Australian Government
Australian Bureau of Agricultural and Resource Economics

ABARE CONFERENCE PAPER 04.1

Incursion Management

An agent based modeling approach

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48th Annual Conference of the Australian Agricultural and Resource Economics Society
Melbourne, 11–13 February 2004

An exotic disease incursion management model was developed to estimate the regional economy effects of a potential karnal bunt incursion in south eastern Queensland. 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 of alternative management strategies for a range of different incursion scenarios. It is also possible to estimate the effectiveness and economic implications of education campaigns to improve the likelihood of detection by farmers in the field or at the silo.

ABARE project 2875
ISSN 1447-3666

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Introduction

Australia has a valued reputation for supplying high quality agricultural products with disease free status to export markets. Disease incursions pose a serious threat to this reputation and could cause significant harm to the agricultural industry and surrounding regional communities, resulting in considerable losses in trade and incomes.

The exotic incursion management (EIM) model was developed to provide estimates of the direct and indirect costs of plant disease and pest incursions, and to evaluate the strategic and tactical response options available to the government in the event of an exotic incursion.

Case study background

In this paper, the modeling framework has been applied to a hypothetical incursion of karnal bunt of wheat in a case study region in south eastern Queensland. Karnal bunt of wheat is caused by the smut fungus *Tilletia indica* Mica, and despite causing only minor yield losses, infected grains emit a fishy odor and are unfit for human consumption (Bonde, Peterson, Schaad and Smilanick 1997). The disease was first discovered in India and is largely confined to the Middle East. However, incursions have also been reported in Mexico, the United States and South Africa. Karnal bunt has never been identified in Australian wheat.

ir currents, vehicles and farm machinery can spread the disease. Karnal bunt teliospores have proven resistant to adverse environmental conditions, remaining viable for up to five years in contaminated soil. The combination of the effect of karnal bunt teliospores on wheat grain quality and the difficulty in controlling an incursion has made karnal bunt the subject of strict quarantine regulations by a number of wheat importing countries. Currently more than twenty countries have karnal bunt on their quarantine list, preventing the import of wheat from any country in which karnal bunt has been confirmed (American Phytophathological Society 1996). It is therefore anticipated that an incursion of karnal bunt would impose significant costs on the Australian wheat industry.

The case study region is located in the western Darling Downs, south of Roma and west of Dalby. 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. More than 1.1 million hectares of crops were grown in the region in 2001, and over half of this was sown to wheat.

Methodology

The EIM model is an agent based model developed using CORMAS, a spatial natural resource and agent based simulation modeling framework based within the VisualWorks programming environment, which allows for the development of applications in SmallTalk (CIRAD 2003). Separate modules within the model capture the characteristics of the disease, the farming system, the incursion response and management of an outbreak in the region and a stylised representation of a regional economy to measure the flow-on effects of an exotic plant disease incursion. For a more detailed description of the model see Elliston, Yainshet and Hinde (2004).

Disease characteristics

A range of potential disease vectors, considered to be the most likely transmission paths for karnal bunt, have been explicitly incorporated into the model. Each disease vector interacts with the spatial environment, with its own patterns of behavior and movement. Contract workers and farmers are able to spread the disease across and between farms as they move throughout the region. Contaminated farm inputs — such as seed or fertiliser — and the wind have also been incorporated as potential transmission vectors. Cellular automata techniques are used to drive the spread of the disease across neighboring paddocks once it has become established. These transmission vectors have been parameterised and are listed in table 1.

Farm system

The farm system is modeled within a weekly time-stepped year. Farmers decide what proportion of their farm to plant to different crops, as well as when to plant them within a planting timeframe that starts in early April and finishes at the end of June. To focus on the agricultural activities most likely to be affected by a karnal bunt incursion, only four activities are included in the model: wheat, feed wheat, sorghum and an aggregate representing all other agricultural activities.

