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Valuing the impact of plant pests and biological controls on New Zealand Agriculture

A Dissertation
submitted in partial fulfilment
of the requirements for the Degree of
Postgraduate Diploma in Commerce

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Lincoln University

by
John Tobias Saunders

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Abstract of a Dissertation submitted in partial fulfilment of the requirements for the Postgraduate Diploma in Commerce.

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The agricultural industry plays a key part of the New Zealand economy. However the incidence of plant pests in New Zealand threaten the viability of the sector. There are various options for controlling and mitigating the impact of these pests, and biological controls offer one potentially valuable solution. Economic analysis of these pests are vital to forming an appropriate policy response at the government level. Much of the literature on bio-security and biological controls focusses on a biological perspective rather than an economic one. This dissertation presents a more comprehensive framework for economic valuations of plant pests, with the use of a modified cost-benefit analysis (incorporating inputs from partial equilibrium trade modelling) to test the economic impact of plant pests and controls responses in New Zealand. Specifically, two case studies are examined: clover root weevil (Sitona lepidus), and its biological control Microctonus aethiopoides; and glassy-winged sharpshooter (Homalodisca vitripennis), and its biological control Gonatocerus ashmeadi. The analysis shows the impacts of clover root weevil, and glassy-winged sharpshooter, if left unchecked, are –NZ$604 million, and –NZ$5 million per year respectively. The biological control options for each pest would mitigate between NZ$338-431 million per year in the case of clover root weevil, and NZ$4 million in the case of glassy-winged sharpshooter.

Keywords: Biosecurity, bio-controls, cost-benefit analysis, partial equilibrium trade modelling, economic valuation, agriculture, New Zealand
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Chapter 1
Introduction

1.1 Introduction

Primary industries are of high importance to New Zealand, contributing $13.1 billion to GDP, or 5.6% of total GDP in 2014, and (including fisheries) accounting for 60.8% of total goods exports in 2016 (Statistics NZ, 2017). This sector, however, is under threat from failures in plant protection, in the form of pests, weeds or plant diseases becoming widespread or developing from new incursions. One recent example of this is the outbreak of Pseudomonas syringae pv. actinidiae (PSA) in kiwifruit, which has been estimated to have cost between $310 and $410 million to New Zealand agriculture over 5 years (Greer & Saunders, 2012).

New Zealand is particularly vulnerable to the impact of weeds, pests, and diseases, due to relatively unfilled biological niches and the absence of some naturally occurring regulatory factors (Goldson et al., 1997), and it has been estimated that more than 90% of this country’s invertebrate pests are non-native invasive species (Barlow & Goldson, 2002). Therefore it is important to assess the impact of such incursions and the means by which this can be offset or minimised.

If a biosecurity threat has been indentified, the process of considering possible responses begins. These responses may include the use of biocontrols. An important stage in identifying an appropriate response to a threat involves analysing the economic ramifications of the biosecurity threat and the possible responses to the threat. This helps inform what constitutes a reasonable response, and to identify a response that can be considered economically justified.

Consequently, the objective of this research is to measure the potential economic impacts of two bio-security incursions in New Zealand and to evaluate the costs and benefits of potential mitigation and control responses available at the farm level including the use of biological controls as a control response.
This dissertation therefore aims to contribute to the literature on economic valuation, particularly surrounding the framework of valuations of bio-security threats and controls. Additionally the dissertation aims to add new knowledge to the discipline by providing information on the impact of two case-studies of specific pest incursions in the New Zealand context.

1.2 Research question

As chapter 2 will explain, a number of contributions have been made by bioprotection researchers to produce monetary estimates of the damage caused by biosecurity incursions. This has included general applications to land-based industries (Suckling & Popay, 1993), with a particular focus on analyses of pasture/forage pests (Prestidge et al., 1991; Goldson et al., 1993; Barlow and Goldson, 2002; Goldson et al., 2005) and weeds (Bourdôt et al., 2012).

Saunders et al. (2017) has cautioned that many previous studies have not used an economics framework, and as a result, there has been little consistency in their methodologies. One notable exception to this was the work of Bertram (1999), which undertook an economic analysis of the issue. Partly in response to these issues this dissertation seeks to add to the literature, by expanding on an economic valuation of pests and bio-controls, in addition it extends the previous analysis with the inclusion of partial equilibrium trade modelling to enable a more robust analysis which includes the impact on trade and prices. This is especially important given New Zealand’s reliance on agricultural trade.

This can be summarised in the following research hypothesis that will be tested in this dissertation:

**Hypothesis:** That proposed biological controls for a potential biosecurity incursion can be evaluated using cost benefit analysis and partial equilibrium trade modelling to provide evidence for the value of the proposed response.

Thus this dissertation aims to demonstrate not only the economic cost to New Zealand agriculture of the spread of biological pests, weeds, and diseases, but also the economic value of different
mitigation responses, with a particular focus on biocontrol responses. In this dissertation, two case studies have been selected describing the spread of specific threats to New Zealand agriculture. The evaluation will be performed using cost benefit analysis (CBA), and a partial equilibrium (PE) model developed specifically to quantify these effects on New Zealand agriculture. The two scenarios have been selected to demonstrate a range of potential threats to different areas of agricultural industry, specifically dairy, and viticulture. Other impacts on New Zealand’s biodiversity profile, and indirect and induced effects upon other sectors however have not been accounted for within the scope of this dissertation.

1.3 Structure of the dissertation

This thesis comprises of six chapters.

Chapter 2 is a review of the relevant literature on economic valuation, with particular attention paid to cost-benefit analyses, bio-protection issues and bio-controls. This section also discusses gaps in the previous literature.

Chapter 3 describes the methodology selected from the literature review in chapter 2 for analysing the dissertation’s research question. The chosen methodology is a CBA, including PE trade modelling to analyse the impact on prices and production levels in New Zealand’s agricultural sector. This modified CBA approach is used to estimate the Net Present Value of biological controls on two case studies of plant pests in New Zealand. This chapter details these tools and how they are implemented for this dissertation.

Chapter 4 presents the case studies. Expanding on the previous methodology section, this chapter provides further detail regarding the composition and data used to construct the two case studies.

Chapter 5 presents the analytical results of the two case studies.
Chapter 6 concludes the dissertation. It summarises the results presented in chapter 5, and offers some discussion on the limitations of the research as presented, with some suggestions for future research.
Chapter 2

Literature review

2.1 Introduction

This chapter examines the literature on economic valuation and cost-benefit analysis, with special reference to pest incursions in New Zealand. These include the costs to the agricultural sector of the incursion and the cost of the methods to offset or minimise the impacts of the incursion. The later includes the methods which require government funding such as bio-control science. As stated earlier, a CBA of their effectiveness will show some of the benefits of this science. Thus economic valuation is used to help justify this requisitioning of resources and assess the outcomes on net social benefit.

2.2 Economic Valuation

At the heart of economic theory is the challenge posed by limited resources; with infinite resources there would be no economics. Economics then asks, with the condition of limited resources, how can we best allocate them to maximise social welfare (Samuelson & Nordhaus, 1989)? Thus economic theory posits the allocation should be such that the wellbeing of relevant parties is increased without decreasing another party’s wellbeing. Here the relevant parties generally refers to all of society, but this is restricted in some cases to certain populations, depending on the context of whomever is proposing the question.

A key way resources are allocated is via the market and from this market prices can be used as an indicator of economic value. Every day, people choose to purchase goods or services, and in doing so are revealing their relative preferences for these goods and services. In idealised free market conditions, this would lead to market prices reflecting the relative marginal value to society, however as markets often have imperfect conditions, this is not always the case. This can be due a number of reasons: lack of equal information on the part of buyers and sellers, imperfect competition, or externalities (Varian, 1996).
A second significant problem with using market prices as a metric for value is that many obviously valuable things have no associated market, such as natural capital. These ‘non-market goods’ would then be excluded if we dealt only with market values. There are some methods however that can be used to define monetary measures of non-market goods, such as revealed or stated preference method, which use methods such as survey tools or secondary data to assess preferences for these goods.

In CBA, both valuation for market and non-market goods are attempts to approximate the marginal opportunity cost (or marginal benefit to society) (Hanley & Spash, 1993). As stated above, ideally this is already captured by the market price for market goods, however as also just discussed, imperfect markets exist and cause price distortion, so this may not always be the case. In these cases where the actual marginal net benefit to society is not represented by the market price, and in cases where no market price exists, prices can be estimated through non-market evaluation techniques. Prices estimated in this way are called ‘shadow prices’ (Hanley & Spash, 1993).

