Viewpoint from a Policy-Maker

The Australian and state/territory governments in partnership with Australia's plant industries established Plant Health Australia (PHA) as a public company in April 2000 with the challenge of taking a partnership approach to key plant health issues and enhancing Australia's ability to respond to emergency plant pests. PHA aims to improve Australia's plant health systems and processes in order that the impact of pests on Australian plant industries—which are worth approximately $21.4bn per year in terms of gross value of production, and provide $5.5bn in export income to Australia—is decreased.

One of the 4 priority areas for PHA is the development of an enhanced emergency plant pest emergency response system. This priority has been addressed through 2 large projects; the development of national industry biosecurity plans and the development of the Emergency Plant Pest Response DEED (EPPRD). The industry biosecurity plans have enabled the key threats for each industry to be identified along with the development of appropriate response strategies. The EPPRD, once enacted, will define the process by which future incursion response is undertaken and will determine the relative cost shares for both government and industry in undertaking the response strategies.

It became evident early on in the development of these projects that there were some gaps in our capacity to ensure the most effective response strategies were undertaken. While contingency (response) plans could be developed for specific pest threats, there was no capacity to evaluate and validate what was proposed. Evidence from past incursion responses had highlighted that often the strategies defined prior to the incursion were not appropriate and most decisions were made 'on the run'. In addition, no cost benefit analysis had been undertaken on any contingency plans.

The other issue that arose was the inability to determine the regional economic impact of an emergency plant pest incursion. Economists could determine the likely impact at the farm gate or at a national level but there was no capacity to measure at the regional level. Given the strong regional focus of Australia's plant industries and the large variation in the size of industries, it was considered essential that Australia's plant health system could determine the impact at a farm gate, a regional, a state and a national level. An accurate measure of this is required by the EPPRD to ensure that the appropriate cost sharing between public and private is achieved.

The bio-economic modelling approach using cellular automata has enabled both of these gaps to be addressed. PHA has invested and worked in partnership with ABARE to develop a proof of concept incursion management model. Further resourcing for the full development of the incursion management predictive simulation system (model) is presently being sought through the Cooperative Research Centre for National Plant Biosecurity. The successful undertaking of this project requires a mix of researchers with a range of expertise in scientific (biology/complex system modelling/climatology/terrestrial data), economic and public policy fields. The system will enhance the strategic assessment of emergency plant pest incursions (proactive assessment) and contribute significantly to the rapid assessment of appropriate control measures during an incursion. These assessments cannot be feasibly done by experimentation. Australia's capacity to successfully control or eradicate an EPP would be greatly enhanced if those managing an incursion response had ready access to appropriate modelling and simulation technology.

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9. Managing Agricultural Pest and Disease Incursions: An Application of Agent-Based Modelling

Lisa Elliston and Stephen Beare

Abstract

An incursion management model was developed to estimate the regional economy effects of a potential exotic pest or disease incursion in the agricultural sector. By developing an agent-based spatial model that integrates the biophysical aspects of the disease incursion with the agricultural production system and the wider regional economy, the model can be used to analyse the effectiveness and economic implications of alternative management strategies for a range of different incursion scenarios. A case study application of the model investigates the impact of a potential incursion of Karnal bunt in wheat in a valuable agricultural producing region of Australia.

Introduction

Australia has a valued reputation for supplying high quality agricultural products with pest free status to export markets (a pest being any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products). Pest incursions pose a serious threat to both consumer confidence and Australia's agricultural production. Incursions can impose significant costs on the economy in the form of lost production, income and trade, as well as damaging unique natural environments.

A wide range of strategies can be put in place to reduce the incidence and effects of pest incursions within Australia. These include border control and surveillance measures that focus on preventing a pest from entering the country or a particular region. In the event of an incursion being identified, containment strategies—such as the establishment of quarantine boundaries—as well as measures to eradicate the pest can be employed. Often a rapid response to an exotic pest incursion is required in order to limit the extent of the incursion and to maximise the likelihood of successful eradication. While real time modelling and evaluation of alternative management strategies has, to date, been infeasible, advance assessments of potential response options have been able to increase preparedness.

