The Influence Of Control Costs On Cooperation In The Management Of Endemic Invasive Species

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EXTENDED ABSTRACT

Invasive species are animals, plants or diseases that have entered Australia from elsewhere and can cause economic, social or environmental harm. Improvements to the management of invasive species that can reduce the costs currently imposed by incursions in Australia are therefore likely to generate significant economic returns to the national economy.

In a previous paper Elliston and Beare (2005) explored the role of landholder cooperation in the eradication of invasive weeds in an agent-based simulation framework. The analysis drew upon a cellular automata (CA) model representing the economic incentives for cooperation. The analysis indicated that cooperative strategies may offer a means of controlling endemic invasive species that might otherwise by regarded as infeasible to control within the existing choice between private and government funded control options. Further, the results suggested that the facilitation of cooperative management of invasive species, such as weeds, is a potentially cost effective role for government.

Trans-boundary impacts, related to the likelihood that the rate of growth in an infestation on one property depends on the level of infestation on neighboring properties, will clearly influence the value of cooperation. However, the economic incentives for cooperation arising from these trans-boundary impacts also depend on a range of factors that relate to the costs and benefits of control. These factors can influence not only the overall gains from cooperation, but the potential to achieve these gains through individual or collective negotiation.

Based on a number of assumptions regarding the cost of control, the incentives for agents to cooperate were mapped into a decision space defined by infestation levels on their own and neighboring properties and partitioned into regions of unilateral inaction (no control), unilateral action (control), and potential control with bilateral or multilateral cooperation.

When control costs were fixed at $2000 and independent of the level of infestation it was possible to develop local cooperation algorithms that led to stable cooperative solutions, with landholder agents undertaking periodic coordinated control.

Altering the control costs to a small fixed component and a larger variable component changed the set structure and the topology of the decision space. Because the no-control, cooperative-control and unilateral-control sets were no longer convex this gave rise to the potential for switching in the negotiation process. Although the cyclical pattern of cooperation control remained, fewer but more widespread control efforts meant that control was less cost effective. Further, when landholder agents do not cooperate in this simulation, the invasive species spreads unchecked and failed to be contained.

A second assumption about the variable cost parameters was made, this time with parameter values chosen such that at high levels of infestation the cost of control is prohibitively high — higher than the capitalized value of the annual return to land. This resulted in the no-control decision space being no longer contiguous, introducing an upper threshold beyond which it is not economic to control the infestation. The results from this simulation suggest that the existence of an upper threshold on the level of infestation that it is economic to control can erode the potential for unilateral or cooperative control across a broader region.

The results presented in this paper indicate that the characteristics of an incursion and its control have a significant bearing on the success of adopting a cooperative approach to the control of endemic invasive species. It is not enough to consider only the economic gains from cooperation. Rather, consideration also needs to be given to how the incentives faced by individuals are affected by the negotiation process.

1. INTRODUCTION

Invasive species are animals, plants or diseases that have entered Australia from elsewhere and can cause economic, social or environmental harm. Although it is difficult to quantify the full cost of invasive species to Australia, it is known to be considerable. Improvements to the management of invasive species that can reduce the costs currently imposed by incursions in Australia are therefore likely to generate significant economic returns to the national economy.

In a previous paper Elliston and Beare (2005) explored the role of landholder cooperation in the eradication of invasive weeds in an agent-based simulation framework. The analysis drew upon a cellular automata (CA) model representing the economic incentives for cooperation. The analysis indicated that cooperative strategies may offer a means of controlling endemic invasive species that might otherwise by regarded as infeasible to control within the existing choice between private and government funded control options. Further, the results suggested that the facilitation of cooperative management of invasive species, such as weeds, is a potentially cost effective role for government.

The work has a natural extension to the management of a range of endemic plant pest and diseases in Australia through the adoption of cooperative control strategies. However, the characteristics of an incursion and its subsequent control can significantly influence the incentives for cooperation, and hence the success or failure of a cooperative control strategy.

