Impact assessment of the investment:

Developing agri-tech solutions for the Australian apple industry (AP16005)

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Hort Innovation

Previous page image courtesy of APAL https://apal.org.au/automation-variable-rate-spray-swarmfarm/

Disclaimer:

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Executive summary

What the report is about

Ag Econ conducted independent analysis to determine the economic, social, and environmental impact resulting from delivery of the apple and pear project AP16005 Developing Agri-Tech Solutions for the Australian Apple Industry. The project was funded by Hort Innovation over the period from June 2018 to January 2022, using the apple and pear research and development levy and contributions from the Australian Government.

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

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

Hand thinning had been the second highest cost for apple orchards due to the high labour cost. AP16005 sought to investigate the potential for new technology to perform autonomous flower density mapping and tree canopy measurement for the apple and pear industry to improve industry productivity with regards to both costs and outcomes (yield and quality).

Key findings

The nominal investment cost of $5.8 million was adjusted for inflation (ABS, 2023) and discounted (using a 5% real discount rate) to a present value (PV) of costs equal to $7.9 million (2022-23 PV).

Project AP16005 developed significant industry knowledge and know-how around flower mapping and thinning, including developing the understanding of what growers need. Importantly, the project also resulted in the development of technology solutions for flower thinning, including the flower mapping and decision support tool *Apple Snapper System*, which was ready for commercialisation via licencing through Hort Innovation, and the *Variable Timing of Application Sprayer*, which can be retrofitted by growers using the *Industry Guide* produced by AP16005. On completion, this combined product offering had the potential to increase quality of apples (increase pack out rates), reduce the effects of biennial bearing of fruit, reduce hand thinning costs, and reduce the volume and cost of chemical thinner, among other potential impacts.

At project completion in January 2022 the *Apple Snapper System* was intended to be commercialised through a third party; however, no clear progress had been made by May 2023, increasing the uncertainty around the final stages of the impact pathway (commercialisation and adoption).

With the relatively conservative assumptions around the likelihood of commercialisation, potential market share, and other impact variables, the estimated benefit was $18.7 million (5% discount rate). Compared to the PV research costs of $7.9 million (5% discount rate) these benefits generated a positive baseline impact with a benefit-cost ratio (BCR) of 2.36:1 attributable to AP16005.

Of the three impact areas modelled the baseline benefits were made up of 78% reduced hand thinning labour costs, and 22% increased productivity (marketable yield), with no reduced chemical cost benefit in the baseline reflecting the uncertainty over this outcome.

Sensitivity testing gave a high level of confidence that AP16005 would generate a positive impact (benefits greater than costs) with 82% of simulated results having a BCR greater than 1. The was a relatively narrow range for the results, with 90% of simulated results falling between 0.66:1 and 3.26:1. The lack of empirical data for the change in marketable yield (both as a result of improved quality and reduced biennial bearing) was a key weakness in this analysis. While all care was taken to use realistic and conservative estimates based on stakeholder consultation, future analysis (and industry confidence to adopt) would be supported by more robust data in this area.

The key findings of the AP16005 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment, cost-benefit analysis, apple, industry development, variable time sprayer

Figure 1. Summary of impact assessment findings

AP16005 Agri-Tech Solutions for the apple Industry

RD&E activities

Total RD&E costs:

- $5.8 million (nominal value)
- 72% R&D levy and Government matching, and 28% SwarmFarm in-kind.

Research activities:

- RD&E to develop the *Apple Snapper System*, for apple flower mapping and variable timing decision support, which informs a *Variable Timing of Application Sprayer*. Activities included hardware selection, software development, individual tree testing, flow rate validation, orchard testing etc.

Extension activities:

- Six magazine articles, written communications, future orchard walks, and eight video updates.
- An industry guide which included how to build the *Variable Timing of Application Sprayer*.

Outcomes

Outcomes:

- Increased knowledge and know-how relating to apple flower mapping and thinning requirements and solutions.
- Industry has potential access to new resources for flower mapping and decision support (*Apple Snapper System*) if subsequent steps for commercialisation are completed.
- Industry has the knowledge to modify existing equipment to become a *Variable Timing of Application Sprayer* to be used in conjunction with flower mapping and decision support.

Industry adoption:

- The *Apple Snapper System* had not yet been licensed to third party at the time of analysis.
- The analysis indicated a total potential market of 72% of planted area by 2037, with 12.5% to 37.5% market share for the *Apple Snapper System*.

Impacts

Environmental impacts:

- Improved biodiversity from decreased average chemical use.

Economic impacts:

- Cost savings from reduced labour requirements, and decreased average chemical use.
- Marketable yield improvement from more accurate chemical use.

Social impacts:

- Improved OHS from decreased average chemical use.

Industry Impact

- Present value costs (PVC) of $7.90 million
- PV benefits (PVB) of $18.66 million over 30 year
- Net present value (NPV) of $10.76 million
- Benefit-Cost-Ratio (BCR) of 2.36:1
- 82% probability of a BCR greater than 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.

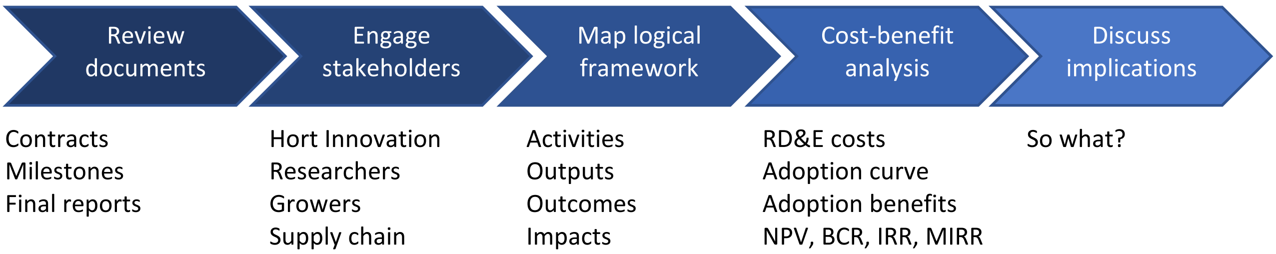
Reflecting its commitment to continuous improvement in the delivery of levy funded research, development, and extension (RD&E), Hort Innovation required a series of impact assessments to be carried out annually on a representative sample of investments of its RD&E portfolio. Commencing with MT18011 in 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).