CBA then assesses the net social benefit of a project or action, to provide evidence on whether it is a ‘rational social decision’. This is similar to the economic idea of Pareto optimality, in which a programme or action is judged to be economically justified if it provides a benefit to some, and no one is made worse off. In practice, there are likely to be winners and losers, but the intervention is still held to be Pareto efficient, and therefore justified, if the losers could be adequately compensated by the winners with the net result remaining positive (Varian, 1996).

Economic valuation is always a comparative process as the basis of the valuation is relative to the opportunity cost of a programme or action. Any costs or benefits are measured relative to what might have been done instead of the proposed policy or action. The value of the next best alternative is referred to as the opportunity cost of the intervention.
2.3 Cost benefit analysis

Cost Benefit Analysis (CBA) is a form of economic evaluation which was developed from the foundations of welfare economics (Pearce, 1983). CBA was first used to guide government decision making in the US. The first example was a basic form of CBA used in the 1936 US Flood Control Act, followed by the ‘Green book’ study by the US federal Inter-Agency River Basin Committee, and the U.S. Bureau of Budget’s ‘Budget Circular A-47’ in 1952. These early examples of the method were the first to use impacts on welfare as a measure of benefits and costs, and to consider the impacts of the policy in the context of the opportunity costs of its implementation. In its earliest forms the method was used primarily by government in policy decisions.

Later, the method became more widespread, being used by government and industry for both policy and investment applications. A series of guides were published by Little & Mirrlees (1974), the OECD (Little & Mirrlees, 1969), and the UN Industrial Development Organisation (Marglin et al., 1972), providing protocol for the thorough application of CBA.

One key component of a CBA is defining the scope of the analysis. Pearce (1983) argues that CBAs should include all parties affected by the proposed policy or action. However with CBAs that are specific to certain regions, such as with national-level policy decisions, it could be argued that the range of the study extends only to impacts on the nation’s inhabitants. In these cases the context of the CBA analysis becomes country-specific.

As the research question is specifically centred on New Zealand in this dissertation, the focus is on CBAs performed in the New Zealand context. To help frame the specific requirements and scopes of CBAs in this context, four key pieces of the literature were selected: the New Zealand Treasury’s guide to performing CBAs (Treasury, 2015), the New Zealand Ministry for Agriculture and Forestry’s guide to CBA (MAF, 2002), the New Zealand Biosecurity Act 1993, and lastly a discussion piece on specifically on evaluations of biosecurity interventions in New Zealand which draws on, and assess literature on CBAs and other similar methods (Dalziel & Hulme, 2016).
The New Zealand context as described in these examples builds on from the general literature in that it accounts for the demands of the New Zealand legal framework, and includes unique facets of the New Zealand case, for example incorporating the impact on Māori culture, and emphasising key areas of impact in the New Zealand context, such as water quality and ecosystems services.

The basis of Cost-Benefit Analysis (CBA) is the following equation:

Equation 1: Net Present Value

\[ \sum_{t} \frac{Benefits_t - Costs_t}{(1+r)^t} \]

Where:

- \( r \) is the discount rate (explained below) and
- \( t \) - time.

CBA assesses all the costs and benefits implied by a particular policy or other intervention. It thus attempts to ascertain if there is a net benefit or loss to society. The costs and benefits are considered against the next best most reasonable alternatives, which may include ‘business-as-usual’, if the policy or intervention does not occur.

A distinctive feature of CBA is that the method aggregates all costs and benefits over time to a single Net Present Value. This is done by discounting future costs and benefits at a predetermined discount rate. This is to account for diminished value over time, based on the assumption that we value things more today than in future. In general the discount rate reflects the opportunity cost of resources invested today, proxied by the returns of a dollar invested in a risk-adjusted financial asset, as described in more detail later.

Different guides and manuals on performing CBAs refer to different amounts of steps in performing an analysis. The Treasury guide to CBA (2015) defines 7 steps, for example, whereas the MAF CBA paper...
(2002) defines 12 steps. Of these approaches the consistent steps required of CBA in its most basic form seem to be the following, where certain steps are broken down or expanded upon in particular guides:

1. Identify the policy outcome scenario(s), and the counterfactual scenario (outcome without policy scenario(s))

2. Identify who would benefit or lose under each scenario

3. Identify what the costs and benefits are under each scenario

4. Quantify the values of these benefits and costs for each scenario

5. Apply a discount rate for future benefits and costs

6. Sum all costs and benefits into a singular Net Present Value (NPV), [equation 1]

7. Perform sensitivity analysis around key parameters

Additional stages and complexity come from expanding the above given steps, for example: considering the time line of the costs and benefits, or defining specific elements of costs. This most simple outline of a CBA underplays the difficulties in performing a rigorous study. In particular defining the counterfactual and quantifying the values of costs and benefits can be difficult, and may require input from specialists and/or considerable data. Each step of the CBA is expanded upon below.

**Identify the policy outcome scenario(s), and the counterfactual scenario (outcome without policy scenario(s))**

The New Zealand Treasury guide for CBA (2015) defines the counterfactual scenario as ‘doing nothing’ or the ‘minimum’, and Kaye-Blake et al. (2010) describes it as ‘what is happening’. It is important to emphasise that the Treasury definition does not necessarily imply that no policy change will occur in the counterfactual, rather that the most likely outcome given the current business as usual should be used. As this scenario is the baseline against which all other scenarios are measured, an exaggerated
or misinformed counterfactual will distort the reported values of all other scenarios and undermine
the validity of the analysis as a whole. Thus the construction of a coherent counterfactual is paramount
to the analysis. However, creating a satisfactory counterfactual is difficult as the counterfactual is
necessarily speculative. It requires a comprehensive understanding of the subject matter and careful
consideration of the possible outcomes, best performed with expert consultation. In the context of
pest impacts, and control options for these, the MAF guide to performing CBAs (2002) highlights that
this baseline scenario is the conditions that might be expected in the absence of the control options,
not in the absence of the pest.

**Identify who would benefit or lose under each scenario**

Treasury’s guide for social CBAs (2015), states that the range of a CBA should cover the impact across
all of New Zealand, the welfare of future generations, and include all potential costs and benefits. It
is also suggested that it is best to use real prices assuming no inflation.

**Identify what the costs and benefits are under each scenario**

Relevant for this study, the New Zealand Biosecurity Act 1993 sets the protocol for assessing
biosecurity pests in New Zealand. The Act requires costs and benefits for all the impacts and then the
control options to be assessed. In these assessments, impact is measured across the following areas:

- Impact on native species
- Impact on threatened species
- Soil loss or erosion
- Degradation of water quality
- Impact on primary production
- International trade
Quantify the values of these benefits and costs for each scenario

Defining the level of impacts of benefits and costs can also prove difficult. Even for goods with market values it can be difficult to procure the necessary data. This is due to several factors. First, sales, production, input and data from the commercial sector are often confidential and thus hard to access. Second, scientific studies on the impacts of pest and bio-controls are often focused on the micro level, farm-level studies or smaller scale, whereas economic assessments are often carried out across the macro level, regional or even national (as in this study). Furthermore as indicated by Kaye-Blake et al. (2010b) the data used in scientific studies are mal-aligned with the data requirements of economic analysis; so even for topics with a large body of research literature, the key data for economic analysis may still be unavailable.

As CBA requires all impacts to be expressed in monetary terms, impacts on goods and services with market values are generally used. However shadow prices can be used in the case of imperfect markets (due to subsidies, for example, or other factors). A drawback of the CBA method is non-market goods or services (those without market values) are harder to quantify. There are ways to overcome this limitation, by performing methods of non-market valuation, such as stated preference methods (including choice experiments, CE), or revealed preference (RP). These methods, however, are complex and costly. Akter and Kompas (2015) is a good example of the use of CE in conjunction with portfolio analysis for biosecurity decision making, where several potential scenarios of spread and pest distribution were used to frame uncertainty in invasion dynamics. Thus non-market evaluation can be used in cases where the predominant impacts are on non-market goods and/or services.

Non-market impacts can be accounted for outside of the CBA by including elements of Multi-Criteria Analysis (MCA), with the CBA used as one criterion for the evaluation within the MCA. This approach
was used by Cook & Proctor (2007), where several incursions of pests and diseases were analysed under several criteria, including production costs, revenue loss, risk, impacts on flora and fauna, cultural loss and impacts on human health. This approach is useful in addressing uncertainty associated with pest incursions, and this technique can also be useful in providing information on what could be included a CBA analysis. In the case of Cook and Proctor (2007), this analysis was used to help ranking the impact of different incursions, rather than quantifying the correct level of response.

