Impact assessment of the investment:

Protecting Australia's citrus genetic material (CT17008)

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Previous page image courtesy of Auscitrus 2023.

Disclaimer:

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Contents

Executive summary

What the report is about

Ag Econ conducted independent analysis determine the economic, social, and environmental impact resulting from delivery of the citrus project *Protecting Australia's citrus genetic material (CT17008)*. The project was funded by Hort Innovation over the period August 2018 to July 2021 using the citrus research and development levy and contributions from the Australian Government. The project was delivered by Auscitrus and NSW DPI.

The analysis applied a five step analytical process to understand the impact pathway and collect supporting data.

Review documents	Engage stakeholders	Map logical framework	Cost-benefit analysis	Discuss implications
Contracts	Hort Innovation	Activities	RD&E costs	So what?
Milestones	Researchers	Outputs	Adoption curve	
Final reports	Growers	Outcomes	Adoption benefits	
	Supply chain	Impacts	NPV, BCR, IRR, MIRR	

Research background

CT17008 continued the work of previous levy investments to support the long-term National Citrus Repository Program. The repository program maintained "foundation tree" clones of 124 public citrus varieties at two facilities in NSW. The program regularly screened for graft transmissible diseases, ensuring the industry had access to clean and true to type genetic material.

Key findings

The nominal investment cost of $0.55 million was adjusted for inflation (ABS, 2023) and discounted (using a 5% real discount rate) to a 2022-23 present value (PV) of costs equal to $0.73 million.

The analysis conducted a detailed evaluation of the CT17008 impact pathway through a logical framework, and a review of the available data to quantify the impact pathway. From this process the impacts were estimated for a reduction in CEVd risk that resulted from the citrus industries investment in CT17008.

The analysis estimated total expected benefits of $4.48 million (2022-23 present value (PV) using a 5% discount rate) accruing between 2024 and 2037. When compared to the total funding from all sources of $0.73 million (2022-23 PV) between 2019 and 2022, the results showed a positive RD&E impact with a net present value (NPV) of $3.75 million, an estimated benefit-cost ratio (BCR) of 6.17 to 1, an internal rate of return of 29% and a modified internal rate of return of 11%.

Sensitivity analysis tested the results for uncertainty around the underlying variables, which was particularly important given the future projections conducted in the analysis. As expected, this sensitivity testing showed a potentially wide range in the results reflecting with a BCR ranging from less than 1.6:1 and 18.3:1 across 1000 simulations of the model.

This sensitivity testing gave a high level of confidence in a positive impact being generated; however, it is also important to consider that the results only quantified one of the identified impacts (decreased risk from CEVd) with the Repository actively screening for citrus graft-transmissible pathogens including viroids (8), viruses (6) and bacteria (3), each of which have the potential to cause damage to Australian citrus production to varying degrees. Of these, stakeholders highlighted the particularly importance of the Repository in reducing the risk of the exotic disease Huanglongbing (HLB), and the endemic diseases CEVd and Citrus tristeza virus (CTV). However, through the evaluation of the impact pathway for these diseases, sufficient data was only available for to value the reduction in CEVd risk faced by citrus growers. Similarly, the logical framework identified additional socio-economic impacts that were not able to be quantified due to data limitations. Given that only one of several impacts was able to be quantified in this analysis, the results represent a conservative estimate of impact.

The key findings of the CT17008 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment, cost-benefit analysis, citrus; biosecurity; germplasm; repository; budwood; graft-transmissible disease

Figure 1. Summary of impact assessment findings

CT17008 Citrus genetic material

RD&E activities

Total RD&E costs:

- $0.55 million (nominal value)
- 53% R&D levy and Government matching, and 47% Auscitrus and NSW DPI in-kind.

Research activities:

- Two New varieties screened and added to the National Citrus Repository, increasing the facility holdings to 124 public citrus varieties.
- Maintain high health status foundations trees, with scheduled testing for key graft transmissible pathogens including viroids (8), viruses (6) and bacteria (3).

Extension activities:

- Updated Citrus Plant Protection Guide 2020
- 3 x presentations at industry field days and technical forums
- 2 x articles in citrus industry news and newsletters.
- 3 x conference presentations / publications
- 1 x Scientific paper

Outcomes

Outcomes:

- Maintained and expanded the quality and depth of industry genetic resources.
- Increased stakeholder awareness and knowledge of graft transmissible diseases, and the importance of using health-tested and true-to-type budwood to minimise exotic and established disease threats.
- Improved research and response capacity through the maintenance of scientific knowledge and industry expertise in citrus diseases.

Industry adoption:

- An estimated 70% to 80% of citrus plantings use clean and true to type material sources from the Repository Program (through the Budwood Propagation Scheme).

Impacts

Industry economic impacts:

- Reduced risk of productivity losses and cost of replanting from the introduction and spread of graft transmissible diseases.

Environmental impacts:

- Reduced risk of higher chemical usage to manage insect vectors associated with some graft transmissible diseases.

Social impacts:

- Continued supply of affordable citrus for consumption, and community spillover benefits from a profitable citrus industry.

Total attributable benefits and impact:

- Present value (PV @ 5% discount) RD&E costs of $0.73 million.
- PV estimated benefits of $4.48 million between 2024 and 2037.
- Net PV (NPV) of $3.75 million.
- Benefit cost Ratio (BCR) of 6.17:1 with a 90% confidence of a BCR between 3.1:1 and 11.0:1

Introduction

Evaluating the impacts of levy investments is important to demonstrate the economic, social and environmental benefits realised through investment to levy payers, Government and other industry stakeholders. Understanding impact is also an important step to inform the ongoing investment agenda.

Reflecting its commitment to continuous improvement in the delivery of levy funded research, development and extension (RD&E), Hort Innovation required a series of impact assessments to be carried out annually on a representative sample of investments of its RD&E portfolio. Commencing with MT18011 in 2017-18, the impact assessment program consisted of an annual impact assessment of 15 randomly selected Hort Innovation RD&E investments (projects) each year. In line with this ongoing program, Ag Econ was commissioned to deliver the *Horticulture Impact Assessment Program 2020-21 to 2022-23* (MT21015).

Protecting Australia's citrus genetic material (CT17008) was randomly selected as one of the 15 investments in the 2021-22 sample. This report presents the analysis and findings of the project impact assessment.

The report structure starts with the general method of analysis used, followed by the RD&E background and an outline of the impact pathway in a logical framework, then describes the approach used to quantify the identified costs and benefits including any data gaps and limitations to the analysis, presents the results including from the sensitivity analysis, and finally discusses any implications for stakeholders.

