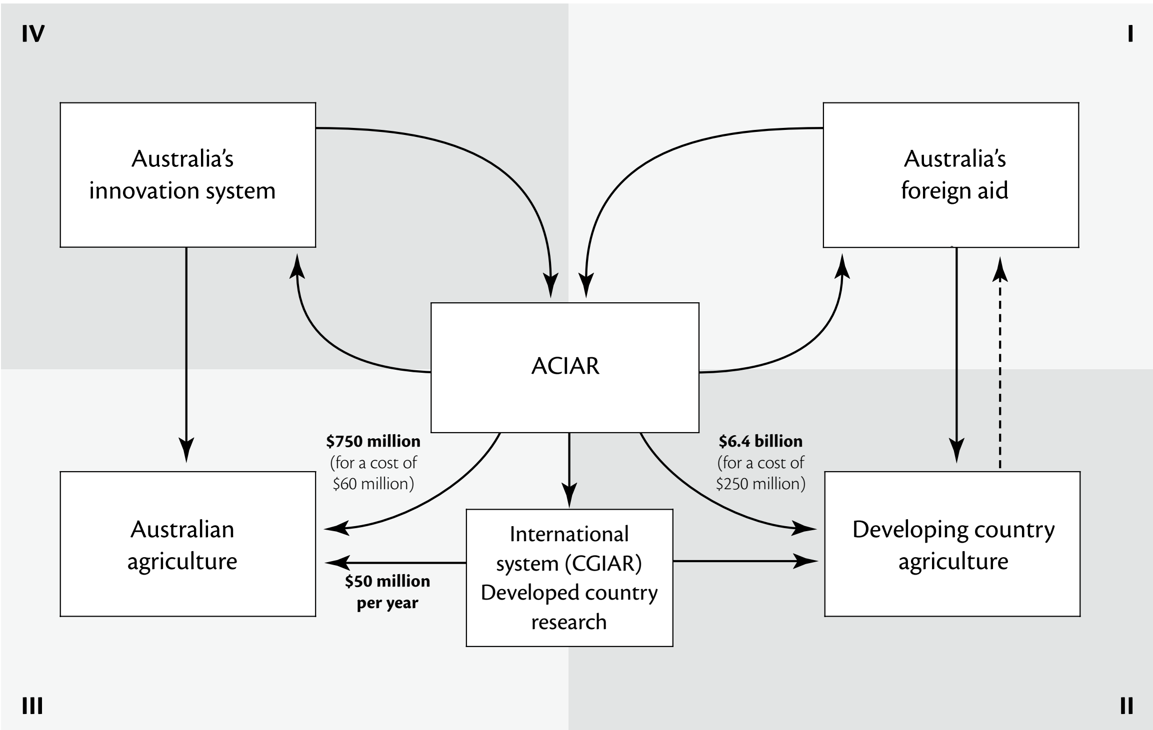


Figure S1. ACIAR's benefits to Australia

1 Unless otherwise specified, monetary values are in Australian dollars.

- This is a very high rate of return. It indicates that, even if there were no other benefits, it more than justifies total ACIAR funding to date of around $1.2 billion.
- ACIAR's strong tradition of impact evaluation is an excellent example of project evaluation in general.
- As well as these quantified benefits, ACIAR's activities are extremely popular in developing-country partners, enhancing Australia's recognition in the region.

Interacting with Australia's innovation system

- ACIAR commissions Australian as well as international research providers and helps generate a number of key interactions with Australia's overall innovation system. These interactions enhance the ways in which overall agricultural research delivers benefits to Australian agriculture, including by:
  - leveraging funding into areas of importance for Australian agriculture
  - providing access to a broader pool of researchers for problems of interest—that is, providing access to international expertise and environments
  - increasing the overall research base for agricultural issues of interest to Australia
  - contributing to the overall stock of knowledge in an international context and thus helping identify both promising areas for research as well as 'dry holes'.
- As part of the international system of agricultural research, ACIAR's interactions with multilateral research organisations also help contribute benefits to Australian agriculture. ACIAR-sponsored evaluations indicate that these benefits come to around $50 million per year.
  - Of course, these benefits cannot all be attributed to ACIAR's funds, but ACIAR's interactions with these agencies are significant.

Generating benefits to Australian agriculture

- ACIAR's impact evaluations, along with additional case studies undertaken for this report, demonstrate that ACIAR-funded projects have also delivered significant quantifiable benefits to Australian agriculture.
- Understanding these benefits and how they arise is a major focus of this report.

Significant quantified benefits to Australia ...

- The summary quantifications presented in this report build on earlier ACIAR analysis (Raitzer and Lindner 2005) but with some key differences:
  - here we are concerned with the total benefits of the research, not just the benefits 'attributable' to ACIAR
  - the benefits reported here mostly fall into the 'potential' category used by Raitzer and Lindner
  - we have added a number of impact assessments to the set used by Raitzer and Lindner.
- Available evidence from past ACIAR-funded projects suggests that they have delivered significant benefits to Australian agriculture.
  - There are 16 impact evaluations (covering 29 projects) for which benefits to Australia have been quantified. In present-value terms (2004 dollars), these benefits come to $605 million.
  - Three of the five additional sets of projects analysed as case studies in this report together generated benefits to Australia of $143 million.
  - These benefits alone ($748 million in total from 35 projects) more than cover the full costs to ACIAR of those projects (which amounted to around $60 million in present-value terms).

... for a range of reasons

- These quantified benefits arise in four main categories:
  - direct production benefits (44% of the total) arising through research findings that directly improve the productivity of Australian agriculture
  - indirect protection from disease or pest incursion (35% of the total) arising through research findings that lower the chance of a disease or pest ever entering Australia
  - direct protection from disease or pest incursion (12% of the total) arising from research findings that allow more effective quarantine or more effective control of disease or pests incursions
  - increased trade benefits (9% of the total) arising through research that increases the value of Australian exports.

... in a range of industries

- These quantified benefits accrued to six main commodity groups.
  - The banana industry received 35% of the total benefits. This is due to the very large benefit arising from the biological control of banana skipper in Papua New Guinea.
  - The grains industry received 30% of the total benefits.
  - Horticulture (including tropical fruits) received 26% of the total benefits.
  - Meat industries (including grazing) received 6% of the total benefits.
  - Wool received 2% of the total benefits.
  - The fishing industry received just under 1% of the total benefits.

There are some issues in interpretation

Potential for sample bias

- These results are based on impact evaluations that have been undertaken for a sample of the projects funded by ACIAR. Because the projects, or groups of projects, chosen for evaluation were not randomly selected, there is a risk of a systematic bias in the results.
- Most of the existing impact evaluations were not chosen specifically to illustrate benefits to Australia—they were generally hand-picked to demonstrate total benefits.
  - We expect upward bias in the total net benefits of the projects selected and, given the relationship between total benefits and Australian benefits, we expect some of this bias to carry over to the Australian benefits.

Most benefits are expected

- Many of the benefits from the impact evaluations, particularly from some of the earlier evaluations, are benefits that were projected to occur after the research was completed. It is possible that these benefits never actually emerged or that the benefits that did emerge were considerably greater.

Attribution

- It is not possible to attribute all of the benefits to ACIAR alone. Given the highly networked nature of Australian agricultural research, the benefits to these projects are likely to have emerged because of a combination of ACIAR funding and previous funding from other agencies.

Skewed frequency distribution of benefits

- The total net benefits (to all recipients) of ACIAR projects range from $1–2 million up to $1 billion, which corresponds to a benefit–cost ratio ranging from 10:1 to 200:1.
- Most of the benefits, however, are concentrated towards the lower end of this distribution—indicating a high probability of a very healthy return, and a low probability of an exceptional return.
- The benefits to Australia are distributed in a similar way.
- This distribution is similar to that found in other meta analyses of research returns.

No evidence of a trade-off

- Within this sample, evaluations with quantified Australian benefits had a slightly lower average *total* benefits than evaluations that did not report Australian benefits.
- However, this difference was not statistically significant, suggesting that there is no evidence of a trade-off between Australian benefits and total net project benefits.

New case studies broadly confirm this picture

- For this project, we have evaluated the Australian benefits of five additional ACIAR-funded research activities (four of them were separate projects while the fifth was a group of related projects). Stratified random sampling was used to select the projects for this part of the study.
- For three of the projects, we were able to quantify benefits to Australia, while for the other two the benefits were qualitative.
- The benefits for the quantified projects were significant, at around $40 million each. These benefits were in the areas of direct pest protection, increased trade and direct production effects. The benefits accrued to the grains and horticulture industries.
- For the two projects for which we were unable to quantify the benefits, there is a significant likelihood that benefits will emerge once additional research is undertaken.
- This illustrates that projects are able to contribute to the stock of knowledge relevant to Australia, even if it is not possible to quantify these benefits.

More evaluations are appropriate

- While ACIAR has a significant body of impact evaluations to draw on, the number (35, covering 65 projects) is small relative to the total number of ACIAR projects undertaken to date (around 900).
- There is a good case for continuing to undertake impact evaluations and to ensure that these focus both on partner country and Australian benefits.
- In all likelihood, significantly more benefits to Australian agriculture will be identified.

1 Introduction

Background

While funding research in developing countries, ACIAR also delivers benefits to Australia and, in particular, to Australian agriculture. This is consistent with ACIAR's charter and, as part of its ongoing efforts to evaluate the impacts of its research, ACIAR is interested in exploring how these benefits come about, what their orders of magnitude are, and exactly what types of benefits there are.

These latter questions are the subject of this report. In it we examine the various ways in which ACIAR-funded research delivers benefits to Australian agriculture. We are concerned with how these benefits come about, whether they can be adequately measured, what drives them and, importantly, whether any measures could increase them significantly without jeopardising the delivery of benefits to developing-country partners.

In their recent meta analysis of some ACIAR impact assessments, Raitzer and Lindner (2005) found that 14% of the potential benefits of ACIAR-funded research accrued to Australia. This amounted to an estimated $480 million (in present-value terms). Our objective here is to update this estimate using a wider set of impact assessments and to look more closely at the nature of these benefits.

This report

Methodology

The basic method used in this report is to combine two sources of information. First, we take information on benefits to Australia from a range of previously published impact assessments. For this component, we have treated the estimated benefits (when placed on a common basis) as a set of sample points from a universe of potential impact assessments. We use this meta-analysis approach to draw inferences about the magnitude of the impact of ACIAR-funded research on Australia, as well as to look for patterns in the determinants of these impacts.

The second source of information is five additional case studies of ACIAR-funded projects undertaken for this report. These projects have not previously been subject to impact assessment and we use them to provide some additional data points for the overall meta analysis, as well as to provide some specific insights into the nature of benefits to Australia.

Outline

This report is structured as follows. Chapter 2 presents a general discussion of the various ways in which ACIAR-funded research generates benefits for Australia and for Australian agriculture. These ideas are based on findings from the material presented in subsequent chapters as well as general analysis from a variety of sources.

Chapter 3 presents the results of a systematic review of published ACIAR impact-assessment material, and considers in detail the relative value of different types of benefits to Australia.

Chapter 4 presents the results of five case studies designed to further illuminate the nature of benefits to Australia. In contrast to the usual procedure for choosing funded research for assessment, four of these five were chosen according to a systematic procedure that essentially randomly chose the projects from within a set that satisfied several broad characteristics. The analyses for the case studies are detailed in Appendix A–E.

Chapter 5 presents some conclusions.

2 ACIAR and benefits to Australia

ACIAR sits at an interface between two systems that, while administratively distinct, have strong linkages. Mostly, ACIAR would be viewed as part of Australia's aid program, funding research that, when successful, generates significant and lasting productivity benefits for agriculture in developing-country partners. Like providing physical infrastructure or delivering education, research is a form of aid that has the potential to continue to deliver benefits well after the funding has ceased.

ACIAR's success in generating benefits for developing-country partners is evidenced in a number of positive impact assessments. This success in turn builds on ACIAR's ability to attract Australia's excellent scientific resources into looking at a particular class of problem. This use of Australian research resources provides the link to the second system—Australia's innovation and research system.

Delivering effective aid

This point is illustrated in Figure 1. Schematically, ACIAR sits between a number of important interactions. The best-known interaction is illustrated in quadrant II of Figure 1, the delivery of research outcomes to developing-country agriculture. A selected set of impact assessments suggests that the benefits delivered in this way have potentially amounted to $3.4 billion as a result of spending around $1 billion (Raitzer and Lindner 2005). Further analysis in this report suggests (see chapter 3 and, in particular, Figure 5) that the total net benefits (coming from ACIAR and other funds) come to around $6.4 billion (all expressed in 2004 dollars).

This is an effective way of transforming aid funds into benefits, and this channel explains the rationale of the first quadrant of Figure 1. Of course, ACIAR does not do this alone; it contributes to, and draws on, resources in the international or multilateral system of agricultural research, represented in the figure by the Consultative Group on International Agricultural Research (CGIAR).

It is difficult to make comparisons with other parts of Australia's aid portfolio, but it is likely that ACIAR's returns are very high in the aid context. ACIAR is also unique in having a systematic series of evaluations by which its work can be measured. Indeed, ACIAR's sustained focus on quantifying the effects of its research provides an excellent example of the effective use of evaluation of funding projects. The analysis in chapter 3 demonstrates how a body of impact evaluation work can contribute to the understanding of drivers of the benefits from a particular form of aid.

As part of Australia's aid program (quadrant I) ACIAR-funded research contributes to the overall objectives of Australia's aid program which are (AusAID 2006, p. 20):

> To assist developing countries to reduce poverty and achieve sustainable development, in line with Australia's national interest.

Given the importance of agriculture to economies in our region, agricultural research which contributes to agricultural productivity clearly has a pivotal role in achieving these objectives

Benefits to Australian agriculture

Less well known, but nevertheless visible in some impact assessments, is the way in which the ACIAR-funded research directly delivers benefits to Australian agriculture (quadrant III). This quadrant will be examined in some more detail below, but some of the specific agriculture industry benefits are summarised in the left panel of Figure 2. This quadrant of benefits arises through ACIAR's ability to combine aid-related funding with Australian research expertise along with the lessons learned overseas, to examine issues that are of benefit to all agriculture around the world.

Interactions with Australia's innovation system

Less well recognised still are the ways in which ACIAR's activities interact with Australia's innovation system to deliver benefits to Australian agriculture (quadrant IV) as well as to our aid program and to developing countries.

Figure 2 makes a distinction between system-wide benefits from ACIAR's activities, and the specific benefits that can accrue to particular agricultural activities. ACIAR's interactions with Australia's innovation system potentially bring system-wide benefits. These arise through ACIAR's ability to:

- leverage funding from Australia's aid program to assist in research and development (R&D) activities
- provide access to a greater pool of researchers (through international linkages) than might otherwise be available for particular issues
- increase the base of research activities, again through international linkages
- effectively explore a variety of research avenues, again through international interactions and so avoid 'dry holes' for future Australian research
- maintain interest in particular research areas that may be of value to Australia.

Specific benefits to Australian agriculture

As the left panel of Figure 2 illustrates, there are diverse ways by which ACIAR-funded research can deliver specific benefits to Australian agriculture.

New production technology

The most obvious of these is through direct productivity benefits, through new production technologies or techniques, or through new breeds and varieties.

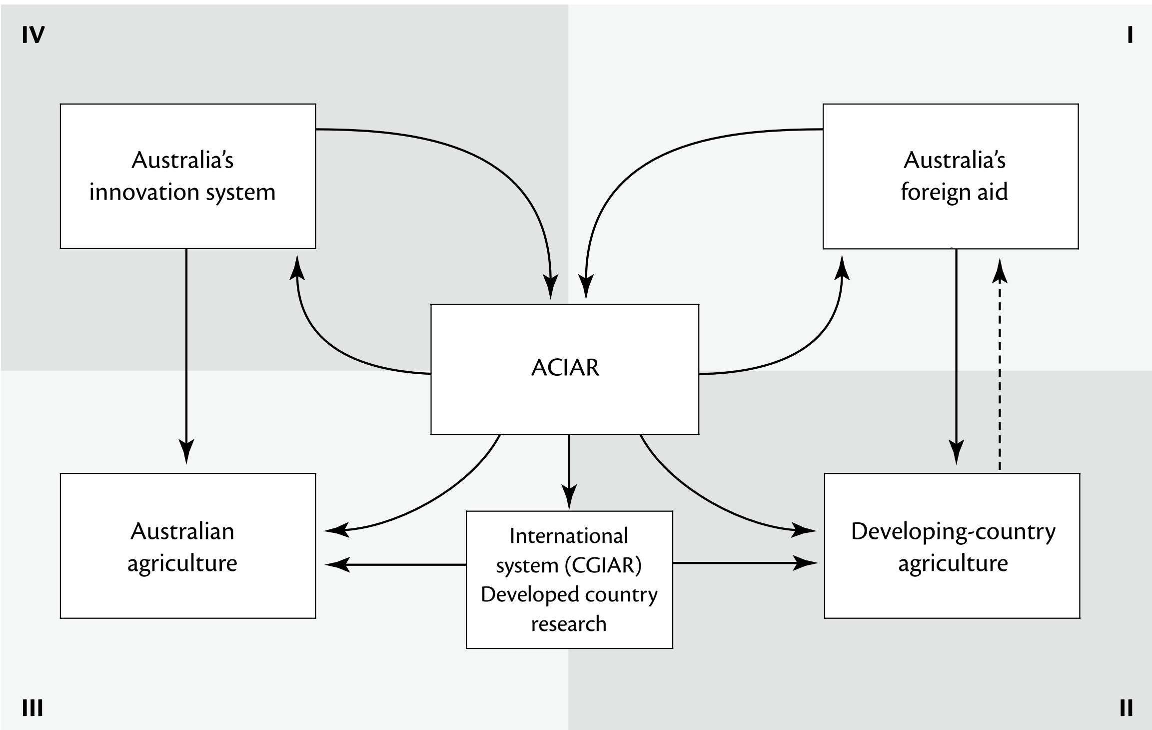


Figure 1. ACIAR: aid and innovation

The first panel of Figure 3 illustrates how these production benefits are typically measured. An increase in productivity appears as a downward (and to the right) shift in the supply curve of a particular product; that is, more can be produced at the same cost, or the same level of production can now come at lower cost. This cost reduction leads to an increase in 'producer surplus', or roughly the profitability of production, and at the same time leads to lower prices for consumers (and an increase in 'consumer surplus').

The net gains to society are typically measured as the shaded area in the first panel of Figure 3, and in evaluating these benefits the identification of *v*, the 'vertical shift in the supply curve' is particularly important. This source of gain is a feature of a number of impact assessments, including that of the sorghum case study discussed in detail in chapter 4.

The extent to which research focused on partner country agriculture can also generate supply shifts for Australian agriculture depends on the commodities and production systems covered by the research. In many partner countries, production systems are very similar to those in Australia, and so research is applicable in Australia as well as overseas.

In some cases, most notably the research undertaken under the umbrella of CGIAR, effects on Australia arise as an indirect spillover from research focused on other countries. Foreign productivity improvements, if not matched by similar improvements in Australia, would tend to lower prices and returns to Australian farmers. By being part of the CGIAR system, Australia is also able to achieve a productivity improvement, leading to higher returns than would otherwise have been the case.

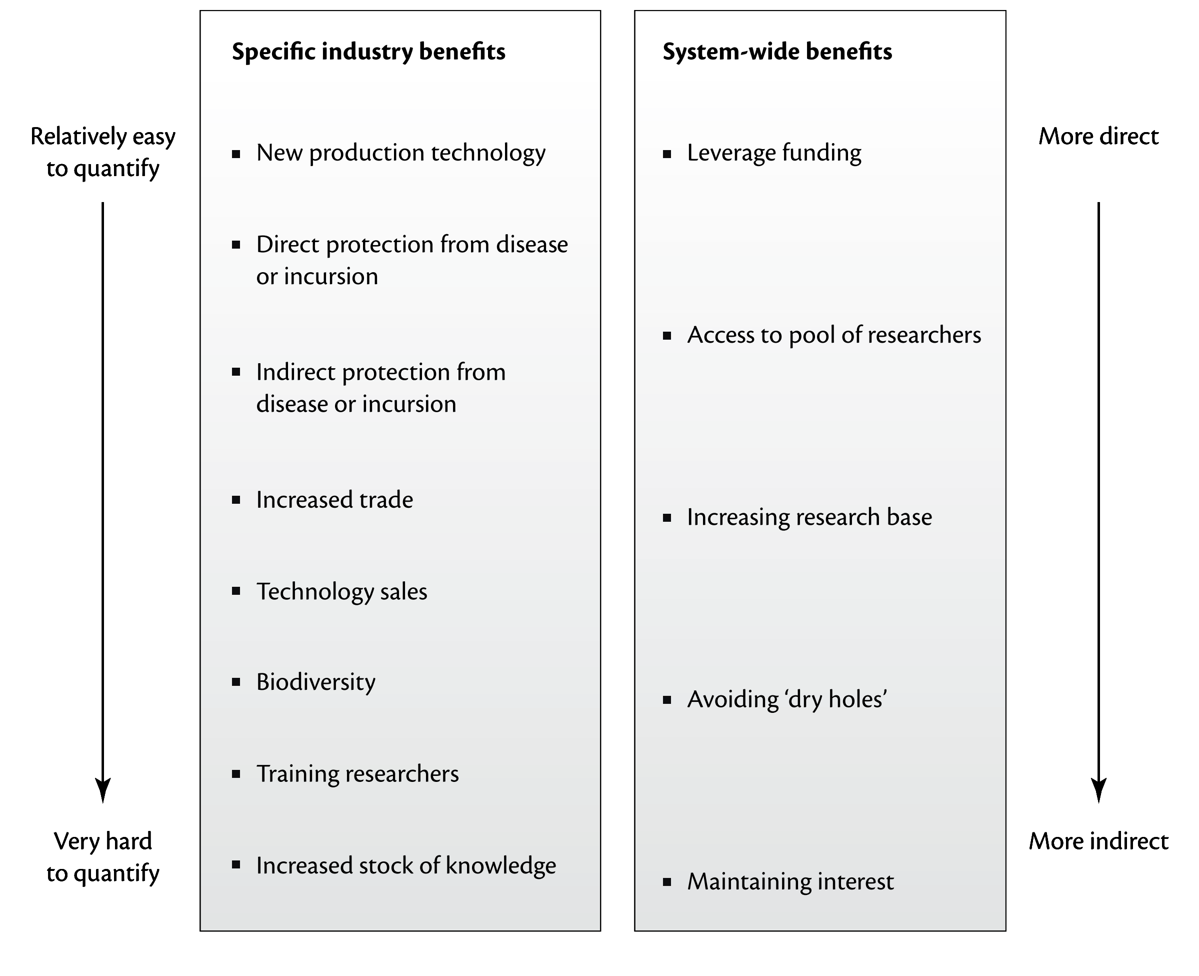


Figure 2. Varieties of benefits to Australian agriculture from ACIAR research

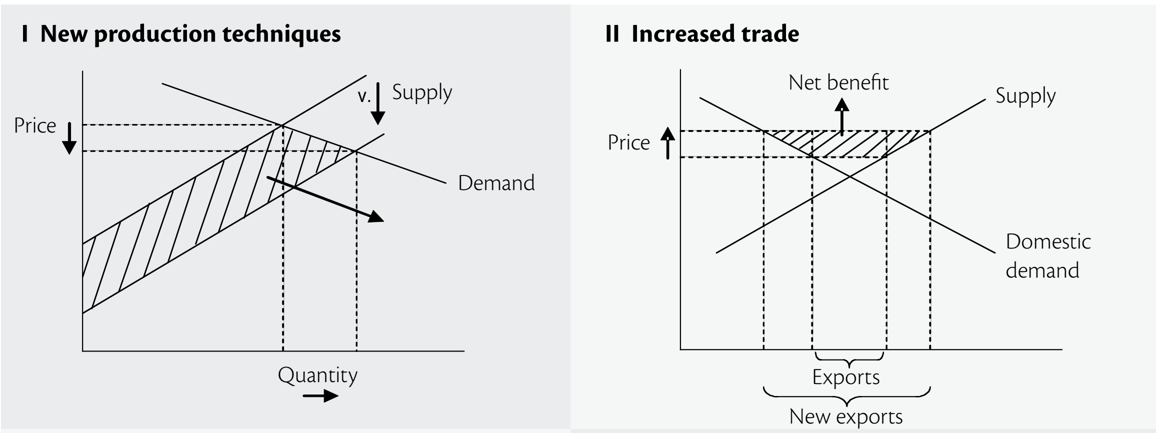
Protection from disease or pests

Benefits can also arise through protection from disease and pest incursions of various kinds. This protection can be direct or indirect. Direct protection is where the disease or pest is attacked in Australia using new techniques developed as a result of the research. Indirect protection occurs when the research attacks the pest or disease in the foreign host country *before* it ever gets the chance to enter Australia.

Typically, the effect of protection from pests or diseases is to avoid a backward shift in the supply curve for one or more products. Evaluation of the benefits is more complex, in this case, however, as the effect of the research is often to lower the *probability* of incursion (see the third panel of Figure 3). Evaluation thus requires knowledge of both *v*, the shift in the supply curve, as well as of the change in the probability of incursion.

Put another way, the magnitude of the benefits of this research depends on both the initial *probability* or *likelihood* of an incursion and the *consequence* of an incursion if it occurs. Research may lower the probability—or provide information on the true probability where it was not known—or it may change the consequence of the incursion.

ACIAR-funded research generates this type of benefit through the largely indirect consequence of the research and because there are some diseases and pests with significant probability and consequence to be of concern for Australian agriculture. For example, the biological control of banana skipper in Papua New Guinea had the indirect effect of ensuring that the skipper was unlikely to ever migrate to Australia. In the case of research on bee mite pests (presented in chapter 4 as a case study), the identification of the actual species underlying the pest led indirectly to a reduced probability of incursion, from which there would also be a significant consequence.