**Apply a discount rate for future benefits and costs**

Selecting an appropriate discount rate for the future impacts of a CBA is another crucial step. Kaye-Blake et al. (2010b) discusses this process. The return on capital can be used to reflect the opportunity costs of investment, or the official cash rate of the Reserve Bank can be used to represent a low-risk investment option. The relative importance of selecting an appropriate discount rate is proportional to the length of the time-frame of the impacts. In particular, when dealing with environmental effects where costs or benefits can manifest over an extremely long-time span, a high discount rate would serve to underestimate longer term impacts and a lower rate could be considered. Moreover there is a debate that a much lower discount rate should be used, especially when public goods are involved in potential environmental impacts.

In previous bio-protection studies, a range of rates have been used. An 8% discount rate is suggested by Sullivan and Hutchinson (2010) as being in line with other regional pest management strategy studies, and is also used in Lubulwa and McMeninam (1998). Other discount rates have been used in similar studies, 4% in US forestry pest studies (Bockerhoff et al., 2012), and 3% in others (Lamoureux et al., 2014). Brockerhoff et al. (2010), uses a 10% discount rate in a CBA study on several eradicable pests. The New Zealand Treasury suggests a 6% discount rate (Treasury, 2016).

**Sum all costs and benefits into a singular Net Present Value (NPV)**
As expressed in Equation 1, the Net Present Value is the single resulting figure of the CBA, which combines all identified costs and benefits, after the application of a discount rate, into a monetary value. The sign of the NPV demonstrates whether the particular study is of net positive or net negative benefit to the country, and thus whether the policy is economically viable or not according to the analysis.

Different scenarios can be compared using a benefit cost ratio. This is calculated by dividing the present value of benefits by the present value of costs. Alternatively an internal rate of return can but calculated to compare across scenarios and compare to the discount rate.

**Perform sensitivity analysis around key parameters**

Sensitivity analysis is the process of accounting for uncertainty in some of the key factors of an analysis. Variations of the outcome (in this case the NPV) can be tested when there are different values for some of the costs and benefits. Doing this allows for a range of NPVs dependant on particular costs and benefits, rather than a singular NPV, or for confidence intervals around the final NPV, showing the range of possible outcomes given different levels of uncertainty in key components of the CBA. This is useful as due to the nature of the analysis many parameters are speculative, and thus subject to some uncertainty. Furthermore in cases where the reliability of some data is imperfect, sensitivity analysis can be used to test what impact this will have on the entire study.

The Treasury guide to CBA (2015), recommends performing sensitivity analysis on individual costs or benefits in the analysis which have a high-level of uncertainty. Also sensitivity analysis can pinpoint areas that may require further exploration.

**2.4 Previous valuations of the impact of pests and the use of bio controls**

Evaluating the impact of bio-controls for mitigating the impacts of pests entails quantifying the physical impacts of the pests, the impact of the bio-controls, the impacts of other likely alternative controls methods, and changes in economic benefits and economic costs each of these components
imply. There is an existing literature on the bio-physical impacts of pests and the consequent effectiveness of bio-controls; however the majority of this literature is from a biological science perspective and focuses on physical implications of bio-controls rather than economic outcomes. Consequently the data and results from the analysis are often not relevant to the data requirements for economic analysis (Kaye-Blake et al., 2010a). There is however a sub-set of the literature which combines biological science with economic analysis, as funding for bio-controls and bio-protection science often requires proof of economic benefit. The New Zealand Biosecurity Act, for example, requires an assessment of pest controls, including a CBA before implementation. A number of techniques have been used to measure the benefits for particular bio-protection programmes. The majority of these studies use CBA or some variation of CBA to quantify the economic impacts.

Page and Lacey (2006) in a paper evaluating the success of biocontrol programmes in Australia uses CBA to analyse 36 different controls. This is done alongside a simple qualitative measure on social and environmental impacts for each case rather than attempting to value these and incorporate the results within a CBA. Both Watson and Mercer (2000), and Basse et al. (2015), use comparisons of costs and benefits, primarily based on the lost production potential and the costs of replacing lost nitrogen fixation with synthetic fertilisers, in assessing the costs of pests in New Zealand, and the potential benefits of biological controls. Basse et al. (2015) include in their analysis the implementation costs of the biocontrol agent, and sensitivities around the values of their cost benefit model. Their paper also highlights the need in future research for including the research costs associated with discovering and vetting a biological control agent, the spread rate of the pest and its biological control.

A series of economic evaluations of bio-controls by Grundy (1989a, 1989b, 1989c) had a CBA element as the central methodological focus; yet while impacts other costs and benefits were mentioned in the analysis, only the potential impact on primary production, and the direct costs of developing and implementing the bio-control were considered in monetary terms. The sensitivity analysis in the
report considered the levels to which the bio-controls would be effective (using a series of level of impact scenarios).

Alternative approaches to CBA have been used to value pest incursions. Some examples are Multi-Criteria Analysis (MCA), replacement cost techniques, averting or preventative expenditure techniques, human capital approaches, production function techniques, and dose response functions (Bicknell, 2003). Kompas and Liu (2013) identify MCA as the main alternative to CBA for biosecurity research, mainly due to the level of uncertainty associated with many case-studies in biosecurity applications. MCA compares outcomes for different polices across a range of different criteria. Unlike CBA the criteria do not have to conform to a singular measure and thus can include qualitative information, which is one benefit of the method. The method was developed to elucidate the decision-making process and to increase transparency for businesses. However, as the criteria are not necessarily comparable, this also means MCA is non-normative; that is to say the analysis cannot suggest which outcome is preferred in-and-of-itself. Kompas and Liu (2013) acknowledge MCA is most appropriate for topics with a high level of uncertainty or in cases where a lack of data makes CBA analysis difficult.

Cost based techniques include production function techniques, which focus on the changes to production and production potential. These methods are valuable ways to assess the impact on production, but are limited in their scope to include effects outside of production since they don’t account for benefits. Furthermore these methods do not account for costs or benefits over time in the same way CBA is able to assess.

A CBA often includes the flow-on impacts on business and personal revenues in different sectors of the economy. Change in revenue to one industry will result in a change in intra-industry spending (indirect), and this in turn will result in a change in incomes, and thus a change in consumer spending (induced). These secondary effects are also known as ‘multiplier effects’ as they are calculated using Input-Output (IO) models comprised of matrices of multipliers expressing the relationships between changes in revenue from one sector to indirect and induced impacts in all other sectors (Weisbrod &
Weisbrod, 1997). General equilibrium models also consider these non-direct impacts, tracking changes in revenue flows between industry, government, and private households, on the assumption that changes in equilibrium prices must be taken into account.

Soliman et al. (2009) compare four approaches to pest risk analysis, including ‘partial budgeting’ (PB), which is analogous to CBA. The study recommends partial equilibrium (PE), or computable general equilibrium (CGE) trade modelling in addition to PB analysis. This is able to capture indirect impacts of pests across a wider sector and also incorporate changes and effects of market price changes from pests (a shortcoming of CBA also acknowledged in Myers et al., 1998). Trade modelling of this type analyses changes in world markets and prices and their impact. Soliman et al. (2009) add the caveat that results produced by trade modelling approaches are to a level more uncertain that PB analysis alone as they rely on a simplification of real world economic dynamics.

The New Zealand Biosecurity Act suggests that analysis should cover changes in primary production and international trade, both of which would be impacted by market price changes. Thus analysis which incorporates some element of PE or CGE modelling may be preferable for assessing the impact of pests, as is seen in other research, using either PE (Mumford, 2002; Surkov et al, 2009; Breukers et al., 2008) or CGE (Wittwer et al., 2006) modelling.

2.5 Gaps in the previous literature

In examining the existing literature, some short-comings are apparent, these primarily stem from disconnects between the aims of economic and biological analysis, highlighted in Kaye-Blake et al. (2010a). This disconnect has led to a prevalence of studies with economic analysis as a secondary focus, and sometimes done in an ad-hoc manner. Thus, the claims from these studies are not always robust.

Further, Kriticos et al. (2005) stresses the need for a clear and robust conceptual framework for communicating the complex impacts of pest incursions to Government and industry, in order to secure the necessary funding to support bio-security research. This includes “estimating the potential
returns from various research instruments”, which is reinforced in Saunders et al. (2017) where a
dynamic evaluation of the spread and impact of pests is proposed, using dynamic prices.