General method

The impact assessment built on the impact assessment guidelines of the CRRDC (CRRDC, 2018) and included both qualitative and quantitative analysis. The general method that informed the impact assessment approach is as follows:

1. Review project documentation including project plan, milestone reports, outputs and final report.
2. Discuss the project delivery, adoption and benefits with the Hort Innovation project manager, project researcher/consultant, growers and other relevant stakeholders (see *Stakeholder consultation*).
3. Through a logical framework, qualitatively map the project's impact pathway, including activities, outputs, and outcomes to identify the principal economic, environmental, and social impacts realised through the project
4. Collect available data to quantify the impact pathway and estimate the attributable impacts using cost-benefit analysis (over a maximum 30 years with a 5% discount rate), and then sensitivity test the results to changes in key parameters.
5. Discuss the implications for stakeholders.

Contracts	Hort Innovation	Activities	RD&E costs	So what?
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	Supply chain	Impacts	NPV, BCR, IRR, MIRR	

The analysis identified and quantified (where possible) the direct and spillover impacts arising from the RD&E. The results did not incorporate the distributional effect of changes to economic equilibrium (supply and demand relationships) which was beyond the scope of the MT21015 impact assessment program. A more detailed discussion of the method can be found in the *MT21015 2021-22 Summary Report* on Hort Innovation project page [Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015)](#).

A Stakeholder Case Study was developed to compliment this impact assessment and illustrate how the identified impacts have been realised in a practical setting. The Case Study can be accessed via the Hort Innovation project page as above.

Project background

The Australian citrus industry —including oranges, mandarins, lemons and grapefruit— had a farmgate production value of $0.9 billion in 2021-22, making it the second highest value fruit industry behind berries. In 2022, the citrus industry had approximately 1500 growers across key growing regions in the Riverland (South Australia (SA)), Murray Valley (Victoria (Vic) and New South Wales (NSW)), Riverina (NSW), and the Central Burnett (Queensland (QLD)) (Hort Innovation 2022a).

Being relatively free from pests and diseases has provided Australian citrus producers with a competitive advantage relative to other major producers, both in terms of production costs and market access. As such, minimising biosecurity risk was identified as a priority outcome (Outcome 2) for the citrus industry in its Strategic Investment Plan (SIP) 2017-2021 (Hort Innovation 2017) to protect the industries competitiveness and profitability, with a key focus area being the prevention of the spread of diseases through budwood (in Strategy 2.1 *safeguard the Australian citrus industry from future biosecurity and phytosanitary risks throughout the value chain*).

Graft-transmissible diseases are spread by propagating infected plant material (e.g. budwood); mechanically through the use of infected cutting tools during grafting, pruning and hedging; and in some cases by aphids or other insect vectors. Major graft-transmissible citrus diseases, such as huanglongbing (HLB), are not known to occur in Australia (at the time of writing); however, there are several endemic graft transmissible viruses and viroids that can cause stunting, yield loss and even death in some scion and rootstock combinations. There is no cure for graft transmissible diseases hence the importance of ensuring that disease-free, true-to-type propagation material is available to prevent incurable diseases from entering citrus nurseries and orchards.

Australian quarantine managed by the federal Department of Agriculture, Water and the Environment (DAWE) significantly reduces the risk of entry of graft-transmissible diseases into Australia. Graft-transmissible citrus diseases are managed within Australia by:

- Surveillance programs for early detection to increase the chance of eradication.
- The post-entry quarantine system managed by DAWE where newly imported citrus varieties undergo pathogen elimination and testing for exotic and endemic plant pathogens before release.
- The National Citrus Repository Program where foundation trees of commercial citrus varieties are maintained in biosecure repositories and tested for citrus pathogens.
- The citrus budwood propagation scheme, managed by a non-profit industry organisation (Australian Citrus Propagation Association) that supplies high health status, true-to-type budwood and rootstock seed to nurseries for tree production.

CT17008 was undertaken to continue the work of previous levy investments to support the long-term National Citrus Repository Program.

Project details

CT17008 provided funding to Auscitrus from 2018 to 2021 (Table 1).

Table 1. Project details

Project code	CT17008
Title	Protecting Australia's citrus genetic material
Research organization(s)	Australian Citrus Propagation Association Incorporated (Auscitrus) (lead) New South Wales Department of Primary Industries (NSW DPI) (supporting)
Project leader	Tim Herrmann (Auscitrus)
Funding period	August 2018 to July 2021
Objective	Maintain a high health status, genetic resource of citrus material of public varieties.

Logical framework

The impact pathway linking the project's activities and outputs, and their assessed outcomes and impacts have been laid out in a logical framework (Table 2).

Table 2. Project logical framework detail

RD&E activities

New varieties

- Two new varieties were added to the Auscitrus repository based on commercial potential assessed by Auscitrus or community/industry interest.
    - 1 x imported mandarin variety (Shiranui) added in 2020 following propagation and processing at the Australian Post Entry Quarantine Facility managed by the Federal Government.
    - 1 x local pomelo variety (K15) added in 2019 following propagation and processing by the Citrus Pathology Team at the NSW Department of Primary Industries' Elizabeth Macarthur Agricultural Institute (NSW DPI EMAI) at Menangle.
- New varieties were tested for citrus pathogens using biological, serological and molecular methods.
- New varieties underwent shoot-tip grafting and heat treatment to remove detected pathogens and the shoot-tip plantlets were then re-tested for pathogens.
- The disease-free varieties were then included in the National Citrus Repository program.
- The disease-free mother tree, and a daughter tree propagated using a bud from the mother tree, were placed in the insect-screened greenhouses at the Dareton (Auscitrus) and (EMAI) NSW DPI facilities to protect the trees from insects potentially carrying diseases.