With responsibility for coordinating and designing policies to improve the ability of Australian agriculture to respond to pest incursions, organisations such as Plant Health Australia and Animal Health Australia require tools to evaluate the effectiveness of potential incursion management strategies for key pests that pose the greatest threat to Australian agriculture.

This chapter documents the development of ABARE/PHA's agent-based Exotic Incursion Management (EIM) model and its application to a disease that affects wheat. The results of several simulation scenarios are presented together with a discussion on the implications for government policy and management of agricultural pest incursions in Australia.

Exotic incursion management model

The EIM model is an integrated bio-economic model that integrates the biophysical aspects of a pest incursion with the agricultural production system and the wider regional economy. While biophysical models and economic models in their own right are capable of offering insights into the impact of a pest incursion, they often miss the complex interaction and feedback effects that exist between agricultural production, the characteristics of the pest, and economic returns.

The multi-agent system approach is ideal for developing a simulation framework to model pest incursions. The agent-based nature of the model enables the simulation of numerous *What if?* scenarios, investigating the sensitivity of both the extent of an incursion and the overall effect on the economy to different assumptions. The results of such simulations then become valuable input into the design of incursion management and response plans.

The EIM model was developed using CORMAS, a spatial natural resource and agent-based simulation modelling framework running on the VisualWorks platform (CIRAD 2003). The spatial component of the modelling framework was particularly important to capture the physical process of a pest moving across the landscape. A cellular automata process is used to drive the spread of the pest across neighbouring paddocks, and a range of potential transmission pathways are modelled explicitly. At the same time, numerous agents including farmers, contractors and quarantine officers—each with their own specific patterns of behaviour and movement—are also interacting in the spatial environment.

The model consists of 4 main components that represent: the pest, the farm system, the incursion management system, and the regional economy. The pest module captures the unique characteristics of the particular pest, including transmission pathways and estimates of the rate of movement or spread. The farm system is modelled on a weekly time-stepped basis and includes production choices and estimates of financial returns. The incursion response and management module incorporates the methods by which the pest is first identified, the process by which potential incursions are investigated, and any subsequent containment and eradication measures that are put in place. A stylised representation of the regional economy is also included to enable calculation of the flow-on effects of an incursion to the wider community.

Karnal bunt case study

The EIM model was used to analyse a hypothetical incursion of the wheat disease Karnal bunt in a region of south eastern Queensland. A number of scenarios were constructed to analyse the ability of specific quarantine measures to contain and eradicate Karnal bunt from the region, and to estimate the likely impact of an incursion on the regional economy.

Karnal bunt of wheat

Karnal bunt of wheat is caused by the fungal pathogen *Tilletia indica* Mitra (Bonde et al. 1997). Karnal bunt teliospores, spread by air currents, vehicles and farm machinery, infect developing wheat heads at the time of flowering. Despite the strong fishy odour of infected grains, only a portion of an infected kernel is replaced with a mass of teliospores with only a few kernels in each head usually infected, making detection of the disease difficult.

Karnal bunt teliospores have proven resistant to a number of adverse environmental conditions, remaining viable for up to 5 years in contaminated soils (Bonde et al. 1997). Despite some recent advances in the development of fungicide treatments and resistant wheat varieties, the primary means of containing the disease is to ban the planting of wheat in affected paddocks for at least 5 years.

