Strategic Agent Behavior with an Invasive Weed

J.M. Chermak
K. Krause
K.M. Grimsrud
J. Thacher
UNM

D. Schimmelpfennig
ERS

J.K. Hansen
NPS

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Will agents manage an invasive species before it becomes an economic problem?

What is the optimal strategy?

How do neighbors’ actions impact decisions?

Are incentives provided?
RESEARCH PLAN

• Focus on invasive weeds in NM that are not yet an economic problem
  - Russian Knapweed
  - Yellow Starthistle
Russian Knapweed

Yellow Starthistle

Source: http://plants.usda.gov
RESEARCH PLAN

• Focus on invasive weeds in NM that are not yet an economic problem
  - Russian Knapweed
  - Yellow Starthistle

• Focus specifically on cattle ranching
NUMBER OF RANCHES

Number of Ranches
- < 100
- > 300
RESEARCH PLAN

• Focus on invasive weeds in NM that are not yet an economic problem
  - Russian Knapweed
  - Yellow Starthistle

• Focus specifically on cattle ranching

• Employ a multi-faceted approach
  - Theoretical and Numerical Modeling
  - Surveys
  - Economic Experiments
  - Numerical Modeling
DYNAMIC NON-COOPERATIVE GAME

Agent $i$’s Problem
Maximize Net Benefits:

$$J_i \left( \theta_{i,0}; \left[ w_i(t), w_j(t) \right]^T \right) = \int_{t=0}^{T} e^{-rt} \left[ B_i(\theta_i(t), w_i(t); A_i) \right] dt$$

subject to:

$$\dot{\theta}_i(t) = f_i \left( g_i(\theta(t)), w(t), \psi \right), \theta_i(0) = \theta_{i,0}$$

where:

- $i,j$ private agents (ranchers) ($i$ does not equal $j$),
- $\theta_i(t)$ defines $i$’s stock of the invasive species (state),
- $w_i(t)$ denotes the management effort of agent $i$ during $t$ (control),
- $A_i$ is a vector of $i$’s characteristics, and
- $\psi$ is the effectiveness of management.
Each agent observes the current conditions and chooses the optimal management level consistent with

\[ \omega_i(t) = \eta_i(\theta_i(t)). \]

A Nash equilibrium occurs if

\[
J_i\left(\theta_{i,0}; \left[\eta_i^*(\theta_i(t)), \eta_j^*(\theta_j(t))\right]_{t=0}^T\right) \geq J_i\left(\theta_{i,0}; \left[\eta_i(\theta_i(t)), \eta_j(\theta_j(t))\right]_{t=0}^T\right)
\]

At this level of generality we can say little concerning the characteristics of the optimal effort path for an individual agent.

Specific functional form - three models:

Open-loop
Closed-loop, open-form (dynamic simulations)
Closed-loop, closed form (LQ form)
**Base Case Results (closed-loop, open-form)**

### Effort

![Effort Graph](image)

### Infestation

![Infestation Graph](image)

<table>
<thead>
<tr>
<th>Initial Infestation (%)</th>
<th>Percent of Initial Infestation Eradicated</th>
<th>NPV ($)</th>
<th>Average Cost of Effort ($/Acre)</th>
<th>Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>90</td>
<td>714.10</td>
<td>2.92</td>
<td>0.00</td>
</tr>
<tr>
<td>20</td>
<td>95</td>
<td>712.75</td>
<td>8.23</td>
<td>0.00</td>
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<td>30</td>
<td>87</td>
<td>552.36</td>
<td>16.20</td>
<td>0.00</td>
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<tr>
<td>40</td>
<td>83</td>
<td>427.06</td>
<td>27.21</td>
<td>0.00</td>
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<tr>
<td>50</td>
<td>78</td>
<td>271.27</td>
<td>41.18</td>
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</table>
Low Carrying Capacity

<table>
<thead>
<tr>
<th>Initial Infestation (%)</th>
<th>Percent Initial Infestation Eradicated Low CC</th>
<th>Percent Initial Infestation Eradicated Base CC</th>
<th>Difference in Initial Period Eradication</th>
<th>NPV ($) Low CC</th>
<th>NPV ($) Base CC</th>
<th>Difference NPV ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>80</td>
<td>90</td>
<td>-10</td>
<td>100.37</td>
<td>714.10</td>
<td>-613.73</td>
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<tr>
<td>20</td>
<td>75</td>
<td>95</td>
<td>-20</td>
<td>50.60</td>
<td>712.75</td>
<td>-662.15</td>
</tr>
<tr>
<td>30</td>
<td>0</td>
<td>87</td>
<td>-87</td>
<td>25.92</td>
<td>552.36</td>
<td>-526.44</td>
</tr>
</tbody>
</table>
Asymmetric Agents