Repository maintenance

- A minimum of 1 tree of each variety was held at the Dareton (Auscitrus) and (EMAI) NSW DPI facilities. Using best practice, CT17008 maintained "foundation tree" clones of 124 public varieties across orange (49), mandarin (40), lemon (10), grapefruit (9), papeda (5), pomelo (3), citron (3), lime (2), kumquat (2), and rootstock (1).
- 9 white grapefruit varieties were also contained within the 'National Repository for Inoculated Citrus Clones'. These trees were inoculated with a mild isolate of CTV. This mild isolate serves to protect against more severe isolates of the virus that may be introduced to trees in the field by aphid vectors.
- Trees undergo scheduled testing for key graft transmissible pathogens.
    - Citrus tristeza virus (CTV). Every tree tested annually in autumn or spring.
    - Citrus viroids. Trees tested on a five year schedule for eight known citrus viroids: citrus exocortis viroid (CEVd), citrus bent leaf viroid (CBLV or CVd-I), hop stunt viroid (HSVd or CVd-II (cachexia)), citrus dwarfing viroid (CDVd or CVd-III), citrus bark cracking viroid (CBCVd), citrus viroid V (CVd-V), citrus viroid VI (CVd-VI) and the recently discovered citrus viroid VII (CVd-VII). These viroids were on a lower testing frequency as they are not transmitted by insect vectors and were therefore deemed to have a lower risk.
    - Citrus tatterleaf virus (CTLV). Tested on a five year schedule.
    - Citrus leaf blotch virus (CLBV). Tested on a five year schedule.
    - Citrus concave gum associated virus (CCGaV) and citrus virus A (CiVA). Newly identified during the project, with first tests undertaken
    - Huanglongbing (HLB). Trees are tested for causal agents '*Candidatus* Liberibacter asiaticus' (CLas), 'Ca. L. americanus' (CLam) and 'Ca. L. africanus' (CLaf) on a five year Schedule.

Propagation

- Small quantities of budwood from the foundation trees were used by Auscitrus to create daughter trees and multiply large numbers of buds for industry. This propagation and distribution is funded through budwood sales at $0.60/tree (Stakeholder consultation).

Quality assurance

RD&E activities

- The EMAI repository is accredited as a New Zealand Ministry of Primary Industries (NZ MPI) offshore quarantine facility for the introduction of new citrus varieties to NZ. A re-accreditation audit was undertaken by NZ MPI in December 2020.
- The Auscitrus nursery facility that houses the Dareton repository is accredited under the Nursery and Garden Industry NIASA program (Nursery Industry Accreditation Scheme Australia), audited annually by independent nursery industry auditors.

Extension and communication

- Extension activities undertaken throughout the project (in conjunction with the industry communication project CT18000) included the production of articles for scientific and industry Academic, industry publications, and presentations at the industry forums.

RD&E outputs

- **1 x final report** on the Hort Innovation website.
- **1 x Scientific paper:** Chambers GA, Bogema DR, Englezou A, Donovan NJ. 2020. First Report of Citrus viroid V and Citrus viroid VI in Australia infecting Citrus. Plant Disease DOI10.1094/PDIS-12-19-2662-PDN. Cited by 3 as of June 2023.
- **3 x Conference publications**
  - Donovan N, Herrmann T, Hancock N. 2019. On the frontline: preparing for the arrival of HLB in Australia [abstract]. Journal of Citrus Pathology 6(1): 60
  - Chambers G, Englezou A, Webster J, Bogema D, Donovan N. 2019. Using Next generation sequencing (NGS) to characterize Australia's living pathogen collection [abstract]. Journal of Citrus Pathology 6(1): 4-5
  - Chambers GA, Donovan NJ, Bodaghi S, Jelinek SM, Vidalakis G. 2018. Citrus viroid VII, a novel citrus viroid found in Lisbon Lemon in Australia. International Conference on Viroids and Viroid-like RNA, Valencia Spain 5-7th July 2018 p 33
- **Update citrus plant protection guide 2020**
- **1 x HLB update at Citrus Connect**
- **1 x Australian Citrus News**
- **1 x Citrus Australia newsletter**
- **3 x Presentations** at WA Citrus Industry Day (2018) and WA and SA Citrus Technical Forums (2018 and 2019)

Outcomes

The key end of project outcome for CT17008 (with the separately funded Auscitrus propagation scheme) was in supporting nursery and grower adoption (propagation and planting) of clean and true to type citrus varieties by providing the necessary resources, and knowledge, and informing expectations with regards to agronomic and disease outcomes.

- **Maintained and improved industry genetic resources**. No CTV was detected in foundation trees in the 'National Citrus Repository for High Health Status Citrus Clones'. All trees in the 'National Repository for Inoculated Citrus Clones' tested positive for CTV each year from 2018 to 2021 (thus indicating successful inoculation). As such, the Australian citrus industry maintained and improved the high health status genetic resource of 124 public citrus varieties. Thereby providing an important resource for:
  - Distribution through citrus budwood propagation scheme (a separate Auscitrus program).
  - Other RD&E such as rootstock breeding (CT18004) and varietal breeding (CT21001).
  - Safeguarding a diverse range of genetic material in a secure backup facility, enhancing Australia's agricultural and food security and resilience.

Outcomes

- **Increased knowledge, awareness and capacity to adopt**. Extension activities undertaken throughout the project (in conjunction with industry communication project CT18000) increased stakeholder awareness and knowledge of graft transmissible diseases, and the importance of using health-tested and true-to-type budwood to minimise exotic and established disease threats. It was estimated that 75% to 80% of newly planted trees were sourced from the Auscitrus facility over the project (Stakeholder consultation).

The project also generated intermediate outcomes by supporting future, and overseas RD&E.

- **Research and response capacity.** The project funded four staff, supporting ongoing research capacity into future citrus propagation, evaluation, and screening. These staff also provided additional capacity in the event of a serious biosecurity outbreak.

Overseas outcomes. As an offshore quarantine facility for the introduction of new citrus varieties to New Zealand, the EMAI facility also supported the management of biosecurity risk for the NZ citrus industry.

Impacts

By providing nurseries and growers access to an expanded selection of clean and true to type citrus varieties CT17008 (in conjunction with the separately funded Auscitrus propagation scheme) reduced the risk posed by graft transmissible diseases, specifically:

- [Economic] Avoided orchard revenue losses, including from reduced plant productivity, and decreased marketable yield from graft transmissible diseases or incorrect varieties.
- [Economic] Avoided orchard and nursery cost increases from additional management practices including removing and replanting disease affected trees or incorrect varieties. With clean planting material there are also avoided increases in ongoing pest-management costs (for diseases spread by insect vectors); costs of supply-chain regulation and compliance; and regional and national costs of containment and eradication.
- [Economic] Avoided international and domestic market access issues from movement bans imposed on the affected areas (DAFF 2011 and PHA 2015).
- [Social] Avoided loss of fresh and affordable domestic citrus, resulting in decreased citrus consumption (FDC 2015) and a decline in associated health and wellbeing benefits (CSIRO 2003)
- [Socio-economic] Avoided loss of industry spillovers that would result from a decline in the citrus industry as a source of employment and economic stimulant to local communities (The CIE 2023).
- Avoided health and wellbeing costs to farm staff including psychological stress and strains on business and community relationships related to biosecurity events (CSIRO 2020 and CSIRO 2021)
- [Environmental] Avoided environmental impacts that would result from increased chemical use to manage the spread of disease insect vectors (Barkley and Beattie 2013, and Australian Gov. 2021).