III Disease or pest incursion

Without research
Expected cost = prob.$_1$* (Cost of incursion)

With research
Expected cost = prob.$_2$* (Cost of incursion)

Benefit of research
=
(prob.$_1$ – prob.$_2$) * (Cost of incursion)

IV Increased stock of knowledge

Without ACIAR
Expected benefit = p success$_1$* (Benefit)

With ACIAR
Expected benefit = p success$_2$* (Benefit)

Benefit from ACIAR
=
(p success$_2$ – p success$_1$) * (Benefit)

Figure 3. Different ways in which benefits arise

Increased trade

Benefits may also arise through increased trade with partner countries as a result of research that may increase demand for Australian products or improve Australia's ability to access foreign markets. Also potentially important is the fact that the research may generate cheaper imports for Australia. While this is unlikely to accrue as a benefit specifically to the Australian agricultural sector, it will appear as an economy-wide benefit to Australia.

The second panel of Figure 3 provides one way of illustrating how an increase in the terms of trade, in particular an increase in export prices, leads to net benefits to Australia. This net benefit consists of a gain to producers, in terms of increased profits, net of a loss to Australian consumers because of the diversion of product to the export market.

The core element in evaluating this type of benefit is in identifying the effective increase in export demand and subsequently export prices that result from the technology or, equivalently, identifying the extent to which foreign demand for Australia's products has increased. The case study of the heat treatment of mangoes presented in chapter 4 is an example of this.

Other hard-to-quantify benefits

Other potential benefits are considerably harder to quantify and include improvements in biodiversity that may be valued by Australians, training of researchers, and general increases in the stock of knowledge that may be applicable in the Australian context.

Increases in the stock of knowledge are particularly important in the context of ACIAR's research, as ACIAR tends to fund research in areas where other research is

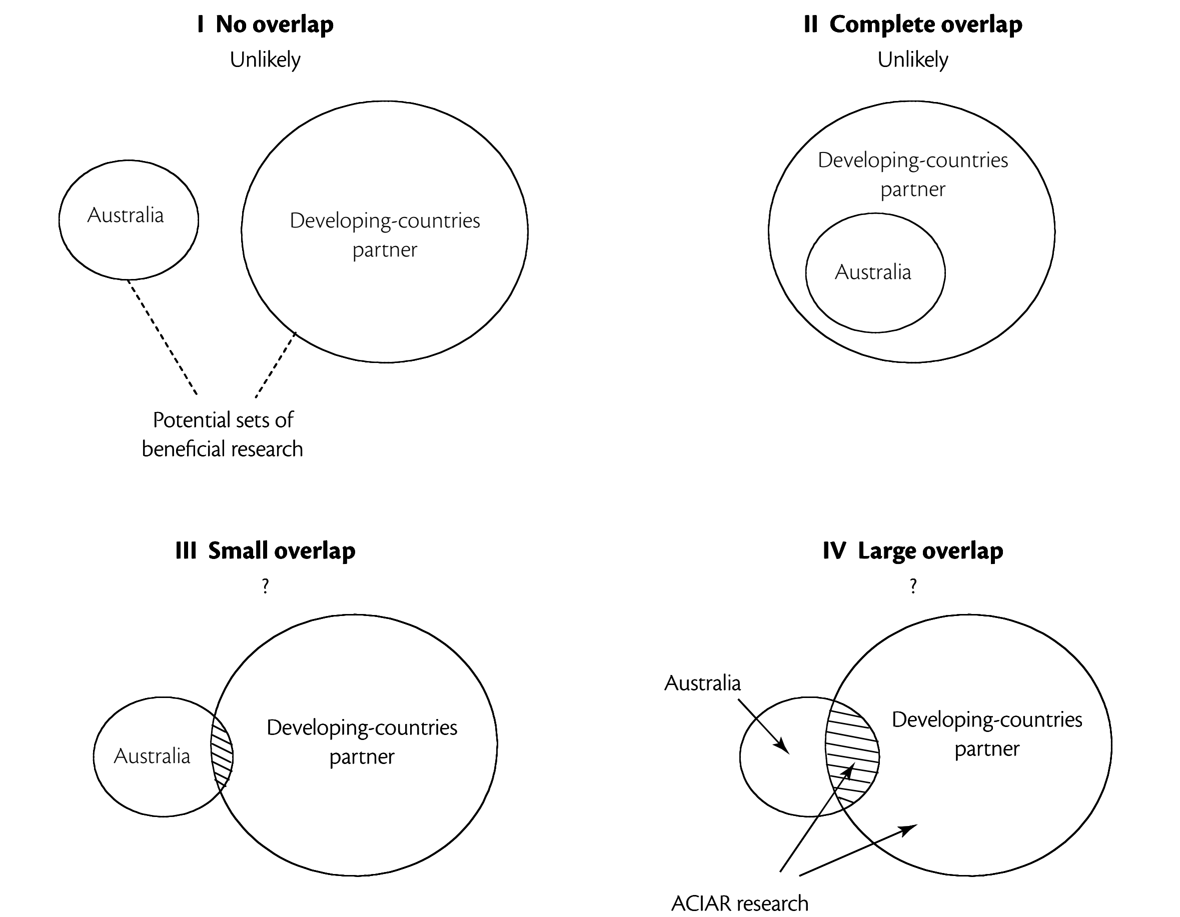


Figure 4. Benefits to Australia depend on the overlap

already taking place. In this context, a contribution of ACIAR's research may be to increase the probability of success of other research (see panel 4 of Figure 3), or perhaps to lower the cost of other research. The case study of increasing the yield of sorghum discussed in chapter 4 is an example of this.

Delivering benefits to both Australia and partner countries

The ability of ACIAR-funded research to deliver benefits to both Australia and developing-country partners depends on the overlap between researchable issues in Australian and foreign agriculture. This is illustrated in Figure 4. If there were no overlaps, then ACIAR would not be able to deliver benefits to Australian agriculture. This situation is very unlikely, given what we already know about benefits to Australia.

Equally unlikely is a situation of complete overlap between Australia and developing-country partners. The truth lies somewhere in between either a small or large overlap.

The results from the impact assessments undertaken to date suggest that this overlap is somewhere between 62% and 85%. That is, for 62–85% of the projects evaluated in an impact assessment there were identified benefits to both Australia and the developing-country partner. Some 62% of projects assessed delivered quantitative benefits to Australia, and 85% delivered either quantitative or qualitative benefits to Australia (see chapter 3, in particular Table 1).

Another important question is the extent to which there is a trade-off between delivering benefits to Australian agriculture and delivering benefits to developing-country partners. There are three reasons why there might be a trade-off.

- First, to the extent that Australian farmers and developing-country farmers compete in particular markets (either in Australia or in some third export market), delivering productivity benefits to competing producers may result in loses for Australian farmers. This is output market or product market competition.
- Second, to the extent that agricultural systems are not the same in Australian and developing-country partners, research resources devoted to developing-country issues may be diverted from alternative uses in Australia. This competition for research resources may result in lower than otherwise returns to Australian agriculture.
- Third, there may be a trade-off in the opposite direction. That is, attempting to deliver benefits to Australian agriculture may divert resources and lower the potential benefits available to developing-country partners.

The analysis presented in chapter 3 uses information available from existing impact assessments to test for each of these trade-offs. While the evidence is a little mixed, there is no strong reason to believe that there is a substantial trade-off.

3 Evidence from existing assessments

The assessments covered

Over the past 15–20 years, ACIAR has commissioned a relatively large number of detailed economic impact assessments of some of its projects. The results of these various assessments, when converted to a common basis, provide a dataset of 35 observations, 16 of which include calculations of the benefits to Australia. These 35 assessments cover 65 projects, as a number of them covered more than one project.[2]

Table 1 shows that, in addition to the 16 impact assessments (covering 29 projects) with quantified benefits to Australia:

- 7 assessments (covering 11 projects) had only a qualitative discussion of benefits to Australia
- 5 assessments (covering 7 projects) expected benefits to Australia to be zero
- 7 assessments (covering 18 projects) did not consider benefits to Australia at all.

Thus, of the subtotal of 28 assessments (covering 47 projects) that did consider benefits to Australia in some form:

- 57% of assessments (covering 62% of projects evaluated) quantified benefits to Australia
- 25% of assessments (covering 23% of projects evaluated) qualitatively discussed benefits to Australia
- 18% of assessments (covering 15% of projects evaluated) considered that there were no benefits to Australia.

Approach used in this report

The analysis we present here is broadly similar to that of Raitzer and Lindner (R&L) (2005), although there are some key differences. Like R&L, we place the benefits (and costs) of the various projects on a common basis by converting the streams of benefits to constant 2004 dollars. We have used the same impact assessments covered by R&L, except that we have not included IAS 8 (*Australian tree species selection in China*) as the projects covered in that assessment were subsequently covered in IAS 30. This gives 28 assessments, to which we have added 7 from the discontinued series of impact assessments that have not been superseded by subsequent analysis of the same projects. These were added to provide a greater set of projects with measured benefits to Australia.

Unlike R&L, we are concerned with examining the *total* benefits of the research (in particular *total* benefits to Australia) rather than the benefits 'attributable' to ACIAR. R&L re-scaled the total benefits by ACIAR's share in the total project budget to provide an estimate of the benefits attributable to ACIAR's funding. The object in their case was to demonstrate that ACIAR's funding was generating net benefits. Here we are concerned with the total benefits that flow to Australia as a result of ACIAR's involvement with the projects.

2 There are more than 35 impact assessment publications, but in a number of cases publications have undertaken additional assessment of projects previously evaluated (to account for more recent information). Here we have included only the most recent evaluations.

Indeed, a fundamental proposition of the research here is that benefits flow to Australian agriculture as a result of ACIAR's interaction with Australia's aid program on the one hand, and Australia's innovation system on the other. Given the complex nature of this interaction, we have not attempted to attribute benefits to the different components.

Most benefits are 'potential'

R&L classified benefits into three types: substantially demonstrated, plausible and potential. Of the impact assessments they considered, there was only one project with substantially demonstrated benefits to Australia (the banana skipper project) and only one project with plausible benefits (the same project). Other projects with benefits to Australia fell into the 'potential' category.

For the work presented here, we have used the potential benefit category. That is, many of the Australian benefits covered here are potential, and many were calculated after the completion of the research but before benefits were actually observed. We cannot be sure—particularly for the older impact assessments—that the expected benefits did actually emerge, or that the benefits that did emerge were not significantly larger than originally anticipated.

This issue is a fundamental feature of the way the impact evaluations have been conducted in the past, and without re-doing them all, it is not possible to provide an answer as to whether this biases the estimates of Australian benefits (relative, for example, to total benefits) in any way.

Bias in the sample?

There are two potential sources of bias in the sample used here to look at benefits to Australia.

First, the projects chosen for impact evaluation, and therefore represented in the 35 impact assessments (16 with Australian benefits) used here, were not randomly selected. We cannot say whether they are representative of the full population of ACIAR-funded projects. Given that the projects were selected on the basis of demonstrating value for money from ACIAR funds, it would be expected that the average total benefits within the sample would be higher than the average for the full population.

This may mean that there is a bias in the measured Australian benefits. As noted below, there is a positive correlation between Australian benefits and partner country benefits, so any systematic bias in selection of projects based on expected *partner* country benefits may also be reflected in the *Australian* benefits.

Table 1. Breakdown of impact assessments: Australian benefits and assessments versus projects

Status of Australian benefits	Impact assessments	Projects covered by the assessments
	Number	Number
Quantified benefits to Australia	16	29
Qualitative discussion on benefits to Australia	7	11
Benefits to Australia expected to be zero	5	7
Benefits to Australia not considered	7	18
Total	35	65
Subtotal: benefits to Australia considered in some way	28	47
For projects with benefits to Australia considered:	%	%
Share with quantified benefits to Australia	57	62
Share with qualitative benefits to Australia	25	23
Share with no expected benefits to Australia	18	15

Source: CIE estimates

The second potential source of bias is that benefits to Australia have often not been the focus of impact evaluations, and so the benefits to Australia may be understated, leading to a downward bias. As Table 1 indicates, a fifth of the evaluations (7 of 35) did not consider benefits to Australia, and a further fifth only discussed benefits to Australia, but did not quantify them. It is possible that there were, in fact, benefits to Australia in these other studies, but they simply were not measured.

One way of checking for any bias is with the case studies selected for this project (see chapter 4). Four of these case studies were randomly selected (within a stratification procedure) and it turns out that half of them had quantifiable benefits to Australia and half did not. This is similar to the proportion with quantifiable benefits from the previously published impact assessments (57% of those evaluations that considered Australian benefits). On the basis of our case studies, we have no reason to expect a bias in Australian benefits. Of course, these four additional studies provide a very low-power test.

Impact evaluation the unit of analysis

It is important to note that, in the discussion that follows, we use the impact evaluation—rather than the individual projects evaluated—as the unit of analysis. This is because those evaluations that examined more than one project did so in order to capture the interactions between the projects, and so it does not make sense to separate estimates of benefits per individual project.

Total project benefits—Australian and partner countries

The total benefit from the 35 impact assessments comes to $6.4 billion (when expressed in today's dollars). As Figure 5 illustrates, this yields total net benefits of $6.1 billion once ACIAR's and other costs are taken into account.

If these benefits are 'attributed' to ACIAR on the basis of ACIAR's share in the total project budget, then the total benefits attributable to ACIAR are $3.5 billion, with benefits net of ACIAR costs of $3.3 billion.

Figure 5 also illustrates the uncertainty around the total benefit estimates. Using information on the variance of the benefit estimates within the sample of 35 impact evaluations, we estimate that the 95% confidence interval for the total net benefits is between $3.2 billion and $9.6 billion, and that the confidence interval for net benefits attributed to ACIAR is between $1.8 billion and $5.7 billion[3].

Figure 6 provides a further indication of the wide variance of estimates within the impact evaluations, by showing the frequency distribution of net benefit results (with the inset showing the frequency distribution of the benefit–cost ratio), while Figure 7 shows the same distribution, but for projects with net benefits of less that $100 million.

The most obvious result from these figures is that the benefits are highly skewed, with the bulk of projects clustering towards the lower end of the distribution, but with a long tail of projects with very high net benefits. Thus, while the average benefit is $175 million, the median benefit is lower at $58 million. The same result is evident even when focusing on the lower end of the distribution; for projects with benefits of less than $100 million, the average benefit is $25 million, while the median benefit is $14 million.

While the returns from all of these projects are very good (with benefit–cost ratios ranging from 200:1 to 10:1), this non-symmetric distribution has some interesting implications. It implies for example that, for a randomly selected project, there is a higher probability of a return at the lower end of the scale than there is of a return at the higher end.

This sort of distribution has often been observed in large analyses of the impacts of research. For example, research by Alston et al. (2000) found a similar pattern in their meta analysis of around 1,800 impact estimates. In their case, the median was around half the mean, with the maximum value being around 70 times the magnitude of the mean. In the case of the Australian results reported here, the median is around a third of the mean, and the largest value is around five times the mean.

3 This confidence interval is constructed using a bootstrap technique applied to the sample dataset (for details of bootstrapping, see Efron and Tibshirani (1991)). This technique involves re-sampling many thousands of times from within the sample, and calculating summary statistics from the resulting thousands of sample points.

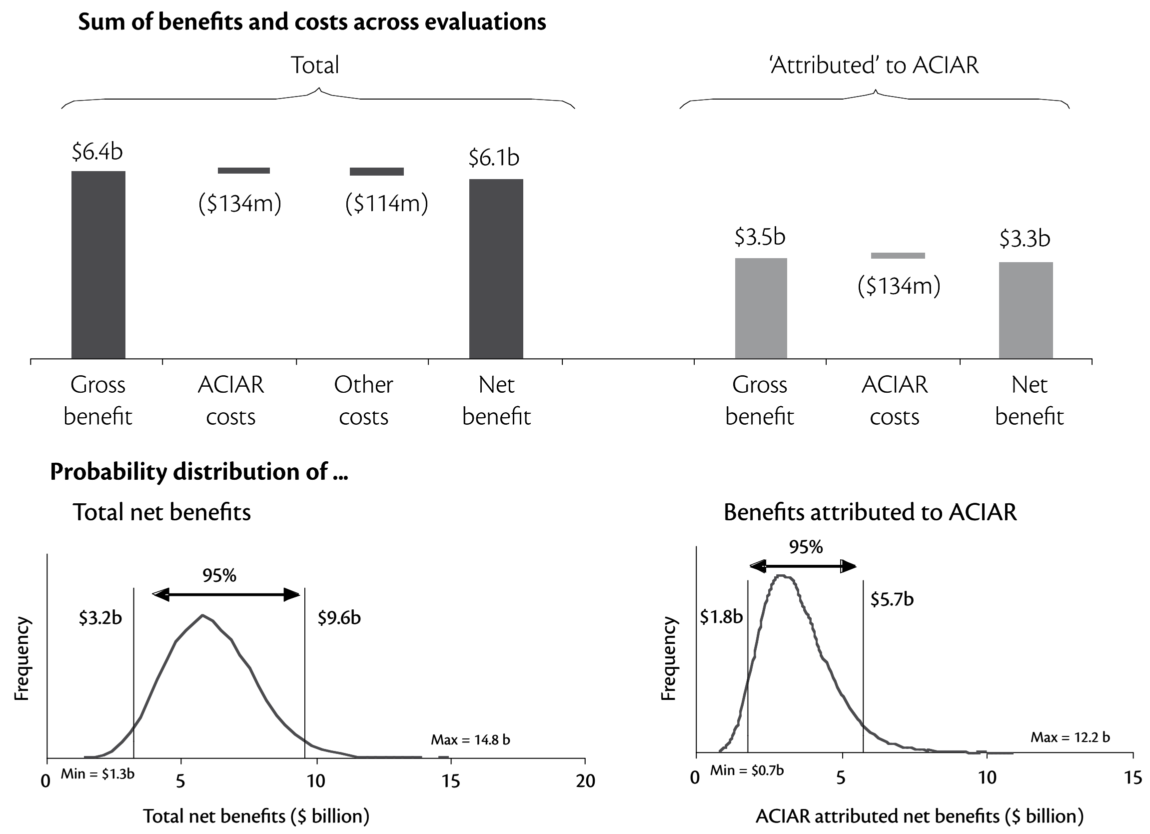


Figure 5. Total benefits of projects contained within assessments. Data source: CIE estimates based on meta analysis of published impact assessments

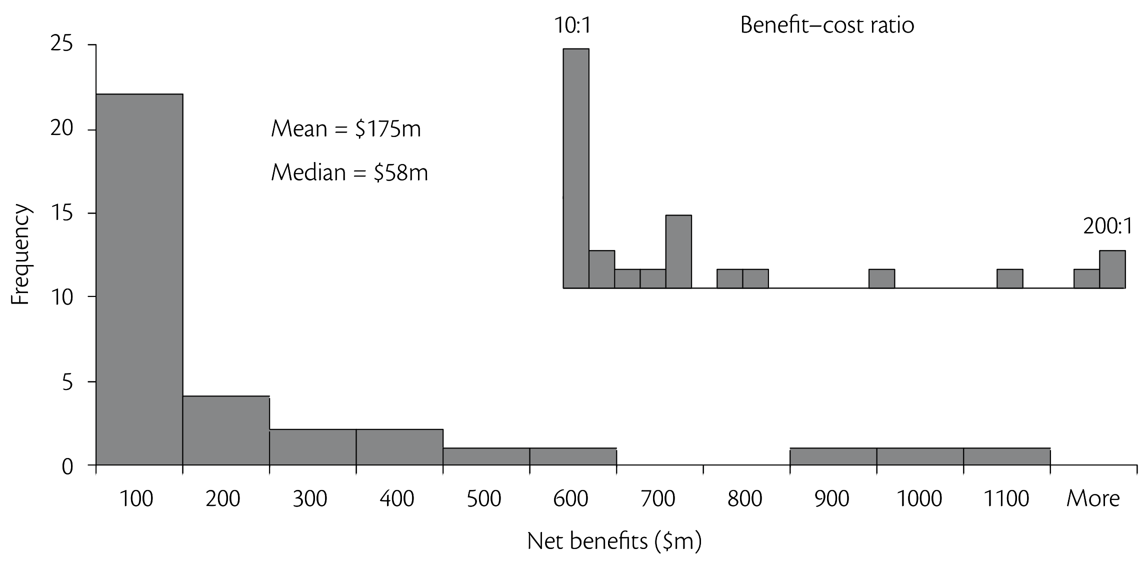


Figure 6. Frequency distribution of total net benefits. Data source: CIE estimates based on published impact assessments

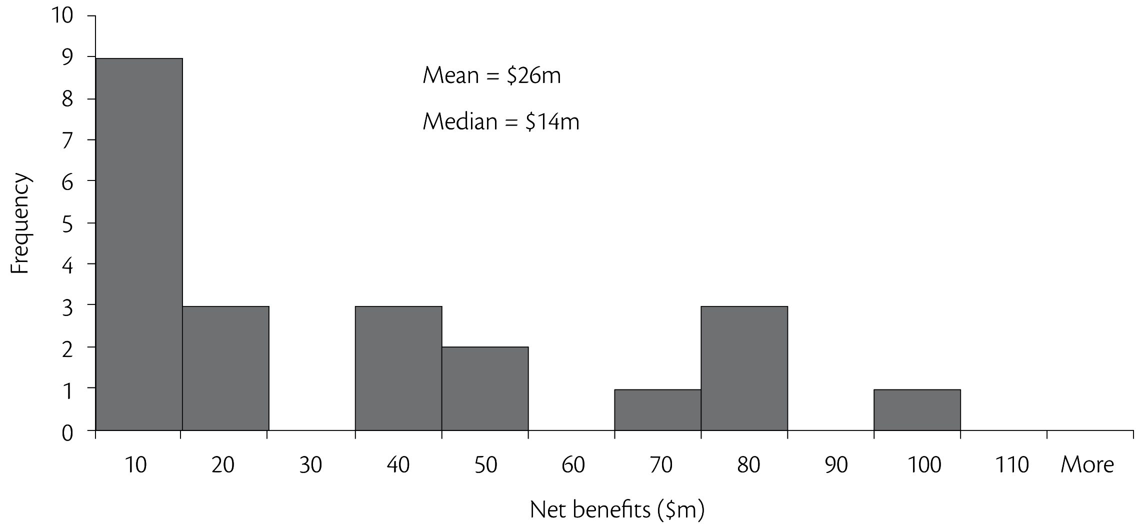


Figure 7. Frequency distribution of total net benefits for projects less than $100 million. Data source: CIE estimates based on published impact assessments

What explains net benefits?

Figures 8 and 9 test two possible explanations for the total net benefits found in the 35 evaluations. Figure 8 compares the project cost with the net benefits of the project. The figure clearly indicates that there is no correlation between total project spending and the net benefits of the project.

Figure 9 compares total net benefits with ACIAR's share in total funding. Again there is no correlation, suggesting that benefits are available regardless of whether or not ACIAR provides the majority of the funds.

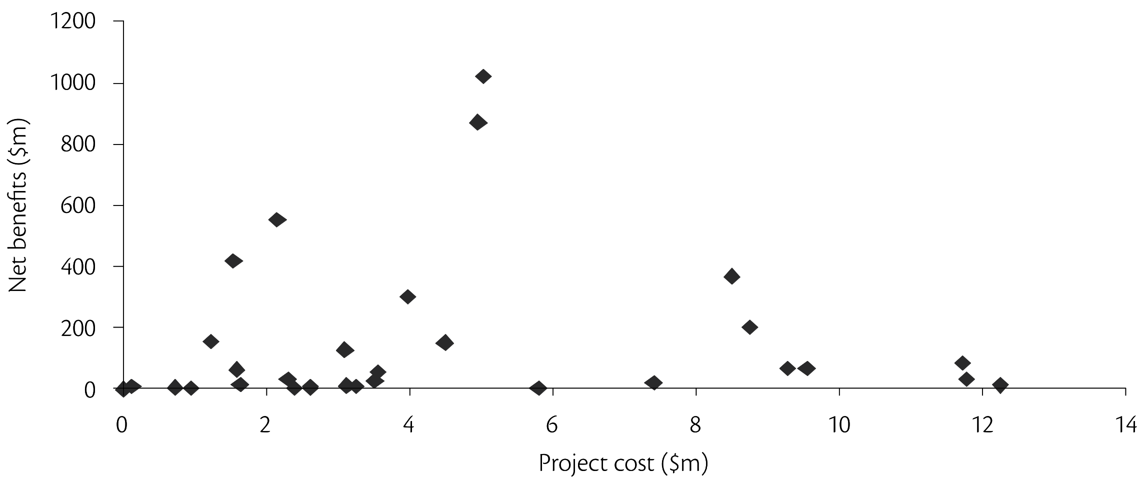


Figure 8. Relationship between total net benefits and project cost. Data source: CIE estimates based on published impact assessments

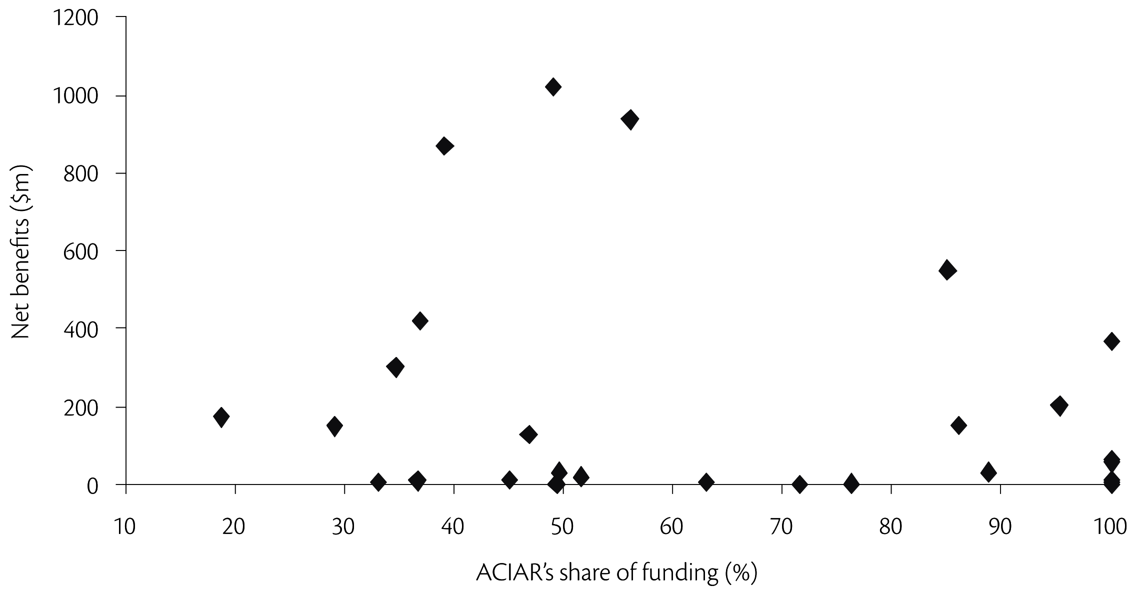


Figure 9. Relationship between total net benefits and ACIAR's share of funding. Data source: CIE estimates

Summary of the benefits to Australia

Table 2 summarises the impact assessments that have quantified estimates of benefits to Australia.