After planting, the two major events in the remainder of the year involve spraying for weeds in July and harvesting crops throughout October, November and December. Farmers decide whether they wish to use contractors to spray for weeds and harvest crops, or whether they will do these activities themselves. During these two periods of time — spraying and harvesting — the disease can be spread across and between farms in the region. At all other times of the year, farmers are randomly moving around their property, potentially spreading the disease.

Based on average yields reported in the case study region, the total volume of wheat, sorghum and other commodities produced on each farm is calculated. The grain produced is sent to the silo and based on average gross margins calculated for the various

Table 1: **Parameters representing the spread characteristics of the disease**

Probability of contractor with teliospore infected machinery infesting a wheat paddock while spraying for weeds (v)	0.00001
Probability of a contractor with teliospore infected machinery infesting a wheat paddock while harvesting (v)	0.5–0.75
Probability of a contractor's machinery becoming infected if they spray for weeds in an infested paddock (v)	0.001
Probability of a contractor's machinery becoming infected if they harvest an infested paddock (v)	1.0
Probability of a farmer with teliospore infected machinery infesting an uninfested wheat paddock elsewhere on their property during harvest time (s)	0.75
Probability of a farmer with teliospore infected machinery infesting an uninfested wheat paddock elsewhere on their property at any other time of the year (s)	0.0001–0.75
Probability of a farmer's machinery becoming infected if they are in an infested paddock during harvest time (s)	1.0
Probability of a farmer's machinery becoming infected if they are in an infested paddock at any other time of the year (s)	0.01–0.0001
Probability of teliospores spreading from one paddock to a neighboring one (due to wind) at harvest time (s)	0.9
Probability of teliospores/sporidia spreading from one paddock to a neighboring one (due to wind) at any other time of the year (s)	0–0.25

All probabilities are expressed per visit (v), or per season (s).

commodities within the case study region, gross receipts for each of the four main commodities are calculated.

Incursion response and management

There are two ways in which an incursion of karnal bunt in the case study region can be identified. First, there is a small chance that farmers will identify bunted grains in their infested paddocks during harvest time. Second, and more likely, the disease can be identified when harvested grain is sent to the silo.

When karnal bunt teliospores are identified at the silo 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 neighboring properties are placed in a buffer quarantine zone. Tactical response personnel visit each of the neighboring properties and search for signs of the disease. If teliospores are found on any of these properties, these properties are upgraded to full quarantine status and all properties neighboring this newly identified farm are then searched. Where signs of infestation are not found on neighboring properties, those properties remain in the buffer quarantine region and the search of other properties stops.

At the same time, any contactors that have visited 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 all the farms 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 neighboring properties begins. Any contractors contacted in this trace back process who were carrying teliospores on their machinery are disinfected before the next season begins.

In the event of an identified karnal bunt incursion, farms in the case study region can be classified as:

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

Because of the limited range of effective eradication measures, any quarantine region must remain in place for five years and farmers within the affected zone face reduced planting options throughout this period.

Fully quarantined farmers are unable to grow wheat of any kind and are assumed to plant sorghum and engage in other agricultural activities such as livestock or other nonwheat crops. Farmers in the buffer quarantine zone are unable to grow wheat for export or human consumption, but are able to grow feed wheat. It is assumed that farmers in this situation plant a combination of feed what and sorghum — together with their other nonwheat agricultural activities — throughout the five year quarantine period. After five years, the teliospores in infested paddocks are assumed to be no longer viable. The planting restrictions are lifted and farmers are able to resume growing wheat.

The regional economy

A twelve sector input–output (I–O) model represents the regional economy. I–O 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 karnal bunt incursion can therefore be traced through the rest of the regional economy in terms of output, employment, income and imports.

The I–O analysis provides estimates of both the direct and indirect impacts of a change in agricultural production resulting from a karnal bunt incursion. The direct — or initial — impact captures the changes in wheat and other grain production and any associated changes in employment and income in the directly affected 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.

Results

All simulations were run over a fifteen year time horizon to generate an indication of the full extent and costs of a disease incursion. All financial estimates are reported in constant 2002-03 dollars and the total effect over the fifteen year period is reported in net present value terms.