Project costs

The project was funded by Hort Innovation, using the citrus research and development levy and contributions from the Australian Government, with additional funding from research partners Auscitrus and NSW DPI (Table 3). Overhead costs were added to the direct project cost to capture the full value of the RD&E investment.

Nominal investment

Table 3. Project nominal investment

Year end 30 June	Hort Innovation project costs ($)	Hort Innovation overheads[1] ($)	Other funding ($)[2] (includes overheads)	Total nominal cost ($)
2019	82,843	13,056	86,533	182,431
2020	87,894	15,773	91,809	195,476
2021	29,000	4,746	30,292	64,038
2022	49,934	8,256	52,158	110,348
Total	**249,671**	**41,832**	**260,791**	**552,294**

1. The overhead and administrative costs were calculated from the Financial Operating Statement of the Citrus Fund Annual Reports, averaging 16.7% for the CT17008 funding period (2019-2022).
2. Other funds from Auscitrus and NSW DPI included in-kind salaries of key staff. These were provided in the contract as a lump sum, so have been apportioned yearly based on Hort Innovation cash costs.

Present Value of investment

The nominal total investment cost of $0.55 million identified in Table 3 was adjusted for inflation (ABS, 2023) into a real investment of $0.63 million (2022-23 equivalent values). This was then further adjusted to reflect the time value of money using a real discount rate of 5% (CRRDC 2018), generating a present value (PV) of costs equal to $0.73 million (2022-23 PV). The results were sensitivity tested changes in the discount rate between 2.5% and 7.5%.

Project impacts

The impact pathways identified in Table 2 were evaluated against available data to determine if their impact could be quantified with a suitable level of confidence.

Data availability to quantify the impact pathways

Reduced risk of planting incorrect varieties (budwood) (rootstock not included until follow on project CY19004)

A clear impact pathway was identified for this impact. Without true-to-type material provided to the industry, there would be an increased risk of planting incorrect varieties as growers sources budwood from unverified material. Risk can be broken down into likelihood and consequences. Likelihood refers to the probability of occurrence, e.g. 1/X planted trees may be the wrong variety without verified true to type material. The consequences of planting a wrong variety include costs relating to tree removal and replanting once the error is identified. As trees take several years to mature and the variety becomes clear there will also be a cost in terms of lost productivity. Data on consequences is available from industry gross margins (e.g. NSW DPI 2018), however, there was no data identified for the change in likelihood of planting incorrect varieties (i.e. with and without the CY17008 repository and associated budwood scheme). Stakeholders identified some examples of incorrect varieties being planted from an unverified source, but were not confident to give an estimate of the change in likelihood. Given the lack of data, this impact was not quantified.

Reduced risk of graft transmissible diseases spreading through industry

Modelling biosecurity risk, and risk reduction, requires data for three key variables.

1. Likelihood of disease (and any vector) entry and establishment. Likelihood of entry considers the potential pathways for disease and vector into a given citrus production area (natural and as a result of human activity) while also considering existing control methods (e.g. national, state, regional, or farm-specific quarantine measures to prevent incursion). Likelihood of disease (and any vector) establishment. Establishment considers whether the disease and vector, upon entering into a production region, has the potential to establish a viable population. Establishment is primarily based on an assessment of climatic and environmental factors.
2. Likelihood of disease and vector spread. This reflects a combination of dispersal mechanisms, availability of hosts, vector presence, industry control measures and geographic and climatic barriers. Industry practices include the use of clean material (through the CT17008 Repository and associated Auscitrus Budwood Scheme), scouting and removal of infected trees, and scouting and control of vectors (such as through chemical control). The availability of clean material through the Repository reduces the likelihood of spread by eliminating a key dispersal mechanism (sale and propagation of infected material). For graft transmissible diseases that are also vector spread (such as HLB, and CTV-OSP) the contribution of the Repository in reducing the likelihood of spread is lower than for non-vector spread diseases.

3. Consequences of disease and vector spread. The consequences of key graft transmissible diseases are well documented for both exotic diseases such as HLB and endemic diseases such as CTV OSP and CEVd (Bevington and Bacon 1977, NSW DPI 2006, DAFF, 2011 and PHA, 2015). Direct farm consequences include lost productivity (plant vigour, gross yield, and marketable yield), increased costs of vector control including chemical applications, increased scouting costs, costs associated with the removal and replanting of infected trees, and market access disruption.

Discussions with stakeholders identified HLB (exotic), and CTV-OSP and CEVd (endemic) as the diseases where the Repository was likely generating the greatest risk reduction impact. While the data on the likehood of entry, establishment and spread was identified for key exotic diseases such as HLB (PHA 2015 and DAFF 2011), the data for endemic diseases is more limited. While CTV-OSP is endemic in Australia, it is currently contained within QLD, and has so far been kept out of the key orange growing regions of Southern Australia. As such, data on likelihood of entry, establishment, and spread are required to understand the risk of CTP-OSP for these areas. Further, for the purposes of quantifying the impact of CT17008, the modelling needs to consider the marginal contribution of clean material (i.e. the repository) to mitigating the risk. While clean planting material is identified as a control mechanism (e.g. PHA 2015 and DAFF 2011) the marginal contributions of individual control mechanisms were not identified in either an Australian or international context. Further, given the complexities of vector spread diseases, the marginal contribution of clean material could not be confidently estimated in this impact analysis. In contrast, while data on the marginal contribution of clean planting material was also not available for CEVd, the decreased complexity of non-vector spread graft transmissible diseases meant that the marginal contribution of clean planting material (being the primary means of spread), combined with estimates on likelihood provided by industry stakeholders, meant that the margin contribution of the Repository to decreased CEVd risk could be confidently estimated through this impact assessment.

Impacts valued and valuation framework

In line with the above, a model was developed to estimate the reduction in CEVd risk, incorporating the above three risk variables. The model incorporated the following specific impacts of CEVd.

- [Economic] Avoided orchard revenue losses, including from reduced plant productivity, and decreased marketable yield.
- [Economic] Avoided orchard cost increases from additional management practices including removing and replanting disease affected trees or incorrect varieties.