Considering the broad range of foci in the literature and the divergence in methodologies used, even
amongst studies broadly applying a version of CBA, there is a lack of consistency and depth in
previous economic valuations of bio-controls. Thus there is room for studies which incorporate some
additional elements into a traditional CBA to evaluate bio-controls, such as non-market valuation,
multiplier analysis, or wider PE or CGE trade modelling.

2.6 Conclusion

This chapter has reviewed the development and use of economic techniques to value possible
interventions in response to a biosecurity threat. In particular, the chapter has discussed cost benefit
analysis, including step by step guides to performing a CBA in a New Zealand context and the
challenges associated with performing the method. Furthermore the pervious uses of CBA in valuing
the impacts of biosecurity threats, and bio-controls, has been presented. Finally the chapter has
discussed some shortcomings and gaps in the existing literature. The following chapter draws on this
review to explain the methodology used for the case studies of this dissertation.
Chapter 3
Methodology

3.1 Introduction

The previous chapter outlined the literature around economic valuation and biological controls. From that literature a modified cost benefit analysis method was developed to analyse the research question of this dissertation. The current chapter explains this method and describes the sources of data that were used in its implementation.

Section 3.2 discusses the modified CBA at the centre of the analysis. Section 3.3 outlines the specifications of the LTEM the model used for the PE component of the CBA. Section 3.4 describes the data needs of the analysis, and which sources were used to fulfil them.

3.2 Modified cost benefit analysis

The method chosen to assess these two case studies is a modified CBA. CBA is widely applied in the literature for this type of research question as shown in the previous chapter’s literature review. The modification is to add elements of PE trade modelling to the CBA to inform price pathways for the relevant agricultural markets, and the flow-on impacts from international trade effects. This PE component was also used to construct and inform each scenario in the case studies. The inputs for this analysis were taken in part from expert consultation and in part from the literature, including farm budgets and cost data taken from the New Zealand Ministry for Primary Industries’ farm models (MAF, 2011a; 2011b; 2011c; 2011d).

This research examined the period from the beginning of the modelled timeframe, 2014, to the forecast horizon, 2030, ten years beyond the final year projected in the PE modelling. It used a 6% discount rate (as recommended by Treasury) to derive the NPV.
As the focus of this study is the impacts of pests on agriculture and the methods to offset or reduce these impacts, the primary component is the direct costs and benefits on primary production. However where appropriate, the impacts upon other sectors are discussed.

For assessing the economic value of the use of bio-controls of insect pests in New Zealand two case studies were selected: clover root weevil (CRW), and glassy-wing sharp shooter (GWSS). These two pests were chosen as they represent two different challenges to New Zealand plant protection. In both cases the affected industry is of significant value to New Zealand. Further a bio-control option exists, and for both invasions there is sufficient literature to reasonably quantify the physical and economic impacts of its implementation. CRW is a plant pest which is already present in New Zealand and impacts pasture utilisation. GWSS is not currently present in New Zealand but is anticipated to reach New Zealand and could become established. GWSS impacts on vineyards through the spread of Pierce’s disease and so presents a potential threat to New Zealand viticulture (Charles & Logan, 2013).

For each of these two case studies the analysis included:

- a baseline projection of agricultural production and profit assuming no impact from pests;

- a projection with pest impacts but no modelled response from government, industry, or farmers (this scenario is unrealistic, but is used to quantify the potential extent of damage from the pest);

- the counterfactual scenario which includes both the impact of the examined pest, and the most likely mitigation strategy employed by farmers; and

- a scenario with the introduction of a biological control agent.

Quantifying the incidences and spread of an insect or weed, and the probable mitigation responses was achieved by compiling data and projections from the literature and personal communication with plant protection specialists, where available.
3.3 Lincoln Trade and Environmental Model

The partial equilibrium modelling component used in this study was obtained using the Lincoln Trade and Environment Model (LTEM). The LTEM provides global and national analyses of price and market dynamics over time. It is a multi-commodity multi-region PE model of international production and trade in agricultural goods. The model has a key focus on New Zealand production and its place in global trade. This includes a focus on dairy products, which are disaggregated into 5 commodities (raw milk, liquid milk, cheese, butter, whole milk powder, skim milk powder). Model specifications are outlined further in Appendix A.1 & A.2.

The LTEM is based upon the VORSIM framework (Saunders and Cagatay 2003, Cagatay et al. 2003, Saunders et al. 2016), and currently includes 23 commodities and 24 regions (including the world, and ‘rest of the world’ an aggregate of all countries not elsewhere designated in the model). The included countries and commodities are listed in Appendix A.1.

The LTEM framework generally includes six behavioural equations and one economic identity for each commodity in each country/region. These behavioural equations are:

- domestic supply;
- domestic demand;
- domestic stocks;
- domestic producer price functions;
- domestic consumer price functions; and
- a trade price equation.

Trade in each country/region in the LTEM is equivalent to domestic production minus total domestic consumption (plus or minus annual changes in stocks). Domestic demand is separated into several
elements (food use, feed use and refined such as crushing oilseeds for oilseed meals and oil), in order that individual behavioural equations can more accurately represent different uses of commodities.

Net global trade must equal zero; hence, the model solves each domestic market and each country/region’s trade in relation to this global condition. In its current iteration the first year of the model’s projections is 2015, and the last is 2020. For the purposes of this research this range (2015-2030) will be the examined period for the CBA.

3.4 Data

Data in the LTEM include country specific producer and consumer prices production and consumption, beginning and ending stocks, producer and consumer subsidies and taxes, tariffs and quotas. In addition, the LTEM contains population data and GDP figures. In order to determine the effects on supply and demand, productivity growth rates, GDP growth rates and population growth rates are included. In the model, elasticities determine the responsiveness of domestic supply and demand to changing prices, production and consumption patterns, or policy measures.

For this research the base projections from the LTEM were used as the benchmark for global pricing and production in the analysis. ‘Base projection’ in this case refers to the model’s standard projection, using its repository of base data and behavioural equations to predict the business as usual scenario, holding the same conditions as present in model’s base year (2014) with the exception of some key macroeconomic factors (GDP and population), and reaching a new equilibrium state in each period. For these macroeconomic elements, international projections were taken from the World Bank (2015). These changing macroeconomic elements allow the model to predict a consistent global equilibrium under these expected macroeconomic factors. In essence this allows for a ‘most likely’ scenario under business-as-usual conditions, which accounts for expected global changes in income and population.

Price and production data at the national level were taken from LTEM, providing a projection of New Zealand agricultural commodities out to 2020. These projections were then disaggregated to the
farm level and normalised to the budgets for MPI’s model farms as of the 2011 farm monitoring reports (Ministry of Agriculture and Forestry: MAF, 2011a; 2011b; 2011c; 2011d). This approach attempts to consolidate national level projections and international trade effects and regional farm level budgets, taken from MPI. The analysis simulates national changes to agricultural production from farm-level impacts of damaging insects and weeds between 2011 and 2030, using linear extrapolations of the projection given by the LTEM.

3.5 Scenario analysis

In order to test the different scenarios considered in the CBA analysis, the most likely outcomes need to be considered. In order to do this a profile of the current and future economic situation in New Zealand agriculture had to be configured. In particular, with research into plant pests the analysis needed to link New Zealand productive and economic profiles at different levels: from farm level changes in production and farm budgets, to regional level changes in the spread and extent of each pest, to national level aggregate production effects, and finally on the global level to account for changes in international trade flows and world pricing effects. Although for most commodities New Zealand is a price-taker, dairy exports are sufficiently significant to have an impact on international dairy prices. Consequently, international market effects can have impacts in two ways, as shown in Figure 3.1 at different levels.
Different sections of the analysis were undertaken by combining different data sources and parts of the methodology. The global impacts, and price and production at the national level were informed by trade modelling performed with the LTEM. The regional level impacts were informed by consultation with experts in the field and from the relevant literature. Farm level impacts were a combination of model farm budgets, to inform the cost structures and production potential of farms, and then expert consultation and information from the literature was used to inform the specific extent and effects of pests, bio-controls, and alternative control mechanisms.
3.6 Conclusion

This chapter has discussed the modified CBA approach selected for this dissertation, including details on PE modelling, data requirements and implementation. The following chapter explains in further detail how this method will be applied to two case studies: CRW, and GWSS. This includes discussing the literature specific to the two case studies.
Chapter 4
Analysis

4.1 Introduction

Using the methodology outlined in chapter 3, the following chapter details the selection and implementation of two case studies in sections 4.2 & 4.3.