Trans-boundary impacts, related to the likelihood that the rate of growth in an infestation on one property depends on the level of infestation on neighboring properties, will clearly influence the value of cooperation. However, the economic incentives for cooperation arising from these trans-boundary impacts also depend on a range of factors that relate to the costs and benefits of control. These factors can influence not only the overall gains from cooperation, but the potential to achieve these gains through individual or collective negotiation.

The structure of the paper is as follows. First, the key elements of the initial paper on the emergence and failure of cooperation in managing invasive species is reviewed. The impact of some alternative control cost relationships on the landholder decision space is then presented, followed by a series of agent based simulations to examine the impact of these on the cooperative solution. Lastly, the policy implications of the results are discussed and areas for future work are suggested

2. REVIEW OF PREVIOUS WORK

In the ordinal paper, the growth of an invasive species was modeled as a logistic growth function (1). The spread of the incursion between properties was modeled as a CA process. The introduction of the invasive species from an external source was represented by a non-negative stochastic disturbance, where the likelihood of the spread of the incursion is a function of the density of infestation across neighboring properties.

$$x_{i,t+1} = x_{i,t} + \alpha x_{i,t}(1 - x_{i,t})(x_{i,t} - \gamma) + \left(w_0 + \sum_{j \in J} w_1 x_{j,t} \varepsilon \right) \quad (1)$$

Each landholder agent is assumed to face an asset replacement problem (2), making the decision to eradicate or not eradicate the invasive species at time t based on the expected net present value of the return to land.

$$\max_u \sum_{t=0}^{\infty} \frac{1}{(1+\delta)^t} \left[s(1 - x_t) - (c_1 + c_2 x_t) u_t \right]$$

subject to

$$x_{t+1} = \begin{cases} +\xi_t & if\ u_t = 1 \\ x_t + \alpha x_t (1 - x_t)(x_t - \gamma) + \xi_t & otherwise \end{cases} \quad (2)$$
$$x_0 = 0$$

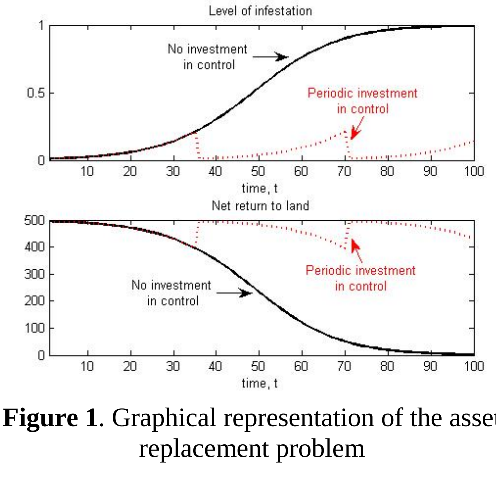

Figure 1. Graphical representation of the asset replacement problem

This can be represented graphically as shown in Figure 1. Each landholder agent owns an asset — in this case the land — which generates a stream of annual returns over time up to some maximum level. The stream of returns generated by the asset, for example, through the growing of a crop or the raising of livestock, declines over time (as if the asset is aging) and this decline in returns is caused by the growth and spread of an endemic invasive species. Each landholder agent periodically makes a 'replacement' decision, which involves an expenditure significantly larger than the return generated by the asset in any one year. Following this investment in control, the productive capacity of the land asset is returns to its maximum potential.

Uncertainty regarding the level of infestation in any given period means that this stochastic optimal control problem does not appear to have a tractable analytical solution. Rather, given a set of parameter values (Table 1), the numerical collocation technique (implemented in MatLab with Miranda and Fackler's (2002) CompEcon toolbox) was used to solve the problem for many different levels of infestation, generating a matrix of optimal strategies.

In Elliston and Beare (2005) it was assumed that control costs were fixed and independent of the level of infestation. Given this, the incentives for agents to cooperate were mapped into a decision space (shown in Figure 2) defined by infestation levels on their own and neighboring properties and partitioned into regions of:

- Unilateral inaction – no control
- Unilateral action to control
- Potential control with bilateral or multilateral cooperation.