The probabilistic nature of many of the model parameters means that multiple simulations need to be run to generate robust estimates that are not dominated by any one single set of randomly determined parameter values. Therefore, a series of 100 simulations was conducted for each scenario and the results presented reflect the average results of those simulations.

Two incursion scenarios have been analysed in this paper. The first involves the introduction of karnal bunt to the case study region by contractor equipment. The incursion begins with just two contractors and spreads across the region by the movement of farmers and contractors, as well as the wind. The second scenario has a diffuse starting point, to reflect a situation where a load of contaminated fertiliser is sold throughout the region.

The effectiveness of different quarantine measures at containing the disease, and the resulting changes in economic performance — both on-farm and in the surrounding regional economy — are compared for the two incursion scenarios.

Spread of the disease

In the scenario where two contractors with contaminated machinery introduce karnal bunt into the case study region the disease is slow to spread across the region (figure 1). In the absence of any quarantine response, less than 60 000 hectares is infested with teliospores within fifteen years.

When the quarantine procedures outlined in the previous section are implemented, with detection of karnal bunt teliospores at the silo set at 50 per cent and farmer detection set to zero, the spread of the disease peaks in the fourth year with almost 14 000 infested hectares. The quarantine procedures are effective at containing the outbreak and the disease is effectively eradicated at the end of the planning horizon. When the likelihood of farmers reporting the presence of teliospores on their property during harvest time is increased from zero to 50 per cent, the spread of the disease is further reduced. The spread of the disease peaks at around 6500 hectares and is reduced to negligible levels by sixth year of the simulation.

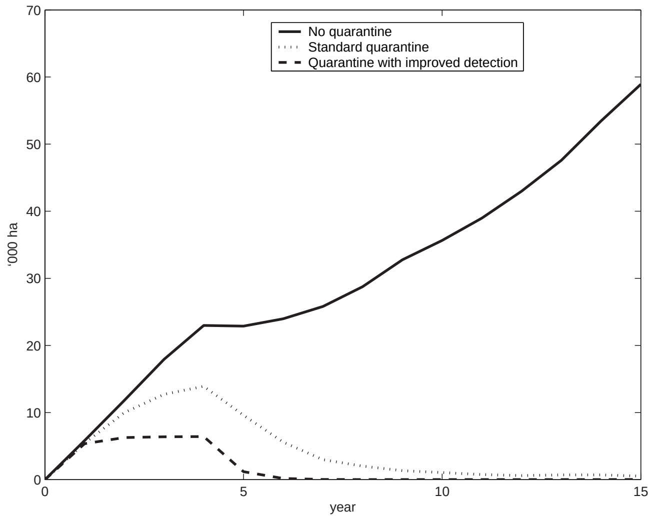

Figure 1: Area infested with karnal bunt, contractor scenario

In the scenario where contaminated fertiliser is sold in the region, it is assumed that half of one per cent of all agricultural land becomes infested with karnal bunt teliospores in the first year of the simulation. Compared with the contractor based incursion, the number of paddocks infested with teliospores is much greater (figure 2). In the absence of quarantine regulations, more than 1.7 million hectares across the case study region are infested with karnal bunt teliospores at the end of the fifteen year planning horizon.

With a 50 per cent likelihood of detection at the silo, and no farmers reporting signs of the disease on their property, the spread of the disease is reduced significantly from that of the no quarantine scenario. The level of infestation peaks at around 360 000 hectares in the fourth year of the simulation, after which quarantine restrictions are effective at reducing the area infested. However, the disease fails to be contained and the proportion of infested area not under quarantine restriction increases. At the end of the fifteen year planning horizon more than 250 000 hectares within the case study region are infested and the disease is spreading at more than 10 000 hectares a year.

When the likelihood of farmers reporting the presence of teliospores on their property during harvest time is increased to 50 per cent, the spread of the disease is reduced in the initial stages, but the infestation is still not effectively contained and eradicated. At the end of the fifteen year planning horizon there is only a minor difference in the area infested compared with the standard quarantine scenario considered.