4.2 Case study 1: clover root weevil

The clover root weevil (Sitona lepidus) (CRW) is a pasture pest native to Europe which was discovered in New Zealand in 1996 (Gerard et al., 2007a), and by 2005 was present in pastures across the North Island (Gerard et al., 2009). Currently the weevil is steadily becoming established throughout the South Island.

All stages of the weevil’s life cycle affect the growth of white clover and this has two impacts on pastures. First is the loss of dry matter through the depletion of clover due to feeding. Second is the loss in nitrogen fixation due to rhizobial root nodule damage.

In most assessments of the effects of this weevil, estimates of the loss to pasture have been based on records of damage found on Waikato dairy farms. In such farms, the weevil causes up to 35% reductions in total dry matter and up to 83% less nitrogen fixed as a result of clover loss (Gerard et al., 2007b). These effects would be less severe nationally due to lower clover content of pastures in other regions. In their assessment of the impact of clover root weevil, NZIER (Wear & Andrews, 2005), used a 10% reduction in output from pasture based industries, to represent loss of pasture production in a ‘medium impact’ scenario. White and Gerard (2006) however, found the weevil caused a 13.7% decrease in total pasture dry matter, through the removal of clover content. Furthermore due to an associated decrease in metabolisable content of pasture, an additional 2.5% decrease in total utilisable energy was also reported. This study has adopted the 10% reduction as a conservative estimate of the CRW’s impact on pasture production.
Another key aspect of the extent of CRW’s impacts is in the spread of the pest. Willoughby and Addison (1997) estimate the spread rate of the weevil at 35 km/year on average. AgResearch provides maps of the weevil’s distribution throughout the South Island (reproduced in Figure 4.1), from the spread rate and change in regions in which the weevil is present between 2013 and 2014 we can estimate that all of New Zealand pasture was affected by the weevil in 2016 and equilibrium populations of the weevil have become fully established in 2017.

Source: Phillips et al. (2013; 2015)

Figure 4.1  South Island distribution of CRW & its biological control agent (2013 & 2014)

For the impact of the clover root weevil on New Zealand agriculture, three scenarios were modelled. The first shows the impact of clover root weevil with no response from farmers, industry, or government. This scenario then represents the full potential impact of the pest, and frames the highest possible impact. The second and third scenarios show active responses. Scenario 2 is the
counterfactual scenario, where farmers increase use of nitrogen fertiliser to offset damage caused by the pest. The third scenario shows the implementation of a biocontrol, the spread of a weevil parasitoid.

**Counterfactual scenario: Increased use of nitrogen**

One current response to the damage incurred by the spread of the weevil is the use of extra nitrogen fertiliser to offset the reduced nitrogen fixation resulting from clover damage and the loss in consumable dry matter on pasture. The assumptions and data informing this mitigation scenario were taken from the NZIER report on the economic impact of clover root weevil (Wear & Andrews, 2005) and the 2010 Lincoln Financial Budget Manual (Pangborn, 2010). It is assumed that clover naturally releases 200 kg nitrogen/year/hectare, and that clover root weevil prevents nitrogen fixation in 50% of the nodules. Therefore, 100 kg of nitrogen must be replaced via fertiliser to maintain pasture production at normal levels. The costs associated with such extra application of nitrogen fertiliser are detailed in Table 4.1.

**Table 4.1 Cost for replacing nitrogen (N) lost due to clover root weevil nodule damage**

<table>
<thead>
<tr>
<th></th>
<th>100 Kg/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>N deficiency</td>
<td>100 Kg/ha/yr</td>
</tr>
<tr>
<td>Urea (46% N) required</td>
<td>217.39 Kg/ha/yr</td>
</tr>
<tr>
<td>Price of Urea (FBM)</td>
<td>$620/t</td>
</tr>
<tr>
<td>Application Cost @ $48.20/ha (FBM)</td>
<td>$10.48/ha</td>
</tr>
<tr>
<td>Cartage Cost for 30km @ $16/t (FBM)</td>
<td>$3.48/ha</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$148.74/ha</td>
</tr>
</tbody>
</table>

Source: Pangborn (2010).

The use of extra nitrogen to mitigate the effects of clover root weevil has been shown to increase total pasture production, but also to cause a slight decrease in total metabolisable energy (White & Gerard, 2006). This is due to a reduction in the clover content of the pasture from weevil activity but an increase in total ryegrass due to the application of nitrogen. For the purposes of modelling this was assumed to equate to pre-weevil production levels, occurring at a lagged rate, one year after the full establishment of the weevil.
This response is sensitive to the cost of nitrogen fertiliser and the capability of land to bear additional nutrient load. This scenario does not take into account negative groundwater effects, which using extra nitrogen fertiliser on a national level would incur. Tait and Cullen (2006) estimate the external costs of dairy farming in Canterbury to surface and groundwater, air, biodiversity and human health at 28.7 to 45 million NZD per annum. Of this amount, $155,000 per annum is the specific impact on surface and groundwater, which would be affected by increased nitrogen use on farm. Greenhouse gas emissions per hectare would also increase with additional fertiliser use.

Furthermore, the negative environmental impacts of nutrient run-off from agricultural use of fertilisers are not included in this study. Nevertheless, it is worth noting that this may be a prohibitive element in the implementation of this mitigation response, especially if nutrient limits are enforced by Regional Councils in future. Such limits may make this scenario infeasible, or at least an unfavourable response to the incursion of the clover root weevil.

**Response 2 & 3: Biological control**

An alternative response to the impacts of clover root weevil is the use of a biological control agent, the wasp *Microctonus aethiopoides* (Irish strain), which is a parasitoid of the weevil (Goldson, Rowarth & Caradus, 2005; McNeill et al., 2006). The wasp usually lays one egg into each adult weevil, rendering the female infertile and killing it upon the emergence of the fifth instar. The wasp was released in 2006 and has since been established in most New Zealand regions, spreading at about 15km a year, which is 20km/year slower than its host (Goldson, 2013).

For the modelling exercise the biological control is presumed to have been introduced at the start of the modelling timeframe, and established nationwide in 2018, two years later than the weevil. Once established and accommodating any associated density-dependent processes, *M. aethiopoides* is assumed to lead to yields of up to 80% of the original potential production (Goldson, 2013). As the level of control given by *M. aethiopoides* varies, two scenarios have been modelled: the first, a lower estimate of 60% of original yields, the second an upper estimate of 80% of the original pasture yield.
As this biological control has already been established, it is modelled as having no additional cost to producers across the time range of the CBA.

4.3 Case study 2: glassy-winged sharpshooter

The glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis*, is a leafhopper insect native to Mexico, which can cause widespread damage to citrus trees, grape vines and arable crops through feeding and the spread of Pierce’s disease (PD). PD affects grape vines by blocking the plant’s xylem leading to vine death within one to five years. PD is caused by a strain of the bacterium *Xylella fastidios*, and there is no known cure for the disease or the direct prevention of it.

While the GWSS causes damage to citrus trees through water loss associated with feeding, its main potential threat to the New Zealand agricultural industry is in its capability to spread the bacterium that causes PD. Insects capable of transmitting this disease already exist in New Zealand, but there are currently no New Zealand vectors of the disease capable of transferring the disease to grape vines (Biosecurity New Zealand, 2008). When the GWSS feeds on an infected plant, the disease-causing bacteria can attach to the sharpshooter’s mouth and colonise its gut, thereby providing a reservoir for the bacteria to be transferred to other plants.

The GWSS spread to California in the late 1980s and from there has spread to French Polynesia in 1999, Hawaii in 2004 and the Cook Islands in 2007, showing the sharpshooter’s ability to be spread through air travel, and move closer to New Zealand. In California, the incursion of GWSS and the spread of PD is estimated to cost the Californian wine industry 110 million USD yearly (Alston et al., 2012); $59 million of this is from the loss of productivity in grape growth, the remaining $51 million is spent on preventative measures and funding the Pierce’s Disease Control Program.

The modelled scenario of the spread of GWSS to New Zealand focuses only on the impact on grape growers, although there is evidence that an incursion would also impact on citrus growers, and native trees and shrubs. The whole of New Zealand is thought to be climatically suitable for GWSS;
however, PD is restricted to areas where the minimum winter temperature is greater than -1°C (Hoddle, 2004), thus it is only a threat to North Island grape growers.

It is assumed that the spread of GWSS in New Zealand would be similar to its spread over California. Maps showing the prevalence of the GWSS in California from the Californian Department of Food and Agriculture (2011) show that it has spread approximately 600 miles over seven years, from this GWSS was modelled to be fully established across the North Island eight years after its first incursion. Following the establishment of the GWSS, grape yields are reduced to zero.