Project *AP16005 Developing Agri-Tech Solutions for the Australian Apple Industry* 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 Council of Rural Research and Development Corporations (CRRDC, 2018) and included both qualitative and quantitative analysis. The general method that informed the impact assessment approach was 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 stakeholders (see *Stakeholder Consultation*).
3. Through a logical framework, qualitatively map the project's impact pathway, including, activities, outputs, outcomes and the principal economic, environmental, and social impacts.
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.



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 the Hort Innovation project page [Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015)](#).

Project background

Project AP16005 was undertaken in response to the case made in project AP16003 (Techmac, 2016) for a *variable rate* spraying solution for apple flower thinning. Existing practice has been to conduct ad hoc inspection of a small sample of trees and apply blanket spray applications based on grower experience and intuition. This is typically followed by further costly and time-consuming hand thinning, which was the second largest cost for growers. Factors such as development stage, variety, and weather influenced the number and timing of spray applications, and the cost of hand thinning,. Some varieties were also susceptible to biennial bearing, which could be made worse by applying too much or too little spray. Early in the project it was assessed that there was a large risk associated with variable concentration and volume spray application, i.e., at different application rates to the label rate. This, as well as the understanding that getting the spray timing right was very important, shifted the focus of the project to *variable timing* of application, rather than *variable rate*. (UNSW, 2022, stakeholder pers. comms)

The Strategic Investment Plan (SIP) outcome relevant to this project was *Outcome 1 Productivity—improving industry profitability and global competitiveness by reducing the average cost per carton* (Hort Innovation, 2017).

Project details

The development of the desired technological solutions for flower mapping, decision support and variable timing of spraying was a large undertaking that required a range of skillsets, and therefore utilised a consortium approach, which included SwarmFarm Robotics, the University of New South Wales (UNSW), Bosch and Adama. The project was contracted to both SwarmFarm Robotics and UNSW, with SwarmFarm Robotics leading the consortium, and ran from June 2018 to January 2022 (Table 1).

Table 1. Project details

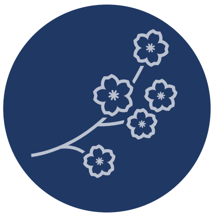
Project code	AP16005
Title	Developing Agri-Tech Solutions for the Australian Apple Industry
Research organization(s)	Advanced Agricultural Systems Pty Ltd (SwarmFarm) The University of New South Wales (UNSW)
Project leader	Andrew Bate (Swarmfarm), Mark Whitty (UNSW)
Funding period	30 June 2018 – 31 January 2022
Objective	The project objective was to develop a product to do autonomous flower density mapping and tree canopy measurement and provide decision support for variable timing of application spraying, specifically for primary chemical thinning.

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, summarised in Table 2.

Table 2. Project logical framework detail

RD&E activities



The three- and half-year long project focussed on developing a pre-commercial product offering which could provide digital "mapping" of flower and canopy development and provide decision support for variable timing autonomous spraying.

- A novel algorithm was developed and tested to estimate flower distribution in real-time while driving along an orchard row. A decision support tool was developed to take the output from the algorithm and map it as a percentage flowering value per portion of a given tree to used by growers to define spray thresholds. Specific activities involved were:
  - Hardware selection (e.g., cameras, LiDARs, GPS, IMU etc)
  - Algorithm / Software development
  - Connected system (connecting the apple snapper software to a cloud service seamlessly)
  - Training pipeline
- Investigate, develop and test how to configure any Airblast or Tower sprayer to have variable timing and variable rate capabilities that can be informed by the algorithm and decision support tool. Specific activities involved were:
  - Hardware design
  - Individual tree testing
  - Flow rate validation
  - Orchard testing
- Extension activities
  - Project AP16005 conducted a range of extension and communication activities throughout project AP16005.

RD&E outputs

- Two final reports highlighting the technical findings of the project, one from UNSW and one from SwarmFarm.
- Intellectual property available through Hort Innovation for licensing a pre-commercial product that could provide digital "mapping" of flower and canopy development and provide decision support for variable timing autonomous spraying collectively known as the "**Apple Snapper System**":
  - Apple snapper software. A novel algorithm that can estimate flower distribution over eight flowering stages from green-tip to petal-fall and can run in real-time while driving along a row.
  - Decision support tool, that takes the output from the algorithm, converts it into a percentage flowering value per portion of a given tree, which is then aggregated and mapped for use in a spray system.
  - Together, the system helped orchardists make better decisions to optimise quality and yield, and to reduce production costs including labour and chemical use.
- Other intellectual property or "know-how" delivered to industry as an industry guide, which details how to configure an orchard sprayer to target individual trees ("**Variable Timing of Application Sprayer**").
- Industry extension:
  - Six magazine articles and written communications
  - Future orchard walk program for first two years (last two years there were COVID restrictions)
  - Eight project video updates
- Research publications:
  - Two journal articles published (Wang, Tang & Whitty, 2020 & Wang, Tang & Whitty, 2021)
  - Two book chapters or papers in conference proceedings (Yem, Tang, Wang & Whitty, 2021 & Hu, & Whitty, 2019)

Outcomes

- The knowledge generated through project AP16005 regarding how growers look at flower thinning was substantial and could not have been achieved without this project. It was particularly important regarding developing the understanding what growers need in terms of flower thinning (including around for example variable *rate* versus variable *timing* of spraying). Before AP16005, no similar solution to for integrated flower mapping, decision support, and variable timing of application spraying existed within the industry. (Stakeholder pers. comms.)
- A rigorously tested product offering (**Apple Snapper System)** that was ready for commercialisation. Commercialisation options were being explored following project completion (January 2022) however, no clear progress had been made by May 2023, generating some uncertainty around the final stages of the impact pathway (commercialisation and adoption).New resources were available to industry through the industry guide, which details how to convert any tower or air blast sprayer into a **Variable Timing of Application Sprayer**.
- Stakeholders noted that the technology rollout and adoption could be challenging due to the high level of technical support required for the technology. This reflects adoption and diffusion frameworks (e.g., Kuehne et al 2017) where access to advisors is a key driver in the speed of technology adoption. In anticipation of this, the project sought to maximise industry awareness and knowledge of the project and products through industry extension activities such as videos and conversations with growers (Stakeholder pers. comms.)