Table 1. Parameter values

		Fixed costs
α	growth rate parameter	0.5
γ	threshold parameter	0.05
ω_0	constant background contribution to the likelihood of infestation	0.0
ω_1	weight of the expected contribution from neighboring properties	0.04
δ	discount rate	0.05
s	net annual return to land	$500
c_1	fixed control costs	$2000
c_2	variable control costs	$0
u	decision to control	[0,1]
x	level of infestation	0–1

Under the assumptions used in the analysis, the partitions were contiguous (there was only one region for each action). At infestation density levels below around 20 per cent on their property, agents are unwilling to control the incursion regardless of the level of infestation on neighboring properties. When the level of infestation increases beyond 20 per cent on their property it can be optimal to control the incursion.

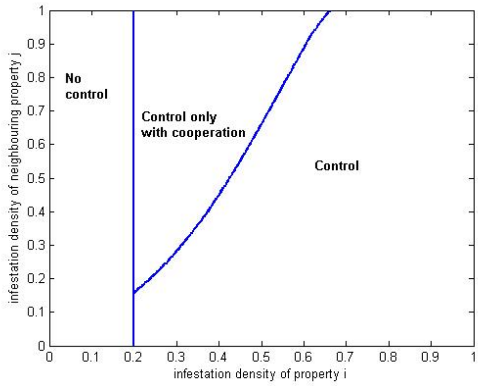

Figure 2. Decision matrix (fixed control costs)

At infestation levels above about 65 per cent, the returns to control exceed the costs regardless of the action taken by one or more neighboring landholder agents. However, for agents with infestation levels between 20 and 65 per cent, their willingness to control depends on the infestation level on neighbouring properties. The region of cooperation in Figure 2 identifies the combinations of infestation levels where the benefits of control are outweighed by the potential for reinfestation unless one or more of the neighboring properties also chooses to invest in control.

Using this decision matrix it was possible to develop local cooperation algorithms that lead to stable cooperative solutions. The algorithms were implemented in Cormas, a spatial natural resource and agent based simulation framework (CIRAD 2003). One hundred landholder agents are assumed to be located on a ten by ten grid. In each time step the endemic invasive species grows and spreads, and landholders are faced with a decision to control or not. This decision is arrived at through an iterative procedure over all plots of land until there is convergence. The decisions of agents located in the region of cooperation are iteratively re-evaluated based on the decisions made by neighbouring agents.

Two scenarios were constructed to investigate the potential value of cooperation. In the first scenario it was assumed that landholder agents do not cooperate with each other but still undertake control when it is in their economic interest. Further, if one agent does chose to control this can affect the subsequent decisions of neighbouring agents. In the alternative scenario neighbouring landholder agents cooperate on an 'I will if you will' basis. That is, any two or more neighbouring agents agree to undertake control in the same period when they are located in the region of cooperation and it is in their individual interests to do so. Clearly, this is just one of many forms of cooperation. To simplify the determination of the economic incentives for cooperation faced by each individual, it was assumed that landholder agents have perfect information regarding the level of infestation on their own and neighbouring properties.

When landholder agents were allowed to access the region of cooperation they were found to undertake periodic coordinated control (Figure 3).

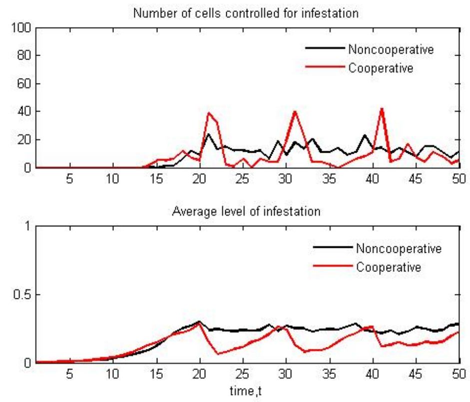

Figure 3. Control behavior and infestation levels (fixed control costs)

For example, in the simulation shown in Figure 3 the maximum number of agents undertaking control in any one period was 42 when they were assumed to cooperate. In contrast, the maximum number of cells eradicated in any one period was 24 when the agents did not cooperate. When the agents were assumed to cooperate the average level of infestation was lower compared with when they did not cooperate. For example, in the simulation shown in Figure 3 the average level of infestation across the one hundred plots of land was less than 13 per cent when the agents undertook coordinated action, compared with 18 per cent when they did not. The net economic returns to individual agents were also higher in the cooperative scenario.