For the assessments with Australian benefits, the benefits to Australia range from 1% to 100% of the total assessed benefits, with an average of 24%.

The total benefits to Australia, in present-value terms, sum to $605 million. The total benefits of projects with benefits to Australia sum to $2.5 billion, while the total benefits of all projects come to $6.4 billion. The share of Australian benefits in total benefits to all projects is therefore 9.5%[4].

Figure 10 shows the frequency distribution of benefits to Australia. Again, the distribution is skewed, with the median being around one-fifth of the mean. This result is not surprising given the results noted above.

4 Raitzer and Lindner (2005) found that Australian benefits came to 14%. The difference is due to the way that they attributed benefits to ACIAR, based on the share of ACIAR funding in total project funding.

Australian benefits by type and by commodity

Figures 11 and 12 show the breakdown of the benefits to Australia by type and by commodity affected.

Almost half the benefits arise as a result of direct production effects, where the productivity of Australian agriculture is improved in some way. There are eight evaluations in this category, with an average benefit of $35 million per evaluation.

The next largest category is that of indirect disease protection, accounting for 42% of the benefits. The benefits in this category are entirely the result of a single project in one evaluation—biological control of banana skipper in Papua New Guinea—which has reduced the possibility of an incursion into Australia and therefore delivered significant benefits to the Australian banana industry.

The third-largest category is direct disease or pest protection, accounting for 8% of the benefits. These benefits come from four evaluations ranging from fish to animal (foot-and-mouth disease and tick-borne diseases) to grain pests and diseases. The average benefit per evaluation is $12 million.

Table 2. Summary of evaluations with quantified benefits to Australia

Project	Benefit to Australia ($m)	Benefit category	Commodity	Australian benefits as a percentage of the total
Assessments from current impact assessment series				
Raw wool production and marketing in China (IAS 4)	15.4	Increased trade	Wool	99
Fruit fly in Malaysia and Thailand (IAS 5)	9.3	Increased trade	Horticulture	99
Reducing fish loses due to epizootic ulcerative syndrome (IAS 7)	1.5	Direct disease protection	Fishing	1
Sulphur test KC1-40 and the growth of the Australian canola industry (IAS 9)	3.9	Direct production	Grains	98
Conservation tillage and controlled traffic (IAS 10)	2.2	Direct production	Grains	44
Postharvest R&D concerning tropical fruits (IAS 11)	101.8	Direct production	Horticulture	48
Biological control of banana skipper (IAS 12)	253.0	Indirect disease protection	Bananas	46
Breeding and quality analysis of rapeseed (IAS 13)	3.2	Direct production	Grains	5
Improved drying of high moisture grains (IAS 14)	16.1	Direct production	Grains	44
Management of FMD in South East Asia (IAS 21)	17.1	Direct disease protection	Meat	37
Diagnosis and control of blue tongue in small ruminants (IAS 23)	0.8	Increased trade	Meat	8
Shelf life extension of leafy vegetables (IAS 32)	1.7	Direct production	Horticulture	1
Conservation tillage in dryland cropping (IAS 33)	145.4	Direct production	Grains	14
Assessment from discontinued economic assessment series				
Tick borne disease control in cattle (EAS 5)	28.4	Direct disease protection	Meat	34
Integrated use of insecticides in grain storage (EAS 9)	2.8	Direct disease protection	Grains	4
Nutritional disorders of grain sorghum (EAS 10)	2.2	Direct production	Grains	9
Total	**604.8**			

Source: CIE estimates based on published impact assessments

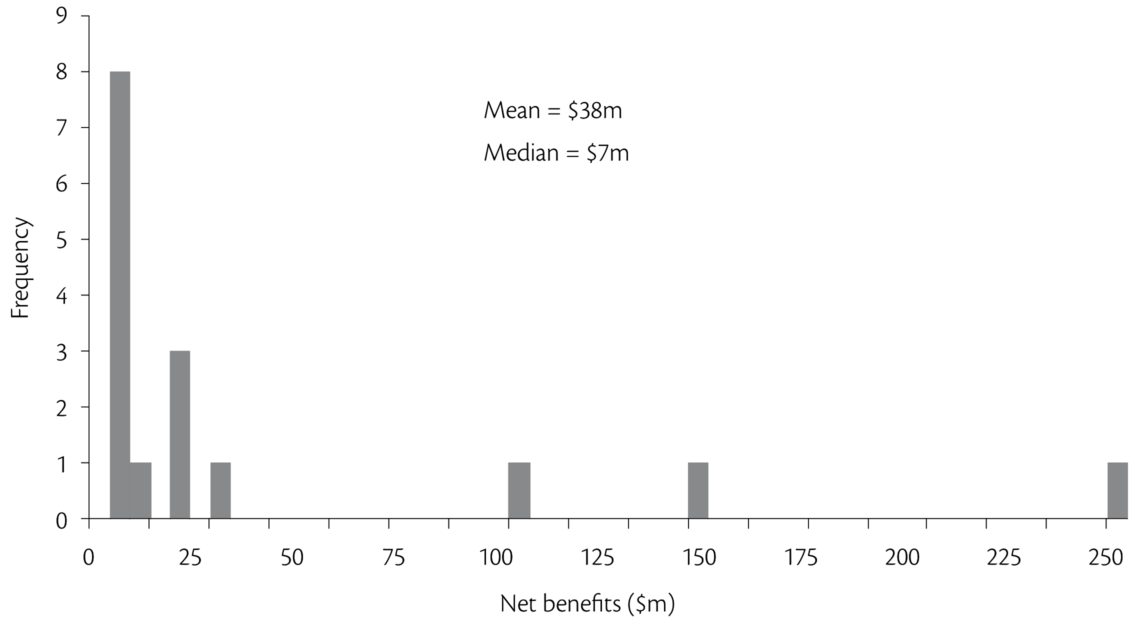


Figure 10. Distribution of benefits to Australia. Data source: CIE estimates

Increased trade is the fourth-largest category and arises from three evaluations with an average benefit of $9 million per evaluation.

In terms of commodities, the largest share of benefits and the largest single benefit accrues to bananas, again a result of the project on the biological control of banana skipper.

The next biggest category is grains, receiving 29% of the benefits. There are seven evaluations in this category, with average benefits of $25 million per evaluation.

Horticulture accounts for 19% of the total benefits, but has the highest benefit per evaluation ($38 million), with three projects covered.

Meat-related evaluations (of which there are three covered here) account for 8% of the total benefits, with an average benefit of $15 million per evaluation. Wool accounts for 2% of the total benefits and it too has an average benefit of $15 million per evaluation, all of which is accounted for by a trade benefit accruing from one project in one evaluation.

Finally, around 0.2% of the total benefits accrue to fishing, coming from a single project evaluation with a benefit of $1 million.

It is important to remember that the data for this comparison come from a very small sample (16 observations), so these breakdowns should be treated with a great deal of caution. Figure 12 also illustrates the range of values for each of the categories. In a number of cases this range is large, so the average provides a misleading indication of any central tendency in the data.

Correlation between Australian and partner country benefits

Potentially, the dollar value of benefits to Australia will depend on a number of factors, including the total available pool of benefits, the share of ACIAR funding in the total project, the commodity coverage of the project and the type of benefits generated.

Figure 13 shows the relationship between benefits to Australia and benefits to the partner country for the 16 evaluations that estimated a benefit to Australia. We have used benefits to the partner country, rather than total benefits, as Australian benefits and total benefits are related by definition because the former is a subset of the later.

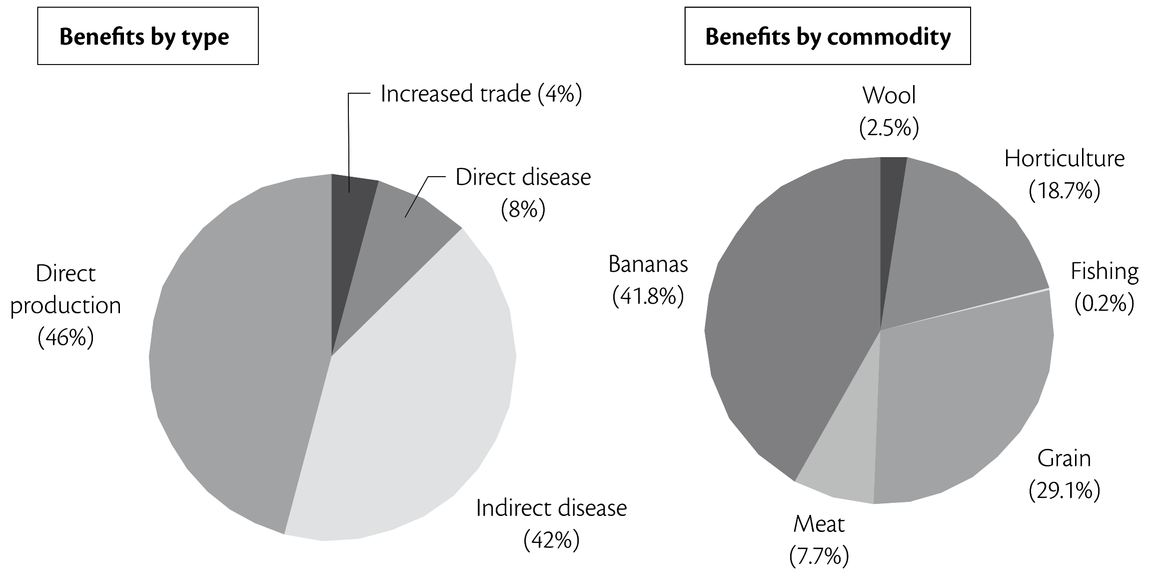


Figure 11. How the benefits to Australia arise: share of benefits by type and commodity. Data source: CIE estimates derived from published impact assessments

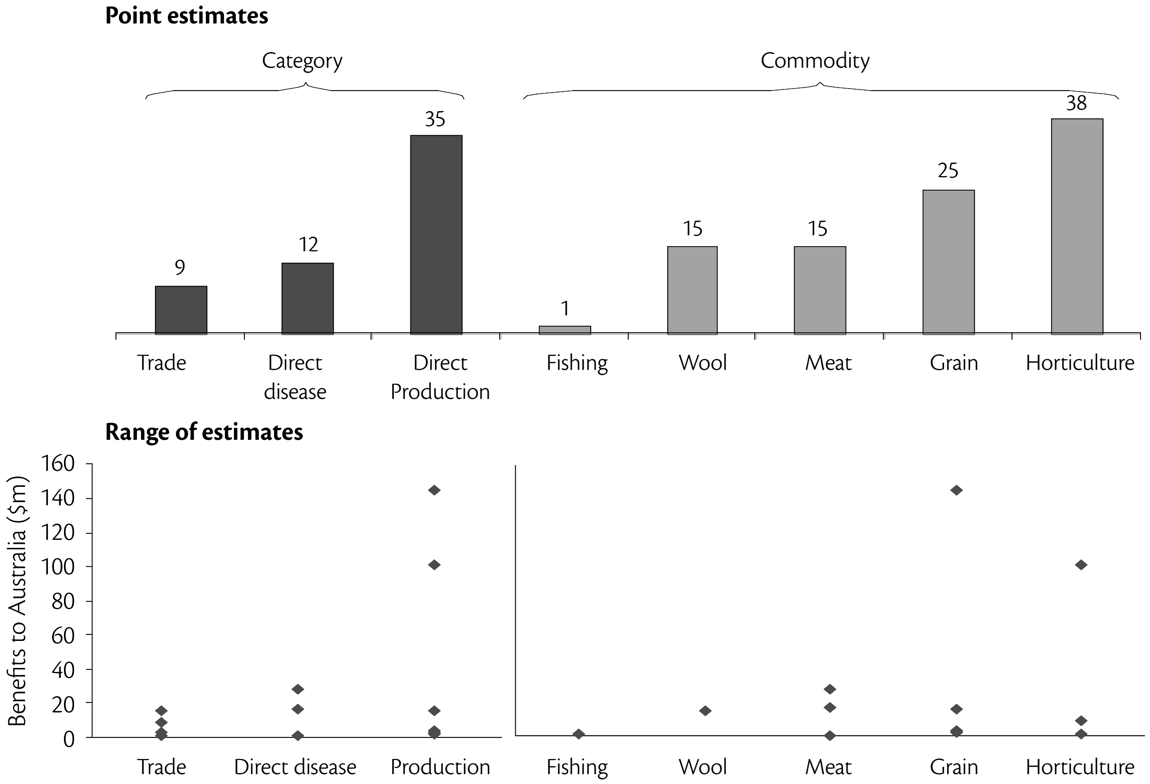


Figure 12. Average Australian benefit ($ million) per evaluation: category and commodity exclude benefits of banana skipper project. The benefits of the single banana skipper project, contributing to indirect disease protection and the banana industry, were $253 million. Data source: CIE estimates derived from published impact assessments

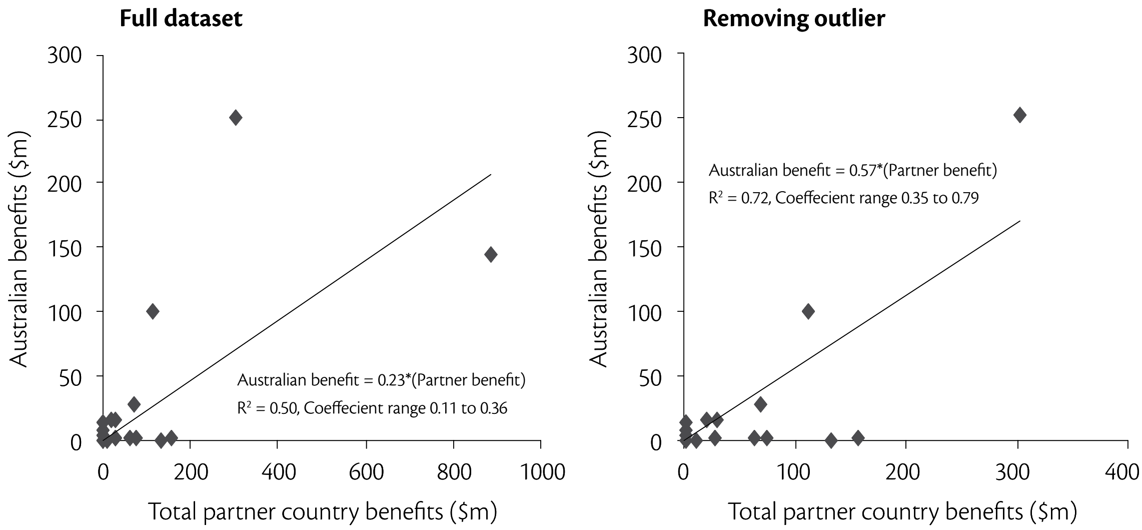


Figure 13. Correlation between benefits to Australia and partner country benefits. Data source: CIE estimates based on published impact assessments

Figure 13 indicates that there is a linear relationship between partner country benefits and Australian benefits. The left-hand graph shows the relationship using all the data points, while the right shows the relationship after removing a single 'outlier', a project in China which yielded very large partner country benefits.

Using the full dataset, the results suggest that, for every $1 of partner country benefits, benefits to Australia are $0.23 (with a range from $0.11 to $0.36[5]). With the outlier excluded, for every $1 of partner country benefits, benefits to Australia are $0.57 (with a range from $0.35 to $0.79[6]).

Note that this relationship is a correlation derived from those projects in which benefits to Australia were calculated. The relationship is not necessarily causal and cannot be applied to the full set of impact assessments.

It might be expected that a range of other factors would influence the relationship between partner country benefits and Australian benefits. However, testing a number of factors including commodity and type of benefit did not improve the basic fit of the relationship in Figure 13.

5 This is the 95% confidence interval. The standard error for the estimate is 0.06, which implies a *t*-statistic of 4.10.

6 This is the 95% confidence interval. The standard error for the estimate is 0.10, which implies a *t*-statistic of 5.53.

It might also be expected that as ACIAR's share of total funding changes, or as the share of other funds, including from other Australian sources, increases, the benefits to Australia would increase. However, funding to complement ACIAR's comes from a variety of sources, not only other Australian funding, and so this effect is not evident in the data.

Australia's share in total benefits by type and commodity

Figure 14 shows Australia's share of total project benefits for different benefit types and commodities. It also shows the individual points underlying these shares, indicating, as before, considerable variation.

The largest Australian share is for increased trade benefits, which is not surprising as the main project in this category had this benefit as its object. The next largest share is for disease protection (both direct and indirect, as this share includes the banana skipper project), at around one-third. The smallest share is for production benefits.

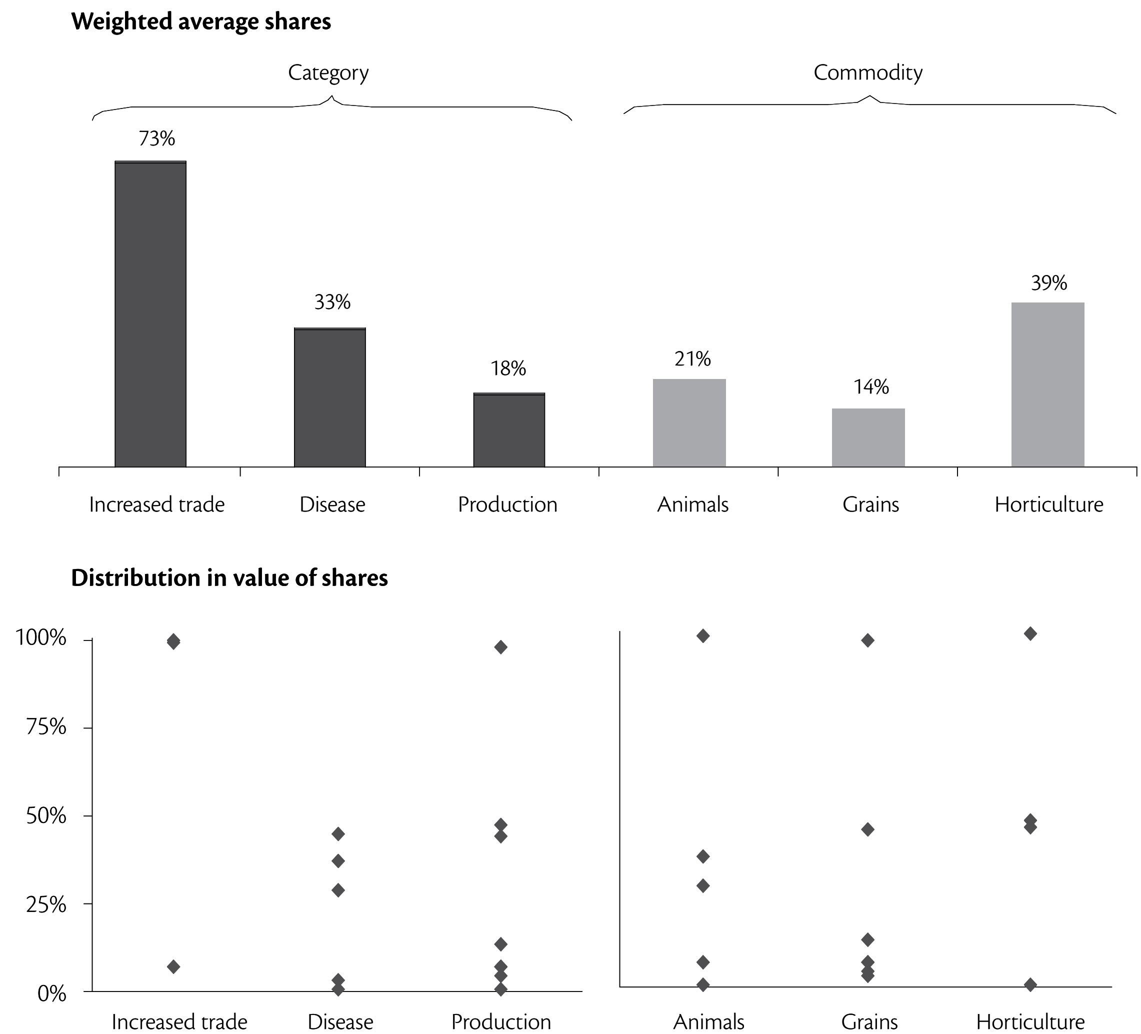


Figure 14. Australian share in total project benefits, by type of benefit and commodity.
Data source: CIE estimates based on published impact evaluations

In terms of commodities, the largest average share was for horticulture, but there is extremely large variance around this average. The next largest share was for animals, followed by grains.

Explaining Australia's share of total benefits

It would be expected that Australia's share of the total pool of benefits would depend on a number of factors.

Figure 15 plots Australia's share of benefits against the total benefits for the project. It shows that there is no systematic correlation between Australia's share and the total magnitude of benefits. Testing for the effect of a range of other factors (including commodity and type of benefit) did not improve the extent of this correlation. This is not surprising, given that Australian and partner country benefits tend to move together.

Figure 16 compares Australia's share of the total project benefits with ACIAR's share of funding in the various projects. There is a positive correlation here—for every 1% increase in ACIAR's share of funding, Australia's share of total benefits increases by 0.48%. This coefficient ranges from 0.26 to 0.70[7].

7 This is the 95% confidence interval. The standard error of the estimate is 0.10, implying a *t*-statistic of 4.62.

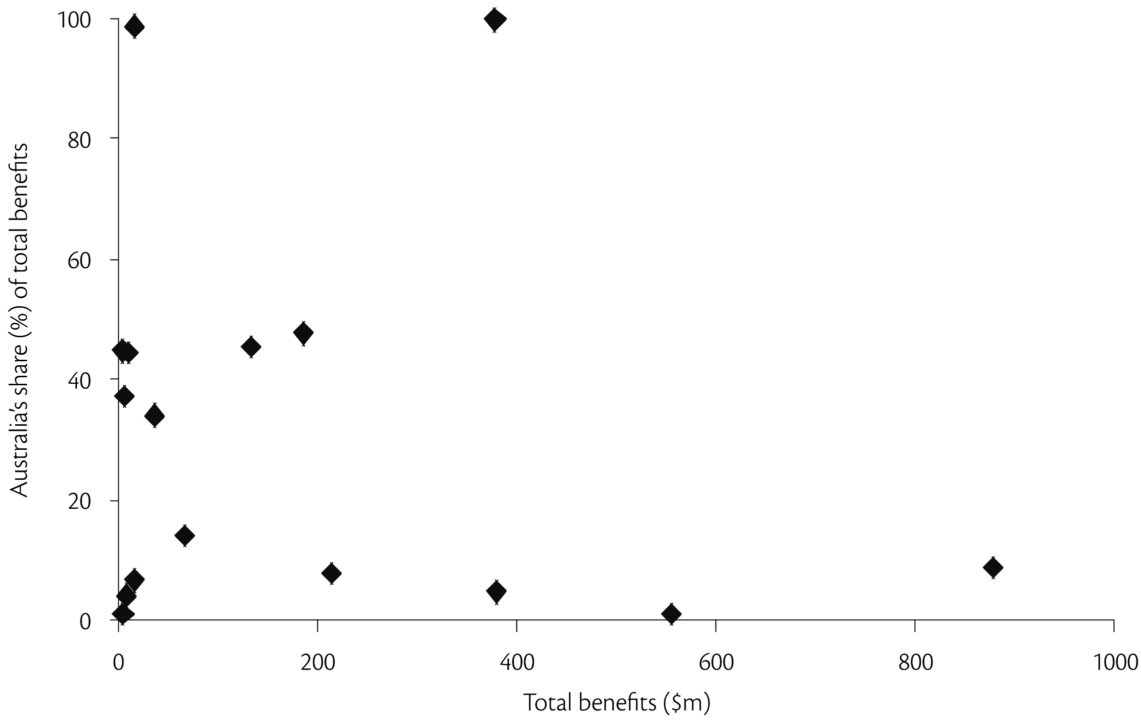


Figure 15. Australia's share of benefits and total project benefits. Data source: CIE estimates based on published impact assessments

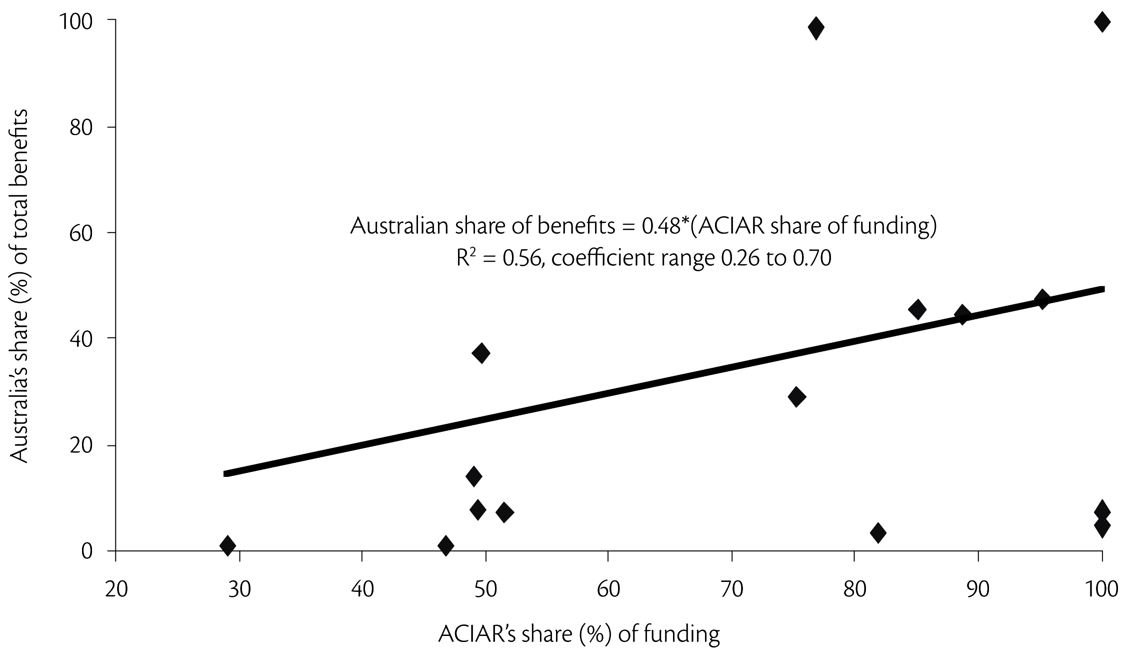


Figure 16. Relationship between Australia's share of benefits and ACIAR's share of funding. Data source: CIE estimates based on published impact assessments

How do the various distributions compare?