Impacts

The product offering that was developed and made ready for commercialisation through project AP16005 has the potential to provide future impact in a range of areas pending commercialisation and adoption by growers. Potential impacts include:

- **[Economic] Increased marketable yield:** The product offering could be used by orchardists to make better decisions about chemical spray applications, which could improve quality (grade) and reduce pack out losses, supporting higher prices.
- **[Economic] Reduced effect of biennial bearing of fruit:** Some apple varieties are susceptible to biennial bearing of fruit, and this could be aggravated by too much or too little spray applied at the wrong times. Applying accurate, tree-by-tree chemical thinning could reduce the effect of biennial bearing of fruit supporting higher average gross yield.
- **[Economic] Decrease in hand thinning labour costs:** Flower thinning has typically been done both by chemical spraying and through hand thinning. Hand thinning is very labour intensive and therefore very expensive, and issues with sourcing labour can also be a significant issue for orchards.
- **[Economic] Decrease in average volume, and therefore cost, for chemical thinner:** The trees within an orchard can vary in height, width, and density, so it is possible that blanket spray applications waste chemicals. More accurate, tree-by-tree chemical application could reduce the volume of chemical applied, and therefore the total input costs.
- **[Environmental] Reduced chemical use with associated negative externalities.** To the extent that there was less chemical use, this could have flow on effects on the environment, for example through improved biodiversity and pollination rates.
- **[Social] Improved health and wellbeing.** Reduced overall chemical use could have a positive impact on the health and wellbeing of workers from reduced chemical exposure. Reduced operating costs, increased fruit quality and reduced overall chemical use may in turn support a greater alignment to consumer preferences, thereby encouraging higher apple consumption with associated health and wellbeing benefits.
- **[Socio-economic]** Increased contribution to regional community wellbeing and resilience from more profitable apple growers.

Project costs

The project was funded by Hort Innovation, using the apple and pear research and development levy and contributions from the Australian Government, with additional funding from research partners SwarmFarm (Table 3). Where relevant, overhead and extension 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 to SwarmFarm ($)	Hort Innovation project costs to UNSW ($)	Hort Innovation overheads[1] ($)	In-kind contributions SwarmFarm[2] ($)	Total nominal cost ($)
2018	1,700,000	150,000	357,018	519,793	2,726,811
2019	600,000	200,000	110,252	224,775	1,135,027
2020	600,000	150,000	126,747	210,727	1,087,474
2021	0	0	0	0	0
2022	466,000	138,000	98,283	169,705	871,988
Total	**3,366,000**	**638,000**	**692,300**	**1,125,000**	**5,821,300**

1. The overhead and administrative costs were calculated from Financial Operating Statement of the Hort Innovation Apple and Pear Fund Annual Reports, averaging 16.6% for the AP16005 funding period (2018-2022).
2. Other funds from SwamFarm 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 of $5.82 million identified in Table 3 was adjusted for inflation (ABS, 2023) into a real investment of $6.84 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 $7.90 million (2022-23 PV). The results were sensitivity tested changes in the discount rate between 2.5% and 7.5%.

Project impacts

The impact pathway identified in Table 2 was evaluated against available data to determine if the impacts could be quantified with a suitable level of confidence. From this process, three impacts were able to be quantified.

Impacts valued and valuation framework

[Economic] Increased marketable yield. The AP16003 final report had noted that the process of chemical spraying in Australia has been described as "spray and pray", as the outcome from each application is unknown. The AP16003 project report further noted that the process is usually "underdone", to avoid overthinning with adverse impacts on yield, with further costly and time-consuming hand thinning typically required later in the season. In contrast, a deliberate and targeted tree-by-tree chemical thinning application process supports a degree of thinning which is optimal in terms of improving quality, including the reduction of the effect of biennial bearing of fruit. A potential increase in marketable yield (from both a reduction in pack out losses and reduced biennial bearing) could result in increased revenue; however, there was no empirical information on yield or quality. In place of any empirical data, a conservative assumption was made that pack-out rates increased by 1 percent (in relative terms) as a result of improved flower thinning.

[Economic] Decrease in hand thinning labour costs. Labour savings include the direct avoided cost of reduced labour use, as well as the avoided production and productivity cost associated with difficulties in sourcing labour in a timely manner (Downham R, and Litchfield F 2022). For direct orchard labour costs, data on hand thinning costs is available through the *Orchard Business Analysis Reports (Ag First 2016-2022)*. These have historically been the second largest cost for growers, due in part to increased labour scarcity driving horticultural wages higher (Xia, 2019). This has been a driving factor in pursuing a technology solution in this area (Downham R, and Litchfield F 2022, and stakeholder consultation). Grower feedback as part of project AP16003 suggested that the efficiency and speed of the manual flower removal and the yield outcome for an individual tree also depends significantly on the experience and judgement of the hand thinner (i.e., there was human error involved in hand thinning).