However, the assumptions used in the original analysis are quite restrictive. In this paper, two alternative assumptions regarding the cost of control are considered to investigate how the set structure and the topology of the decision space is affected. In turn, the effect of changes in this topology on the extent and pattern of cooperation are also explored.

3. ALTERNATIVE COST ASSUMPTIONS

The assumption that control costs are fixed and independent of the level of infestation was replaced with an assumption that control costs are variable and increase with the level of infestation (table 2).

Table 2. Cost parameter values

		Sim. 1	Sim. 2
C_1	fixed control costs	\$500	\$500
C_2	variable control costs	\$7500	\$15000

3.1. Simulation 1

Altering the control costs to a fixed component of \$500 and a variable component of \$7,500 altered the set structure and the topology of the decision space from the simulation where control costs were assumed to be fixed (Figure 4). Similar to the fixed cost case there is a lower threshold below which the landholder agents will not control the infestation on their properties. However, it declines from around 20 per cent infestation in the case where control costs are fixed to just over 5 per cent in this variable cost simulation.

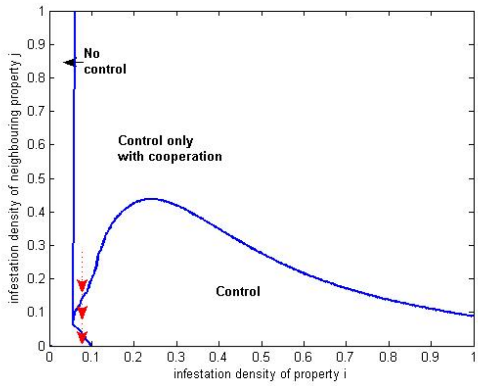

Figure 4. Decision matrix (Variable control costs, simulation 1)

More significantly, the no-control, cooperative-control and unilateral-control sets are no longer convex. This gives rise to the potential for switching in the negotiation process. This is illustrated by the arrowed line in Figure 4. As an individual agent negotiates with neighbors, the agent can move from a region of cooperation, to unilateral control and finally to no control. This occurs as the negotiations change the agent's expectations about how neighboring properties influence future infestation levels on their properties.

A further difference in the decision matrix is that at high levels of infestation on their property, landholder agents are no longer willing to take unilateral action to control the infestation. Rather, control will only be undertaken by landholder agents that agree it is in their mutual interest to do so.

The results of the agent based simulation when costs of control are variable differed somewhat from those where control costs are fixed (Figure

5). When landholder agents do not cooperate with each other there is very little investment to control the infestation. As a result the invasive species spreads unchecked and fails to be contained. When the landholder agents are assumed to cooperate with each other enough control occurs to keep the invasive species in check. This suggests that when the costs of control take this form there is significant economic benefits generated by agent cooperation.

However, the cyclical pattern of control is different to that of fixed cost scenario. In the fixed cost scenario there are fewer but more widespread control efforts. In this variable cost simulation the frequency of cooperative control efforts is greater but less intense, which is clearly less cost effective. This may be due, at least in part, to negotiations under the cooperative 'I will if you will algorithm' failing to fully capture the incentives for cooperation that exist**.**

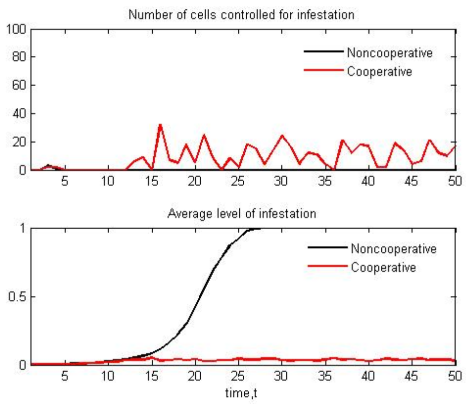

Figure 5. Control behaviour and infestation levels (variable control costs, simulation 1)

3.2. Simulation 2

A second assumption about the variable cost parameters was made to further investigate changes in the structure and topology of the decision space. This time parameter values were chosen such that at high levels of infestation the cost of control is prohibitively high – higher than the capitalized value of the annual return to land (Table 2). This significantly altered the decision space (Figure 6).