Figure 17 shows the cumulative frequency distribution for four different benefit types:

- benefits to Australia (this is the cumulative version of Figure 10)
- benefits to the rest of the world
- total gross benefits
- total net benefits (this is the cumulative version of Figure 7).

Because these benefits are all of different magnitudes, each distribution has been normalised in the figure so that they can be compared. We have used the cumulative frequency distribution for this comparison, as visually this is the best way of illustrating differences between distributions.

Figure 17 shows that while total net benefits, total gross benefits and benefits to the rest of the world are distributed very similarly, the benefits to Australia are slightly more skewed to the left than these other benefit measures. This implies that the chance of extremely high benefits to Australia is lower than is the case either in total or to the rest of the world.

Comparison of projects with and without Australian benefits

Figures 18 and 19 present the frequency distributions of total net benefits after having divided the sample into two categories: projects *with* benefits to Australia and projects *without* benefits to Australia. That is, the comparison here looks at total (to all countries) net (after excluding research costs) benefits, but distinguishes between two types of project: a project *with* benefits to Australia in the total benefits versus a project *without* any benefits to Australia in the total benefits.

Figure 18 presents results for the full range of benefits, and Figure 19 focuses on projects with benefits of less than $100 million.

Figure 18 shows that projects with Australian benefits have lower average net benefits than projects without Australian benefits, and slightly lower median benefits.

Figure 19 illustrates that this effect is reversed somewhat for projects with total net benefits of less than $100 million. In this case, the average net benefits to projects with Australian benefits are greater than the average net benefits of projects without Australian benefits.

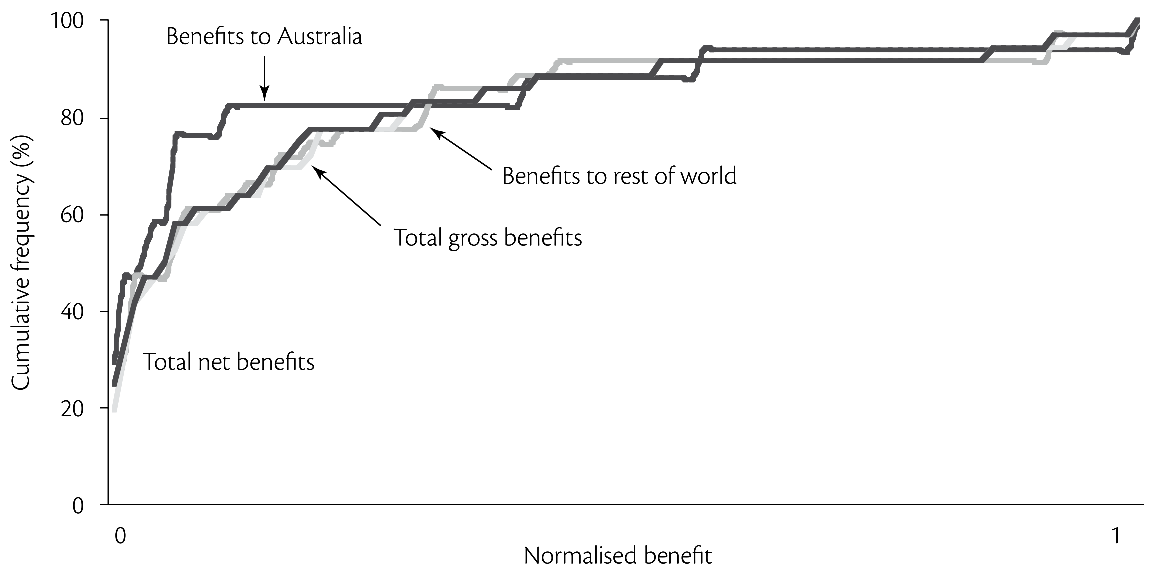


Figure 17. Cumulative frequency distributions of various benefit flows. Data source: CIE estimates

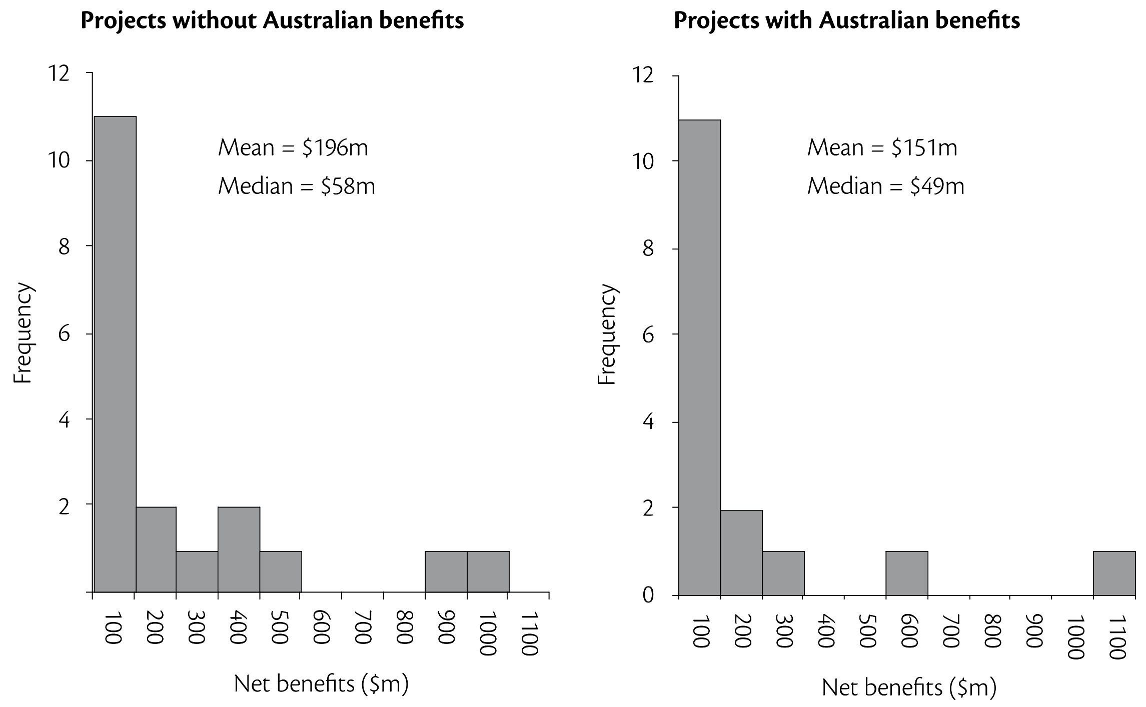


Figure 18. Distribution of total net benefits for projects with and without Australian benefits. Data source: CIE estimates

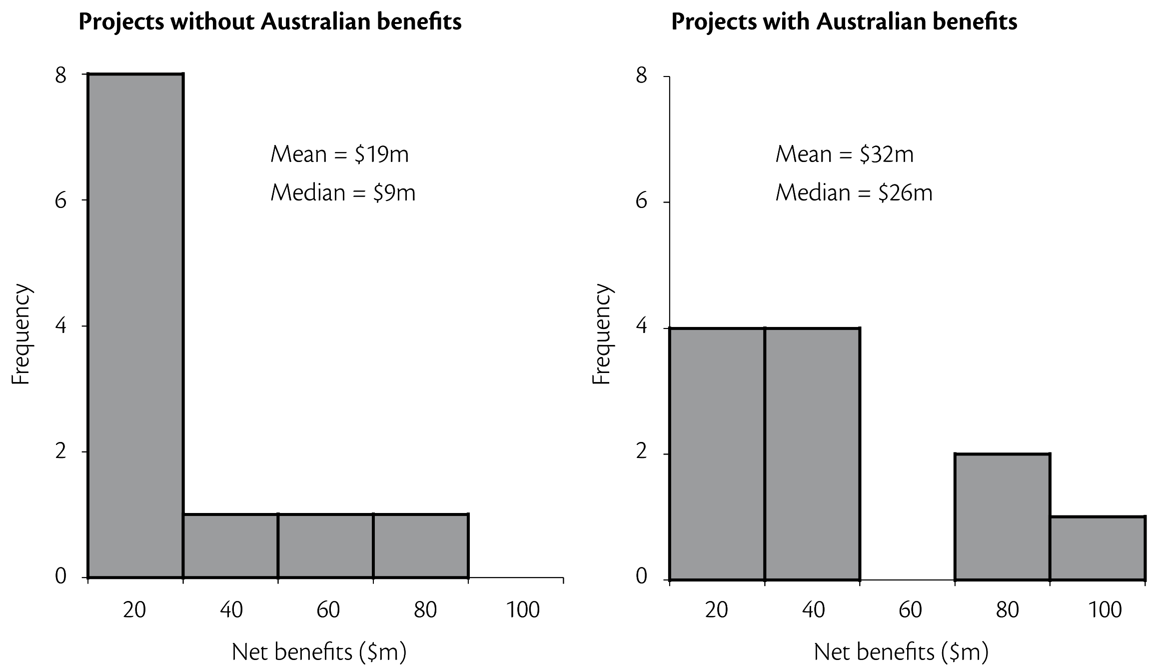


Figure 19. Distribution of total net benefits for projects with and without Australian benefits, for projects with benefits less that $100 million. Data source: CIE estimates

Figure 20 presents the cumulative frequency distribution for the two types of projects. This is based on the same data as Figures 18 and 19 and shows the very slight difference in the shape of the distributions.

How significant are these differences?

The difference between the mean values is relatively small, and given that these results come from a small sample, it is important to test whether the difference is statistically significant.

Using conventional formulae:

- the standard error for the mean benefit of projects *with* Australian benefits is $67.4 million, which implies a 95% confidence interval from $7.6 million to $294.9 million
- for projects without Australian benefits, the standard error for the mean is $65.4 million, which implies a 95% confidence interval from $58.4 million to $333.1 million
- as these confidence intervals overlap considerably, we cannot conclude that the mean values are significantly different.

We also tested the significance of the difference in the mean using a bootstrap procedure (see footnote 2).

- While the average difference in net benefits (projects without Australian benefits less projects with Australian benefits) is $45 million, the 95% confidence interval of this difference ranges from –$137 million to $220 million.
- As this confidence interval includes zero, we conclude that the difference between the means is not significantly different from zero. Indeed, the bootstrap data indicate that there is a 30% chance that benefits for projects with Australian benefits are greater than benefits for projects without Australian benefits.
- We also find that there is no significant difference between the medians of the two sets of estimates.

Implications

That there is no significant difference in total net benefits for projects with and without Australian benefits indicates that there is no trade-off between delivering benefits to Australia and the total net benefits of a project.

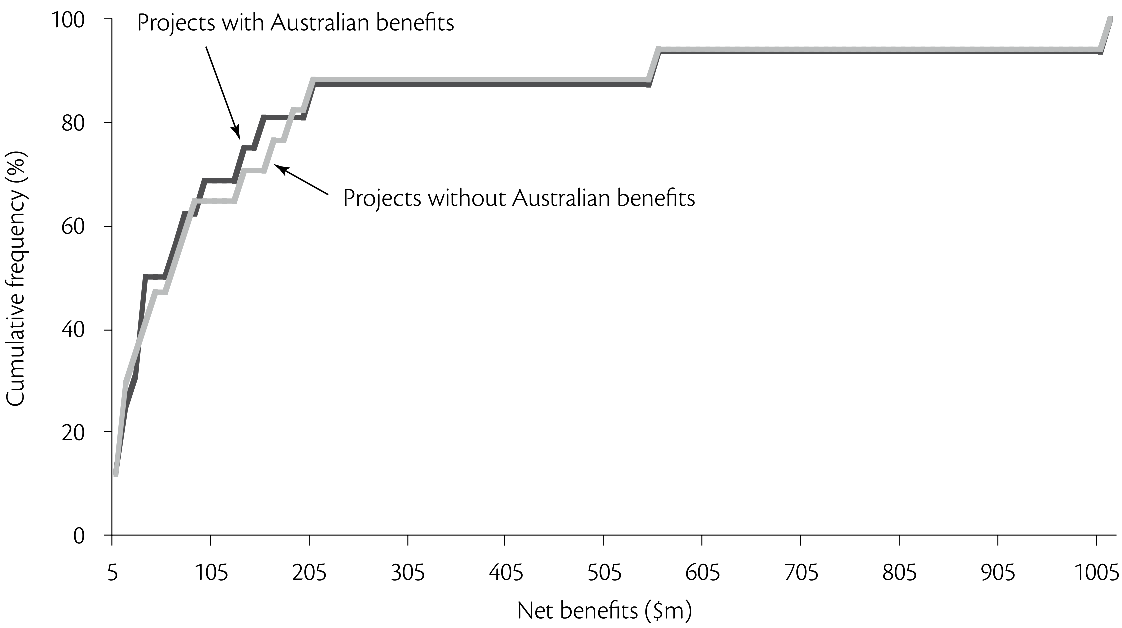


Figure 20. Cumulative frequency distributions of projects with and without Australian benefits.
Data source: CIE estimates based on published impact assessments

Multilateral linkages

In addition to the bilateral projects summarised in the range of existing impact assessments, three additional studies have looked at the impact on Australia of research undertaken in three international agencies. These are:

- International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), analysed in Brennan and Bantilan (1999)
- International Centre for Agricultural Research in the Dry Areas (ICARDA), analysed in Brennan et al. (2002)
- International Maize and Wheat Improvement Centre (CIMMYT), analysed in Brennan and Quade (2004).

The benefits estimated in these studies are different from those from the bilateral funding, as ACIAR is only one international contributor to the multilateral organisations, and is only one of a range of Australian organisations that deals with the multilateral agencies.

Nevertheless, it is important to understand how the research of these agencies affects Australian agriculture. Table 3 summarises the estimated average annual benefits from research by each of the international agencies.

Table 3. Benefits to Australia of research by international agencies

International agency	Commodity	Average annual benefit ($ million (2004))
ICRISAT	Sorghum	2.0
	Chickpeas	0.7
ICARDA	Barley	3.0
	Durum	−1.1
	Chickpeas	1.5
	Faba beans	7.6
	Lentils	6.1
CIMMYT	Wheat	33.4
Total		53.2

Source: CIE estimates based on Brennan and Bantilan (1999), Brennan et al. (2002) and Brennan and Quade (2004)

4 Evidence from new case studies

The projects

As part of the analysis for this project, we undertook five additional case studies. Four of these were not hand-picked, but rather randomly selected within particular stratified criteria.

Selecting the projects

The procedure for selecting the case studies was as follows.

First, we examined the 100-word summaries of all completed ACIAR projects and used this information to answer the question: if this project were to have benefits to Australia, which category would they fall into?

Such an exercise is broadbrush and subject to many limitations. Most importantly, the 100-word summaries in the ACIAR database are summaries taken from the *project proposal*, so at best they reflect the *intent* and not the *outcomes* of the project. Nevertheless, this exercise provides some indication of the likely distribution of benefits to Australia from ACIAR-funded research.

Next, we compared the distribution of potential benefits from the 100-word summaries with the distribution of benefits from completed impact assessment studies. This comparison is presented in Figure 21. This gives a sense as to whether the completed assessments were in some sense representative of the total population of benefits. Apparent shortfalls in the coverage of particular benefit categories formed the basis for the selection of four projects for more detailed impact analysis.

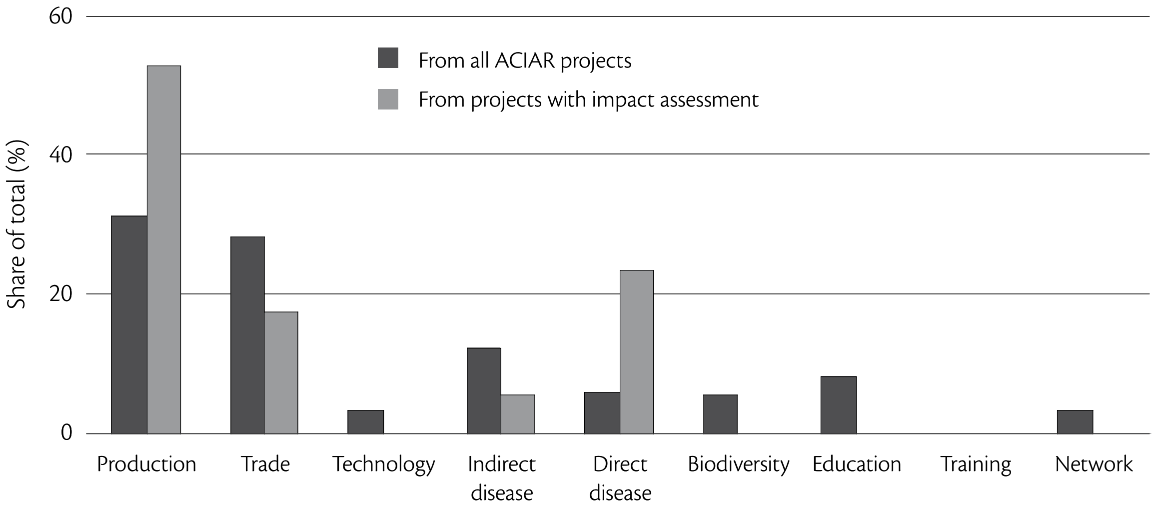


Figure 21. Shares of projects by category: all projects and projects with an impact assessment.
Data source: CIE estimates

Figure 21 indicates that we needed to select projects in the categories of:

- trade
- technology
- indirect disease
- biodiversity.

In addition, we specified that:

- the projects should have been completed before 2000
- the projects should have had a substantial budget (at least $1 million in present-value terms).

Through this method, the projects for case studies emerged. It is very important to note that these projects were not hand-picked. That is, in contrast to common practice in selecting projects for impact assessment, these projects were not chosen because there was already some indication of positive benefits. Rather, these projects emerged as a result of a particular selection procedure.

During the course of our research, it became clear that an additional project (or group of projects) relating to ACIAR-funded research on mite pests of bees would help illustrate some of the points emerging from the analysis, and so a fifth project group to form a case study was hand-picked for examination.

The projects selected

The projects selected for the case studies are summarised in Table 4. Table 5 presents a more detailed description of the projects, using the actual 100-word summaries from the ACIAR documentation. Table 4 also summarises the bee mite studies that were chosen as additional case studies.

Table 4. Projects selected for case studies

Project	Category	Completion date	Approximate present value of total budget ($m)
Projects selected according to stratified categories			
FST/1993/016: Tree growing on salt-affected soils in Pakistan, Thailand and Australia	Biodiversity and production	Mid 1997	2
PHT/1990/051: Development of heat systems for quarantine disinfestation in tropical fruit	Trade and direct disease control	Mid 1995	4
CS1/1990/012: Flowering behaviour and subsequent productivity of mangoes	Trade and production	Mid 1999	4
CS1/1994/968: Overcoming production constraints to sorghum in rainfed environments in India and Australia	Trade and production	End 2000	3
Bee mite projects subsequently selected			
AS2/1990/028: Improved methods in the epidemiology and control of mites and other disease of bees in Papua New Guinea	Direct disease/pest control	Mid 1994	0.5
AS2/1994/017: Control of bee mites in Irian Jaya	Direct disease/pest control	Mid 1999	0.4
AS2/1994/018: Improved methods for bee development and control of bee mites in Papua New Guinea	Direct disease/pest control	Mid 1999	0.5
AS2/1999/060: Control of bees and bee mites in Indonesia and the Philippines	Direct disease/pest control	Mid 1996	0.6

Source: CIE

Summary of outcomes of case studies

For three of the five case studies, we were able to quantify benefits of the research (Table 6). One of these (heat treatment of tropical fruit) could be considered as substantially demonstrated benefits, while the other two (sorghum productivity and mite pests of bees) should be considered as potential benefits.

The total benefits to Australia from these case studies ($143 million), increase the estimate of total quantified benefits to Australia from $605 million (Table 2) to $748 million. The average benefits per project remain the same at around $21 million per project with quantified benefits.

Table 5. Description of randomly selected projects

Project	One hundred word summary
FST/1993/016: Tree growing on salt-affected soils in Pakistan, Thailand and Australia	Soil salinity, sodicity (excess sodium), waterlogging and combinations of these have led to serious declines in crop productivity and the creation of unproductive wastelands in Pakistan, Thailand and other Asian countries, as well as in Australia. An earlier ACIAR project (No. 8633) evaluated a wide range of tree and shrub species suited to these sites. This project will continue the research through three subprojects. Subproject 1 aims to improve the productivity on salt-affected land of trees and shrubs that performed well in earlier trials and to overcome environmental constraints to growth. Subproject 2 will study water use of key species on salt-affected land, and Subproject 3 will develop a database that records performance of a range of trees and shrubs on salt-affected land and predicts their site suitability and growth potential.
PHT/1990/051: Development of heat systems for quarantine disinfestation in tropical fruit	Fruit fly infestations are a serious technical barrier to international trade in staple fruits and vegetables, and the need for acceptable quarantine disinfestation measures is rated highly by countries in which fruit fly occurs. Heat treatment is a viable method for many fruits and has the additional benefit of being residue-free. This project seeks to expand the use of several different heat treatments across a wide range of commodities and establish protocols for disinfestation procedures that can be applied to many fruits and vegetables. This will eventually open up new export markets for Southeast Asian countries and Australia.
CS1/1990/012: Flowering behaviour and subsequent productivity of mangoes	Both Australia and Thailand have extensive mango industries, but changeable seasons cause fruit yields to fluctuate up to 150% from year to year. Consistent levels of flowering and fruit-set are paramount to sustaining high and reliable yields, and this project will investigate how environmental factors such as water supply and temperature affect the initiation of flowering. Next researchers will study how cold temperatures affect the fruit development steps of pollination, ovule fertilisation and embryo development in Australian and Thai cultivars. These studies will identify cultivars more suited to specific growing regions. Ultimately the knowledge gained will lead to practices that substantially improve mango production.
CS1/1994/968: Overcoming production constraints to sorghum in rainfed environments in India and Australia	In parts of Australia and India sorghum productivity has not increased over the past 20 years, largely because water and nitrogen are in short supply and insect damage high. This project will seek to overcome these constraints by deploying an integrated approach comprising genetic engineering, plant breeding and crop modelling. The scientists will use genetic transformation techniques to develop varieties resistant to sorghum shoot fly. They will improve plant breeding and selection methods to develop sorghum types better suited to the rabi (post-rainy) crop in India and the summer dryland crop in Australia. Also, a model developed by incorporating data from climate x water x nitrogen interactions will be used to construct and test for the best crop management combinations under the Indian and Australian conditions.

Source: ACIAR project documents

Table 6. Summary of benefits from case studies

Project	Nature of benefits	Quantified benefits ($m present value)
FST/1993/016: Tree growing on salt-affected soils in Pakistan, Thailand and Australia	Potential, not quantifiable	Not quantified
PHT/1990/051: Development of heat systems for quarantine disinfestation in tropical fruit	Demonstrated, quantifiable	23
CS1/1990/012: Flowering behaviour and subsequent productivity of mangoes	Potential, not quantifiable	Not quantified
CS1/1994/968: Overcoming production constraints to sorghum in rainfed environments in India and Australia	Potential, quantifiable	36
Bee mite projects (4 projects)	Potential, quantifiable	84

Source: CIE estimates

Lessons from the case studies

The full details of the case studies, which will also be published as full impact assessments once the analysis of benefits to partner countries is completed, are presented in Appendixes A–E.

Tree growing on salt-affected soils

Salt is a major problem in Australian agriculture. This project, which is in fact one of a large number of ACIAR-funded projects concerned with related problems, looked at one aspect of the problem. It considered which tree and shrub species would best be able to withstand salinity, and therefore would be appropriate for use in agriculture—particularly as an additional crop that would make use of otherwise unproductive land.

This project is an example of ACIAR-funded research contributing to a fundamental knowledge base in an area of broad concern both within Australia and within the partner countries for the project (Thailand and Pakistan). Despite considerable progress during the course of the project, the new knowledge has not been finalised and is not as yet embodied in a single package suitable for Australian farmers to adopt if it were to prove profitable. In this case, we were unable to quantify the benefits of this project to Australia.

Heat systems for quarantine disinfestation

This project provides an illustration of one of the ways in which ACIAR's research can lead to increase trade—in this case exports—in Australian products.