Impacts unable to be valued

Additional economic impacts were not quantified as they were not found to be as relevant to CEVd relative to other graft transmissible diseases and associated vectors (particularly HLB and its vectors).

- [Economic] Avoided costs of supply-chain regulation and compliance; and regional and national costs of containment and eradication.
- [Economic] Avoided international and domestic market access issues from movement bans imposed on the affected areas (DAFF 2011 and PHA 2015). Market access was not identified as a significant issue for CEVd.

The social and environmental impacts identified through the logical framework could not be quantified for the following reasons.

- [Social] Avoided loss of fresh and affordable domestic citrus, resulting in decreased citrus consumption and a decline in associated health and wellbeing benefits. The spread of HLB in the United States was identified as a key factor in reducing citrus consumption (FDC, 2015). The health benefits of citrus consumption are well documented e.g. (CSIRO 2003); however, there was insufficient data linking citrus unit consumption (e.g. Servings or kg per year) with specific health outcomes and their associated healthcare and productivity costs (e.g. an X% reduction in the incidence of heart disease with an associated annual healthcare cost of $X million per year and productivity cost of $X million per year).
- [Socio-economic] Avoided loss of industry spillovers that would decline as in the citrus industry as a source of employment and economic stimulant to local communities. The CIE (2023) highlighted the flow-on (spillover) effects of the citrus industry as a source of employment and economic stimulant to regional communities. By supporting increased industry productivity and sustainability, CT17008 supports a corresponding increase in spillovers to local communities. While this analysis quantified the direct impacts for citrus industry production and value, the flow-on effects require additional analysis using economic models that capture regional and national linkages, which are beyond the scope of the R&D impact assessment program (CRRDC 2018). Increased resilience also relates to avoided health and wellbeing costs associated with biosecurity events. These health and wellbeing effects, such as avoided or reduced psychological stress that can affect growers and their communities, may be more profound than the direct

economic impact (CSIRO, 2020 and CSIRO 2022). The CSIRO research also noted that health and wellbeing affects are harder to quantify than economic impacts, which is consistent with the lack of data identified through this analysis.

- [Environmental] Avoided environmental impacts that would result from increased chemical use to manage the spread of disease insect vectors. Use experiences in attempting to slow the spread of HLB have included increased chemical sprays of 74% to 94% in an attempt to control the insect vector populations (Barkley and Beattie 2013). There is a recognised link between farm chemical use and harmful off-target effects on rivers, the ocean, the atmosphere, animals and plants if not managed safely (Australian Gov. 2021). A reduced need for pesticides to manage insect vectors reduces these potential environmental impacts. However, no data was identified to link per unit changes in chemical use with a quantifiable unit change in environmental quality, so this impact was unable to be valued.

Data and assumptions

The required data relating to the impact pathway was collected from the project documents and other relevant resources (Table 4). Where available, actual data was applied to the relevant years, with estimates applied for any data gaps and projections into the future based on analytical techniques (for example correlations and trend analysis), or stakeholder estimates, or both. A data range was incorporated to reflect underlying risk and uncertainty. This was particularly relevant where estimates were needed due to data gaps, and where projections were made into the future. These ranges were then analysed through sensitivity testing (see *Results*).

Table 4. Summary of data and assumptions for impact valuation

Variable	Value	Source & comment
General data and assumptions		
Discount rate	5% (± 50%)	CRRDC Guidelines (2018)
Annual Plantings Navel Orange (ha)	414 (± 29%)	The Australian Citrus Tree Census (2021) shows 13% of 11,253 ha being 0-4 years = average 293 ha per year (used as the lower range). The NSW DPI (2018) GMs show typical tree age of 21 years. Assuming uniform replacement of 1/21 over 11,253 ha gives 536 ha replacement annually (upper range). With the average of these used in the baseline.
Annual Plantings Valencia Orange (ha)	236 (± 29%)	The Australian Citrus Tree Census (2021) shows 13% of 6408 ha being 0-4 years = average 167 ha per year (lower range). The NSW DPI (2018) GMs show typical tree age of 21 years. Assuming uniform replacement of 1/21 over 6408 ha gives 305 ha replacement annually (upper range). Average midpoint.
Annual Plantings Mandarin (ha)	397 (± 6%)	The Australian Citrus Tree Census (2021) shows 27% of 1787 ha being 0-4 years = average 422 ha per year (lower range). The NSW DPI (2018) GMs show typical tree age of 21 years. Assuming uniform replacement of 1/21 over 1787 ha gives 372 ha replacement annually (upper range). Average midpoint. Sub-varieties are not specified.
Auscitrus budwood propagation scheme adoption (% plantings)	78% (± 3%)	Proportion of industry plantings that are drawn from the Repository (through the Auscitrus budwood propagation scheme) (Auscitrus and Nursery consultation)
Fruit price Navel Orange ($/t)	493 (+30% & −54%)	NSW DPI (2022) GMs and consultation with NSW DPI Citrus Development Officer.
Fruit price Valencia Orange ($/t)	256 (+53% & −45%)	NSW DPI (2022) GMs and consultation with NSW DPI Citrus Development Officer.
Fruit price Imperial Mandarin ($/t)	496 (+51% & −29%)	NSW DPI (2018) GMs and consultation with NSW DPI Citrus Development Officer.
Fruit price Afourer Mandarin ($/t)	661 (+36% & −24%)	NSW DPI (2018) GMs and consultation with NSW DPI Citrus Development Officer.
GM budget yields and costs	Various	NSW DPI GM budgets for Navel and Valencia oranges (2022), and for Imperial and Afourer mandarins (2018) adjusted with updated citrus prices as above.
R&D Counterfactual attribution	75% (± 33%)	Levy funding for the Repository was not provided for 2009-2010, which was instead funded through Auscitrus voluntary contributions (CT09002). During that period the Repository continued to operate, but with reduced services that were not considered sustainable (financially