[Economic] Decrease in average volume, and therefore cost, for chemical thinner. Studies focused on variable rate (volume) spraying applications have shown reduction in spray loss and airborne spray drift (project AP16003 report), however the focus of the sprayer developed as part of AP16005 is variable timing (i.e. targeting selected sections of trees with the label amount of spray depending on the flowering stage, not a variable volume). Further, current practices may have resulted in too little, rather than too much, spraying so the net effect is uncertain. Discussions with stakeholders also noted that the impact on chemical use was not likely to be a big contributor to cost savings. Reflecting this uncertainty, there were no chemical cost changes in the baseline, with results tested for a conservative +5% and -5% change in costs.

For the above three impacts, a gross margin analysis was undertaken to assess the farm-level adoption costs and benefits drawing on project and related data and discussions with industry stakeholders. This was scaled up to an industry level by estimating an adoption and diffusion curve using stakeholder feedback and available data to inform inputs into the CSIRO ADOPT framework (Kuehne et al 2017). The attribution of the full results was considered in relation to other contributing R&D, and a suitable outcome attribution factor was applied. Finally, the potential for the research to have been conducted without levy investment was also considered, with results adjusted down by an estimated R&D counterfactual factor.

Impacts unable to be valued

[Environmental] Reduced chemical use with associated negative externalities. There is a recognised link between farm chemical use and harmful effects on rivers, the ocean, the atmosphere, animals and plants if not managed safely (Australian Gov, 2021) including for common chemical thinning products (e.g. BPDB, 2023). Decreased on-farm chemical use reduces these potential environmental impacts. However, no data was identified to link per unit chemical use with environmental impacts, so this impact was unable to be quantified.

[Social] Improved health and wellbeing. There is a recognised link between farm chemical use and short and long-term health effects for farm workers if not managed safely (NSW Gov 2020) including for common chemical thinning products (BPDB, 2023 and APVMA, 2007). Decreased on-farm chemical use reduces potential exposure and associated health risks.

However, no data was identified to link per unit chemical use with health effects, so this impact was unable to be quantified. In addition to reduced farm worker risk, an increase in fruit quality and reduced overall chemical use may in turn support a greater alignment to consumer preferences for visual appeal and sustainability. Fresh, affordable, and locally grown are three of the key drivers in Australian consumer purchasing behaviour for fruit, vegetable and nuts (Kantar, 2022). Further, there is a recognised link between health and wellbeing benefits and apple consumption (APAL, 2023; Hort Innovation, 2020) and fruit and vegetable consumption more broadly (Angelino et al, 2019, Mujcic et al, 2016). A more sustainable supply of quality and affordable domestic produce therefore supports consumption and associated health and wellbeing outcomes. However, to quantify this in the context of cost benefit analysis requires a clear relationship between unit consumption and unit health and wellbeing, as well as a dollar value for unit health and wellbeing changes. A lack of available data or stakeholder estimates meant that these relationships and values could not be estimated.

[Socio-economic] Increased contribution to regional community wellbeing from more profitable apple growers. The CIE (2023) highlighted the broader socio-economic effects of the apple industry for Australian production regions. The industry contributed over $0.5 billion in valued added (contribution to gross domestic product) and directly supported 1,818 full time employees primarily in regional economies. While this impact assessment is a first step in understanding and quantifying the direct effects on industry production and value, the flow-on effects require additional analysis in economic models that capture regional and national linkages, which are beyond the scope of the R&D impact assessment program (CRRDC 2018). However, the analysis and results from this impact analysis will provide an important input into any future regional or national economic impact modelling.

Data and assumptions

For the impacts where valuation was possible, the necessary data was collected from the project documents and other relevant resources. 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. Where estimates were used, a data range was considered to reflect underlying risk and uncertainty, which was further analysed through in sensitivity testing (see *Results*). A summary of the key data, assumptions and sources is provided in Table 4.

Table 4. Summary of data and assumptions for impact valuation

Variable	Value	Source / comment
Discount rate	5% (± 50%)[1]	CRRDC Guidelines (2018).
Hectares planted	9,533 ha	AgFirst (2022).
Number of growers	500 (± 50)	Techmac (2016).
Years to bring to market	2 years (± 1 year)	The Apple Snapper System was developed and made ready for commercialisation; however, it had not yet been taken on by a third party for commercialisation and the timing for when this might occur was uncertain (stakeholder pers. comms).
Likelihood of commercialisation	50% (± 50%)	The Apple Snapper System was ready for commercialisation via licencing through Hort Innovation at the completion of the project. Commercialisation through a third party was being explored, however it has not yet been achieved at the time of analysis. A mid-point estimate of 50% likelihood has been used in the analysis.
Adoption of Variable Timing of Application technology	72%	An adoption and diffusion curve for Variable Timing of Application technology was estimated using stakeholder feedback and available data to inform inputs into the CSIRO ADOPT framework (Kuehne et al 2017) (see Appendix A). The specific market share of the Apple Snapper System was considered below. .
Market share of Apple Snapper System	25% (± 50%)	It is not clear how large of a market share the Apple Snapper System may achieve once introduced to the market, as there are other companies potentially capable of providing a similar offering (stakeholder pers. comms). The analysis assumed a

[1] Note that when percentage changes apply to percentage variables, they relate to relative change, e.g., a 50% increase in the discount rate of 5% is 7.5%.