The major outcome of this project, which was jointly funded with the Queensland Department of Primary Industries, was a fruit (applied to mangoes) treatment system that satisfied the requirements of a particular destination country (Japan) but without destroying the quality characteristics of the fruit. This meant it remained possible to achieve a premium price in the Japanese market, effectively leading to a terms-of-trade improvement for Australian exporters.

The available evidence suggests that this has led to an increase in export returns to the Australian industry. While this is offset to some extent by Australian consumer losses, there is still a net gain.

Flowering behaviour and productivity of mangoes

This project involved ground-breaking research into the phenology of mango trees before flowering, and is generally considered to have led to genuine increases understanding of aspects of mango flowering behaviour.

At this stage, however, there is no evidence of this knowledge changing the behaviour of growers and so we have been unable to quantify the benefits of the research. It is expected, however, that as the mango industry continues to develop, and as other strategies for productivity increases have been adopted, the information will be of value at some point in the future.

Overcoming production constraints to sorghum

This project involved the identification of a sorghum variety that is ultimately expected to lead to an increase in yields. In some ways, this project is an example of a very typical area of agricultural research, as breeding of various kinds has been an extremely important component of productivity improvement in Australian agriculture.

In terms of better understanding the ways in which ACIAR-funded research generates benefits to Australia, this project illustrates one way in which ACIAR-funded research can:

- contribute to shortening the time needed to develop a new variety
- lead to an increase in the probability of success of the development process.

Mite pests of honeybees

This set of projects provides a very clear example of how research in one area (entomology) can have a significant influence in other areas—in this case quarantine management and the horticultural industry. It also provides a clear indication of how knowledge, by allowing for better management decisions, can generate significant economic benefits.

Mite pests of honeybees—which are endemic in some parts of the world and have recently become established in New Zealand—have the potential to wipe out wild populations of honeybees in Australia, significantly increasing the cost of pollination within horticultural industries. This is effectively a productivity loss to horticultural industries, leading to a loss of producer welfare.

The research in this set of projects has allowed more precise identification of which mites cause problems for honeybees. It turns out that not all mites that could enter Australia are of concern, and that there is a considerably lower probability than originally expected of the dangerous mite entering the country. This has allowed the better focusing of quarantine efforts, which has had the effect of reducing the probability of an incursion.

Updated benefits by commodity and type

The new case studies provide three additional data points that can be used to update some of the information presented in chapter 3. Figure 22 presents updated estimates of the share of total benefits by type and by commodity. Compared with the estimates presented previously in Figure 11, the increased trade share has increased from 4 to 9% (as a result of the heat treatment project) and the direct disease share has increased from 8 to 18% (as a result of the bee mite projects).

Figure 23 presents the revised estimates of the average Australian benefit per evaluation, and compares these with the original estimates (presented in Figure 12). The estimates for each of trade, disease and production have increased, as have the estimates for grain and horticulture.

The change in shares by category and product, as well as the average benefit per evaluation, reflects the fact that the estimates are based on a relatively small number of impact evaluations. The addition of further data is likely to continue to change the value of these estimates.

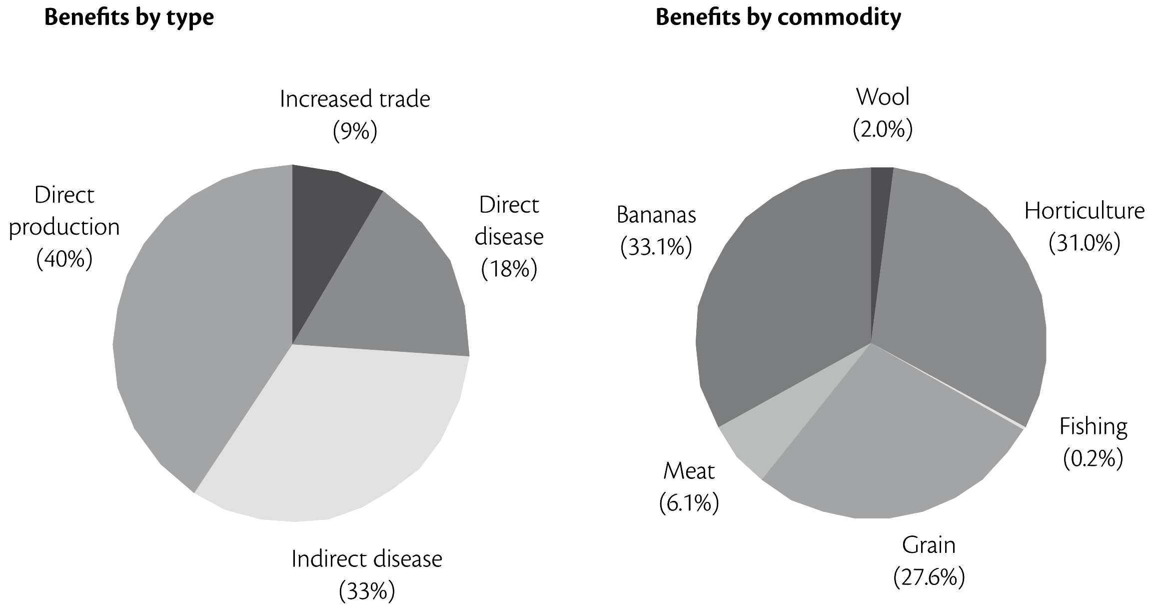


Figure 22. Share of benefits by type and commodity, updated from Figure 11 to include case studies.
Data source: CIE estimates

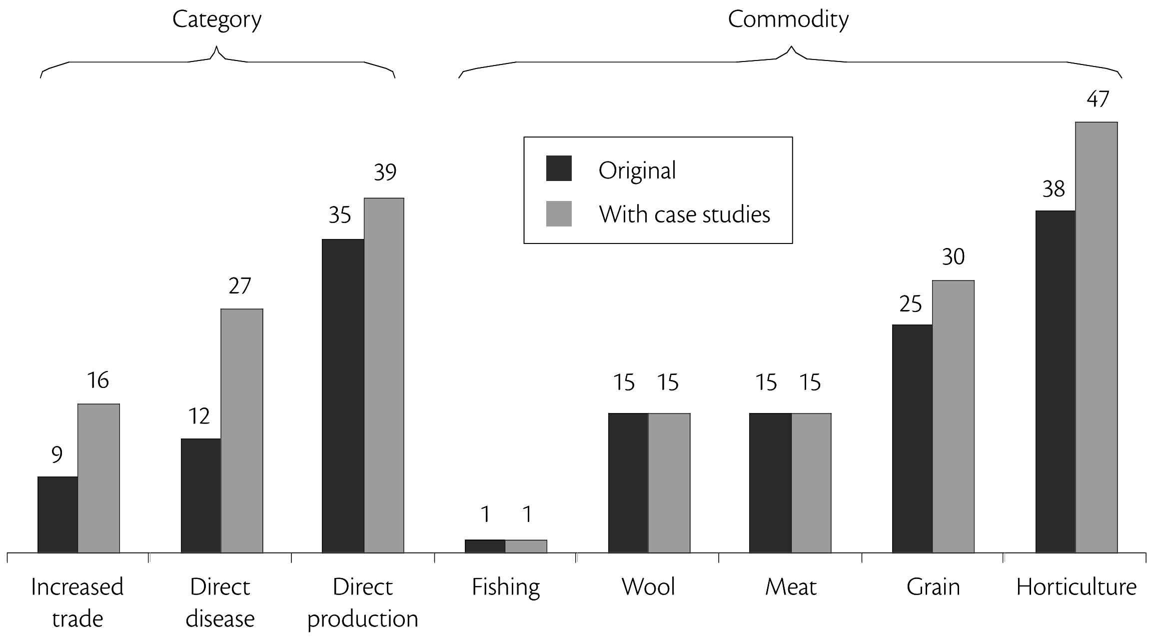


Figure 23. Average Australian benefit ($ million) per evaluation, updated from Figure 12 to include case studies.
Data source: CIE estimates

5 Conclusions

The analysis of both past impact assessments and five new case studies clearly indicates that ACIAR-funded research generated benefits to Australian agriculture, and to Australia more broadly, in a number of ways.

How do benefits to Australia come about?

ACIAR contributes to general national objectives through its contribution to Australia's international aid program. The available evidence suggests that funding R&D forms a very effective means of delivering aid to developing-country partners. The main evidence for this comes from a number of impact assessments undertaken by ACIAR over the past 15 years or so.

The quantified benefits to Australian agriculture resulting from ACIAR-funded research arise through a number of mechanisms including:

- direct production enhancements
- trade benefits
- protection from diseases and pest incursion—either within Australia, or before the pest or disease ever comes to Australia.

More qualitative benefits arise through the fact that ACIAR research:

- increases the stock of knowledge that other research is able to build on
- can increase the probability of success of ongoing agricultural research
- allows for more interactions within the Australian agricultural R&D community and provides a greater base against which to test R&D ideas
- maintains researcher interest in areas that might otherwise not attract research funding.

What is the order of magnitude of the benefits?

The total estimated benefits to Australia from ACIAR-funded R&D come to $750 million (in present-value terms). This sum is comprised of:

- $605 million in benefits from 16 already published impact assessments ($38 million per assessment), covering 29 projects ($21 million per project)
- $143 million from three case studies undertaken for this report ($48 million per case study), covering six projects ($24 million per project).

The total number of projects with quantified benefits to Australia covered by these estimates (35 projects) is very small relative to the total potential number of projects with benefits to Australia. This total number is at least 450 projects if we consider that around half of all ACIAR-funded projects are likely to have quantifiable benefits to Australia.

Even if the estimates summarised here a significantly biased upwards, it is likely that more benefits to Australia will be discovered as more impact evaluations are undertaken.

Are there systematic factors that determine the magnitude of benefits to Australia?

The benefits to Australia do vary by commodity and by type of benefit, although within each commodity and type there is considerable variation, so it is difficult to be sure whether these differences are significant, or whether they are simply a result of the small sample.

Within the projects that have quantified benefits to Australia, there is a close positive correlation between benefits to Australia and benefits to developing-country partners. Depending on the specification used, we estimate that for every $1 million of partner country benefits, there are between $0.11 million and $0.79 million of Australian benefits.

Australia's share of total benefits found within a particular assessment is positively correlated with ACIAR's share of funding for projects within that assessment. We estimate that for every 1% increase in ACIAR's share of funding, there is a 0.26–0.70% increase in Australia's share of total benefits.

Is there any evidence of a trade-off between Australian benefits and partner country benefits?

As noted above, Australian benefits tend to increase along with partner country benefits, so there is no direct evidence of a trade-off between benefits to Australia and benefits to partner countries. It is important to note, however, that the impact assessments that considered benefits to Australia did not as a rule account for potential trade losses as a result of increased productivity from competing suppliers. It is possible that there is a trade-off, but that it has not been detected in the impact assessments undertaken to date.

Another important trade-off is the extent to which total benefits are reduced as a result of attempting to also deliver benefits to Australia. We tested for this effect by comparing the average benefits of assessments with and without Australian benefits. While there was a small difference in the average, it was not statistically significant.

How certain are these conclusions?

The key source of information for the analysis presented here is a combination of the already published impact assessments, and five additional case studies undertaken for this report. As noted above, this yields a very small sample size when compared with the total number of projects undertaken by ACIAR to date.

The addition of the case studies to the already published information did not significantly change estimated Australian benefits per project with quantified estimates (which remained at around $21 million), but did significantly change the estimated breakdown of benefits by type and by commodity.

This implies a reasonable level of confidence in total benefits per project, but considerably less confidence in the breakdown of these benefits.

Appendix A Tree growing on salt-affected soils

Background

The project 'Tree growing on salt-affected soils in Pakistan, Thailand and Australia' (FST/1993/016) aimed at:

- providing an increased range of tree and shrub species for planting on salt-affected sites in Pakistan, Thailand and Australia to provide fuel wood and other wood products
- defining appropriate establishment techniques for different species under a range of environmental conditions.

Salt-affected land is a major problem in many parts of the world. In particular, soil salinity, sodicity, waterlogging and combinations of these have rendered large tracts of land, particularly across Pakistan and Thailand, largely unproductive for agricultural purposes. Australia also suffers from salt-affected land.

- In Australia, dryland salinity adversely affects agricultural or pastoral yields on approximately 3.3 million hectares, while another 5.7 million hectares are considered to be at risk of salinisation.
- The economic impact of salinity and soil-health problems in Australian agriculture has been estimated at approximately $200 million per year in 2000, increasing to $300 million by 2020. This measure considers only the yield gap—the difference between agricultural profits with and without soil health. The off-farm impacts have been estimated to be as high as $90 million a year, increasing to $150 million per year by 2020. In present-value terms, the on-farm and off-farm affects are estimated to cost Australia around $2.5 billion and $1.3 billion, respectively (NHT 2002).

One of a number of related projects

FST/1993/016 is one of a number of ACIAR-funded projects looking at the interaction between land use, ground water and trees, and aspects of the land, including salinity (there are, of course, many other ACIAR-funded projects related to forestry in general, but those listed here all have a soil–water–tree interaction component):

- 'Forage shrub production from saline and/or sodic soils in Pakistan' (FOG/1986/019), which evaluated halophytic (salt-tolerant) forage species, especially *Atriplex* (saltbush) species, for use in revegetating salt-affected land in Pakistan
- 'Australian woody species for saline sites in Asia' (FST/1986/033), which undertook research into extending the range of salt-tolerant trees and shrubs, and to identify nutritional constraints that limit establishment and early growth on these soils
- 'Improving and sustaining productivity of eucalypts in South-East Asia' (FST/1991/015) aimed to increase the yield of Thai eucalypt plantations while maintaining long-term productivity of forest land
- 'Improved tree establishment for tropical dryland conditions in East Africa' (FST/1991/026), which investigated some of the problems associated with tree establishment in dryland regions, by subjecting promising lines of dryland species to a range of variables under glasshouse and field conditions

- ‘Multipurpose tree and sandalwood silviculture in eastern Indonesia’ (FST/1990/043) developed a management regime for those species selected for the West Timor environment, with other trials in the drier environment of East Sumba
- ‘Predicting tree growth for general regions and specific sites in China, Thailand and Australia’ (FST/1991/027) addressed the problem of insufficient information during reforestation programs using a variety of computer-based programs to monitor climatic and soil conditions;
- ‘Groundwater control measures for salinity management and agriculture in the Khon Kaen area, north-east Thailand’ (LWR1/1992/022) investigated groundwater flows and the salt loads they carry, and tested methods for reducing salt levels in the landscape.

Budgets

Table A1 presents the budget for Project FST/1993/016. Project funding was from a range of sources, with roughly half made up from ACIAR funds.

Intended outputs

The intended outputs of ‘Tree growing on salt-affected soils in Pakistan, Thailand and Australia’ were to:

- improve the productivity of key tree species on salt-affected land, through
  - identification superior genetic materials in species, provenances and progeny trials and establish seed orchards for dominant strains
  - further evaluation of the impact of salt on the imbalance of plant growth
  - evaluation of the impact of improved rhizobia strains on the growth of acacias
  - determination of the impact of size and age of seedlings on the response to salt under controlled conditions
- determine the water use of key species on salt-affected land
  - determine daily and annual water use by single trees and plantations of a variety of species, and validate models for predicting water use from tree size, soil and climate variables
  - determine seasonal variation in root zone soil moisture, salinity and watertable depth beneath plots of key species irrigated with saline water
- develop a tree and shrub performance database for salt-affected land and provide predictions of growth
  - collect, collate and enter trial data from salt-affected sites in Pakistan, Thailand, Australia and other countries into a PC tree-performance database
  - predict site suitability and potential growth of key species for specific regions in Pakistan, Thailand and Australia using simulation modelling
  - update the publication *A bibliography of forage halophytes and trees for salt-affect land: their use, culture and physiology* produced by projects FOG/1986/019 and FST/1986/033.

Table A1. Project budget FST/1993/016

	1993–94 ($)	1994–95 ($)	1995–96 ($)	1996–97 ($)	Total ($)
Total ACIAR expenditure	121,032	256,520	182,954	89,891	650,397
Other support (cash and in-kind)					
Commissioned organisations	58,782	120,698	123,242	62,843	365,565
Australian collaborators	26,500	15,000	15,000	7,500	64,000
Developing-country partners	20,200	37,100	34,800	17,500	109,600
Other support total	105,482	172,798	173,042	87,843	539,165
Grand total	**226,514**	**429,318**	**355,996**	**177,734**	**1,189,562**

Source: ACIAR (1994).

Key outcomes

The overall outcome of the project is an enhanced ability for researchers, particularly in Pakistan but also in Australia and Thailand, to better manage salt-affected land through improved knowledge of appropriate tree and shrub species able to withstand salinity.

Specifically, the project component outcomes were:

- identification of the most productive germplasm of proven tree species for a variety of salt-affected soils
- refining key cultural techniques for optimising tree survival and growth on salt land
- evaluation of the water use of trees in saline conditions and their likely impact on shallow, saline watertables
- evaluation of the correct water-management procedures for sustainable tree growing on a variety of salt-affected soils
- development of a greater ability to predict how well a range of tree species and provenances will grow on salt-affected sites in specific regions of Pakistan, Thailand and Australia.

ACIAR's project review

The project's completion report determined that the project met the stated objectives. It found that the overall outcome was an enhanced ability for researches, particularly in Pakistan, but also in Australia and Thailand, to better manage salt-affected land.

That is, the results of the project have enabled researchers to advise farmers on species to plant, planting techniques and the environmental benefits, particularly with regard to water use and watertable control by trees. The research trials have clearly demonstrated the potential for increasing agricultural productivity on salt-affected wastelands.

Furthermore, the project has demonstrated the ability to grow trees and shrubs on salt-affected land that was previously considered wasteland. The project has provided scientists in Pakistan, Thailand and other developing countries with the most recent techniques when determining plant suitability, particularly in water-use measurement, and how to apply these techniques to research on reclaiming salt-affected land using trees and shrubs. The research in Thailand usefully contributed to the data already in place on salt-affected land in the tropics.

In Pakistan, the project review found that the project has been a catalyst, increasing the existing knowledge and awareness of overseas scientists to such an extent that salt-land research in Pakistan is now established and advancing. In Thailand, the impact is less clear. The fight against salinity still appears to be of little interest outside of academic circles. In order for the research to have a broad impact, the demand for solutions to salinity problems would have to increase.

Outcomes mostly academic

However, while the project has had positive impacts at an academic level, the project reviewers determined that the application of the research from the project has had only a limited impact on farmers in Pakistan and Thailand, the eventual end users of the research products. This significantly attenuates the impacts of the project.

Potential benefits to Australia

Currently, Australia faces significant economic and social costs from salinisation of agricultural and rural land, particularly within the Murray–Darling Basin in south-eastern Australia and in the south-west of Western Australia. It is estimated that 2.5 million hectares of land are affected by salinity, with the potential for this to increase to 15 million hectares. Much of this is Australia's most productive agricultural land.

Within Australia, the project has had a range of potential benefits, but it is not possible to quantify these as there is yet no evidence that the results of the research have been adopted.

The primary potential positive impact of the project on Australia is that the amount of salt-affected land would be reduced. A second impact relates to the potential for a productivity boost due to agricultural yields improving through crop diversification. Additionally, Australian researches benefit directly through the collation of relevant research findings.

Potential for land rehabilitation through lowering watertables

In Australia, over 7,000 broadacre and dairy farms (9.0%) have signs of surface waterlogging which has led to some negative impact in almost all (6,300) of these. Of these 6,300 properties, roughly a quarter (1,600) have experienced significant problems due to waterlogging (see Table A2).

The strategic planting of trees in water recharge and discharge locations is considered by researchers to be one approach to halting the spread of salinity.

Water use per unit of land area by trees is an important determinant of the capacity of trees to lower watertables. There are several examples within Australia of significant lowering of saline watertables under or near plantations and agro-forests, particularly in Western Australia and Victoria, where a 2 metre lowering of the watertable was achieved under an 8-year-old eucalypt plantation.

The degree of effectiveness of tree species and plantations depends on the tree density, the proportion of area planted, crown cover, root architecture, soil hydraulic characteristics and groundwater dynamics. Furthermore, individual tree water use is closely linked with leaf and stem cross-sectional area.

By undertaking the research, the data acquired allow researchers to make predictions on likely tree species performance. Combined with other information, researchers and land managers would have a broad spectrum of tree species data that could be used to help determine the optimum species to plant on salt-affected ground, as well as the optimal planting locations.

Potential for income generation through alternative crops

The ACIAR project has undertaken valuable research into determining tree water use and long-term salinity of root zones of a broad range of native Australian tree species. Being able to identify the most appropriate and productive tree species on salt land, and ensure their

Table A2. Australian broadacre and dairy farms impacted by salt-affected land

	Number of properties affected	Per cent of all properties
Dryland salinity		
Showing signs of	10,932	14.0
Impacting upon business	8,855	11.3
Significant problems from	3,608	4.6
Irrigation salinity		
Showing signs of	2,343	3.0
Impacting upon business	2,343	3.0
Significant problems from	609	0.8
Soil sodicity		
Showing signs of	5,466	7.0
Impacting upon business	5,193	6.7
Significant problems from	929	1.2
Surface waterlogging		
Showing signs of	7,028	9.0
Impacting upon business	6,325	8.1
Significant problems from	1,616	2.1

Source: ABARE (2006).

survival through land and water-management practices has real potential to improve agricultural incomes and productivity. The end result, once implemented, would be to make large areas of marginal land in Australia available for income-earning activities. Potential sources of revenue include:

- growing trees for construction timber
- growing native Australian shrubs digestible for fodder production.

In addition to growing trees and shrubs for use on their own land, farmers may benefit from the research by the establishment of a domestic market for useful tree species; that is, there may be scope for expanding the supply and demand for plant nurseries.

Contributing to and collating relevant research findings

The final potential benefit to Australia relates to the collection of research findings. Assembling all available knowledge may markedly assist academics and government and forestry officials in applying and distributing the research findings from this project, as well as other related projects.

Related to the benefits associated with positive research findings, the project may also benefit other researchers and land managers by identifying potentially fruitless research avenues.

Costs of implementation

In order to lower watertables using techniques developed as part of this project, agricultural firms would be required to plant significant areas of land. While the opportunity cost of the land can be assumed to be zero given its degraded state, there is still a direct financial cost and opportunity cost associated with planting trees. Furthermore, there are costs associated with accessing the research findings and determining the appropriate tree species to use.

Conclusion

If the outputs of the project are implemented into widespread land-management practices, there is potential that land management within salt-affected areas of Pakistan, Thailand and Australia will sufficiently change so as to reduce the impact of salinity. Clearly, however, this is conditional on the research findings being widely disseminated and applied and being integrated with the variety of other research efforts in this area.

Appendix B Heat systems for quarantine disinfestation

The project

Quarantine restrictions, although designed to prevent the transmission of diseases and pests across borders, are an impediment to trade. Even within Australia the flow of fruit and vegetables is restricted to prevent the movement of pests between and within states. The work undertaken under project PHT/1990/051 was designed to allow producers of tropical fruits in developing countries and Australia to meet the requirements of quarantine laws more easily and thus promote trade with other countries as well as within countries such as Australia. The study involved Australia, Thailand and the Philippines.

Of major concern are the Oriental fruit fly (OFF) and the Queensland fruit fly (QFF). The OFF is arguably the most destructive member of the fruit fly family and can be found in South-East Asia, Hawaii and South America. The QFF is considered to approach the OFF in seriousness as a pest. The implications for both pests are clearly posing problems with exports and imports within the region and to and from Australia.

In addition to the problem of pests, Japanese and US authorities have required each country to prove its disinfestation procedures on a fruit-by-fruit and pest-by-pest basis necessitating the doubling up of substantial amounts of work. By developing and proving the efficacy of heat systems in disinfesting a range of fruit flies in a range of fruits, the ACIAR-funded research hoped to demonstrate that a general approach to disinfestation may be an effective solution in future and reduce unnecessary repetition of research in this area.

Background

Disinifestation by fumigation with ethylene dibromide (EDB) has been accepted in the past, but environmental and health concerns have resulted in its enforced reduction in use in developed markets. Heat treatment presents a feasible alternative and has the added benefit of being residue-free.

There are several ways of treating fruit and vegetables with heat, but the three that show most promise are vapour-heat treatment (VHT), hot-air treatment and hot-water treatment. VHT was first used in Florida in 1929 to disinfest citrus of fruit fly and since then treatments have been developed for other fruits.

VHT typically consists of heating the fruit by subjecting it to forced steam airflow at around 90% humidity for 2–4 hours which raises the core fruit temperature to about 46 °C for about 10 minutes. This treatment, however, can result in damage to the fruit due to vapour condensation. This has led to the development of reduced-humidity treatments. These treatments subject the fruit to similar conditions but at a relative humidity of 80%. This latter method is commonly referred to as hot-air treatment.

Hot-water treatment is the most efficient and least expensive way to raise the temperature of fruit but results in a high level of fruit damage due to the longer treatment times required.

Importing countries are primarily concerned that treatments performed by the country of origin are effective in disinfesting the fruit. With varying requirements from fruit to fruit and pest to pest, each individual exporting country is required to prove the suitability of their methods to each importing country. The ACIAR-funded project (PHT/1990/051) aimed to remedy this by developing commercially applicable heat-disinfestation schedules for tropical fruits through quantifying the responses of significant insect pests, pathogens and fruit to the various forms of heat treatment. This was expected to illustrate commonality in responses and, it was hoped, lead to more rapid development of acceptable heat-treatment protocols.

The program was broken into two separate but closely related sub-programs:

- *entomology*, for the examination of the efficacy of the treatments in disinfesting the fruit
- *fruit quality* to optimise the fruit quality while maximising the disease and pest-control aspects.

The products of major interest to this study were mangoes, lychees, mangosteens, papayas and cucurbits.

Collaborative activities between Australia and Thailand and the Philippines served several purposes.