		or from a disease risk perspective) in the long run (Stakeholder consultation). It is possible, but not likely, that the repository could have operated without levy funding for the period covered by CT17008, which would likely have resulted in reduced services and outcomes.
Reduced risk of planting and replanting infected trees		
Without Repository likelihood of disease material	15% (+29% -14%)	No data or quantified estimates were identified for the potential risk of graft transmissible diseases without a Repository program. Stakeholders stated that the risk would be "moderate to very high". A baseline risk was calculated based on 70% likelihood of infection among non-certified trees tested at 60% and 90%. E.g. with 78% of industry using clean material from the Repository, the baseline disease risk would be (1-78%) x 70%= 15%. If the repository were no longer available, the risk would grow by the rate of annual (unclean) plantings. E.g. with a uniform replanting rate of 4% of total industry plantings per year the risk grows by 5% x 70% = 3% per year, to a new risk level of 16%+3%=19% in year 2, then 19%+3% = 21% in year 3 etc.
With Repository likelihood reduction	90% (± 10%)	No official data or estimates were identified for the contribution of the Repository in reducing the risk of graft transmissible diseases; however, the Repository has been recognised as the primary factor in reducing the prevalence of CEVd in Australian citrus (NSW DPI 2008), and stakeholders stated that CEVd would be "reduced close to zero" so an 80% to 99% reduction was applied using the same method as above.
Yield reduction (consequences)	56% (± 13%)	Yields can be reduced by 50% on citrange rootstock and 65% on trifoliata rootstock from lost productivity (plant vigour, gross yield, and marketable yield) (Bevington and Bacon 1977).
Time before replanting	5 years	Infected material would not be immediately evident, but would present as slower development and reduced yields. A 5 year period was assumed based on Stakeholder consultation, including 3 years of establishment (with costs) and 2 years of reduced yields at which point infected trees are identified, removed and replanted.
Outcome attribution (adoption of clean planting material)	30% (± 66%)	Industry adoption of clean material from the Repository also depended on the citrus budwood propagation scheme (as the conduit for supplying clean planting material to industry). The annual cost of the propagation scheme was estimated at $800,000 per year (Stakeholder pers comm) compared to approximately $80,000 per year for the repository identified in CT17008, suggesting an attribution of 10% of impact to CT17008on a funding share basis. However, given the mutual dependence of the propagation scheme the repository, an equal 50% attribution was also considered, with an average of 30% in the baseline.

Results

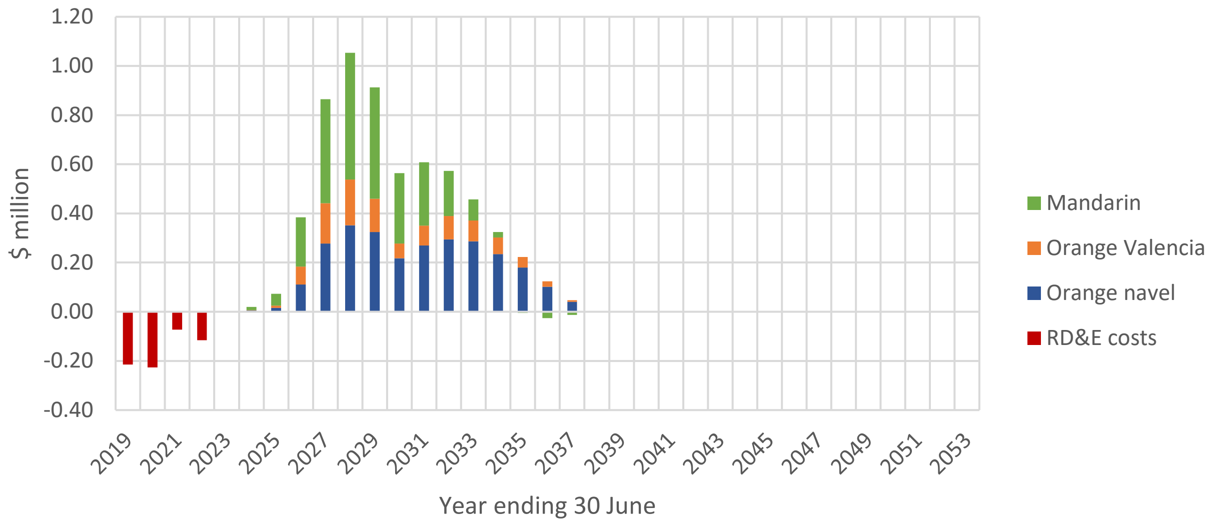
The analysis identified PV costs (PVC) of $0.73 million (2022-23PV) between 2018-19 and 2021-22, and estimated PV benefits (PVB) of $4.48 million (2022-23 PV) accruing between 2024 and 2037 (Table 5). When combined, these costs and benefits generate a net present value (NV) of $3.75 million, an estimated benefit-cost ratio (BCR) of 6.17 to 1, an internal rate of return (IRR) of 29% and a modified internal rate of return (MIRR) of 11%.

Table 5. Impact metrics for the total investment in project CT17008

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	0.73	0.73	0.73	0.73	0.73	0.73	0.73
PVB ($m)	0.00	1.95	4.10	4.48	4.48	4.48	4.48
NPV ($m)	0.73	1.23	3.37	3.75	3.75	3.75	3.75
BCR	0.00	2.69	5.65	6.17	6.17	6.17	6.17
IRR	Negative	20.7%	28.5%	28.9%	28.9%	28.9%	28.9%
MIRR	Negative	15.9%	17.8%	15.0%	12.9%	11.6%	10.6%

Figure 2 shows the annual undiscounted benefit and cost cash flows for the total investment of CT17008, showing total RD&E costs compared to benefits. Across the three citrus varieties the share of benefits reflected the relative planting area, yield, and gross margins, with Navel Oranges accounting for 42% of benefits, Valencia Oranges 17%, and Mandarins 41%. Cash flows are shown for the duration of the investment plus 30 years from the last year of investment.

Figure 2. Annual cash flow of undiscounted total benefits and total investment costs