Economic performance of the region

Contractor scenario

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

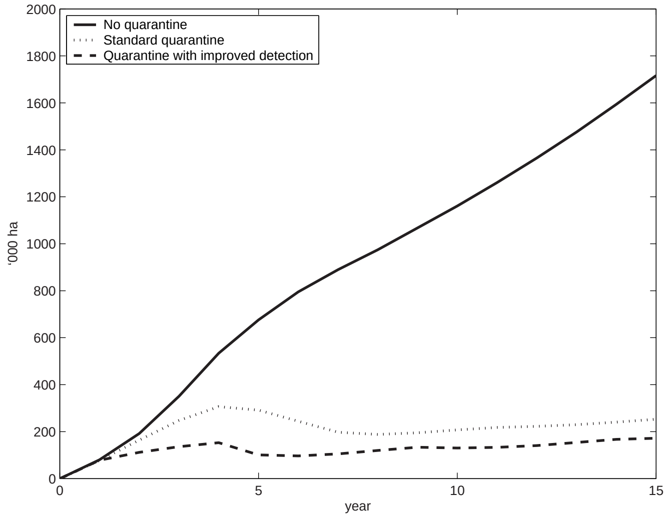

Figure 2: Area infested with karnal bunt, fertiliser scenario

Table 2: **Regional economy effect of alternative incursion scenarios, $m**

	Initial (direct)	Flow on (indirect)	Total
Contractor incursion, standard quarantine	−3.4	−1.3	−4.7
Contractor incursion, improved farmer detection	−2.0	−0.8	−2.8
Fertiliser incursion, no quarantine	−41.1	−15.8	−56.9
Fertiliser incursion, standard quarantine	−84.8	−33.5	−118.3

adverse economic effects of a karnal bunt incursion are relatively minor. Over the fifteen year planning horizon, an incursion contained with the standard quarantine response with no reporting of the disease by farmers results in a loss of production valued at around $3 million in net present value terms (table 2).

By converting the annual change in the gross value of production of wheat and other grains reported for each of the fifteen years to equivalent changes in wheat and other grain exports it was possible to estimate the wider regional economy effects of the incursion. The indirect, or flow-on, effects are calculated as the combined effect of all subsequent changes in the initially affected industries, as well as in the other industries. They are caused by changes in purchases by the wheat and other grains industries, as well as by industries from which the wheat and other grains industries would normally purchase. Any changes in household demand as a result of changes in wages and salaries flowing from changes in employment are also included. Over the fifteen year planning horizon, the indirect effect of the hypothetical incursion on all industries is estimated to be $1.3 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 a hypothetical karnal bunt incursion in the case study region. It is estimated that over the fifteen year planning horizon, the decline in 2003 prices is $4.7 million.

When 50 per cent of farmers in the case study region report signs of the disease on their property during harvest the incursion is contained sooner and the overall economic effects of the outbreak are reduced. Over the fifteen year planning horizon, the loss value of production is valued at around $2 million under this scenario. When the direct and indirect effects of changes in production are aggregated across the region, the decline in economic performance is $2.8 million.

The almost $2 million difference in the economic performance of the region under these two 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 scenario

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 base incursion scenario. Over the fifteen year planning horizon an outbreak of the disease that is not contained by any quarantine measures results in a net loss of agricultural production valued at around $41 million, compared with a reference case of no disease. When the indirect effects are added to this the economic impact of the disease incursion is an estimated $57 million over the fifteen year planning horizon.

The failure of quarantine measures to contain the infestation means that the economic performance of the region is even more adversely affected if quarantine measures are put in place. Over the fifteen year planning horizon the net loss of agricultural production is estimated at more than $80 million when detection at the silo occurs with a probability of 50 per cent and farmers to not report signs of the disease on their property. This converts to a loss in regional income of almost $120 million.