- The first was to broaden the research to include fruit fly species not present in their respective countries, thus allowing the applicability of results to be extended beyond what it would otherwise be if the project was restricted to in-country research only.
- Second, a more indirect effect of capacity building in the collaborating countries by training scientists and researchers in new techniques and methods was sought. This capacity building had a valuable spinoff to Australia in increasing levels of pest management and quarantine capability so reducing the risk of pests spreading throughout the region and to Australia. There was also the parallel opportunity for Australian researchers to broaden their experience and expertise, giving greater efficiency to their activities.
- The opportunity to expand research programs in Australia into low-priority areas where significant problems exist but there are insufficient or no funds available to address the problems was a third objective of collaborative activities.
- Finally, of considerable significance to Australia, was the opportunity to increase research activities on seasonal fruit by utilising the complementary production cycles of the Northern and Southern Hemispheres, so reducing the time frame of the study by having fruit available all year round.

Entomology

The aims of this sub-program were to develop broadly applicable heat-treatment schedules for tropical fruits to acceptable standards for quarantine purposes. Comparisons between different treatments were made to determine the relationship between the disinfestation conditions and the method by which they were achieved, the fruit in question and the fruit fly species being examined.

Researchers from each country tested the efficacy of various treatments for the disinfestation of fruit fly while also examining the adverse effects each might have on the fruit itself. They did this by identifying the most heat-resistant strain of fruit fly in each country, infesting various fruits with the fly and then subjecting these fruits to the treatments being tested.

Fruit quality

The aims of this sub-program were to optimise the disinfestation treatments to minimise the damage to fruit and maximise the pest disinfestation and disease control of the treatments. Pre- and postharvest factors have been found to vary the tolerance of fruit to various forms of heat treatment and these were investigated. An understanding of these factors was needed in order to construct schedules that would remain applicable to fruit grown under different conditions. This would also allow for the reduction of fruit injury in commercial treatment processes and assist in developing methods which resulted in uniform quality between batches.

The Australian mango industry

During the period of the project, mangoes were the most significant tropical fruit crop to Australia. In the years immediately before 1991 the average price of a tray of mangoes (7 kg) was $17 in Australia while prices in Japan and the USA were as high as $32.

Industry estimates put production of fresh produce at approximately 14,000 t in 1991–92 and this had grown to around 77,087 t in 2004–05. The proportion of production that has been exported has remained steady at about 4–5% per year throughout this period, with the remainder being made up of domestic consumption and processing.

It is difficult to compile a comprehensive picture of mango production and exports, as the main sources of information (the Australian Bureau of Statistics (ABS), the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF), the Queensland Department of Primary Industries (QDPI) and industry associations) all differ in their estimates.

Table B1 presents ABS and DAFF mango production figures by state. These estimates are based on a survey and are generally lower than industry estimates. They indicate, however, that the majority of production is in Queensland. For the estimates of benefits we make, we use Queensland production and export estimates (see Table B3).

Costs

The total costs include those incurred by doing the actual research and those involved in the adoption of new technology.

Research costs (Australia and collaborating organisations)

Research funding comes from a number of sources but was predominantly provided by Australia via ACIAR and the QDPI. Table B2 outlines the funding arrangements for the project.

Table B2. Funding contributions for project PHT/1990/051

Country – organisation providing funds	Amount ($)
Australia – ACIAR	959,557
Australia – QDPI	1,126,200
Thailand	151,600
Philippines	217,150
Total	2,454,507
Total Australian component	2,085,757

Source: ACIAR (1991)

Table B1. Australian mango production by state

Season	NSW	NT	Qld	Qld percentage of total production	WA	Total
1990–91	331	1,003	10,303	88	281	11,918
1991–92	183	2,020	11,756	81	568	14,527
1992–93	139	4,211	26,084	84	566	31,000
1993–94	117	3,897	18,799	78	1,400	24,213
1994–95	–	5,530	30,612	81	1,575	37,717
1995–96	–	5,666	20,445	74	1,607	27,718
1996–97	273	2,668	28,366	88	1,095	32,402
1997–98	–	–	–	–	–	36,567
1998–99	–	–	–	–	–	26,372
1999–2000	–	5,244	30,770	81	1,922	38,071
2000–01	386	6,718	28,233	75	2,060	37,398
2001–02	259	6,071	32,361	79	2,281	40,973
2002–03	260	6,704	29,300	75	2,706	38,970
2003–04	433	6,027	28,516	77	2,192	37,169

Source: DAFF (2004), ABS (2003, 2004, 2005)

Adoption costs

Adoption costs include all costs associated with setting up new heat-treatment facilities, training of personnel and any increased production costs. Currently there are two plants in Australia with an average cost of $1.5 million to $1.7 million each. The actual costs of treating the fruit are minimal but the packing costs increase substantially due to the need to prevent reinfestation of the fruit after treatment.

Trade diversion

If the research leads to produce being diverted away from Australian consumers in order to supply foreign markets there may be a negative effect on Australia in the form of price increases. DAFF figures suggest that, in fact, trade is being diverted away from less-lucrative foreign markets in order to satisfy demand in Japan. Australian Mango Industry Association comments also imply that Australia will continue to produce more than it consumes for the foreseeable future and, as such, a rise in domestic prices is not an issue of any significance.

Benefits

The benefits are likely to come from a variety of sources.

Pest prevention

By reducing the possibility of a pest or disease entering the country via imported fruits, the research will assist in the protection of the existing Australian fruit industry. In 2004–05 Australian mango production was estimated to be worth $175 million. Other fruits may also be affected by the introduction of pests such as fruit fly and so the indirect effects may be much larger, but we have not considered this source of benefits in our analysis here.

International trade

Discussions with the Australian Mango Industry Association revealed that the only foreign market requiring heat treatment of any sort is Japan. This came about in December 1996 when Japan's Ministry of Agriculture, Forestry and Fisheries (MAFF) agreed that the use of vapour-heat treatment was a suitable method of fumigation against papaya fruit fly, and opened up Japanese markets to Australian producers. This decision came a little over 12 months after the completion of PHT/1990/051 and is arguably attributable to the work performed and proposals submitted to Japan as part of the project. Exports of mangoes to Japan have since grown from 211 tonnes in 1997–98 to 537 tonnes in 2004–05. On average, Australia exports 4–5% of total production, and 0.76% of total production goes to Japan.

Australia is also currently in negotiations with South Korea, New Zealand, China and the USA about market access. In all of these instances, the heat treatments investigated in PHT/1990/051 are proposed as measures for disinfestation.

The direct competitive threat to domestic producers from imports is low as most foreign producers are in the Northern Hemisphere and are therefore out-of-season with Australia. There may be a threat to acceptance of mangoes, however, if lower-quality produce is imported in Australia's off-season and the image of mangoes is damaged. This does not appear to be an issue at present.

Australia has begun to import mangoes from the Philippines, Haiti and Mexico and, in July 2004, DAFF prepared a draft policy for the import of mangoes from India. The policy document suggests that the methods investigated by ACIAR are measures suitable for preventing the incursion of pests from India.

Data on volumes imported are hard to source but it is understood that the quantities are very small at this stage and they will therefore be omitted from the analysis.

Intra-country trade

Some Australian states have stringent regulations applying to the importation of fruit from other states or from other areas within the state in order to prevent the spread of pests. South Australia is one of these states and has accepted the findings of PHT/1990/051. It has written into legislation that the methods outlined in the project are effective in eliminating pests and are sufficient to allow the importation of mango fruit from other states.

Sales of technology

Before the project was undertaken, a Japanese company was the main supplier of heat-treatment plants. Some of the staff involved in the project collaborated with a local manufacturer to develop a treatment plant that would take advantage of the knowledge gained during the research. The aim of this was to sell the treatment plants but due to problems with prototyping and the manufacturer abandoning the venture no sales have materialised. The current owner of the sole plant made during this work is acting as an agent for the technology but remains more focused on the treatment of fruit than sales of the equipment.

Research outputs

At the time of the project there were three other related research programs in progress which either benefited from or assisted PHT/1990/051. In addition to this, one non-ACIAR program was commenced as follow-on research, while another, also non-ACIAR, has begun, not as a follow-on, but as a direct result of the research findings. These findings have also resulted in the publication of 47 papers and reports.

Net benefits

The net benefits are calculated as being the total benefits accrued minus total costs incurred, which includes the research costs and the costs of adoption of the new technology. The major benefit quantified here comes from the removal of a barrier, with a resulting increase in trade. The only country, however, requiring heat treatment as a condition of trade is Japan. Table B3 shows production and export figures for Australian mangoes. Given the cyclical nature of mangoes, the production over the period 2001–02 to 2004–05 was averaged to obtain a mean production of 58,416 tonnes per annum. A similar process was applied to prices, to arrive at $2.27 per kilo.

Given that the heat-treatment regime is required in order to conduct trade with Japan there is a premium paid for mangoes in that country. We estimate that the export f.o.b. price into Japan ranges from $5.238 to $6.402 per kg, a premium of 131–182% over Australian domestic prices.

The benefits from trade are calculated as being the difference between the price received in the Japanese market and the Australian domestic price. Using these figures we can estimate the gains from trade in mangoes with Japan to be worth between $1,305,920 and $1,818,080 per year.

Figure B1 shows the underlying basis for this calculation. The new technology effectively allows an increase in the export price, which leads to an increase in exports and a reduction in domestic demand. The net benefit of this is the increase in producer surplus, less the reduction in domestic consumer surplus, equal to the area *abcdef*. We approximate this using the area *fbce*, which is equal to the initial export volume multiplied by the increase in price.

It is important to note here that, although Australia currently benefits from this restrictive policy, other countries are introducing similar technologies and processes for exports. Although Australia is out of season with the majority of mango producers in the

Table B3. Mango production and export data

Year	Total production[a]	Total exports	Japan exports	Percentage of total production exported to Japan
2004–05	77,087	3,112	537	0.70
2003–04	45,117	2,479	395	0.88
2002–03	62,175	4,714	523	0.84
2001–02	49,284	2,887	306	0.62

a All production and export figures quoted are in tonnes.

Source: Department of Primary Industries and Fisheries, Queensland.

Northern Hemisphere, most notably India, these countries may have an impact on Australian exports over time. In addition, should the restrictive Japanese policy be replaced or even removed entirely, Australia may lose the competitive edge it currently has. Although it is difficult to establish why the price premium exists it appears that it is mainly a result of the restrictive policies in place. As more mangoes become available year-round in Japan it is possible that consumption patterns will change and demand will be smoothed out over the entire year. This may have the dual effects of reducing demand for Australian mangoes as consumers switch to fruit from other countries and an increase in the supply of mangoes in general.

This loss of benefits may be countered with new trade deals currently being negotiated with other countries, but these cannot be estimated yet due to the large uncertainties involved.

The costs incurred in conducting this trade come predominantly from increased labour and material costs, as the fruit must be packed in materials which give protection from reinfestation. The packing costs for domestically sold fruit range from \$0.44 to \$0.47 per kg. These costs increase by \$1.09–1.26 per kg to \$1.53–1.73 based on a 13–17% rejection rate. The costs of the actual treatment are negligible at around \$0.003 per kg. In terms of percentage change over normal domestic costs, this represents an increase of 226–293%. This extra cost multiplied by the quantities involved must be subtracted from the benefits gained in order to arrive at a final net benefit figure.

We suspect that there is some sort of linkage between costs and the premium paid by Japan that will prevent a scenario of high costs and low premiums occurring whereby the gains would be lowered to \$751,520. In the case of low costs and high premiums (which is probably equally unlikely), the gains could be as high as \$1,338,980 per annum.

Table B4 presents the present value of the projected net benefits from the project.

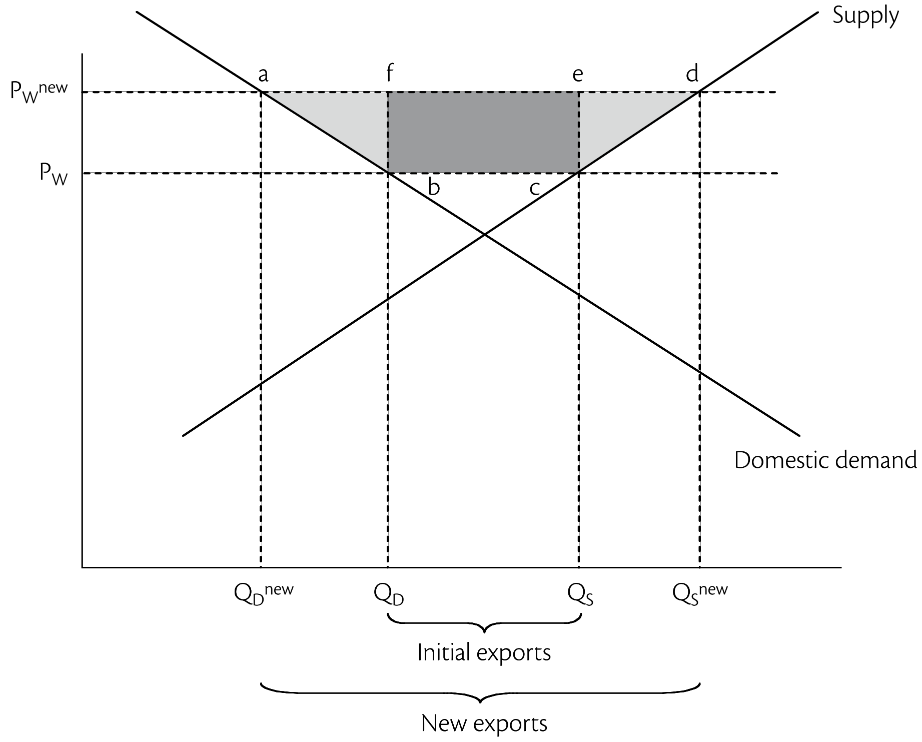


Figure B1. Value of increased exports

Alternative baseline

How long the benefits to Australia continue depends on how long it is before competitor countries introduce the same technology and begin to erode the benefits to Australia by claiming some of the export premium.

If a new technology is introduced in this way, the net benefits will be capped. Table B5 shows the capped net benefits of the ACIAR project if a new technology is introduced after 10 years.

Table B4. Net benefits after 30 years: present value at 5% discount rate

Scenario	Net benefits (net of all Australian research costs)	Gross benefits (net of adoption costs only)
Case 1 – 0% mean growth	$10.9m	$12.9m
Case 2 – 4% mean growth	$21.1m	$23.2m
Case 3 – 8% mean growth	$41.5m	$43.5m

Source: CIE Simulations

Table B5. Net benefits after 30 years, with new technology after 10 years

Scenario	Net benefits (net of all Australian research costs)	Gross benefits (net of adoption costs only)
Case 1 – 0% mean growth	$1.87m	$3.95m
Case 2 – 4% mean growth	$3.02m	$5.11m
Case 3 – 8% mean growth	$4.40m	$6.48m

Source: CIE Simulation.

Appendix C Flowering behaviour and productivity of mangoes

Overview

Australian mango growers suffer from unpredictable yields, characterised by annual fluctuations in yield and quality on an on-year–off-year basis often referred to as 'biennial bearing'. The inconsistent production and quality of mangoes offered for sale affects growers' ability to meet the demands of their customers and to develop new markets, particularly export markets. This represents a significant productivity bottleneck for mango growers and the uncertainty with which it is associated leads to great difficulties in developing the industry.

Low productivity in mangoes is associated with low and irregular bearing. A major cause of this is flowering failure. Before this project, little was understood about the reproductive physiology of mango. Research into floral induction had been inconclusive, no focused effort had been made to define critical criteria for pollination and fertilisation, and little research attention had been paid to observations regarding the responses of different mango varieties to a range of environmental conditions.

ACIAR project No. CS1/1990/012 conducted ground-breaking research into the phenology (life-cycle events) and physiology of mango trees preceding flowering, including a study of the effects of water deficit and cold temperatures at the time of flowering.

The problem

Unpredictable yields are a challenge for the Australian mango industry. Not only do farmers' incomes fluctuate as a result of the pattern of high yields one year followed by low yields the next, but so do the incomes of all those involved in the value chain. Consumers are also faced with wildly fluctuating market prices.

Yield fluctuations make it difficult for market agents and supermarkets to promote mango effectively, because they cannot reliably predict cropping levels in advance. In addition, it is difficult to predict the price, which makes marketing mangoes against other fruits problematic. A standard strategy when faced with low availability would be to market the mango as a high-price luxury purchase, a one-off treat, but low yields are often accompanied by poor-quality fruit, which effectively rules out this approach.

These volume and price effects flow on to spinoff industries, such as processors, leading to difficulties in maintaining long-term contracts. For example, an Australian producer of processed fruit products succeeded in gaining shelf space at a major supermarket chain for a mango in syrup product, but subsequently lost the contract as the following year's low mango yield precluded provision of the product in the required amount.

The research

ACIAR project CS1/1990/012, 'Flowering behaviour and subsequent productivity in mango', had the clearly stated objective (Whiley 1997):

> To improve the sustainable production of mango cultivars growing in the sub-tropical and tropical environments of Thailand and Australia so that domestic and export markets could be reliably serviced with quality fruit yielding higher financial returns to growers.

The aim of the research conducted in both Australia and Thailand was not to increase mango yields per se, but to reduce the variation in year-to-year yields and thus enable the mango industry to plan its future development from a position of greater certainty. This was to be achieved through meeting a number of specific objectives relating to observed problems in flower production, fruit setting and survival in either subtropical conditions (Maroochy, Chiang Rai) or tropical conditions (Darwin, Pichit, Sisaket), or both. The various studies carried out under the umbrella of this project were intended to help the development of better management strategies and identify cultivars more suited to specific growing regions.

Research was conducted into the relationship between the flowering and fruit yield of different mango varieties to enable scientists to determine those most suitable for adaptation to a cooler climate and the minimum temperature at which the different varieties could be successfully cultivated. Potential improvements to management strategies were also to be sought.

Research outputs

The experiments carried out under this project led to a number of significant outputs. The research:

- demonstrated for the first time that pre-flowering water stress promotes early and more intense mango flowering in low latitude tropics where temperatures remain too high for flowering to be induced by cool nights
- demonstrated variation in photosynthetic performance, water relations and bearing behaviour among six mango varieties in response to different environmental influences
- identified a major physiological limitation to mango productivity in northern Australia
- tested, selected and standardised a low-cost and reliable sap-flow measuring system for water-use studies in mango—before this there had been no accurate estimate of true tree water-use under the Northern Territory conditions
- developed a direct method for monitoring the average sap flux densities at several measuring points, which greatly improves the quality of sap-flow measurement in orchards. with minimum need for expensive data loggers
- designed an 'ambient temperature gradient auto-compensating system' for improving quality of sap-flow measurements in young tropical fruit trees under orchard conditions
- established daily and seasonal water-use patterns of mango trees of different cultivars and ages, which provided the industry with a baseline for improving irrigation scheduling and water-use efficiency
- made progress towards inducing off-season flowering using the application of chemical treatments
- found that removing panicles (branched clusters of flowers) could significantly increase tree yield.

Research outcomes

The project review report found (Whiley 1997) that:

> … the problems of erratic flowering and low productivity had not yet been solved, although a better understanding of the contributory factors has undoubtedly been generated.

This has been confirmed in conversation with members of the project team who continue to work in this area, and scientists subsequently involved in mango flowering research.

Particular research outcomes attributable to the project include:

- the major physiological limitation to productivity identified by the project is now included in the assessment of progeny in mango breeding and selection programs

- subsequent research in the Northern Territory has continued to use the low-cost, reliable sap-flow measuring system standardised during the project—it has also been successfully adapted to other tropical crops
- eco-hydrologists in Canada have adopted the direct method developed by the project for monitoring the average sap-flux densities at several measuring points
- knowledge gained about watering and nutrition practices was disseminated to growers in subsequent workshops funded by grower contributions and the Australian Government's 'FarmBis' initiative
- the scientific results were
  - recorded and made publicly available in a number of reports to ACIAR, including those by Lu and Chacko (1996), Lu (1997), Lu et al. (1997) and Lu and Murray (2000)
  - presented at the ISHS 6th International Mango Symposium (Lu and Chacko 1999a,b)
  - presented as the invited keynote paper in the Proceedings of the ISHS International Symposium on Tropical and Subtropical Fruits, 2000 (Lu 2000)
  - subsequently published in a number of scientific journals (Lu 1997, 2001, 2002; Lu and Chacko 1998, 2000; Lu et al. 2000).

Identifiable research outcomes in terms of adoption of the research outputs by growers are hard to detect, however. On the whole, the scientists consulted did not consider the findings directly applicable to the industry, except in terms of the change in understanding among growers about the impact of irrigation and nutrition on mango yields that the workshops mentioned above helped facilitate.

Potential benefits to Australia

Many of the benefits resulting from this project are difficult to quantify. This must not be interpreted as the project yielding no benefits, however. All the scientists consulted stressed the importance of ACIAR's research-funding agenda. ACIAR is seen as funding areas of research outside the high-priority areas covered by industry groups. The scientists all strongly expressed a belief that these fundamental areas of research would otherwise be neglected because they tend not to lead to immediate, identifiable benefits for the industry.

Quantifiable benefits

New knowledge resulting from the project contributed a significant amount of content to the Queensland Department of Primary Industries and Fisheries (QDPIF) *AgriLink mango information kit* (QDPIF 1999). The kit was launched in October 1999 with 1000 copies printed. By early 2006 at the latest, all copies had been sold at approximately $100 per copy, bringing in revenue of $100,000 over six years for the QDPIF.

Taking into consideration that ACIAR's contribution to the project funding comprised approximately 30% and that other information was also included in the information kit, it would be incorrect to attribute the whole $100,000 to this project. As a conservative estimate, 30% of the revenues from the kit further divided by two to take account of 50% of the kit's content coming from sources other than the project, reduces to $15,000 the amount reasonably attributable to ACIAR.

Unquantifiable benefits

The scientists consulted believe that, since this project produced hitherto unknown fundamental scientific knowledge, the real benefits of the project have yet to be realised. It was commonly expressed that mango research had since concentrated mainly on postharvest topics, which are considered to lead to more immediate, quantifiable benefits. Realising future benefits attributable to this project was thus considered a matter of availability of funding for research that builds on the preharvest knowledge this project provided.

Three categories of unquantifiable benefits were identified, namely:

- changed orchard management practices
- subsequent research and publications
- capacity building.

Changed orchard management practices

QDPIF maintains that the research outputs have subsequently led to changes in orchard management practices as a result of the growers' workshops mentioned above, which were implemented independently of this project. The changed practices relate in particular to watering behaviour and tree nutrition. At the time of writing, no studies have been carried out to confirm this, however, so it must be regarded as anecdotal evidence only.

A flow-on effect of changed watering behaviour was observed in the Northern Territory, where water usage is now more evenly distributed over the whole year than was previously the case. This is associated with an environmental benefit due to the resulting reduction in peak demand on aquifers. Again, this observation is based on anecdotal evidence rather than substantive adoption studies.

Subsequent research and publications

From a scientific perspective, the project led to some significant insights into the behaviour of mango trees during the reproductive cycle. All the scientists consulted referred to the strong platform provided by the project's findings for subsequent research into the effects of nutrition on flowering and internal disorders.

Of particular interest is an extensive field study carried out by Horticulture Australia Limited (HAL) in conjunction with growers in Queensland into the effectiveness of two chemical treatments—experimented with by the ACIAR project under evaluation—to induce off-season flowering. HAL is now selling the final project report commercially (HAL 2001).

Capacity building

All of ACIAR's projects lead to the building of capacity for individual scientists and organisations in Australia. Of particular note in this respect are two scientists who started their research careers on this project.

Dr P. Lu was a CSIRO postdoctoral fellow when the project commenced in 1994. He subsequently became the leader of the project in the Northern Territory after the death in 1997 of his former supervisor, E.K. Chacko. He continues to research mango flowering and productivity and is now widely published and acknowledged as an international expert in this field. In conversation with Dr Lu, he stressed that the work he carried out under this project has formed the platform for everything else he has done since.

Dr Chris Searle was also a postdoctoral fellow when the project began. His career has followed a similar trajectory to Dr Lu. He recently resigned, however, and could not be contacted for interview within the scope of this evaluation.

Connected to the human capacity built by the project, it was also generally acknowledged by the scientists consulted that ACIAR-funded projects on the whole facilitate the procurement of much-needed laboratory equipment that scientists can use to further develop their research skills.

Costs

ACIAR reports that its project costs were $764,462. Note that this sum covers only to the period from 1 July 1994 to 30 June 1997. It does not include the subsequent two-year extension to the project until 30 June 1999, about which no information is available.

The total costs of the project (1994–1997) were $2,583,262. QDPIF contributed approximately 40% ($1,067,970) and CSIRO 15% ($404,400). The Government of Thailand provided the remainder ($346,410).

Appendix D Overcoming production constraints on sorghum

The project

Sorghum is an important crop in India and in parts of Australia's cropping region. However, productivity in India has not improved, with relatively static yields over the past several decades due to insect damage and shortages in water and nitrogen. In India, shoot fly and stem borer are the major pests, while in Australia midges and *Helicoverpa armigera* are the problem species. The project 'Overcoming production constraints to sorghum in rainfed environments in India and Australia' (CS1/1994/968) was commissioned through the Queensland Department of Primary Industries and Fisheries (QDPIF) and involved the University of Queensland (UQ) and the National Research Centre for Sorghum (NRCS) in India. It sought to overcome the abovementioned constraints by deploying an integrated approach comprising genetic engineering, plant breeding and crop modelling. The project began in July 1996 and was completed in December 2000.

The overarching goal of the project was to raise sorghum yields by developing genetic-engineering and crop-management techniques to prevent insect damage and to make more efficient use of available water and soil nitrogen in Australian and Indian sorghum-growing regions. The project therefore simultaneously explored both genetic and agronomic aspects of crop improvement.