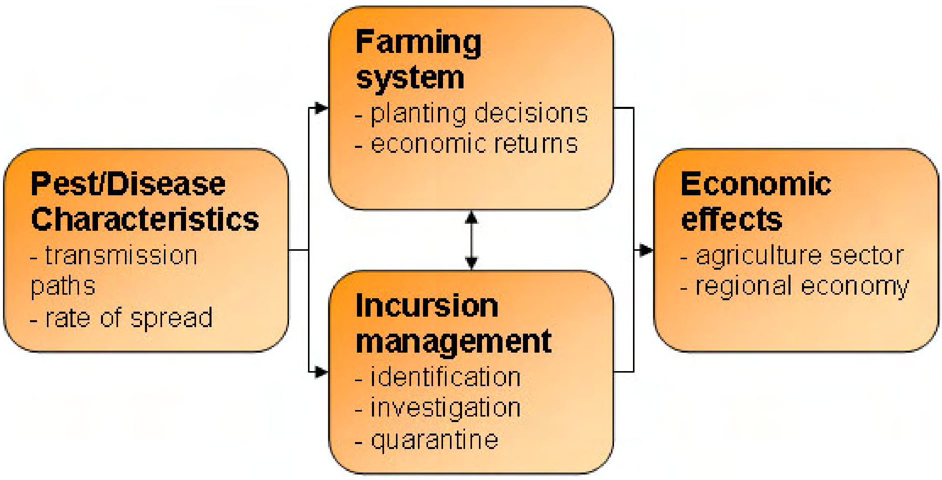
Case study region

The south eastern Queensland case study region was chosen because it is a significant producer of high quality export wheat in Australia. The region relies heavily on the agricultural sector, with almost 60 per cent of all businesses belonging to the agriculture, forestry and fishing industry (OESR 2003). Around 90 per cent of all land in the region consists of agricultural holdings. In 2001 more than 1.1 million hectares of crops were grown in the case study region, over half of which was sown to wheat. The wheat produced in this region is generally of a high quality and attracts a significant price premium on world markets. In the event of a Karnal bunt incursion in Australia, wheat producers, including those in south eastern Queensland, would likely lose immediate access to valuable international markets due to the quarantine restrictions imposed by wheat importing countries.

Customised model

The generic EIM agent-based modelling framework was customised to analyse the impact of Karnal bunt in the case study region (Figure 9.1). A range of transmission pathways were explicitly incorporated into the model. These included the wind, farmers and their machinery, contractors and their machinery, and farm inputs such as seed and fertiliser. Each disease pathway interacts with the spatial environment, with its own patterns of behaviour or movement. For example, contract workers and farmers are able to spread Karnal bunt teliospores across and between farms as they move throughout the region. Subsequently, the disease may spread across neighbouring paddocks by wind or the movement of machinery on-farm.