Variable	Value	Source / comment
		25% market share.
Relevance of Apple Snapper System	10 years at 100%, then declining to 0% over next 20 years	The Apple Snapper System was assumed to have full relevance (100%) for 10 years, and subsequently decline to 0% relevance over the next 20 years until year 30 reflecting likely ongoing technological advances and potential changes in orchard production systems.
Class 1 price	$2.57 / kg	AgFirst (2022), average of 2017 to 2021, adjusted for inflation.
Non-class 1 price	$0.60 / kg	AgFirst (2022), average of 2017 to 2021, adjusted for inflation.
Class 1 pack-out rate	70.2%	AgFirst (2022), average of 2017 to 2021.
Change in class 1 pack-out rate due to using product offering	+1% (± 100%)	Conservative assumption given a lack of empirical data. A multi-year trial on commercial farms is necessary to understand the impact of the ag tech solution on the Class1 pack-out rate (stakeholder pers. comms).
Average gross yield	47.7 t / ha	AgFirst (2022), average of 2017 to 2021.
Business model	Varies by component	Different pricing models were applied to different components of the technology (SwarmFarm 2019). This may be developed differently depending on the commercialisation path chosen by a third party. • The vision system (the apple snapper software) was assumed to operate under a three-year lease model in the analysis. The farmer may hire rather than lease the vision system, as farmers only need access for a short period of time, however this is not considered in the analysis. Larger growers would likely buy their own system, but this is also not considered in the analysis. • The decision support tool is assumed to be a software as a service (SAAS), rather than a sale. This facilitates regular updates and improvements and was a popular way to deliver software. • The Variable Timing of Application Sprayer was assumed to be for sale to growers, also as a retrofit kit.
Vision system (apple snapper software)	$15,000 (± 33%) on a 3-year (± 2 years) lease with a 50% (± 50%) trade in value	Estimate of upfront capital cost was based on stakeholder pers. comms. Lease term and trade in value were estimated.
Decision support tool	$2,000 per year (±10%)	Estimated based on stakeholder pers. comms.
Variable Timing of Application Sprayer	$20,000 per year upfront cost (±25%), with a 10-year life and a 50% replacement capex cost (±50%)	Estimate of upfront capital cost based on stakeholder pers. comms. Life and replacement cost % were estimated.
Hand thinning costs	$4,736 / ha (± 10%)	AgFirst (2016-2021), average of 2017-2021, adjusted for inflation.
Hand thinning cost reduction	-66% (± 50%)	There was no empirical data on the extent to which hand thinning costs would reduce with product offering, and a multi-year study on commercial farms may be required to establish this. Ideally there would be no need for hand thinning, although there may need to be a 'last pass' (stakeholder pers. comms). A baseline assumption of a 66% reduction was used, tested at 33% and 99%.
Chemical cost	$837 / ha (± 10%)	Techmac (2016) used an estimate of $650 / ha for the chemical costs, which has also been used for this analysis, adjusted for

Variable	Value	Source / comment
		inflation.
Chemical cost change	0% (tested -5% and +5%)	Stakeholder comments suggested that a reduction in chemical use and cost was unlikely to be a large contributor to cost savings. Further, there were factors which may both increase and decrease volume. Reflecting the uncertainty without empirical data, a 0% change was used in the baseline, tested at a 5% cost increase and decrease.
Outcome attribution	100% (- 50%)	The modelled costs and savings can be directly attributed to the knowledge and technology developed in project AP16005 (stakeholder pers. comms).
Counter-factual attribution	100% (- 50%)	The development of the product offering is unlikely to have occurred without the funding, especially in terms of developing the understanding of what growers need in terms of flower thinning (stakeholder pers. comms).

Results

The analysis identified a PV costs (PVC) from all sources of $7.90 million (2022-23 PV) between 2018 and 2022 and estimated PV benefits of $18.66 million (2022-23 PV) accruing between 2022 and 2052 (Table 5). When combined, these costs and benefits generate a net present value (NPV) of $10.76 million, an estimated benefit-cost ratio (BCR) of 2.36 to 1, an internal rate of return (IRR) of 10.7% and a modified internal rate of return (MIRR) of 7.7%.

Table 5. Impact metrics for the total investment in project AP16005

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	7.90	7.90	7.90	7.90	7.90	7.90	7.90
PVB ($m)	0.00	0.40	5.26	12.16	16.30	18.22	18.66
NPV ($m)	-7.90	-7.50	-2.65	4.26	8.40	10.32	10.76
BCR	0.00	0.05	0.67	1.54	2.06	2.31	2.36
IRR	Negative	Negative	1.2%	8.3%	10.1%	10.6%	10.7%
MIRR	Negative	Negative	2.0%	7.4%	8.2%	8.1%	7.7%

Figure 2 shows the annual undiscounted benefit and cost cash flows for the total investment of AP16005. 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

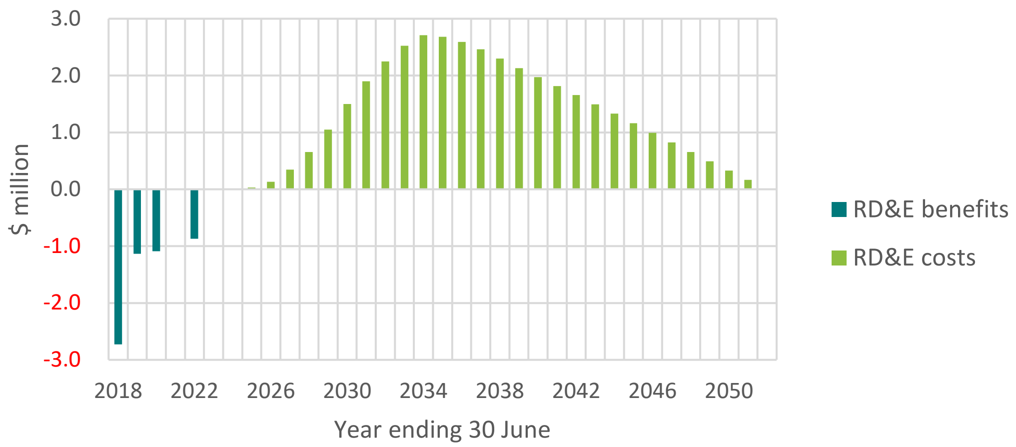
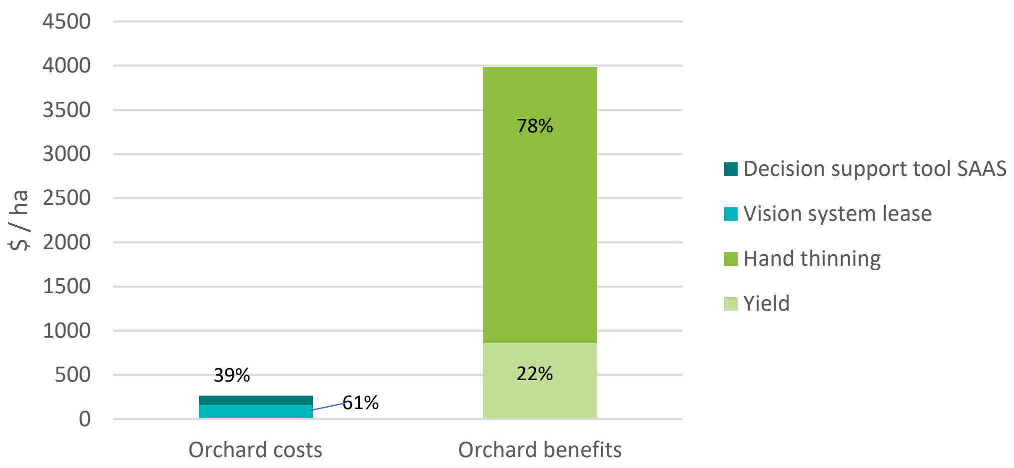