The project used an integrated approach involving plant breeding and genetic engineering, crop physiology, and crop modelling to:

- enhance genetic transformation techniques to aid development of sorghum varieties with high and stable levels of resistance to sorghum shoot fly
- develop methods to improve the efficiency of selection for plant breeding through better analysis and design of testing across multiple environments
- develop improved crop models and climatic and soil databases to enable simulation of water and nitrogen effects on crop production and prediction of the consequences of management manipulations of the crop.

The research

Each of the above objectives was addressed through separate but interacting sub-projects.

- *Genetic engineering for insect resistance*. Here two tissue-culture and regeneration systems were developed for use in the genetic transformation of sorghum into variants that are resistant to shootfly and other pests.
- *Improved breeding methods*. This involved constructing a database of advanced yields trials for *rabi* sorghum. These trials were conducted by the All India Coordinated Sorghum Improvement Program (ACISIP).
- *Improved management strategies*. Here soil, climate and crop growth data from past and current sorghum experiments were collated and assembled into the CROPBAG electronic database. The physiological basis of the response of key Indian and Australian sorghum genotypes to climate, water, and nitrogen interactions was quantified by measurement and modelling

Research and development costs

The estimated expenditure on the project by ACIAR and other organisations over the 3-year period is shown in Table D1.

Project outputs

In the first sub-project, a sorghum transformation system was developed using the microprojectile system known as a particle inflow gun (PIG) made at the University of Queensland. This technology was transferred to India's NRCS and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Two tissue-culture and regeneration systems were also developed for use in genetic transformation. At the National Research Centre for Plant Biotechnology (NRCPB) in Delhi, efforts were undertaken to achieve expression of insecticidal genes in the meristem of sorghum in order to overcome shoot-fly damage.

Transgenic sorghum plants were produced with *Bacillus thuringiensis* (Bt) genes to confer resistance to the stem-borer insect, but these plants were not analysed at the time of project completion. (Subsequent analysis at UQ demonstrated resistance to stem borer had not been achieved.) At the time of project completion, no transgenic sorghum plants had been produced in India, but capacity had been built up, particularly at NRCS in Hyderabad.

An important result from the sorghum genetic-transformation system developed in this sub-project is the potential capability to incorporate different Bt genes that target specific insect pest species.

The sub-project focused on developing stem-borer resistant lines, with no effort at controlling shoot fly, because of the failure to rear shoot-fly larvae *in vitro* (that is, in an artificial environment). Insect growth and survival were not of a sufficient level to test for the efficacy of insecticidal proteins in genetically transformed sorghum. The considerable difficulties associated with breeding shoot fly were not anticipated by Australian researchers before the start of the project.

The second sub-project led to enhanced breeding options through the compilation of a database of yield trials. Analysis revealed that genotype (that is, plant trait) and environment (G × E) interaction accounted for 77% of total genetic variance for grain yield. Regional adaptation patterns were identified and five near homogenous groups were found. As a result, an optimal multi-environment trial program that would reduce the time taken for variety trials from 3 to 2 years and the number of locations from 31 to less than 20 was recommended.

Table D1. Estimated costs of project CS1/1994/968

	Year 1 ($)	**Year 2 ($)**	**Year 3 ($)**	**Total ($)**
ACIAR costs	244,545	268,542	275,650	788,737
Commissioned organisation and Australian collaborators:				
QDPI	97,500	97,500	97,500	292,500
UQ	72,500	72,500	72,500	217,500
CSIRO	40,000	40,000	40,000	120,000
Developing country partners:				
ICAR	62,500	62,500	62,500	187,500
ICRISAT	100,000	100,000	100,000	300,000
Others: GRDC	70,000	70,000	70,000	210,000
Grand total	687,045	711,042	718,150	2,116,237

a Contributions of organisations besides ACIAR are derived from salaries and on-costs associated with the involvement of project scientists from these organisations.

Source: ACIAR

In the third sub-project, use of the APSIM–SORG growth model in India has allowed the identification of problem targets for consideration in further modelling and experiments. Surprisingly, high radiation use efficiency (RUE) was found in the Indian hybrid CSH13R. (RUE measures the efficiency of conversion of intercepted solar radiation to biomass.) In addition, productivity on deeper soils was found to be substantially higher than that achieved on shallow soils. Using the model and assuming the absence of shoot fly, an analysis of the effects of soil depth, nitrogen content, sowing date and maturity was completed, enabling an improved understanding of sorghum response to these management practices.

Benefits to Australia

Better-directed breeding of new varieties has resulted from experience gained by Australian researchers through helping their Indian counterparts develop a database of advanced yield trials in India that led to the devising of an optimal multi-environment trial program.

More efficient crop management has been achieved due to enhancement of the APSIM–SORG sorghum crop growth simulation model, which has been used by QDPIF, CSIRO and UQ. Information gained from the *rabi* seasonal conditions has extended the utility and accuracy of the model for a wider range of soils and environments. The information on crop physiology and agronomy is being used by Australian scientists in trying to improve the productivity of sorghum in Australia, particularly when grown under terminal drought stress.

In particular, Australian researchers are currently attempting to engineer dwarf forms of the Indian hybrid CSH13R, whose high RUE was identified in the ACIAR-funded project. In its Indian form, the hybrid is too tall for Australian conditions. If successful, this variety should see widespread adoption in Australia within the next several years, particularly in Queensland.

According to the researchers involved in the project, grain production may ultimately improve by 4–5% as a result of better choice of available sorghum varieties, better-directed breeding of new varieties, and more efficient crop management.[8] Total annual production in Australia ranges from 0.8 to 1.7 Mt a year, with an average yield of about 2 t/ha currently. An increase in Australian production of 5% is worth about $10 million annually and will have a significant effect on the profit margins of producers.

Australian researchers and scientists have also benefited from the two-way exchange of training opportunities in genetic engineering, tissue culture, database development and analysis, and simulation studies. UQ and QDPI have benefited from the scientific publications that followed the project's discoveries, which have burnished their research reputations.

Quantifying benefits to Australia

The most important result of the ACIAR-funded project, from Australia's perspective, was the identification of the Indian hybrid CSH13R with very high RUE. As explained previously, Australian researchers are currently attempting to adapt the Indian hybrid to Australian conditions. Researchers believe that, if these efforts prove successful, this variety should see widespread adoption in Australia within the next several years.

Once adopted, it is expected that the new variety will increase yields, and so will lead to an increase in producer and consumer surplus in a way that can be analysed using the usual demand and supply framework.

In this case, however, there are important issues of attribution to take into account. The ACIAR-funded research has not fully delivered a yield increase yet, as other researchers are continuing to work on the issue. However, it is reasonable to expect that the ACIAR-funded research has both brought forward in time the benefits that will ultimately accrue, and has increased the probability of success of the research into the new variety. These two effects are illustrated in Figure D1.

To estimate the potential benefits from this aspect of the ACIAR-funded research project, we assume that the project has brought forward the discovery of the new variety by 5 years and increased the probability of its successful adoption from 0.6 to 0.8. That is, we assume that if ACIAR had not funded the project in question, it

8 Assoc. Prof. Ian Godwin, pers. comm., 9 May 2006.

would be another 5 years before the hybrid would have come into use. We assume that adoption takes place fairly rapidly over 5 years (from 2011 onwards with the ACIAR-funded research and from 2016 without the ACIAR-funded research). Sorghum yield increases cumulatively by 4.5% through this period over and above the underlying trend.

Historical data from 1961 to 2005 from the Australian Bureau of Agricultural and Resource Economics (ABARE) are used to (linearly) project the area of sorghum cultivation and 'underlying' sorghum yields between 2006 and 2025. 'Underlying' sorghum yields refers to projected future sorghum yields assuming that the new high-RUE variety is never adopted. Using these 'underlying' sorghum yields, we compute two future yield paths, one associated with the ACIAR-funded research project and another with the hypothetical alternative research project that takes place 5 years after the actual ACIAR-funded one.

We use actual ABARE data on Australian sorghum producer prices for 1996 to 2001. To compute producer prices from 2002 to 2025, we use the average of actual prices between 1991 and 2001 and assume an annual inflation rate of 2%. Operating costs are based on 2002 Grains Research and Development Corporation (GRDC) data and, again, an annual inflation rate of 2% is assumed. We assume that fixed costs are the same in the presence or absence of the ACIAR-funded research. As an approximation, we assume that the present value of implementation costs associated with the actual ACIAR-funded project and the later, hypothetical one are the same.

Table D2 presents estimates of the benefits to Australia and costs associated with the ACIAR-funded research project over a 30-year period (spanning 1996 and 2025) under a range of discount rates. The results show that the research produces benefits to Australia that outweigh the project costs. At a discount rate of 5%, the project is expected to generate benefits of $35.9 million with a benefit–cost ratio (BCR) of 18.1. The project's internal rate of return (IRR), representing the interest rate at which the project would generate zero returns in net present value terms, is 23.5%.

Sensitivity analysis

The base case results of the research are driven by various assumptions. To test the sensitivity of the results to some of these assumptions, a range of values is placed around several of the key assumptions outlined previously. We allow the increase in probability of successful

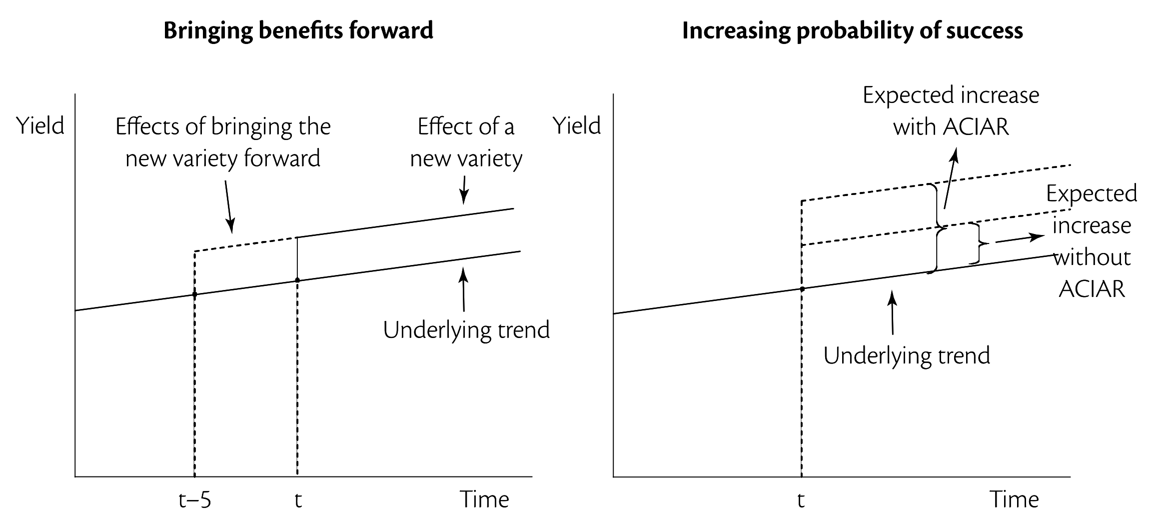


Figure D1. Bringing benefits forward and increasing probability of success discovery and adaptation as a result of the ACIAR-funded research project to vary between 0 and 0.4, the improvement in yield to range from 2.5% to 6.5%, and the number of years the project has brought forward key discoveries to vary from two to eight (see Table D3). The values in the 'medium' column correspond to those used in the main benefit–cost analysis.

Table D4 shows the results of the sensitivity analysis. The net present value of Australian benefits from the research project ranges widely from $3.6 million to $97.0 million. The benefit–cost ratio varies between 1.8 and 49.0 while the internal rate of return lies between 11.1% and 31.5%. The minimum figures correspond to the case where there is no change in the probability of successful discovery and adaptation, the yield gain is 2.5% over 4 years, and the project brings forward key discoveries by 2 years. Conversely, the maximum figures correspond to the case where the probability of successful discovery and adaptation increases by 0.4, the yield gain is 6.5%, and the project brings forward discoveries by 8 years.

Table D2. Results of the benefit–cost analysis under varying discount rates

Discount rate (%)	NPV of R&D costs ($m)	NPV of benefits ($m)	BCR	IRR (%)
0	2.07	94.6	45.6	23.5
5	1.98	35.9	18.1	
10	1.89	14.6	7.7	

Source: CIE calculations

Table D3. Parameter values used in sensitivity analysis

Assumption	Low	Medium	High
Change in probability (0–1) of successful discovery and adaptation with ACIAR-funded research	0	0.2	0.4
Improvement in yield with ACIAR-funded research (%)	2.5	4.5	6.5
Length of time ACIAR-funded research brings discovery forward (years)	2	5	8

Source: CIE

Table D4. Results from sensitivity analysis

	NPV of benefits ($m)	BCR	IRR (%)
Minimum [a]	3.6	1.8	11.1
Maximum [a]	97.0	49.0	31.5
Mean	35.9	18.1	23.5

a Assumes a 5% discount rate

Source: CIE estimates

Appendix E Mite pests of honey bees

Bees provide much more than just honey to the Australian economy. Many agricultural crops depend partly or fully on bees for pollination. Australia is one of the few countries relatively free from pests and diseases that may threaten both hived colonies and the feral population of the European honey bee (*Apis mellifera*), the most commonly used bee for honey production. Protecting Australian bees is therefore vitally important for maintaining production levels as well as securing a future for live bee exports.

Four related projects undertaken by ACIAR in the 1990s aimed to reduce the threat of incursion of pests and diseases of bees, and to develop a strategy to deal with such an event should it occur. The projects were mainly focused on parasitic mites that have devastated bee colonies throughout the world and are present in nearby countries.

The first of these projects, AS2/1990/028, began in 1991 and was targeted at improving methods of control of mites and diseases that are present in Papua New Guinea. This then led to subsequent projects engaged in similar subject areas but with varying geographic focuses. Project SFS/2004/030 began recently and is due to finish in 2009.

The completed projects have resulted not only in the development of improved control mechanisms, but also the identification of previously unknown genotypes of mites. The most recently completed of these projects, AS2/1999/60, aimed to extend the research findings of the preceding projects and apply them to circumstances in Indonesia and the Philippines.

The Australian honeybee industry

Each year the Australian honey-bee industry produces between 20,000 and 30,000 tonnes of honey, along with a range of other products. The estimated gross value of production for the industry is around $65 million annually although this is highly variable depending on the volumes produced. Rodriguez et al. (2003) estimated that 85% of this value is derived from honey, with the remaining 15% coming from other bee-related products. Approximately one-third of the honey produced is exported, making Australia the tenth-largest exporter of honey in the world.

In addition to honey, the industry generates income from the production of beeswax, queen and packaged bees, pollen, royal jelly, propolis and bee venom. The gross value of production of these products is around $10 million annually.

Pollination services

The Australian honey-bee industry also adds value to the economy through the provision of pollination services. Gill (1989) attempted to value the contribution of these services and arrived at a figure of $1.2 billion annually. Gibbs and Muirhead (1998) revisited the study and derived a similar figures, while Gordon and Davis (2003) revised the value of pollination services upwards to a maximum of $1.7 billion per year. All of these studies, while differing in the final values placed on pollination, reinforce the importance of bees to the Australian economy. It is important to note that, while the most significant contribution of the bee industry comes in the form of pollination, the actual payments made to beekeepers for these services amount to only $3.3 million per year.

The mite pests studied by the research

The research work done by ACIAR in the four projects considered have concentrated on the threat that parasitic mites pose. Two groups of these mites in particular—the *Varroa* genus and *Tropilaelaps clareae*—would prove to be particularly devastating to the Australian economy.

If either of these mites were to enter the country and remain undetected long enough to become established, many horticultural industries, along with honey-bee related products, would experience a sizeable drop in production, some of it permanent, and an increase in ongoing costs.

Varroa

These mites are completely reliant on their host for survival and were originally found on the Asian hive bee. They have proven harmless to their native host and have subsequently not threatened these bees. One reason for them not proving fatal for these colonies is that they can reproduce only on the drone bees and leave the worker bees unaffected.

The mite triggers a virus in the bee, causing them to emerge weak and with damaged wings, but sufficient of them are strong enough to mate and so the colony may continue to thrive even in the presence of the mite. When the mite crosses into the European honey bee it successfully reproduces on worker bees as well as drones, resulting in dire consequences for the hive in question.

The mites were found in Indonesia during the 1970s but were totally harmless to the European honey bee, as they could not reproduce. In other parts of the world, however, the mite proved fatal to bees of the same species.

Further investigation showed that the mite was actually different from those found in other parts of the world and the *Varroa* genus was subsequently redefined into two distinct groups: *Varroa jacobsoni* and *Varroa destructor*. The *V. jacobsoni* species-complex included the genotypes that where harmless to the European honey bee while the *V. destructor* complex included two strains that were not. It was the latter strains that were found in other parts of the world.

Varroa mites are present in nearly all agricultural regions of the world, the only exceptions being Papua New Guinea and Australia. Those parts of the world that have had incursions have seen marked declines in bee numbers and face higher costs for maintenance of managed hives due to mite presence. In New Zealand, feral European honey bees virtually disappeared only four years after the mite was detected there.

Tropilaelaps clareae

The *T. clareae* mite is arguably a threat to Australia of greater magnitude than that of *V. destructor*. Also harmless to its native host but fatal to the European honey bee, its introduction once again would have dire consequences for Australian industries relying on the honey bee.

The mite is completely reliant on the bee brood for survival and cannot survive on adult bees, a characteristic that has been exploited to achieve successful eradication of this pest from islands near Irian Jaya. The eradication methods employed involved the use of chemicals but could not be extended to Irian Jaya due to logistical problems. Further research focused on the feasibility of using formic acid as a cheaper means of control and equipping local staff with the knowledge and techniques for eradication.

The quarantine challenge

The closeness of these countries and the presence of the pests present significant quarantine problems for Australia. The introduction of *T. clareae* would potentially cause greater losses than *V. destructor* in Australia. Its establishment would lead to a decline in hived European honey-bee colonies and would decimate the feral population. Such an impact would see production of honey fall, losses in the export market for live bees and huge adverse impacts on crops due to reduced pollination levels. The output of other bee related products would also be affected. Table E1 lists previous events and illustrates the real possibility of incursions.

Table E1. Incursions and potential incursions of possible carriers of honey-bee pests

Date	Agent	Place	Comments
Early 1970s	*Apis dorsata*	Fremantle	From Java, Indonesia. No further details.
February 1994	*Apis scutellata*	Fremantle	A nest of live bees was found on a container. Destroyed.
April 1995	*Apis cerana*	Near Brisbane	No further details.
June 1996	*Apis cerana*	South Australia	No further details.
February 1997	*Apis scutellata*	Fremantle	Abandoned nest only. Originated from Durban in South Africa.
December 1997	Bumblebee (*Bombus vosnesenskii*). Not the same as that in Tasmania	Buderim, Queensland	Not diagnosed till May 1999. *Kunzenia* sp. mites were found which are basically scavengers in bumblebee nests—not significant for *Apis cerana*.
June 1998	*Apis cerana*	Darwin	Nest discovered by a local beekeeper. Eradication program instituted and intensive surveillance.
July 1999	*Apis dorsata*	Sydney	Air freight from Penang, Malaysia—computer motherboards. Examination showed no mites.
September 1999	*Apis cerana*	Brisbane	Asian honey bees were detected on a ship (ex Singapore, Lae and Port Moresby) berthed in Brisbane. A swarm of approximately 50–100 absconded but follow-up monitoring revealed nothing.
December 1999	*Apis cerana*	Brisbane	Introduced with heavy earth-moving equipment from Lae, Papua New Guinea (PNG). Hive of 5,000 bees destroyed. DNA test showed the bees were Java Flores type. *Varroa jacobsoni* found.
March 2000	*Apis dorsata*	Brisbane	A swarm was found under a container at the Brisbane wharves. Destroyed.
January 2002	*Apis cerana*	Melbourne	Swarm on a container ship from Lae, PNG. Destroyed. Inspection revealed *Varroa jacobsoni*.
January 2002 (or earlier)	*Aethina tumida*	Richmond, NSW	Discovered October 2002 but probably already present for at least a year. Means of arrival unknown.
December 2002	*Apis cerana*	Brisbane	One bee found on ship from PNG. Follow-up surveillance in Hamilton area revealed nothing.
February 2003	*Apis dorsata*	Vessel off northern Australia	Oil tanker from Singapore. A 'quite large swarm' found by crew and (inexpertly) destroyed before arrival. Only dead bees found. No mites seen on inspection.
February 2003	*Apis dorsata*	Vessel off northern Australia	Vessel from Indonesia. Seven dead and one dying bee found. No evidence of swarm found, despite repeated checks. No mites found on inspection.
May 2003	*Bombus terrestris*	Fisherman Islands, Brisbane	A single bee was found by the Australian Quarantine Inspection Service.
May 2004	*Apis cerana*	Cairns	Vessel from PNG. Swarm of *Apis cerana* found in hold on arrival in port. Bees destroyed. Spread considered unlikely. No mites found on inspection.
Nov 2004	*Apis cerana*	Brisbane	Vessel from PNG. Nest of *Apis cerana* found under a container in port. Bees destroyed. Spread considered unlikely. *Varroa jacobsoni* found on inspection, Surveillance for *Apis cerana* put in place within 6 km radius for 12 months.

Source: Boland (2004)

While the projects did incorporate research into *T. clareae*, anecdotal evidence suggests that little progress was made with this particular mite. The majority of the work focused on *Varroa* so this study also maintains its focus on the *Varroa* species-complex of mites.

Economic impacts of an incursion

There are two components needed to calculate the economic cost of an incursion.

- First is the *potential* cost if the pest establishes. This potential cost is best measured as a loss in economic surplus.
- Second is the *probability* of an incursion which, along with the probability of the success of eradication attempts, is used to calculate (using a probabilistic Markov-chain analysis) the *expected* cost of an incursion; that is:
- the expected cost of an incursion = probability of incursion × potential cost of incursion.

Component 1: the potential cost if the mite is established

If the mites become established in Australia, there will be a shift in the supply curve of:

- honey and related products
- crops that rely on pollination services.

For honey and other bee-related products the effects are obvious: a decline in the bee population will result in a reduction in those products directly related to bees. If the incursion results in a total demise of the bee population, supply will be reduced by 100%, with a complete loss in producer surplus.

If we consider what would happen to most crops in the face of a total decline in the bee population, the story is not so clear cut. The majority of crops would retain *some* level of output, although it would be lower than it would have been had there been no incursion. Table E2 shows that, of the 37 crops considered in this analysis, only 8 would experience a complete loss of production.

Table E2. Crops included in the analysis

Crop type	Degree of dependence on honey bees for pollination (%)a
Almond	100
Apple	90
Apricot	70
Asparagus	90
Avocado	100
Bean	10
Blueberry	100
Broccoli	100
Brussels sprout	30
Cabbage	30
Carrot	100
Cauliflower	100
Celery	100
Cherries	90
Cotton lint	20
Cucumber	90
Grapefruit	80
Kiwi	90
Lemon and lime	20
Lettuce	10
Lupin	10
Macadamia	90
Mandarin	30
Mango	90
Nectarine	60
Onion	100
Orange	30
Papaya	20
Peach	60
Peanut	10
Pear	50
Plum and prune	70
Pumpkin	90
Strawberry	40
Watermelon	70

a Dependence on honey bees reports the relationship between crop production and honey-bee pollination services. Removal of all honeybees would see pollination and hence product supply decline by the reported figure.

Source: Gill (1989).

The remaining crops would experience only a drop in output that would vary with their dependence on honey bees. For instance, if honey bees were completely wiped out, the supply curve for strawberries would shift to the left by 40%.

This shift in the supply curve occurs because the bees form an integral part of production for these crops. Even if the pollination services are now provided by managed services, the supply curve will still shift due to the fact that now this input has increased in price.

Calculating the potential losses (component 1)

Gordon and Davis (2003) developed a model to calculate the loss of producer surplus for the 37 crops listed in Table E2. We have used this model and supplemented it with a simple model of the honey-bee industry using the typical supply-shift framework.

Depending on the size of the initial shock—which we assume varies from 10–20% of the dependence factor in Table E2, the loss of producer surplus would range from \$178 million to \$357 million (in present value terms). This figure needs to be adjusted to account for a number of other factors including:

- the time of the incursion (i.e. how many years from now)
- the duration of the initial impact
- the ongoing costs of the initial incursion
- the underlying growth rate of the industry.

Figure E1 illustrates these factors using two scenarios, one with an incursion and one without. The continuous curve in the chart shows the 'without incursion', or baseline case, while the other curve shows what would happen in the event of an incursion.

During the pre-incursion period, the two curves are the same but after the incursion they diverge. At this point the supply curves of the crops and honey-bee related products all shift according to their dependence on bees and the degree to which the population of bees is affected. Some time will pass before farmers and beekeepers can adjust to the incursion, so there will be a period during which the incursion will have a quite-marked effect on production costs and hence producer surplus. After this period, production will recover, but producer surplus will always be lower due to the higher

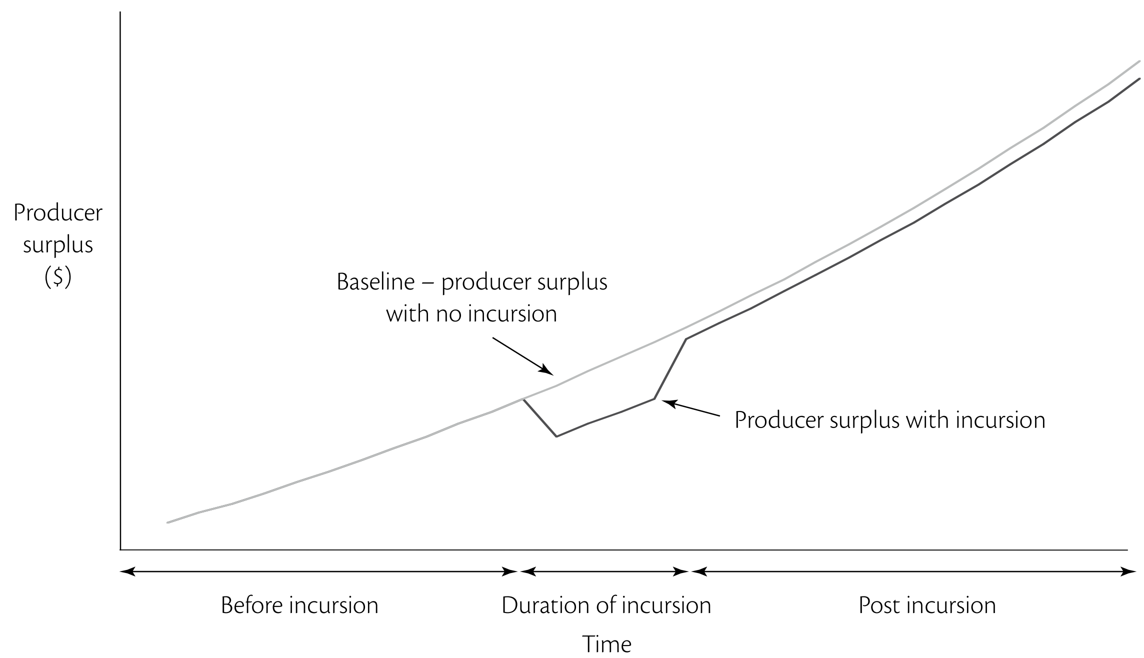


Figure E1. Illustrating the change in producer surplus production costs. The cumulative difference between the two scenarios is the net present value of the potential losses incurred by the establishment of the mite.