Figure 9.1. Structure of the EIM model



Farm Component

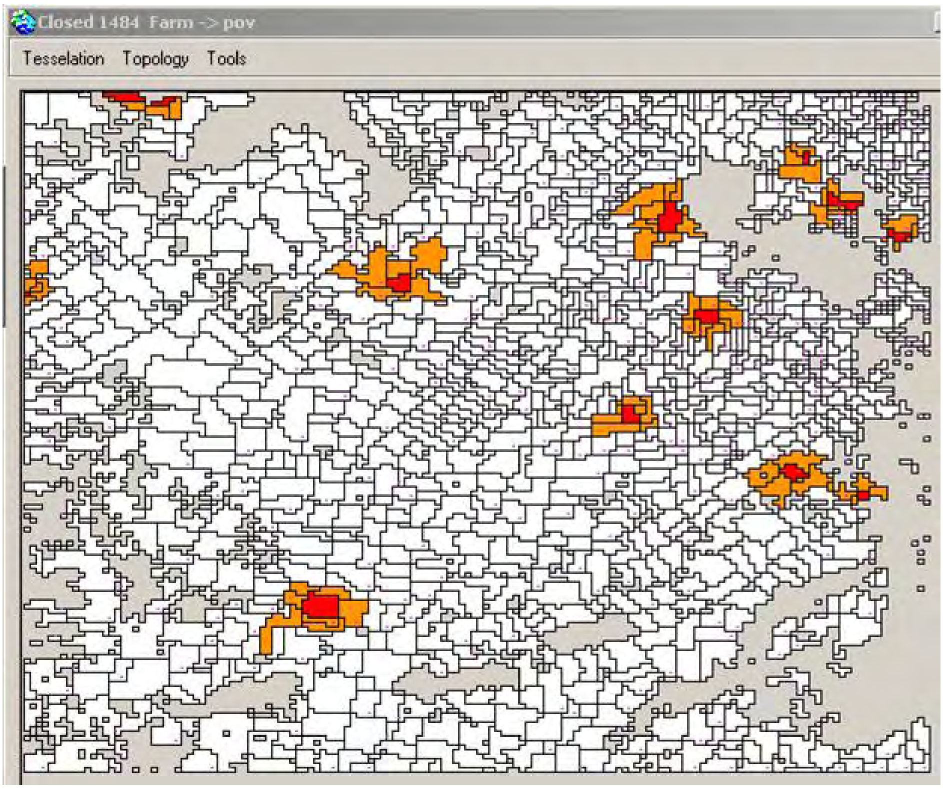
The farm system captures the decisions made by farmers to plant different crops. 4 major agricultural activities are included in the model: wheat for export, wheat for domestic animal feed requirements, sorghum and an aggregate representing all other agricultural activities. The timing of planting, spraying for weeds, harvesting and the use of contract labour is all determined within this module. These key events are included in the model because they capture the most likely ways the disease can spread. For example, during spraying and harvesting, Karnal bunt teliospores can be spread across and between farms in the region. At other times of the year farmers move around their farm, potentially spreading the disease if it is present on their property. Based on average yields reported in the region, the total volume of wheat, sorghum and other commodities produced on each farm is calculated. Based on average prices, gross receipts for each of the major commodities are calculated.

The model allows for the identification of a Karnal bunt incursion in one of two ways. First, farmers can identify signs of diseased crops on their property. Second, teliospore infested grain can be identified when harvested grain is sent to the silo and inspected for quality.

Quarantine Component

When diseased crops are identified, a quarantine response is triggered to investigate the extent of the incursion and attempt to contain it so that it cannot spread further. The farm from which the infected grain came is immediately quarantined and a tactical response officer is dispatched to the property. All neighbouring properties are placed in a buffer quarantine zone (Figure 9.2). Tactical response personnel visit each of the neighbouring properties and search for signs of Karnal bunt. If the disease is identified on any of the properties, these properties are upgraded to full quarantine status and all properties neighbouring the newly identified farm are then searched. Where signs of infestation are not found on neighbouring properties, those properties remain in the buffer quarantine region and the search of other properties is stopped.

Figure 9.2. Spatial visualisation of the environment: Quarantine response



At the same time, any contractors that have visited Karnal bunt infested farms that are now fully quarantined are identified to trace back the source of the incursion and limit its spread. In the first instance, contractors identified in this process are asked to provide a list of farms that they have visited during the year. Tactical response personnel are then dispatched to each of these farms in order to identify the extent of the incursion. Where an infestation is identified on a property, that property is fully quarantined and the search through all neighbouring properties begins. Any contractors contacted in this trace back process who were found to be carrying teliospores on their machinery are disinfected before the next season begins.

In the event of an identified disease incursion, farms can be classified as:

- identified as having an infestation and fully quarantined;
- identified as not having the infestation but in a buffer quarantine zone because neighbouring properties have the infestation; or
- not quarantined, either clear of the infestation or not yet identified.

The planning options available to farmers are then restricted for a period of years based on their level of quarantine. Farmers identified as having the disease are quarantined and are unable to grow grain crops for 5 years. Neighbouring farmers that form the buffer zone are unable to grow grain crops in the first year after an incursion is identified. In the remaining years of the 5 year quarantine period, wheat grown on these farms can only be used to feed livestock within the region.