Figure 3 shows the annual undiscounted benefits and costs at an orchard level on a per ha basis. The 66% reduction in hand thinning costs accounts for 78% of the baseline benefits, with the 1% yield increase accounting for the remaining 22% (note chemical costs were unchanged in the baseline).

Figure 3. Breakdown of baseline orchard level costs and benefits

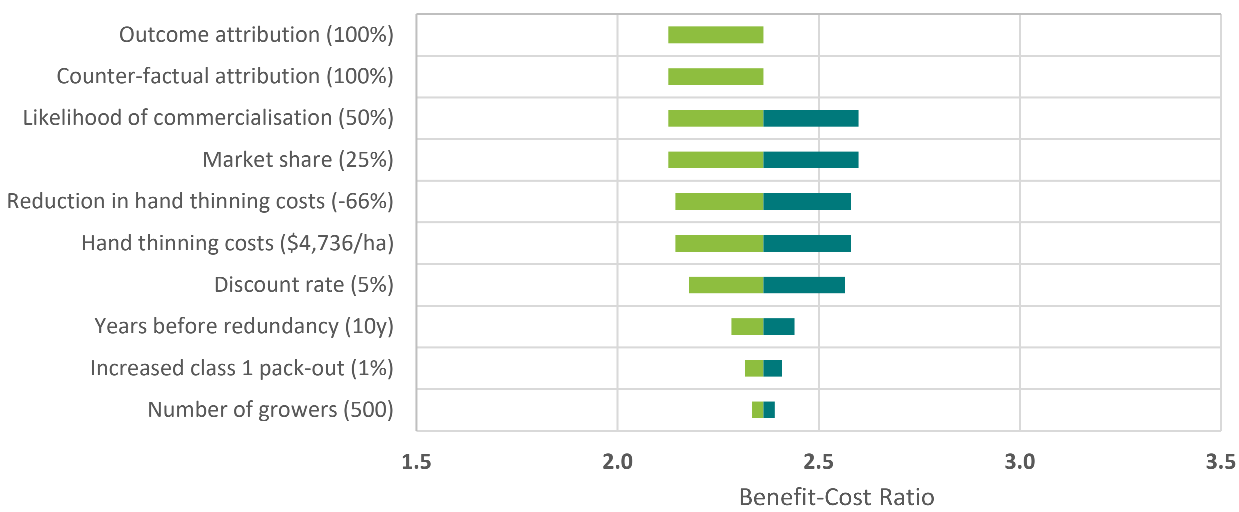


Sensitivity analysis

Given the risk and uncertainty associated with several underlying modelling inputs (particularly due to the forward projections inherent in the impact assessment process), the results were tested for their to sensitivity to changes in all variables where a potential value range was identified (Table 4).

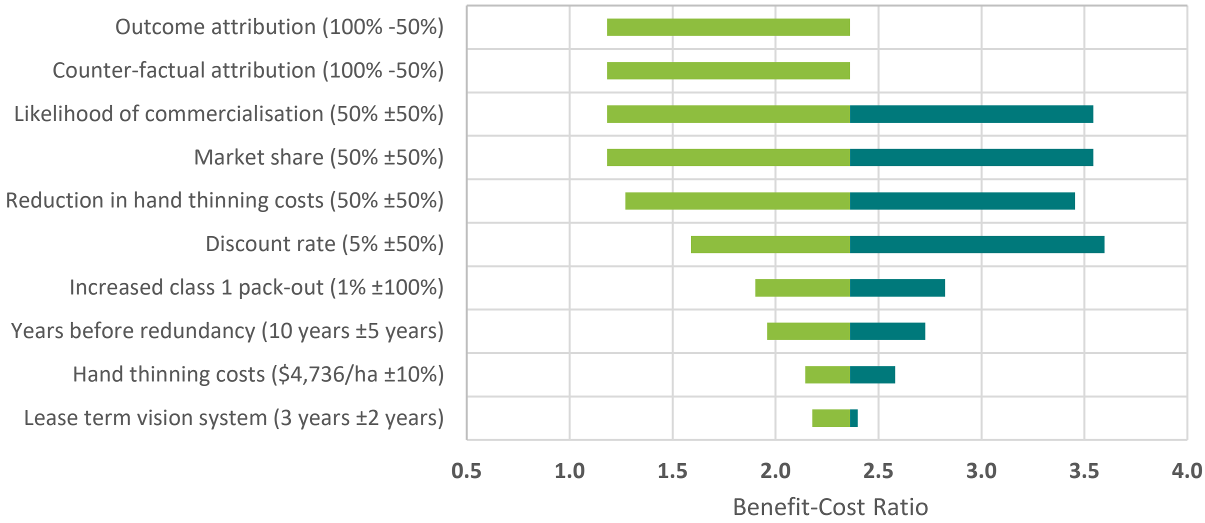
Results were first tested for sensitivity to uniform changes in underlying variables. This highlighted that the results were most sensitive to 10% changes in the counterfactual attribution and outcome attribution, likelihood of commercialisation and market share (Figure 4). As the outcome and counterfactual attribution were at 100% in the baseline results, only the downside is shown.