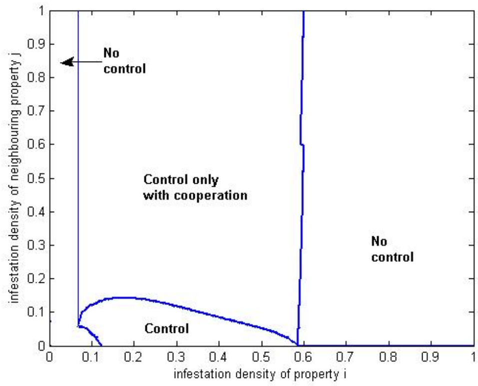

Figure 6. Decision matrix (Variable control costs, simulation 2)

First, the no-control decision space is no longer contiguous. Altering the variable cost parameters in this manner introduces an upper threshold beyond which it is not economic to control the infestation. For landholder agents with infestation levels above around 60 per cent it is not worth controlling the infestation on their property. If infestation levels reach this upper threshold, the landholder agent has no incentive to unilaterally or cooperatively undertake control and remains an ongoing source of infestation to neighboring properties.

The results of the agent based simulation when the variable costs of control are increased differed further still (Figure 7). The increased region of no control and the reduced region of unilateral control reduces the incentive of landholder agents to manage the invasive species on their properties through both unilateral and cooperative control. For example, over 50 time periods the invasive species is controlled on fewer than 40 plots in the cooperative scenario, and fewer than 5 plots in the non-cooperative scenario.

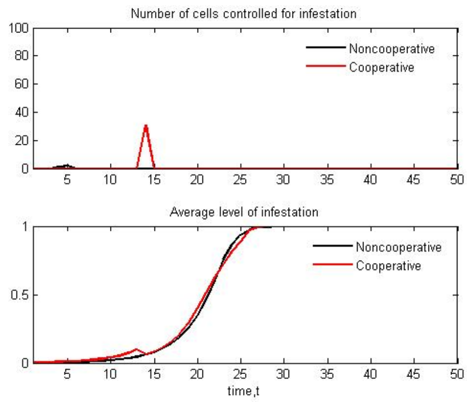

Figure 7. Control behaviour and infestation levels (variable control costs, simulation 2)

With such low levels of control, in both the cooperative and the non-cooperative scenarios, the invasive species spreads unchecked, reaching maximum infestation within approximately 30 time periods.

The existence of an upper threshold on the level of infestation that it is economic to control can clearly erode the potential for unilateral or cooperative control across a broader region.

4. POLICY IMPLICATIONS AND FURTHER WORK

In Elliston and Beare (2005) it was shown that the level of investment in the control of an endemic invasive species is suboptimal if landholders are unable or unwilling to undertake cooperative action and instead operate completely on their own. When it was assumed that the cost of control was fixed and independent of the level of infestation cooperative action to control an endemic invasive species generated a better outcome in terms of lower infestation and higher net economic returns.

However, the results presented in this paper indicate that the characteristics of an incursion and its control have a significant bearing on the success of adopting a cooperative approach to the control of endemic invasive species. It is not enough to consider only the economic gains from cooperation. Consideration also needs to be given to how the incentives faced by individuals are affected by the negotiation process.

This has policy implications for the management of endemic invasive species such as woody weeds in the western division of New South Wales. A range of factors including low real wool prices and lower productivity growth, on average, compared with that achieved in other agricultural regions mean that the costs of control exceed the current value of the land. When infestation levels exceed an upper threshold on these properties landholders will have no incentive for either unilateral or cooperative control. Further, they remain a constant source of reinfestation to other properties, potentially imposing the same cognitions on their neighbors.

The results presented in this paper represent a preliminary investigation of the factors that influence cooperation between landholders in the management of endemic invasive species. There is a need to explore these issues further to better understand how the set structure and topology of the decision matrix changes the potential for cooperative negotiations to succeed. Further work is also required to investigate how the choice of different negotiating strategies may also affect the problem.

5. REFERENCES

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