In all scenarios considered, when the disease is first identified the price for wheat produced in the region, even wheat that is free of the disease, receives a lower price. The price for wheat only returns to the higher export price after the disease is deemed to have been eradicated from the region on the basis that no new incursions are identified for at least one year.

Regional Component

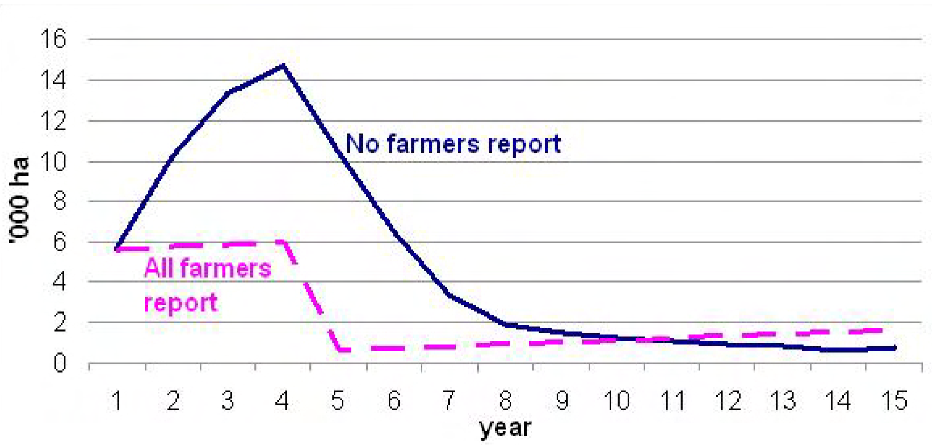
A 12 sector input-output model represents the regional economy of south eastern Queensland. Input-output tables contain the supply and demand of goods and services in an economy over a particular period, along with the interdependencies between the industries and associated primary factors of production. Changes in the value of agricultural production as a result of a disease incursion can therefore be traced through the rest of the regional economy in terms of output, employment, income and imports. The input-output analysis provides estimates of both the direct and indirect impacts of a change in agricultural production resulting from a disease incursion. The direct—or initial—impact captures the changes in the value of production and any associated changes in employment and income in the directly affected agricultural industries, as well as any changes in imports required by these industries. Subsequent changes in all other industries and the directly affected industries form indirect or flow-on impacts.

Scenario-based results

Incursion scenarios

2 different incursion scenarios, with different levels of farmer detection and reporting were analysed to investigate the importance of early detection on the likelihood of eradicating the disease and the overall economic cost of a Karnal bunt outbreak. The first scenario involved a limited and slowly expanding incursion with Karnal bunt introduced into the case study region by contractor equipment. The incursion begins with just 2 contractors and spread across the region by the movement of farmers and contractors, as well as the wind. The second scenario represented a diffuse starting point with potentially rapid expansion, with a load of fertiliser contaminated with Karnal bunt sold throughout the region at the beginning of the simulation.

Figure 9.3. Area infested, contractor scenario



Contractor based incursion

2 contractor-based incursion scenarios were investigated. In the first scenario, the likelihood of teliospore infested grain being identified at the silo was assumed to be 50 per cent, and farmers did not report signs of the disease on their property. In the second scenario, the likelihood of detection at the silo remained at 50 per cent and all farmers reported signs of the disease on their property. When farmers do not report signs of the disease on their property the area infested increases from around 5,500 hectares in the first year to more than 14,000 hectares by the fourth year of the 15-year simulation (Figure 9.3). At this point in time, almost 80 per cent of all infested land had been identified and quarantined. As a result, the extent of the incursion is curtailed and the area infested reduces to negligible levels by the end of the planning horizon.