**Counterfactual Scenario: Replanting vines**

The counterfactual response scenario for the incursion of GWSS and PD is to uproot the vines and replant. This option is extremely costly, incurring both the cost of replanting all affected vines, but also the loss of revenue from a cessation of production as the new vines mature. In modelling, the new vines are assumed to take four years to mature. The capital costs of replanting per hectare, shown in Table 4.2, are spread over 30 years.

**Table 4.2 Breakdown of costs associated with replanting vines**

<table>
<thead>
<tr>
<th>Cost of plant material</th>
<th>$16,566</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of vine guards</td>
<td>$3,012</td>
</tr>
<tr>
<td>Pulling old vines</td>
<td>$8,031</td>
</tr>
<tr>
<td>Planting vines</td>
<td>$5,722</td>
</tr>
<tr>
<td>Replanting</td>
<td>$331</td>
</tr>
<tr>
<td>Training for 3 years</td>
<td>$1,807</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$35,469</td>
</tr>
<tr>
<td>Lost grape income for 3 years</td>
<td>$45,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$80,469</td>
</tr>
<tr>
<td>Lost wine income for 3 years</td>
<td>$195,840</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$276,309</td>
</tr>
</tbody>
</table>

Source: Personal communication from Glen Creasy.

The replanting of affected vines restores productivity; however, it does not grant any increased resistance against future incursions of GWSS. Future infections of the new vines are possible, but this response scenario, as modelled, only demonstrates the impacts of a single replant with no second incursions occurring within the shown period.
Response 2: Biological control

The second response scenario for the GWSS case study is the establishment of a parasitoid of GWSS. Many species of parasitic wasps have been considered and used for the control of the GWSS in California and elsewhere. For this model, we focus on Gonatocerus ashmeadi, which has been used effectively in controlling the GWSS in Tahiti. G. ashmeadi has reduced populations of GWSS in Tahiti by over 90% one year after release, and up to 95% on eight islands across French Polynesia (Grandgirard et al., 2008). G. ashmeadi is thought to have no negative effects on other New Zealand insect fauna (Charles, 2012), and thus could be introduced promptly following an outbreak of GWSS.

It has been argued that the colder climate of New Zealand will be less suitable for the establishment of G. ashmeadi (Charles & Logan, 2013), suggesting that the parasitoid may be less effective across the whole of New Zealand than it has been in California and the Pacific. In the warmer regions of the North Island the wasp should still be effective, although slower to respond to increases in populations of GWSS. As the model’s aim is only to assess the impacts of the spread of PD on North Island vineyards, which are predominantly located in the warmer regions, we have assumed the wasp to be effective in areas with the GWSS. Given the success of G. ashmeadi in French Polynesia (Grandgirard et al., 2008) a conservative estimate of an 85% reduction in the populations of GWSS has been made. It is also presumed that the GWSS would take eight years to become established across the North Island.

There have been no extra costs assumed for the establishment of G. ashmeadi, although it is recognised that this would incur costs via the New Zealand Environmental Protection Authority.

4.4 Conclusion

This chapter has presented the two case studies, one which is already present in New Zealand, and the other a plausible future incursion into the country. Each case study has associated scenarios, designed to demonstrate the value and impact of different potential outcomes.

The next chapter presents the results of this analysis.
Chapter 5

Results

5.1 Introduction

This chapter presents the results of the modified CBA of the two cases studies: clover Root Weevil (section 5.2), and glassy-winged Sharpshooter (section 5.3). Results are shown in a time-series for total losses, and mitigation potential. Then the NPV is calculated in total value, annuitized value, and annuitized value per hectare.

5.2 Case study 1: clover root weevil

Figure 5.1 illustrates the outputs of the model for the clover root weevil impact scenarios. The base scenario shows the business-as-usual projections from the LTEM for New Zealand’s pastoral sector without any impact from clover root weevil. The ‘CRW’ scenario shows these projections with the damage caused by the incursion and eventual establishment of the clover root weevil in New Zealand pastures. Three recovery scenarios are shown in Figure 5.1. Additional N use (+ N use) shows the effect of extra nitrogen fertiliser to compensate for the decrease in clover N fixation and total dry matter. Biological control 60% and 80% show respectively the establishment of the parasitoid biological control giving yields at 60% and 80% of the CRW scenario.

As can be seen in Figure 5.1, the CRW causes initial damages until 2015, before paralleling the base at a lower rate. +N use creates an additional initial decrease in total profits due to the additional costs of nitrogen fertilisers before alleviating costs, whereas the biological controls show a gradual recovery of profits from 2012 until 2019.
**Figure 5.1  Clover root weevil’s impact on New Zealand pastoral profits until 2030**

Table 5.1 shows the total loss from the incursion of clover root weevil within the timeframe of the modelling exercise at over $11 billion. Nitrogen replacement or the first recovery scenario would mitigate over $5 billion worth of losses, whilst the full establishment of the parasitoid biological control at by 2018 would mitigate over $6 billion NZD at 60% parasitism. At the 80% figure this amounts to the parasitoid biological control being worth $400-$500 million per year.

**Table 5.1  Total change in pastoral profits 2012-2030, for a range of clover root weevil scenarios**

<table>
<thead>
<tr>
<th></th>
<th>Total (NZ$millions)</th>
<th>Mitigation (NZ$millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover root weevil</td>
<td>-11,467</td>
<td>-</td>
</tr>
<tr>
<td>Additional N use</td>
<td>-6,156</td>
<td>5,311</td>
</tr>
<tr>
<td>Biological control 60%</td>
<td>-5,054</td>
<td>6,413</td>
</tr>
<tr>
<td>Biological control 80%</td>
<td>-3,278</td>
<td>8,189</td>
</tr>
</tbody>
</table>

Figure 5.2 shows the total losses incurred by clover root weevil against the mitigation resulting from the three response scenarios. The 80% biological control has the greatest mitigation, whereas the additional use of nitrogen and the 60% biological control give similar mitigation rates by 2030.
Figure 5.2  Total loss and mitigation in pastoral profits 2012-2030, for clover root weevil scenarios

Table 5.2  Total change in pastoral profits annuitized, for clover root weevil scenarios

<table>
<thead>
<tr>
<th></th>
<th>Total (NZ$millions)</th>
<th>Mitigation (NZ$millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover root weevil</td>
<td>-604</td>
<td>-</td>
</tr>
<tr>
<td>Additional N use</td>
<td>-324</td>
<td>280</td>
</tr>
<tr>
<td>Biological control 60%</td>
<td>-266</td>
<td>338</td>
</tr>
<tr>
<td>Biological control 80%</td>
<td>-173</td>
<td>431</td>
</tr>
</tbody>
</table>

Table 5.2 illustrates the profits for each scenario annually, and Table 5.3 shows the annuitized profits by hectare. Clover root weevil is then expected to reduce pastoral profits on average by $81 per hectare, where additional N could mitigate about half of this, and the biological control between 55% and 72%.
Table 5.3  Total change in pastoral profits annuitized per ha, for clover root weevil

<table>
<thead>
<tr>
<th></th>
<th>Total (NZ$)</th>
<th>Mitigation (NZ$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover root weevil</td>
<td>-81.36</td>
<td>-</td>
</tr>
<tr>
<td>Additional N use</td>
<td>-43.68</td>
<td>37.68</td>
</tr>
<tr>
<td>Biological control 60%</td>
<td>-35.86</td>
<td>45.50</td>
</tr>
<tr>
<td>Biological control 80%</td>
<td>-23.26</td>
<td>58.10</td>
</tr>
</tbody>
</table>

5.3 Case study 2: glassy-winged sharpshooter

The majority of New Zealand’s viticulture profits come from vineyards in the South Island. Thus, whilst the GWSS is expected to cause great losses in North Island vineyards, it would have a relatively small effect on New Zealand’s grape industry as a whole, as shown in Figure 5.3.

Figure 5.3  The impact of the glassy-winged sharpshooter on New Zealand’s viticulture profits 2012-2030

The effects on North Island growers is shown in Figures 5.4 and 5.5, and Table 5.4. The GWSS creates a steady decline in the profitability of viticulture over the modelled period. Replanting creates a sharp decline, losing profitability swiftly as infected vines are uprooted, followed by a long plateau as
the sharpshooter spreads causing additional vineyards to replant their vines. This period ends in 2026 where sufficient new vines have matured to compensate for areas still undergoing replanting. From this point the industry quickly recovers, although it will not reach base levels due to the continued incurred capital costs of replanting.