Figure 4. Hurricane graph (10% change in variables)



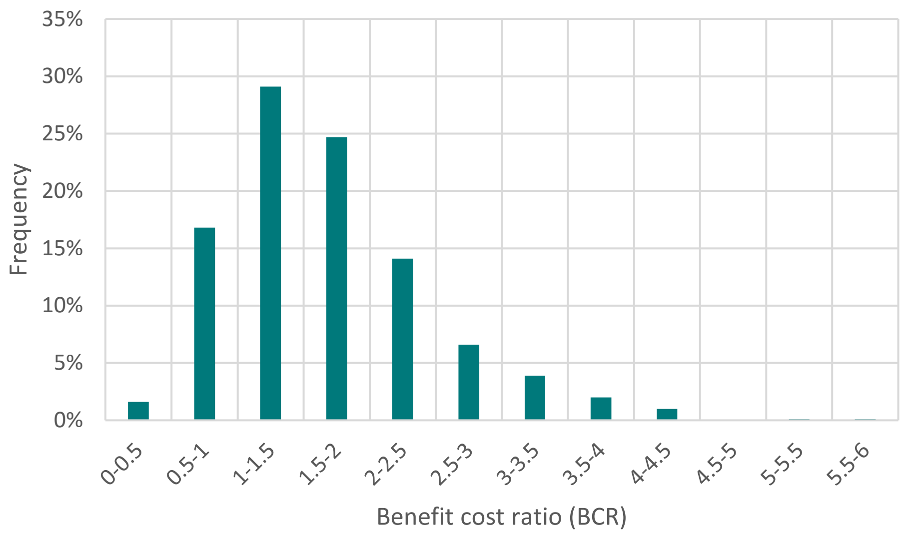
Results were then tested for sensitivity to the identified full range of potential variability for each data input to highlight the variables that were most likely to affect the results. This analysis showed that the results were most likely to be affected by the same variables Figure 4, with the exception that the results were more sensitive on the upside to changes in the discount rate (reflecting the long timeline for impact) and the baseline hand thinning costs became less significant (Figure 5). The significance of the market share and stakeholder comments regarding the potential for other market entrants in this technology area highlights the importance of achieving commercialisation soon to maximise market share and impact. The plus and minus 5% change in chemical costs were relatively insignificant (reaching a maximum of 1% of total benefits and resulting in a BCR range of between 2.33:1 and 2.39:1) so the results are not shown. Even with no yield or chemical cost changes, the reduction in hand thinning costs is sufficient to ensure a positive return on investment. A minimum reduction in hand thinning costs (relating to the effectiveness of the systems) of 25% is required for the RD&E investment to break-even.

Figure 5. Hurricane graph (full range change in variables)



Finally, the full range of potential 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 0.26:1 and 5.82:1, with 90% of results falling between 0.66:1 and 3.26:1 (i.e. excluding the lower probability of an extreme high or low value), and a 82% probability of a BCR greater than 1 (Figure 6). This indicates a low level of risk regarding this investment generating a positive impact.

Figure 6. Impact histogram (1000 simulations)



Implications and learnings

Project AP16005 developed significant industry knowledge around flower mapping and thinning, including developing the understanding of what growers need (stakeholder consultation). This culminated in the development of technology solutions for flower thinning, including the flower mapping and decision support tool *Apple Snapper System*, which was ready for commercialisation via licencing through Hort Innovation, and the *Variable Timing of Application Sprayer*, which can be retrofitted by growers using the *Industry Guide* produced by AP16005. On completion, this combined product offering had the potential to increase quality of apples (increase pack out rates), reduce the effects of biennial bearing of fruit, reduce hand thinning costs, and reduce the volume and cost of chemical thinner, among other potential impacts.

At project completion in January 2022 the Apple Snapper System was intended to be commercialised through a third party; however, no clear progress had been made by May 2023, increasing the uncertainty around the final stages of the impact pathway (commercialisation and adoption). A likelihood of commercialisation figure was applied (25% to 75% in the next 1 to 3 years) to account for this uncertainty, effectively reducing the full potential benefit to be a “risk adjusted” benefit. Conservative assumptions relating to potential market share (12.5% to 37.5%), as well as for improvements in pack out rate (0% to 2%), hand-thinning cost reductions (33% to 99%), and chemical cost changes (-5% to +5%) were also applied. Given this conservative approach, the positive baseline impact (BCR 2.36:1) and an 82% chance of a positive impact given the identified variable ranges gives a high confidence that AP16005 will result in a positive impact for the apple industry.

Of the three impact areas modelled the baseline benefits were made up of 78% reduced hand thinning labour costs, and 22% increased productivity (marketable yield), with no reduced chemical cost benefit in the baseline reflecting the uncertainty over this outcome. Sensitivity testing showed that the maximum benefit of reduced thinning chemical was only 1% of total baseline benefits. Even with no yield or chemical cost changes, the reduction in hand thinning costs is sufficient to ensure a positive return on investment. A minimum reduction in hand thinning costs (relating to the effectiveness of the systems) of 25% is required for the RD&E investment to break-even.

Reflecting the uncertainty over the remainder of the impact pathway, the results were most sensitive to the likelihood of commercialisation, and likely market share of the Apple Snapper System. The significance of these variables and stakeholder comments regarding the potential for other market entrants in this technology area highlights the importance of achieving commercialisation soon to maximise market share and impact.

The lack of empirical data for the change in marketable yield (both as a result of improved quality and reduced biennial bearing) was a key weakness in this analysis. While all care was taken to use realistic and conservative estimates based on stakeholder consultation, future analysis (and industry confidence to adopt) would be supported by more robust data in this area.