In contrast, when farmers report signs of the disease on their property the extent of the incursion is reduced, with a maximum of 5,900 hectares infested by the fourth year of the simulation. More than 95 per cent of all infested land is quarantined in the fourth year and the ability of the disease to spread is reduced. The area infested is reduced significantly. Despite a slightly higher level of infestation in this scenario compared with the scenario where no farmers report in the latter years of the simulation, more than 95 per cent of the infested land is quarantined and the likelihood of the disease being eradicated within another 5 years is high.

The combined effect of the low level of infestation in the region and the ability of quarantine measures to contain an outbreak caused by contractors, means that the adverse economic effects of this hypothetical Karnal bunt incursion are relatively minor. Over the 15-year planning horizon, an incursion, even when no farmers report signs of the disease on their property, results in a net loss of production valued at around $58 million in net present value terms (Table 9.1).

Table 9.1. Regional economy effect of alternative incursion scenarios

	Initial Direct	*Flow-on Indirect*	*Total*
	$m	$m	$m
Contractor incursion, no farms report	–58.0	–22.3	–80.4
Contractor incursion, all farms report	–55.6	–21.5	–77.1
Fertiliser incursion, no farms report	–430.2	–165.3	–595.5
Fertiliser incursion, all farms report	–368.9	–141.5	–510.3

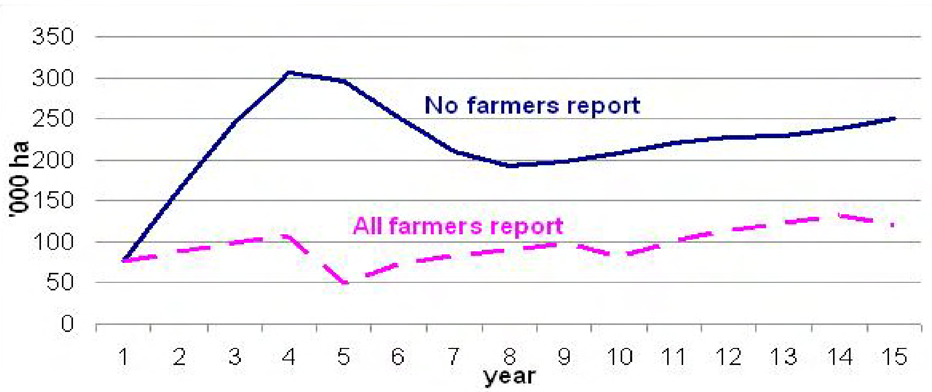
Over the 15-year planning horizon, the indirect effect of the hypothetical incursion on all industries is estimated to be around $22 million (in 2003 prices). The total industry and consumption effects, reflecting the indirect effects along with the initial (direct) effects, capture the overall impact of this particular Karnal bunt incursion. It is estimated that over the 15-year planning horizon, the decline across the case study region is around $80 million (in 2003 price).

When farmers report signs of the disease on their property the incursion is contained in a shorter period of time and the overall economic effects of the outbreak are reduced. Over the 15-year planning horizon, the loss in value of production is estimated at under $56 million. When the direct and indirect effects of changes in production are aggregated across the region, the decline in economic performance is $77 million. The $3.3 million difference in the economic performance of the region under these two contractor based incursion scenarios provides an indication of the value associated with improving the likelihood of detection by farmers on their property. This in turn can provide a benchmark against which expenditure aimed at improving farmer awareness of the disease, and therefore the likelihood of detection, can be assessed.

Fertiliser based incursion

2 fertiliser based incursions, with the same likelihood of detection at the silo and on-farm, were also investigated. When farmers do no report signs of the disease on their property, the area infested increases from around 76,000 hectares in the first year to more than 300,000 hectares by the fourth year of the simulation (Figure 9.4). Unlike the contractor scenario, only around two-thirds of all infested land has been identified and quarantined at this point in the simulation. As a result, despite the reduction in infestation between the fifth and eighth years of the simulation, the disease fails to be contained and the area infested continues to increase throughout the remainder of the planning horizon.