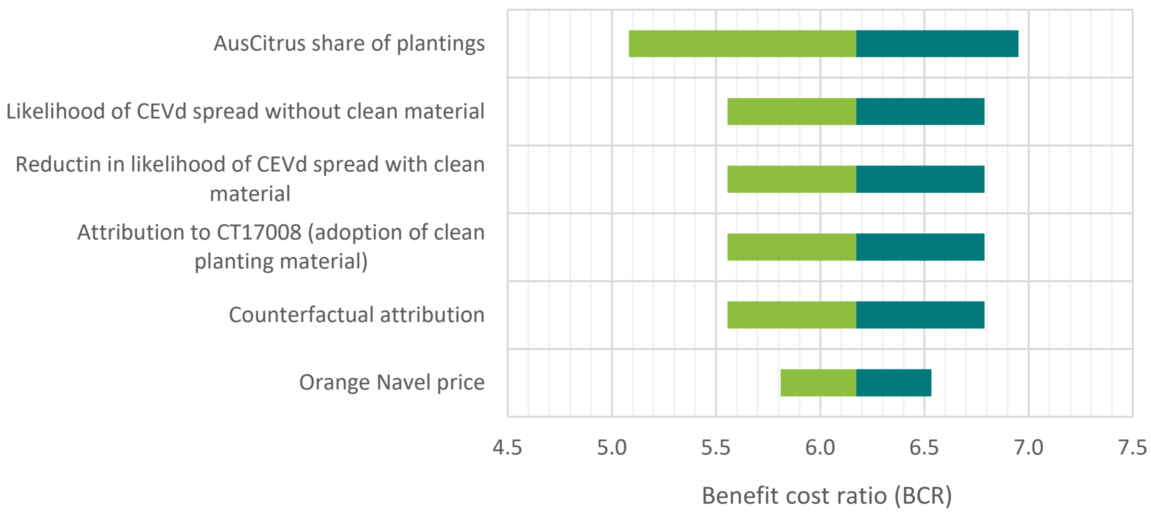


Sensitivity analysis

Given the risk and uncertainty associated with a number of underlying modelling, the results were tested to sensitivity to changes in 20 variables where a potential value range was identified (as shown in Table 4). The results were first tested for sensitivity to individual changes in the variables, followed by combined changes.

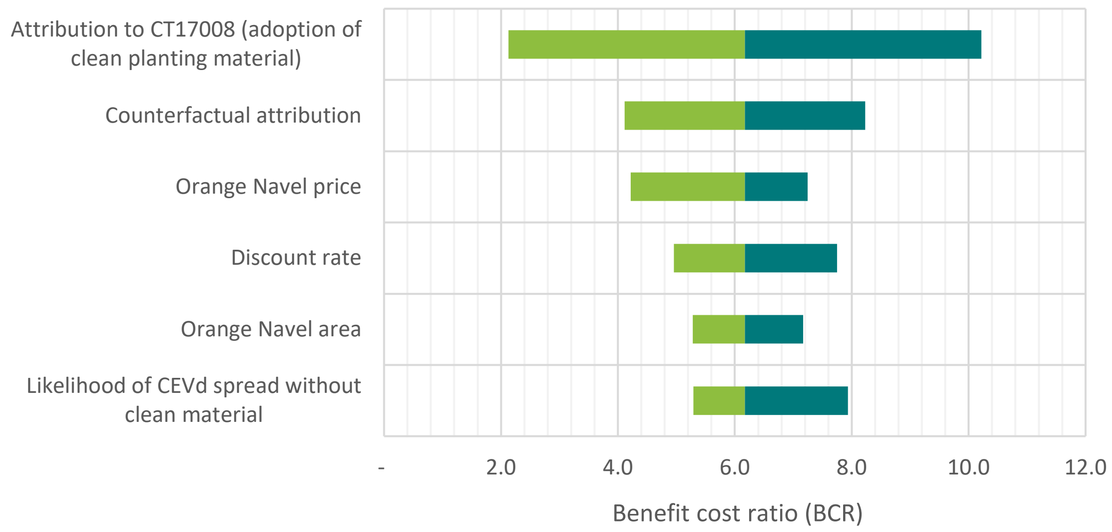
Individual changes of a uniform 10% were undertaken to identify the variables to which the results were most sensitive. The results were most sensitive uniform changes to the six variables shown in Figure 3. The largest change in the results came from a 10% change in the Auscitrus share of plantings which reflects the adoption of outputs from CT17008 and therefore drives the magnitude of change. The results were also sensitive to estimates of the likelihood of CEVd spread with and without clean plant material, the attribution the use of clean planting material to the Repository (considering the contribution of the Auscitrus propagation scheme), and the R&D counterfactual attribution (whether the investment would have been undertaken without Hort Innovation levy investment).

Figure 3. Variables to which the results were most sensitive for uniform 10% changes



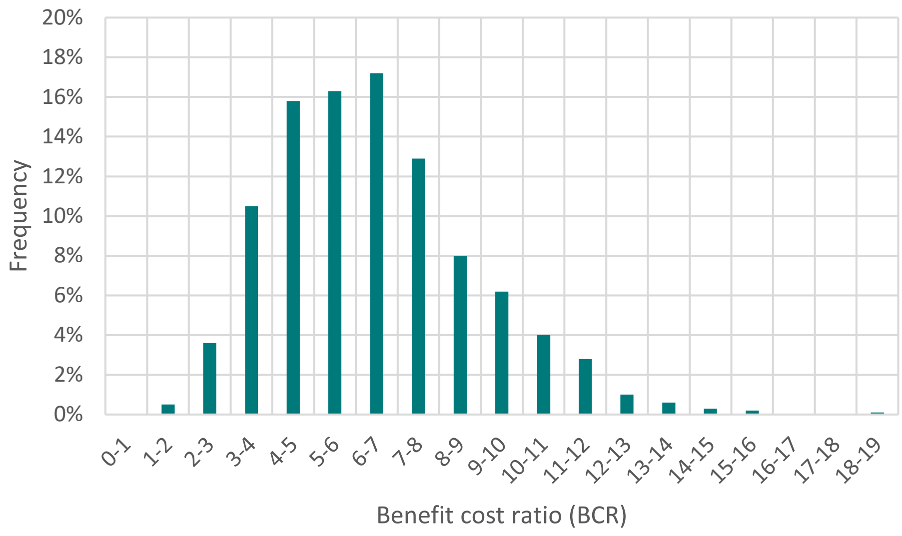
The results were next tested for sensitivity to changes across the full value range for each variable (tested individually) to reflect the differences in risk and uncertainty for each variable, with the most significant variables shown in Figure 4. The variable with the greatest potential influence on the results was outcome attribution, owing to the sensitivity of the results to changes in this variable and the wide range of values estimated (reflecting the uncertainty over this figure). The results were also shown to be sensitive to changes in the navel orange price (particularly on the downside) and planted area as a result of the wide potential variation in these values. Of note, the impact remained positive to all changes in individual variables.

Figure 4. Variables to which the results were most sensitive when tested at their full range



Finally, the full range of potential variation in the impact was estimated using @Risk stochastic modelling to incorporate the combined effect of changing all variables across their full ranges over 1000 simulations. This process showed an impact (BCR) range of between 1.6:1 and 18.3:1, with 90% of results falling between 3.1:1 and 11.0:1 (i.e. excluding the low probability tails) (Figure 5). All 1000 simulations had a BCR greater than 1:1 (benefits greater than RD&E costs). While the wide range of results reflects the high level of risk and uncertainty relating to many variables (as reflected in Figures 4 and 5), this testing gives a high level of confidence that the investment generated a positive impact.