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**
Kathryn Young, Hort Innovation Head of Sustainability R&D	RD&E process owner / manager	✓	✓	✓	✓	✓		✓
Vino Rajandran, Hort Innovation Head of Production R&D	RD&E process owner / manager	✓	✓	✓	✓	✓		✓
Mark Whitty, UNSW	RD&E practitioner	✓	✓	✓	✓	✓	✓	✓
William McCarthy, SwarmFarm	RD&E practitioner		✓	✓	✓	✓	✓	✓

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 (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

ADOPT Adoption and Diffusion Outcome Prediction Tool

APAL Apple & Pear Australia Ltd

CRRDC Council of Rural Research and Development Corporations

CSIRO The Commonwealth Scientific and Industrial Research Organisation

DST Decision Support Tool

GPS Global Positioning System

IMU Inertial Measurement unit

Lidar Light detection and Ranging

RD&E Research, Development and Extension

SAAS Software as a service

SIP Strategic Investment Plan

UNSW The University of New South Wales

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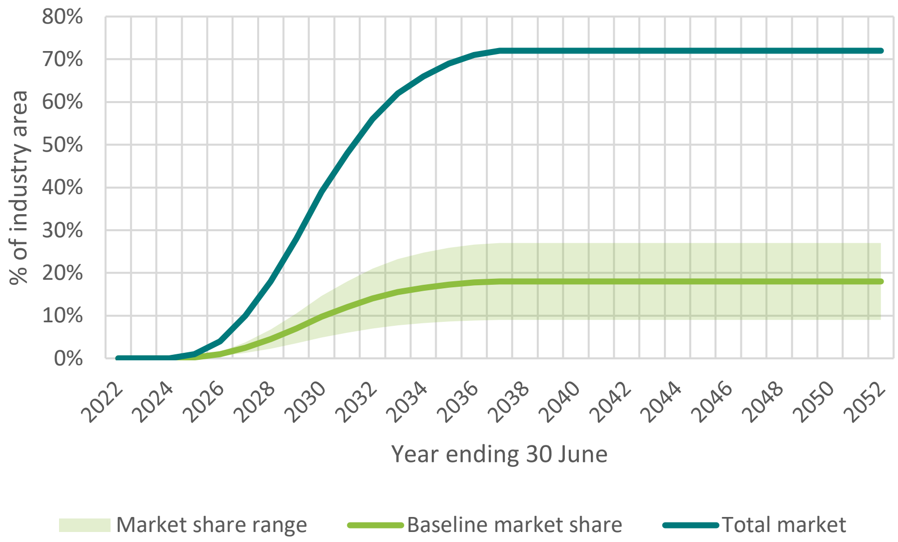
Appendix A. Adoption and diffusion using the ADOPT framework

Appendix A includes the estimated adoption and diffusion curve for Variable Timing of Application technology and the market share of the Apple Snapper System developed in AP16005. The adoption and diffusion curve was estimated based on stakeholder consultation and available data which were incorporated into the CSIRO ADOPT framework (Kuehne et al 2017). It was not clear how large of a market share the Apple Snapper System may achieve once introduced to the market, as there are other companies potentially capable of providing a similar offering (stakeholder pers. comms). The analysis assumed a 25% share of the total market (i.e. 25% of 72%) tested at 12.5% and 37.5%. Figure 7 shows the resulting Total Market curve for flower mapping and decision support technology, and the assumed market share of the *Apple Snapper System*.

Figure7. Estimated adoption and diffusion of variable timing spray technology, and market share of the Apple Snapper System



ADOPT inputs

1. What proportion of farms have maximising profit as a strong motivation?

A majority all have maximising profit as a strong motivation.

2. What proportion of farms has protecting the natural environment as a strong motivation?

About half have protection of the environment as a strong motivation.

3. What proportion of farms has risk minimisation as a strong motivation?

About half have risk minimisation as a strong motivation.

4. On what proportion of farms is there a major enterprise that could benefit from the technology?

Almost all of the target farms have a major enterprise that could benefit.

5. What proportion of farms have a long-term (greater than 10 years) management horizon for their farm?

About half have a long-term management horizon.

6. What proportion of farms are under conditions of severe short-term financial constraints?

Almost none currently have a severe short-term financial constraint

7. How easily can the innovation be trialled on a limited basis before a decision is made to adopt it on a larger scale?

Easily trialable.

8. Does the complexity of the innovation allow the effects of its use to be easily evaluated when it is used?

Difficult to evaluate effects of use due to complexity.

9. To what extent would the innovation be observable to farmers who are yet to adopt it when it is used in their district?

Difficult to observe.

10. What proportion of growers use paid advisors capable of providing advice relevant to the innovation?

About half use a relevant advisor.

11. What proportion of growers participate in groups that enable discussion relevant to the innovation?

About half are involved with a group that discusses farming.

12. What proportion of growers/advisors will need to develop substantial new skills and knowledge to use the innovation?

Almost all need new skills and knowledge.

13. What proportion of growers would be aware of the use of trialling of this innovation in their district?

About half will be aware that it has been used or trialled in their district.

14. What is the size of the up-front cost of the investment relative to the potential annual benefit from using the innovation?

Moderate initial investment.

15. To what extent is the adoption of the innovation able to be reversed?

Easily reversed.

16. To what extent is the use of the innovation likely to affect the profitability of the farm business in the years that it is used?

Small profit advantage in years that it is used.

17 To what extent is the use of the innovation likely to have additional effects on the future profitability of the farm business?

Small profit advantage in the future.

18 How long after the innovation is first adopted would it take for effects on future profitability to be realised?

1-2 years.

19. To what extent would the use of the innovation have net environmental benefits or costs?

Small environmental gain advantage.

20. How long after the innovation is first adopted would it take for the expected environmental benefits or costs to be realised?

1-2 years.

21. To what extent would the use of the innovation affect the net exposure of the farm business to risk?

Small reduction in risk.

22. To what extent would the use of the innovation affect the ease and convenience of the management of the farm in the years that it is used?

Small increase in ease and convenience.

Ends.