Figure 9.4. Area infested, fertiliser scenario



When farmers report signs of the disease on their property, the extent of the incursion is reduced significantly, but still fails to be eradicated. The area infested follows a cyclical pattern and at the end of the 15-year planning horizon almost 120,000 hectares of land is infested. The much larger incidence of infestation across the region and the failure of quarantine measures to adequately contain the disease when it is brought into the region via contaminated fertiliser results in the economic impact of this scenario being much larger than the contractor based incursion scenario.

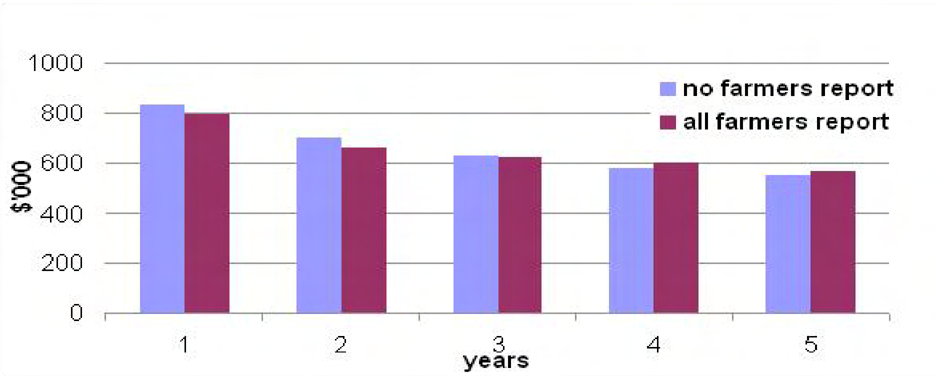
Over the 15-year planning horizon, a fertiliser based incursion where farmers do not report signs of the disease results in a net loss of agricultural production valued at around $430 million, compared with a reference case of no disease (Table 9.1). When the indirect effects are added to this, the economic impact of the disease incursion is estimated at more than $595 million over the 15-year planning horizon. When farmers do report signs of the disease on their property the extent of the incursion is reduced and the economic impact of the incursion is correspondingly reduced. The net loss in agricultural production that results from the fertiliser based incursion falls to around $369 million when farmers report signs of the disease on their property. This converts to an overall loss in regional income of $510 million.

Once again, the difference in the economic performance of the region under the two fertiliser based incursion scenarios provides an indication of the value associated with improving the likelihood of detection by farmers on their property.

Incentives to self report

The results presented in the previous section indicate that the region as a whole is better off when farmers report signs of the disease on their property. However, an analysis of the gross receipts earned by farmers identified as having the disease suggests that at least in the initial years of the simulation, farmers are unlikely to have an incentive to report signs of the disease on their property.

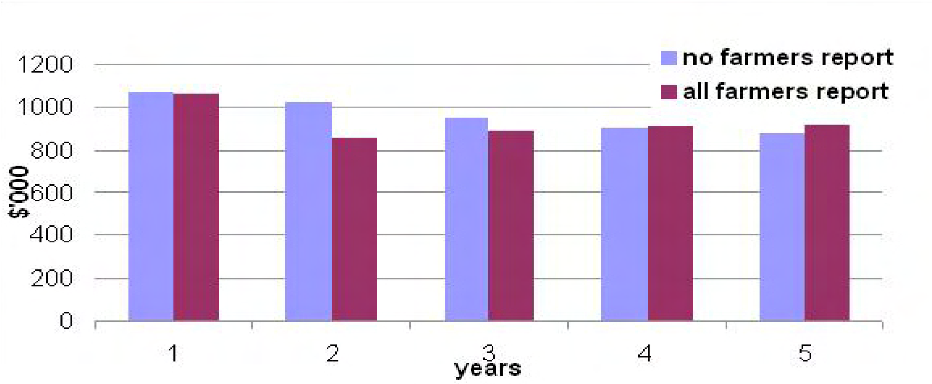
Figure 9.5. Receipts per infested farm, contractor scenario



In the contractor based incursion scenario the receipts per infested farm for the scenario where no farmers report signs of the disease on their property are higher than the scenario where all farmers report for the first 2 years (Figure 9.5). In the third year the receipts per farm are on average equivalent. In subsequent years, when the quarantine measures take effect and the disease is contained, the receipts per infested farm are higher under the scenario where farmers report signs of the disease on their property.