![Graph showing the impact of the glassy-winged sharpshooter on North Island viticulture profits 2012-2030.]

**Figure 5.4** The impact of the glassy-winged sharpshooter on North Island viticulture profits 2012-2030

**Table 5.4** Total change in viticulture profits 2012-2030, for the glassy-winged sharpshooter scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total (NZ$millions)</th>
<th>Mitigation (NZ$millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glassy-winged Sharpshooter</td>
<td>-88.72</td>
<td>-</td>
</tr>
<tr>
<td>Replanting</td>
<td>-76.65</td>
<td>12.07</td>
</tr>
<tr>
<td>Biological control</td>
<td>-19.45</td>
<td>69.27</td>
</tr>
</tbody>
</table>
Figure 5.5  Total loss and mitigation in viticulture profits 2012-2030, for the glassy-winged sharpshooter scenarios

The first response modelled for the arrival of the GWSS was replanting affected vineyards. This is found to be an ineffective mitigation response for the modelled period. Two additional observations should be made regarding this response. First, over a longer period of assessment it would eventually become a profitable option if vineyards can remain in operation without production for the four years needed for new vines to mature. Secondly, there is no guarantee that secondary incursions of the GWSS and PD would not occur. With this in mind this recovery option is highly unsatisfactory, incurring high capital costs, risk of future infection and a four-year regrowth period without production for affected vineyards.

Table 5.5 shows the change in profits annuitized over the modelled period; here glassy-winged sharpshooter causes losses of almost 5 million NZD per hectare. The biological control response, G. ashmeadi, given the assumed rates of parasitism, mitigates over 85% of these losses.
Table 5.5  Total change in viticulture profits annuitized, for the glassy-winged sharpshooter scenarios

<table>
<thead>
<tr>
<th></th>
<th>Total (NZ$millions)</th>
<th>Mitigation (NZ$millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glassy-winged sharpshooter</td>
<td>-4.93</td>
<td>-</td>
</tr>
<tr>
<td>Replanting</td>
<td>-4.26</td>
<td>0.67</td>
</tr>
<tr>
<td>Biological control</td>
<td>-1.08</td>
<td>3.85</td>
</tr>
</tbody>
</table>

Table 5.6 shows the change in annuitized viticulture profits by hectare. The GWSS on average costs North Island viticulture $620.08 per hectare. Replanting vineyards over the modelled period mitigates on average almost $95 per hectare, although with future costs incurred. The biological control is most effective mitigation response over the modelled period, saving almost $550 per hectare per year in otherwise sustained losses.

Table 5.6  Total change in viticulture profits annuitized per hectare, for the glassy-winged sharpshooter scenarios

<table>
<thead>
<tr>
<th></th>
<th>Total (NZ$)</th>
<th>Mitigation (NZ$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glassy-winged sharpshooter</td>
<td>-620.08</td>
<td>-</td>
</tr>
<tr>
<td>Replanting</td>
<td>-535.72</td>
<td>84.37</td>
</tr>
<tr>
<td>Biological control</td>
<td>-135.95</td>
<td>484.13</td>
</tr>
</tbody>
</table>

5.4 Conclusion

This chapter has presented the results from the two examined case studies. This included the net present value of each examined scenario, and these values broken down by year and per hectare.
The following chapter will present some analysis of the results presented in this chapter, as well as some discussion of the limitations of the research, and potential areas for expansion in future research.
Chapter 6
Conclusion

6.1 Introduction

This study has focused on the use of bio-controls as an economically efficient means for controlling plant pests in New Zealand.

The agricultural industry is vital to New Zealand’s economy, with agriculture, forestry, and fishing accounting for 29% of goods producing industries in 2017 (StatsNZ, 2017). Yet it is at risk of economic damage by insect pests and diseases. While New Zealand is afforded some protection to outside incursions of plant pests due to its geographic isolation and natural borders, it is still at risk of incursions through increasing tourism and international trade. The New Zealand Ministry for Primary Industries is responsible for New Zealand’s biosecurity through border protection and pest management strategies.

Some examples of economically significant incursions in the past have been: giant buttercup \textit{(Ranunculus acris)}, which costs New Zealand $118 million annually (Bourdot & Saville, 2002); and Psa-V \textit{(Pseudomonas syringae pv. Actinidia)}, which cost the New Zealand kiwifruit industry between 310-410 million NZD over five-years. Psa-V would have also eradicated the production of the golden kiwifruit variety outside of the Bay of Plenty region, had an alternative resistant variety not been developed (Greer & Saunders, 2012).

This dissertation has reviewed the literature on economic evaluations and on methods of assessing economically efficient interventions or policy responses. The review concluded that many of the existing studies on the efficacy of bio-controls were performed from a biophysical standpoint, rather than an economic one, meaning the results were somewhat ad hoc. This gap in the literature indicated a direction for future research.
Consequently, this dissertation introduced a modified CBA analysis, using PE modelling to provide additional data on production and price forecasts in a CBA framework. This was applied to valuing two case studies of pests and their respective control options, including a viable bio-control option for each. The case studies of CRW and GWSS were selected as they impacted significantly on agricultural production, and represented two different challenges to New Zealand: one is pre-existing; while the other is currently not present in New Zealand, but is likely to be in the future.

6.2 Summary of main results

The hypothesis set out for testing at the beginning of this dissertation, was as follows:

Hypothesis: That proposed biological controls for a potential biosecurity incursion can be evaluated using cost benefit analysis and partial equilibrium trade modelling to provide evidence for the value of the proposed response.

The key methodology used was CBA, with a component of PE trade modelling used to expand on the impacts on the agricultural sector by better framing future pricing and trade dynamics that are key to understanding profits in New Zealand agriculture. Using this method the two examined pest case studies both showed strong economic impacts.

Table 6.1 shows the total net present value for each scenario. This includes the impacts over the 18 year period examined in the study (2012-2030) with an 8% discount rate applied. The NPV of the biological control (comparative to the counterfactual) is between $1.1 billion and $1.7 billion, in the case study of CRW, and $57.2 million in the case of GWSS. In both case studies from the perspective of this CBA the biological control option is more economically rational than the proposed counterfactual.
Table 6.1  Net Present Value (million NZ$)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Clover root weevil</th>
<th>Glassy-winged sharpshooter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial pest damage</td>
<td>-11,467</td>
<td>-88.7</td>
</tr>
<tr>
<td>Counterfactual</td>
<td>-6,156</td>
<td>-76.7</td>
</tr>
</tbody>
</table>

Value relative to counterfactual

| Biological control | 1,102-1,776 | 57.2 |

As shown in Table 6.2, per year the CRW costs New Zealand 604 million dollars, this is reduced by between $58-151 million with the use of the bio-control, depending on the establishment rate of the bio-control. Alternatively, GWSS would cost New Zealand $4.9 million yearly if it established in New Zealand and could wipe out the viticulture industry in the North Island. Relative to the counterfactual bio-controls could curtail this amount by $3.2 million, mitigating over 90% of the costs associated with PD.

Table 6.2  Net Present Value Annuitized (million NZ$ per year)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Clover root weevil</th>
<th>Glassy-winged sharpshooter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial pest damage</td>
<td>-604</td>
<td>-4.9</td>
</tr>
<tr>
<td>Counterfactual</td>
<td>-324</td>
<td>-4.3</td>
</tr>
</tbody>
</table>

Value relative to counterfactual

| Biological control | 58-151 | 3.2 |

In each of these cases the bio-control options has a positive net present value. In comparison to the counterfactual scenario (the next best control option), the bio-control option seems to be the preferable control approach, even given the lower bounds of the bio-control’s impact in the case of CRW. This result however may be differ under a more comprehensive CBA, as the analysis does not cover the social and environmental costs of some impacts from the counterfactual scenarios, in particular the impacts of increased nitrogen use in the counterfactual scenario for CRW, and the replanting of vines in the counterfactual scenario for GWSS.
Consequently, the research reported in this dissertation provides evidence in support of the hypothesis being tested.

6.3 Limitations and further research

The scope of this project excluded the modelling of further scenarios, or an extended sensitivity analysis for all projections of insect and weed impacts, and of mitigation responses. The inclusion of these would strengthen the robustness of the conclusions drawn, although this dissertation has given a broad economic perspective of the challenges to plant protection and has provided estimates of the potential economic damage to New Zealand by plant threatening insects and weeds, as well as of the economic outcomes of some responses.