Results aggregated over the fifteen year planning horizon mask significant trends in the data (figure 3). The value of agricultural production under the scenario where no quarantine measures are put in place steadily declines over the fifteen year planning horizon. While it is higher in the first six years of the simulation compared with the scenarios in which quarantine measures are implemented, in the later half of the simulation the economic returns of all three scenarios are similar.

This pattern reflects the failure of quarantine measures to contain a contaminated fertiliser based incursion of karnal bunt. If the rate of spread of the infestation across the region under the scenarios with and without quarantine restrictions converges, there is little value in implementing quarantine restrictions. It is also clear that improved detection of the disease by farmers during harvest does not improve the situation. The initial upfront costs incurred as a result of the increased area under quarantine restrictions are never offset by benefits in the future because the outbreak fails to be contained.

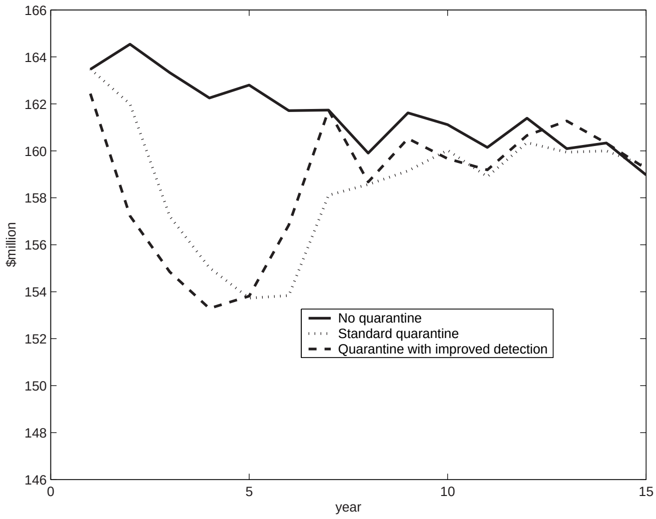

Figure 3: Value of wheat and sorghum production, fertiliser scenario

Discussion

The results presented in this paper indicate that different incursion management responses are required depending on the nature of the incursion. The ability of quarantine measures to effectively eradicate or contain is therefore a critical consideration, but will vary depending on the nature of the specific incursion and its spread characteristics.

Based on the values used to parameterise the spread characteristics of karnal bunt teliospores, it appears unlikely that a diffuse and widespread incursion that results from the distribution of contaminated fertiliser or seed could be eradicated or even contained. This is consistent with the karnal bunt incursion in the United States, where the disease was first identified in 1996 in Arizona, southern California and Texas, with subsequent spreading to additional areas in 2001 (South African Department of Agriculture 2001).

While the value of increased detection of karnal bunt teliospores on-farm was demonstrated for the contractor based scenario, the process by which farmers are persuaded to report infestations on their property is not clear. While the economic performance of the region as a whole is improved by the increased reporting of the disease and its subsequent earlier eradication, individual farmers facing quarantine restrictions may have an incentive to not report signs of infestation. It is likely that transfer payments would be required to maintain individual farmers' incomes to eliminate this disincentive to report.

Further work

With further refinements, the detail and accuracy with which the disease and case study region are modeled can be improved. Proposed additional work includes expanding the expansion of transmission vectors and the range of agricultural activities modeled explicitly. It is also likely that the representation of transport systems in the model will be significantly improved.

Additional sensitivity analysis would prove useful in quantifying the relationships that exist between the likelihood of detection, the effectiveness of different types of quarantine responses and the economic effects of an incursion. For example, with expanded coverage and duration of quarantine boundaries, it may be possible to contain a contaminated fertiliser based incursion. The incentive for farmers to report the presence of karnal bunt teliospores on their property is currently being explored in a subsequent paper and will attempt to estimate the magnitude of payments required to persuade farmers to act in the interests of the whole regional community.

The modeling framework used to analyse the effects of a karnal bunt incursion in this paper is capable of being adapted to analyse the incursion of other plant diseases and pests. It is anticipated that following peer review additional development of the framework will occur so that the model can be extended to analyse the spread of both weeds and insect pests in other case study regions.

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