Similar results were observed for the fertiliser based incursion scenario. Average receipts per infested and quarantined farm were higher in the first 3 years of the simulation under the scenario where no farmers report signs of the disease on their property (Figure 9.6). In the final years of the simulation this trend reverses and the average receipts per infested farm are higher when farmers report signs of the disease on their property.

Figure 9.6. Receipts per infested farm, fertiliser scenario



These results indicate that while the region as a whole benefits from an early reporting of the disease, individual farmers have little incentive to report signs of infestation, at least during the early years of the simulation. This is an important result, because the ability to successfully contain a disease such as Karnal bunt is likely to depend critically on it being identified within the first few years of its introduction to Australia. Further, the estimated economic costs of a Karnal bunt incursion presented in this chapter include only the costs incurred within the case study region. If Australia's major wheat export markets were to refuse all wheat produced within Australia, the additional cost of the incursion across the rest of the country is likely to be significant, particularly if the disease cannot be eradicated.

Government policy implications

The findings from these scenarios suggest that successful eradication is possible if a Karnal bunt incursion was to begin with the importing of contaminated machinery by a contract worker and be identified early. In contrast, a widespread and diffuse incursion, for example as a result of the sale of contaminated fertiliser, is likely to lead to a rapid expansion of the disease that fails to be eradicated despite a range of containment and eradication strategies. These results have important implications for the allocation of biosecurity resources to reduce the economic impact of a Karnal bunt incursion. Given the apparent low likelihood of successful eradication, consideration should be given to allocating resources to border control activities that reduce the likelihood of the disease entering Australia. Further, given the importance of early detection to successful eradication, resources allocated to regular surveillance and monitoring may also be warranted. In contrast, if the disease is well established before being identified, the economic return on investment in eradication activities is likely to be negligible.

The results from this analysis also demonstrate the ability of improved farmer detection and reporting to reduce the overall economic costs associated with a potential Karnal bunt incursion. The results highlight the need to provide appropriate incentives to farmers in order to obtain the estimated benefits to the regional economy. For example, to ensure self reporting, farmers with the disease may require financial payments to offset the disadvantages associated with reporting the disease and being placed under quarantine restrictions.

This ability to investigate the incentives to engage in strategic behaviour that farmers face is likely to greatly enhance the accuracy with which the effect of proposed containment strategies can be assessed. Further, it can assist in the development of any incentive structures put in place to encourage farmers to report signs of infestation early.

Conclusion and perspective

The initial case study application of the EIM model indicates that it can be used for assessing the likely effectiveness of alternative management strategies in the event of an exotic plant disease incursion such as Karnal bunt. The simulation environment allows decision makers to better understand the key characteristics likely to influence the economic assessment of alternative management strategies. This in turn provides an indication of where resources should be optimally allocated to reduce the impact of pest incursions, and be incorporated into biosecurity planning processes such as the development of contingency management plans.

The EIM modelling framework is generic in nature and is capable of being adapted to analyse a wide range of incursion scenarios, as well as the incursion of other plant pests. A case study of *fireblight*, a bacterial disease that affects apples and pears, is currently being undertaken to assess the likely effectiveness and impact of proposed management strategies in the event of an incursion. Additional development of the agent-based modelling framework is also being undertaken to develop a rapid incursion management simulation model to assist in the development of optimal control strategies for emergency plant pests as part of the Co-operative Research Centre for National Plant Biosecurity.

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