Expanding on the limitations of a lack of comprehensive sensitivity analyses, the CRW case study included two scenarios for the bio-control option. This gave a range of impacts depending on the effectiveness of the bio-control’s establishment. This was the only sensitivity analysis performed. Future research could expand on this by testing the sensitivity of the results to various levels of other key attributes, such as spread rate and effectiveness for bio-controls, or the initial pest. Similarly while the modelling was used to help accuracy in future pricing, some sensitivity around these prices would have helped increase the robustness of the findings. Additionally the sensitivity of pricing for fertilisers used in the counterfactual scenario in the CRW case scenario could also be expanded upon.

The research would benefit further if some elements of wider economic impact were incorporated. In particular Input-Output multipliers could be used to expand the analysis to cover indirect and induced impacts. Such analysis could be used to test the impacts of each case study on sectors of the economy beyond agriculture, and employment multipliers could then be used to test the impact of jobs across all sectors. Additionally the research costs incurred in finding and testing a viable bio-control, and the costs of releasing the bio-control were not accounted for within the analysis, which would have been valuable to compare with the benefits of the bio-controls.
Furthermore the PE modelling element in the study used a static analysis of pricing. For dairy, however, New Zealand is a price making market internationally, and so impacts on production would be likely to have world price effects in global markets. Ideally the results of the study would be run again through the model to test any secondary impacts from this pricing effect. This impact has not been included in this analysis, but would be a valuable addition in future research.

The base year of the PE model (the last year of actual data) was 2012. Given greater resources for this study, a later base year could have been used. This would have required gathering more recent data for all countries and commodities included in the model. As there are currently 23 commodities and 24 regions included in the model this task would have required resources in excess of those available for this project. The inclusion of a later base year would have increased the reliability of the projections given by the PE model.

Overall this dissertation has demonstrated the potential effectiveness of bio-controls as a means for mitigating the impact of specific pests. I have done this using a coherent economic framework for examining the potential damage of pests, using a combined CBA/PE trade modelling approach. This methodology allowed for combining various elements including product pricing and trade dynamics, with farm level models and pest impacts. This approach also allowed for the mapping of future prices to inform pest impacts over a longer time-frame. Overall, based on the positive NPV for both bio-control scenarios in the two examined case studies, the research hypothesis of this dissertation can be accepted. Bio-controls are an economically rational option for the control of insect pests, at least as demonstrated by the two examined case studies.
Appendix A
Technical detail

A.1 Model specification

Modelling Specifications LTEM

<table>
<thead>
<tr>
<th>Model</th>
<th>LTEM: Lincoln Trade and Environment Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelling Approach</td>
<td>Partial equilibrium</td>
</tr>
<tr>
<td>Temporal Properties</td>
<td>Comparative static (with short term dynamics through sequential simulation)</td>
</tr>
<tr>
<td>Solution Type</td>
<td>Non-spatial, net global trade</td>
</tr>
<tr>
<td>Solution Algorithm</td>
<td>Newton's global algorithm</td>
</tr>
<tr>
<td>Parameters</td>
<td>Synthetic</td>
</tr>
<tr>
<td>Commodity Coverage</td>
<td>23</td>
</tr>
<tr>
<td>Country Coverage</td>
<td>22 (Rest of the World; World additional)</td>
</tr>
</tbody>
</table>

Behavioural Equations (per commodity and country)
- Domestic supply:
  - feed
  - food
  - processing
- Domestic demand
- Stock variation
- Producer price
- Consumer price
- Trade

Economic Identify | Net trade


**LTEM Commodity coverage**

<table>
<thead>
<tr>
<th>Wheat</th>
<th>Oilseed meals</th>
<th>Poultry</th>
<th>Liquid milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>Vegetable oils</td>
<td>Eggs</td>
<td>Apples</td>
</tr>
<tr>
<td>Other grains</td>
<td>Beef and veal</td>
<td>Butter</td>
<td>Kiwifruit</td>
</tr>
<tr>
<td>Rice</td>
<td>Pork</td>
<td>Cheese</td>
<td>Grapes</td>
</tr>
<tr>
<td>Sugar</td>
<td>Sheep meat</td>
<td>Whole milk powder</td>
<td>Wine</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>Wool</td>
<td>Skim milk powder</td>
<td></td>
</tr>
</tbody>
</table>
Countries in the LTEM

<table>
<thead>
<tr>
<th>Argentina</th>
<th>European Union (28)</th>
<th>New Zealand</th>
<th>Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>India</td>
<td>Norway</td>
<td>Turkey</td>
</tr>
<tr>
<td>Brazil</td>
<td>Indonesia</td>
<td>Paraguay</td>
<td>United States</td>
</tr>
<tr>
<td>Canada</td>
<td>Japan</td>
<td>Russia</td>
<td>Uruguay</td>
</tr>
<tr>
<td>Chile</td>
<td>Republic of Korea</td>
<td>Singapore</td>
<td>Rest-of-World</td>
</tr>
<tr>
<td>China</td>
<td>Mexico</td>
<td>South Africa</td>
<td>World</td>
</tr>
</tbody>
</table>

A.2 Model equations

Producer price

\[(1) \ P_{r,c,t} = w_{p,c,t} \cdot s_{r,c,t} \]

- \( P_p \) – producer price
- \( w_p \) – world price
- \( s_p \) – producer market support

Prices in the model are linked to a world market price for each commodity, with a second modifier of price transmission specific to each country period and commodity. A similar equation is used to express consumer price in the model with a measure of consumer price support, rather than producer price support. These price support mechanisms represent the price wedge in supply and demand pricing and are used as a catch-all representation for government support, duties and taxes.

Domestic supply

\[(2) \ Q_{s_{r,c,t}} = a \cdot \sum_{c} p_{p_{r,c,t}}^{\beta_{r,c}} \cdot p_{c_{r,i,t}}^{\beta_{r,c}} \cdot q_{s_{r,i,t-1}}^{\beta_{r,c}} \cdot (1 + gr_t) \]

- \( Q_s \) – quantity supply
- \( p_p \) – producer price
- \( p_c \) – consumer price
- \( gr \) – growth rate

The supply equation for the LTEM is shown in equation (2), this shows the supply in the model for each commodity is a function of its own producer prices and cross-prices for commodities that are substitutes or compliments, the price of input commodities, a lag of previous consumption, and lastly...
a growth rate. There are variations on this generic supply equation for some commodities: be it in the different inputs, or for processed commodities such as milk commodities from raw milk, and oil and oilseeds meals from oilseeds. These processed commodities are more dependent on the quantity processed of their parent commodity.

**Domestic demand**

\[
Q_{d_{r,c,t}} = a \cdot \sum_c p_{c_{r,c,t}}^{\beta_{r,c}} \cdot \left( \frac{g_{d_{r,c}}}{p_{p_{op}}} \right)^{\beta_{r,c}} \cdot (1 + gr_t)
\]

Q\(_d\) – quantity demand  
\(pc\) – consumer price  
\(gdp\) – gross domestic product  
\(pop\) - population  

Demand in the LTEM (equation 3), similarly to production, is foremost a function of its own price and cross prices with a growth rate. The difference is demand is also a function of per capita income, this part of the equation ensures quantity demanded is responsive to changes in domestic population and income over time, this component is key as exogenous changes in population and income are the primary motivators of change in modelled projections.

**Domestic stocks**

\[
Q_{st_{r,c,t}} = a \cdot q_{st_{r,c,t-1}}^{0.1} \cdot \sum_c \left( q_{s_{r,c,t}} q_{d_{r,c,t}} \right) \cdot p_{c_{r,c,t}}^{0.2}
\]

Q\(_st\) – quantity stocks  
\(qs\) – quantity supply  
\(qd\) – quantity demand  

Stocks in the model are a function of consumer price and the total budget of domestic consumption and production.

**Net trade**

\[
Q_{t_{r,c}} = q_{s_{r,c}} - q_{d_{r,c}} - \Delta q_{st_{r,c}}
\]

Q\(_t\) – quantity net trade  
\(qs\) – quantity supply  
\(qc\) – quantity demand  

\(gst\) – quantity stocks  
\(r\) – region  
\(c\) - commodity
Net trade in the model (equation 5) is a simple arithmetic, supply minus demand and change in stocks year to year, but this help illustrates the condition the model solves to. Each domestic market is defined by its production, stocks and demand. The model solves for a sum of zero for all domestic net trades (equation 6), this is done through the manipulation of world prices for all commodities.

**World market clearing**

\[ W_t = \sum_r q_t_{r,c} = 0 \]

Wt – net world trade  
qt – quantity net trade  
\( r \) – region  
\( c \) – commodity
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