The nature of such events means that there is a degree of uncertainty surrounding the timing of the incursion, duration of the incursion, the amount of damage which persists after adjustment has taken place etc.

To model this, we have made a number of assumptions, the results of which are set out in Tables E3 and E4. Table E3 show the present value of the loss of producer surplus under alterative assumptions for the initial shock as well as persistence of the shock over time. For example, with an initial shock of 10%, the cost is $178 million, which converts to a total cost (over time) of $651 million if 10% of the initial shock is persistent, $782 million if 15% of the initial shock is persistent, and so on. The potential loss of producer surplus ranges from $651 million to $1.6 billion.

While Table E3 assumes a 6% growth rate of the horticultural industry (based on recent history), Table E4 shows the effect of different assumed growth rates (but holding persistence at 10%). It shows, for example, that lowering the growth rate from 6% to zero roughly halves the potential cost of the incursion.

Component 2: calculating the expected loss

The above analysis gives the potential loss of an incursion. The next step is to calculate the expected loss of an incursion, taking into account the probability of entry and subsequent responses to that entry.
For this we have applied the Markov-chain-based incursion assessment model (IAM) developed by the Centre for International Economics (CIE 2004). The Markov-chain approach depicts the world as a series of states in time, with the probability of arriving at each state dependent upon the state before it. This enables

Table E3. Loss of horticulture and honey producer surplus, assuming a 6% growth rate of horticulture

Initial shock	Percentage of shock that is persistent	Present value ($m) of potential cost of incursion
10% ($178m)	10	651
	15	728
	20	809
15% ($268m)	10	964
	15	1,092
	20	1,221
20% ($357m)	10	1,300
	15	1,456
	20	1,598

Source: CIE estimates

Table E4. Varying the growth rate, but holding persistence at 10%

Initial shock	Value ($m) at specified growth rate			
	0%	4%	6%	8%
10% ($178m)	249	463	651	912
15% ($268m)	378	694	964	1,377
20% ($357m)	501	925	1,300	1,854

Source: CIE estimates

various probabilities of arrival to be assigned to each state, depending on the path taken to get there. In the majority of cases to which such models have been applied there is a simple starting point and several possible end points. The unique characteristic of the approach taken by the CIE is that the model is recursive. Figure E2 explains the approach.

Currently, no mites are established in Australia so we begin with a pest-free starting point. At this stage there is a probability of the mite entering the country (*P1*), at which point we can either detect it early (*P2*) or late (*1 – P2*). Assuming we detect it early, there is then a probability that the mite can be eradicated (*P3*) or not (*1 – P3*). And so it goes until we end up at the right-hand side of the diagram in one of two states, either mite-free or with the mite established. At this stage, most implementations of the Markov chain would end but in reality this is not the case. If the mite becomes established, then the world as we know it has changed, but if we return to the pest-free state the model must be run again starting at the beginning, albeit at a later time, to be realistic. The CIE approach allows the model to be solved for an infinite period of time.

Knowing the expected cost when an incursion takes place (see above) we can solve this model backwards and obtain the expected costs in today's terms given the probabilities and other costs assigned to each stage.

The probabilities used for each point in the chain are summarised in Figure E3.

Outcomes of the research

ACIAR undertook a series of projects commencing in the early 1990s, the last of which was completed in 2001, with the main source of benefits accruing to Australia arising from the work done to reduce the probability of entry. The work was multifaceted and involved investigating a number of aspects of bees and mites. Table E5 provides an outline of the projects, the time frames in which they were completed and the total Australian contribution for each.

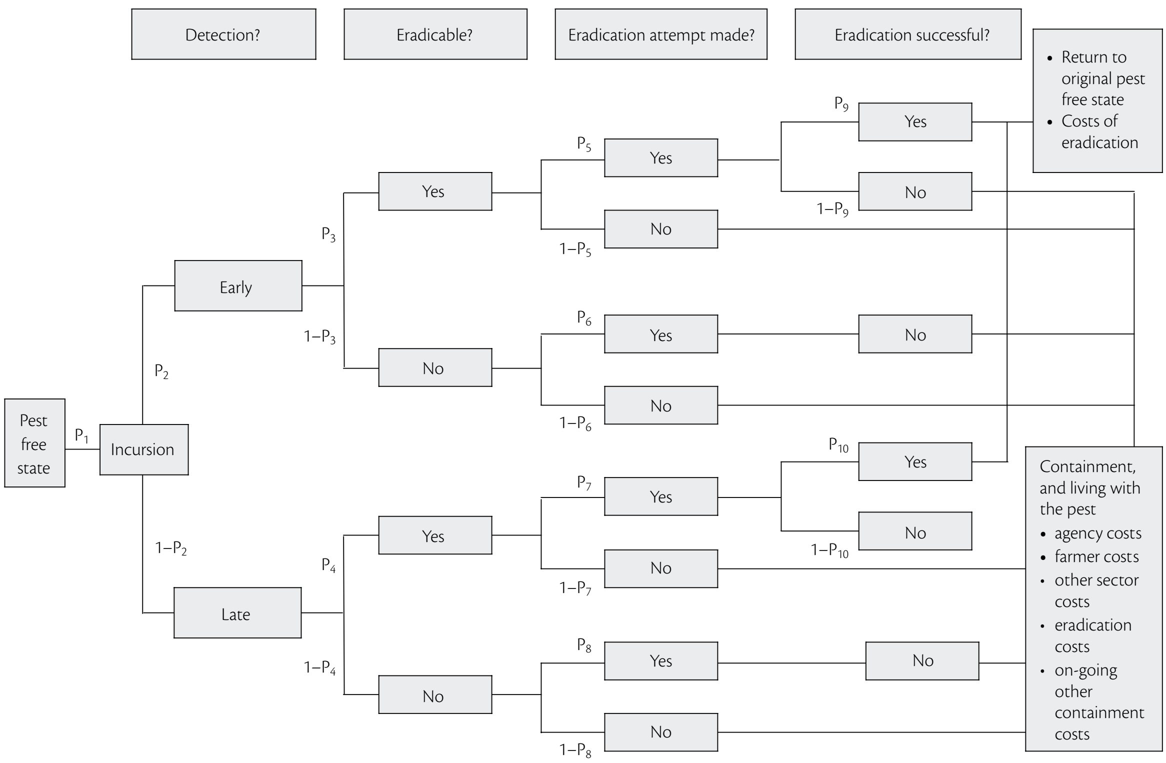


Figure E2. A Markov-chain approach to calculating expected costs

Probability	Value
Probability of entry – P1	0.02–0.99
Given entry:	
Probability of early detection – P2	0.7
Given early detection:	
Probability that mite is eradicable – P3	0.25
Given that mite is eradicable:	
Probability that eradication attempt is made – P5	0.95
Given that eradication attempt was made:	
Probability that eradication is successful – P9	0.5
Given that mite is not eradicable:	
Probability that eradication attempt is made – P6	0.9
Given late detection:	
Probability that mite is eradicable – P4	0.1
Given that mite is eradicable:	
Probability that eradication attempt is made – P7	0.95
Given that eradication attempt was made:	
Probability that eradication is successful – P10	0.5
Given that mite is not eradicable:	
Probability that eradication attempt is made – P8	0.9

Figure E3. Probabilities used in the model. Source: talks with Australian Department of Agriculture, Fisheries and Forestry

Table E5. ACIAR research projects on bees

Project Number	Project Title	Australian contribution ($)	Project start date	Project finish date
AS2/1990/028	Improved methods in the epidemiology and control of mites and other disease of bees in Papua New Guinea	442,248	01/01/91	30/06/94
AS2/1994/017	Control of bee mites in Irian Jaya	366,117	01/07/95	30/06/99
AS2/1994/018	Improved methods for bee development and control of bee mites in Papua New Guinea	491,966	01/07/95	20/06/99
AS2/1999/060	Control of bees and bee mites in Indonesia and the Philippines	567,156	01/07/01	30/06/05

Epidemiology

Researchers first sought to understand the epidemiology of the pests in question. This part of the research led to the redefinition of the *Varroa* complex into different genotypes: those that are harmless to the European honey bee—*V. jacobsoni;* and those that are fatal—*V. destructor*. It also enabled a better understanding of the reproductive cycles of *V. destructor*, *V. jacobsoni* and *T. clareae* mites. This latter part of the epidemiological studies showed that the mites required a 'signal' to trigger their reproductive cycle and that this trigger was provided by only certain bees. The presence of this signal in the European honey bee made them susceptible to infestation by the mites.

Defence

While the aim of the ACIAR research was primarily to assist the collaborating countries, a secondary objective was to prevent or reduce the probability of an incursion of the mite into Australia. Table E1 shows that bees have been found on ships entering Australian ports on several occasions, indicating there is a very real possibility of an incursion happening. Should the research outlined above not succeed in preventing entry, a suitable response strategy must be developed.

The research aided in the development of strategies to:

- educate those involved in the prevention of an incursion
- design protocols to deal with incursions should they occur
- introduce alternative pollinators that are not susceptible to the mites.

Impacts of the research

The impact that the research has had in terms of probabilities can be broken into two distinct components:

- perception
- reality.

Before the research it was perceived that all mites in the *Varroa* species-complex would be destructive to Australian bees but this was in fact untrue, as only a *destructor* strain is dangerous. Given the high incidence of *Varroa* being found in cargo, on board ships etc. the probability of entry has historically been estimated as quite high. The realisation that these mites were *jacobsoni* and therefore not a threat has not changed the reality but has altered the perception of reality thereby reducing the value assigned to *P1* in Figure E3. Recognition of the true probabilities offers justification for the reduction of resources dedicated to the prevention and detection of an incursion.[9]

The argument for reducing *P1* does not end here, however. Having more knowledge about the nature of the mites has also allowed a more effective allocation of resources in detecting the pest, thereby reducing the real probability of entry. The reallocation of resources together with a change in perception has reduced the risk category of *V. destructor* from 'high' to 'very low' as defined by Biosecurity Australia (2001).[10] This reduces the value of *P1* from around 0.85 to approximately 0.02.

The increased knowledge about the *Varroa* complex of mites also alters the response of appropriate authorities should an incursion take place. Suppose a mite-infected bee lands on Australian shores after journeying from a foreign port. If this bee is detected by the relevant authorities, a decision on the appropriate response will be made. If they believe (as was the case before the research) that all *Varroa* mites are dangerous, they will embark on a costly eradication program that may not be necessary. Since the research, the authorities have been able to correctly identify which mites are a threat and take action only when required. This concept is illustrated in Figure E4. In short, the research eliminates false positives.

9 This statement assumes that:
- resources are already adequately deployed based on existing beliefs about the probability of entry
- the current allocation of resources is based on the associated risk posed by the mite.

10 The probability values given here are based on personal communications with various experts in a number of government departments and agencies. No published estimates of these probabilities based on rigorous analysis are known to exist.

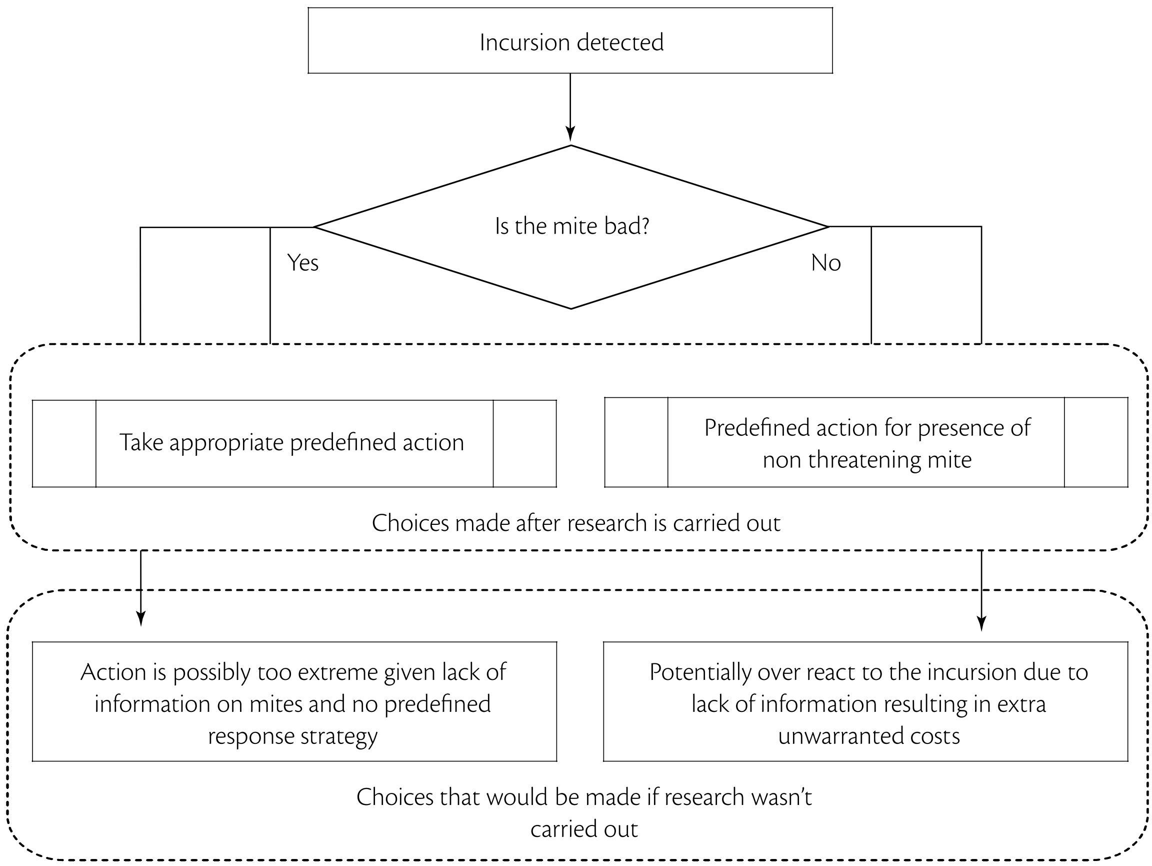


Figure E4. Decision tree

Baseline

Before the research was carried out, it was thought that the probability of a destructive mite from the *Varroa* complex entering Australia was around 0.85 when in fact it was closer to 0.04. Being more aware of the real probability allows a more realistic level of resources to be allocated to the detection of *Varroa*. In addition, those resources that are still allocated to mite detection can be more efficiently utilised and their effectiveness increased, further reducing the probability of entry.

In order to measure the effects of both portions of the research, two baselines will be considered—one with probability of entry of 0.85 and another with 0.04. The movement away from the first of these baselines, from 0.85 to 0.04, is considered as the benefit of recognising the true state of the world, while the remaining change can be attributed to actually altering the state of the world.

Each shock was applied simultaneously to all crops and bee-related products, resulting in an expected loss of producer surplus due to an incursion of $178 million, $268 million and $357 million for the 10%, 15% and 20% shocks, respectively. The baseline for the amount of residual damage, or lasting effect, of an incursion was set at 10%.

Recognising the true state of the world

Table E1 showed the number of incidents and incursions that have happened since the early 1970s. The number of instances in which *Varroa* was present is significant, but closer inspection of the data reveals that none of these involved the *destructor* strain. The realisation that the *jacobsoni* and *destructor* strains are distinct from one another allowed a reassessment of the probability of entry from around 0.85 to approximately 0.04.

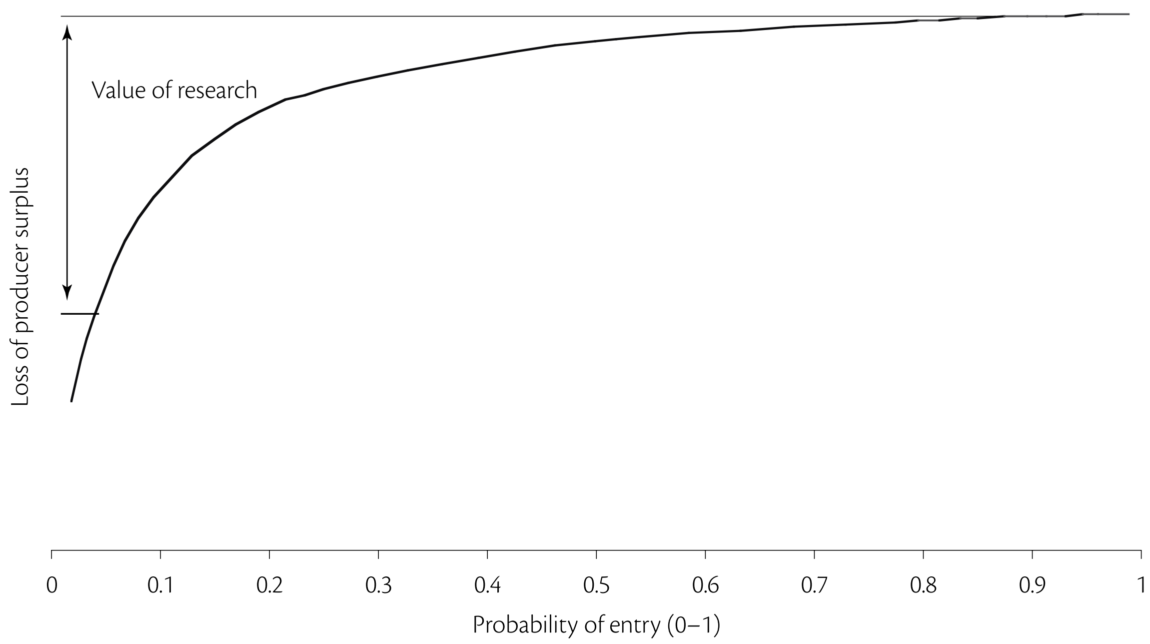


Figure E5. Relationship between probability of entry and loss of producer surplus

As Figure E5 shows, the relationship between the probability of entry and the expected loss of producer surplus is nonlinear. The value of the research can be deemed to be the reduction in the loss of producer surplus that is gained by reducing the probability of entry. At higher probabilities of entry, a larger change is necessary to achieve the same level of reduction in producer surplus than would be required at lower probabilities.

Reducing the probability of entry from 0.85 to 0.04 reduces the net present value of the expected loss of producer surplus by $14.5 million per year over a 30-year period. This represents a reduction of 56% suggesting that the resources devoted to detection of the *Varroa* mite could be approximately halved and put to more productive use elsewhere.

Better use of remaining resources

By offering a greater level of understanding about the bees, mites, and the likely methods by which an incursion might happen, the research has allowed for more effective allocation of resources dedicated to detection. This utilisation of the remaining resources in a more targeted and effective way may see the probability of entry reduce to approximately 0.02, representing a further saving of $4.2 million per year.

Sensitivity analysis

The probabilities and shocks used in the analysis have been chosen based on recommendations made by experts in their fields. Given the highly subjective nature of these recommendations and the surrounding uncertainties, these values were varied to test for sensitivity. Table E6 shows combinations of varying probability of entry and initial supply shock values.

From Figure E6 it is apparent that by doubling the initial shock the annual cost in terms of producer surplus is approximately doubled. Regardless of the supply shock applied, the nonlinear relationship between the probability of entry and the expected loss of producer surplus remains.

Sensitivity to other changes

Many changes will occur throughout the duration of the incursion, some of which may include:

- lower crop output levels
- increased production costs

Table E6. Effect on average annual cost ($ million) of changing the probability of entry

Probability of entry	10% initial shock	15% initial shock	20% initial shock
0.02	7.1	10.3	13.8
0.04	11.2	16.3	21.8
0.08	15.8	23.1	30.9
0.15	19.7	28.7	38.3
0.25	22.1	32.2	43.1
0.50	24.4	35.5	47.5
0.85	25.4	37.1	49.6
0.99	25.7	37.4	50.0

Source: CIE simulations

- higher costs of beekeeping
- introduction of more paid pollination services
- farms switching to non-bee-dependent crops.

All of these factors will contribute to ongoing costs, the end result being a lasting effect of the incursion. The amount of the initial shock that remains permanent will affect the producer surplus that is lost permanently.

The eradication costs applied in the model are estimates only; actual costs may differ. Testing for the sensitivity of the analysis to varying eradication costs reveals that the expected losses of producer surplus vary little with a change in eradication costs.

Table E7 shows the reduction in the loss of producer surplus for various scenarios assuming the probability of entry is reduced from 0.04 to 0.02. It shows that doubling the percentage of damage that is persistent

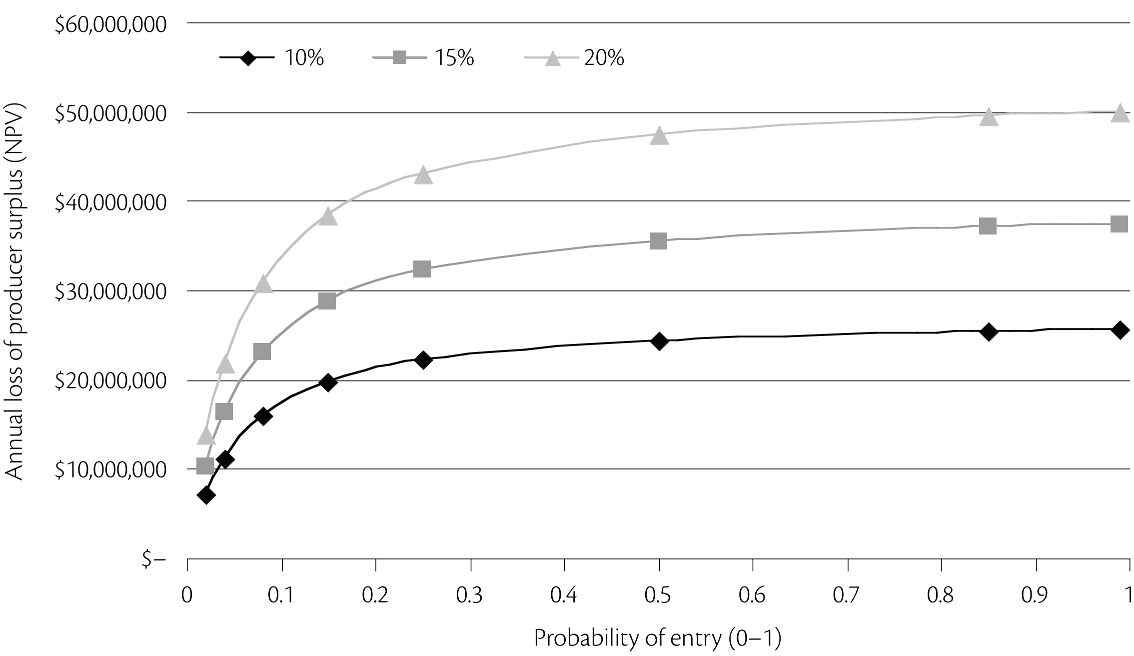


Figure E6. Relationship between probability of entry and loss of producer surplus. Data source: CIE simulations

Table E7. Changes in other factors, assuming a reduction in probability of entry from 0.04 to 0.02

Initial shock (%)	Percentage of shock that persists	Eradication cost ($m)				
		20	**40**	**60**	**80**	**100**
10	10	4.2	4.4	4.6	4.8	5.0
	15	4.6	4.8	5.0	5.3	5.5
	20	5.1	5.3	5.5	5.7	6.0
15	10	6.0	6.3	6.5	6.7	6.9
	15	6.8	7.0	7.2	7.5	7.7
	20	7.6	7.8	8.0	8.2	8.4
20	10	8.1	8.3	8.5	8.7	8.9
	15	9.0	9.2	9.4	9.7	9.9
	20	9.9	10.1	10.3	10.5	10.7

Source: CIE simulations

increases losses by approximately 21% in most cases. Similarly, a fivefold increase in eradication costs will result in only $0.8 million to $0.9 million in extra losses depending on the scenario.

Conclusions

Assuming the research has reduced the real probability of entry from 0.04 to 0.02, the change in expected loss of producer surplus has been reduced by $4.2 million annually. The research to date has incurred costs of only $1.87 million. Even if the research resulted in the probability of entry falling from 0.99 to 0.85, the reduction in the loss of producer surplus would still be $0.3 million per annum, enough to recover the initial research costs in 6.2 years.

The analysis shows the major benefits that accrue to Australia will arise from research that can further reduce the probability of entry or, alternatively, alleviate the damage caused by such an incursion. The results are not as sensitive to changes in either eradication costs or the amount of the initial shock that has a lasting effect, but work in these areas would still prove to be valuable.

Any research that affects all these variables simultaneously would clearly be of greater benefit than the research being investigated here. Short of developing a mite-resistant bee, however, this is unlikely, and so the research appears to have been a worthy use of the funds.

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