Figure 5. Impact histogram. Distribution of results over 1000 simulations.



Implications and learnings

The analysis identified a clear pathway to impact for CT17008. The project was successful in supporting a high level of nursery and grower adoption (propagation and planting) of clean and true to type citrus varieties by providing the necessary resources and knowledge, and informing expectations with regards to agronomic and disease outcomes. This was achieved in conjunction with the not-for-profit Auscitrus budwood scheme (as the conduit for supplying clean planting material to the industry).While the Repository included screening for a range of potential graft transmissible diseases, discussions with stakeholders indicated the benefit of the Repository scheme was greatest for HLB, CTV-OSP, and CEVd.

By breaking down the risk of graft transmissible diseases into key factors relating to likelihood (of entry, establishment, and spread) and consequences (such as yield reduction), the analysis identified that there was only sufficient data to quantify the change in CEVd risk resulting from the Repository. In contrast, HLB and CTV-OSP lacked data relating to how likelihood (of entry, establishment, and spread) changed as a result of the provision of clean planting material through from the Repository. Further, as CTV-OSP and HLB can also be vector spread, with significantly more complex entry and spread pathways than purely graft transmissible diseases such as CEVd, stakeholders did not have sufficient confidence to provide an estimate of risk change as a result of the Repository.

The analysis was also restricted to four citrus varieties (navel and Valencia orange, and imperial and afourer mandarin) due to a lack of production data for different varieties, and disease consequence data (i.e. productivity implications) for different diseases screened at the repository. Future analysis would benefit from improved data with regards to these variables.

Beyond the farm level productivity impacts, additional social and environmental impacts were identified that could also not be quantified due to data limitations. These included the projects support for the provision and consumption of citrus fruit, with associated health and wellbeing effects, and the support for regional community resilience from a more sustainable citrus industry.

The several data gaps highlight the reliance of impact assessments on external data or assumption to confidently quantify the full impact pathway. It also highlights the importance of identifying and collecting key data to ensure that RD&E success can be measured and understood. This would include identifying metrics in the early stages of project or program delivery (such as through a monitoring and evaluation framework) and collection of this data through the course of the project or potentially through separate investment.

Despite the data gaps limiting the impact assessment to focus on the industry benefits of CEVd risk reduction, the results showed a high baseline impact (BCR) of 6.17:1. Given uncertainty in many of the data inputs, particularly regarding projections of benefits into the future, the results were tested for sensitivity to changes in the underlying variables across their identified potential ranges. While the sensitivity testing showed a wide potential range of results with a 90% range of between 3.1:1 and 11.0:1 (reflecting the potential variation and uncertainty in the underlying variables) the positive impact for all 1000 tested scenarios gave a high level of confidence that clean planting material generates a positive impact for the citrus industry.

Stakeholder consultation

Where possible, Ag Econ sought to engage multiple stakeholders across key areas of the logical framework and impact pathway to augment existing information and data sources, and reduce any uncertainty or bias from individual stakeholders. All stakeholders were engaged through telephone or online meetings, with follow up emails as necessary. Consultation followed a semi-structured approach in line with broad topics relating to the impact pathway and associated data requirements. Table 6 outlines the stakeholders consulted as part of this impact assessment and the topics on which they were consulted.

Table 6. Stakeholder consultation by theme

Stakeholder details		Consultation topics						
Stakeholder and organisation	**Stakeholder type**	**Related research**	**Research inputs**	**Research outputs**	**Research immediate outcomes**	**Follow on research**	**Stakeholder adoption**	**Impact areas and data**
Vino Rajandran, Hort Innovation Head of Production R&D	RD&E process owner / manager	✓	✓	✓	✓	✓	✓	✓
Ben Callaghan, Hort Innovation R&D Manager	RD&E process owner / manager	✓	✓	✓	✓	✓		✓
Tim Herrmann, Auscitrus Manager	RD&E practitioner	✓	✓	✓	✓	✓	✓	✓
Nerida Donovan, NSW DPI Citrus Pathologist	RD&E practitioner	✓			✓			✓
Steven Falivene, NSW DPI Citrus Development Officer	RD&E practitioner (external to project)							✓
Jonathan Chislett, Chislett Farms Nursery General Manager	RD&E beneficiary and levy payer			✓	✓		✓	✓

Glossary of economic terms

Benefit-cost ratio (BCR)	The ratio of the present value of investment benefits to the present value of investment costs.
Cost-benefit analysis (CBA)	A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue.
Direct Effects	Impacts generated for the funding industry as a result of adoption of the RD&E outputs and recommendations, typically farm level outcomes relating to productivity and risk.
Discounting and Present Values	The process of relating the costs and benefits of an investment to a base year to reflect the time value of money or opportunity cost of RD&E investment. The analysis applies a real discount rate of 5% in line with CRRDC Guidelines (CRRDC 2018) with results sensitivity tested at discount rates of 2.5% and 7.5%.
Economic Equilibrium	Due to a market's underlying supply and demand curves, changes in supply will have an impact on price and vice-versa. The Economic Equilibrium is the point at which market supply and price are balanced. Estimating the magnitude of market response to changes in supply or demand is a complex and demanding task that is considered beyond the scope of most CRRDC Impact Assessments (CRRDC 2018).
Gross Margin (GM)	The difference between revenue and cost of goods sold, applied on a per hectare basis and excluding fixed or overhead costs such as labour and interest payments.
Internal rate of return (IRR)	The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.
Modified internal rate of return (MIRR)	The internal rate of return of an investment that is modified so that the cash inflows generated from an investment are re-invested at the rate of the cost of capital (in this case the discount rate).
Net present value (NPV)	The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.
Nominal and real values	Nominal values reflect the actual values in a given year (e.g. contracted RD&E expenses). These are converted to real (inflation adjusted) values to make them comparable across time.
Spillover Effects	Impacts generated for stakeholders who did not fund the RD&E, including other agricultural industries, consumers, communities, and the environment.

Abbreviations

CEVd Citrus exocortis viroid

CRRDC Council of Rural Research and Development Corporations

CSIRO The Commonwealth Scientific and Industrial Research Organisation

CTV OSP Citrus tristeza virus (CTV) causing orange stem pitting (OSP)

HLB Huanglongbing, "citrus greening disease"

RD&E Research, Development and Extension

SIP Strategic Investment Plan

EMAI NSW Department of Primary Industries' Elizabeth Macarthur Agricultural Institute at Menangle.

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