<table>
<thead>
<tr>
<th>Initial Infestation (%)</th>
<th>Percent of Initial Infestation Eradicated</th>
<th>NPV ($)</th>
<th>Average Cost of Effort ($/Acre)</th>
<th>Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>i  j</td>
<td>i  j</td>
<td>i  J</td>
<td>I    j</td>
<td>i  j</td>
</tr>
<tr>
<td>10 20</td>
<td>90 90</td>
<td>714.10  647.84</td>
<td>2.94</td>
<td>8.77</td>
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<tr>
<td>10 30</td>
<td>80 83</td>
<td>711.00  553.97</td>
<td>3.03</td>
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<tr>
<td>10 40</td>
<td>100 75</td>
<td>708.67  431.24</td>
<td>3.30</td>
<td>26.58</td>
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<tr>
<td>10 50</td>
<td>100 72</td>
<td>707.86  278.56</td>
<td>3.34</td>
<td>40.27</td>
</tr>
</tbody>
</table>
Summary of Numerical Results

Baseline:
• Can manage infestation, high initial effort optimal

Low CC
• Infestation < 30%, can manage
• Infestation > 30%, no optimal management solution
• Increased time horizon results in higher infestation level solutions

Asymmetric Agents
• High infestation agent realizes positive externalities from low infestation agent
• Low infestation agent needs to exert more effort

Do ranchers follow optimal strategies?
SURVEY
Choice Question Example

<table>
<thead>
<tr>
<th></th>
<th>Russian Knapweed</th>
<th>Yellow Starthistle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in carrying capacity if not managed</td>
<td>5 %</td>
<td>15 %</td>
</tr>
<tr>
<td>Probability infestation spreads to area ranches, if not managed</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Percent of area ranches managing this weed</td>
<td>50 %</td>
<td>90 %</td>
</tr>
<tr>
<td>Degree of infestation in local area</td>
<td>Medium</td>
<td>Light</td>
</tr>
<tr>
<td>Total weed management cost</td>
<td>$100 0</td>
<td>$250 0</td>
</tr>
</tbody>
</table>

I would be more likely to: **Check one**

1. Manage the Yellow Starthistle infestation
2. Manage the Russian Knapweed infestation
3. Not manage either infestation
4. Manage both infestations

**Attribute Levels:**

- Carrying Capacity: 5%, 15%, 30%
- Probability Spread: Low, Medium, High
- Percent Others Managing: 10%, 50%, 90%
- Local Infestation: Light, Medium, Heavy
### Example Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All data</th>
<th></th>
<th></th>
<th>RK/YS choices only</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Std Err</td>
<td>P-values</td>
<td>Estimate</td>
<td>Std Err</td>
<td>P-values</td>
</tr>
<tr>
<td><strong>Russian Knapweed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ArealInfest: Heavy</td>
<td>0.34</td>
<td>0.11</td>
<td>&lt;0.01</td>
<td>0.47</td>
<td>0.18</td>
<td>0.01</td>
</tr>
<tr>
<td>ArealInfest: Medium</td>
<td>0.33</td>
<td>0.11</td>
<td>&lt;0.01</td>
<td>0.24</td>
<td>0.18</td>
<td>0.19</td>
</tr>
<tr>
<td>(\alpha_{RK})</td>
<td>0.057</td>
<td>0.11</td>
<td>0.60</td>
<td>0.16</td>
<td>0.16</td>
<td>0.34</td>
</tr>
<tr>
<td><strong>Yellow Starthistle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ArealInfest: Heavy</td>
<td>0.047</td>
<td>0.107</td>
<td>0.66</td>
<td>0.11</td>
<td>0.18</td>
<td>0.56</td>
</tr>
<tr>
<td>ArealInfest: Medium</td>
<td>-0.035</td>
<td>0.108</td>
<td>0.74</td>
<td>0.16</td>
<td>0.18</td>
<td>0.37</td>
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<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Othr)</td>
<td>0.037</td>
<td>0.010</td>
<td>&lt;0.01</td>
<td>0.052</td>
<td>0.017</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>(Othr^2)</td>
<td>-0.0017</td>
<td>0.0042</td>
<td>0.68</td>
<td>-0.010</td>
<td>0.0075</td>
<td>0.15</td>
</tr>
<tr>
<td>Sprd: High</td>
<td>0.22</td>
<td>0.077</td>
<td>&lt;0.01</td>
<td>0.48</td>
<td>0.12</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Sprd: Medium</td>
<td>0.17</td>
<td>0.072</td>
<td>0.02</td>
<td>0.32</td>
<td>0.12</td>
<td>0.01</td>
</tr>
<tr>
<td>CCN</td>
<td>0.33</td>
<td>0.034</td>
<td>&lt;0.01</td>
<td>0.63</td>
<td>0.062</td>
<td>&lt;0.01</td>
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<tr>
<td>CCN^2</td>
<td>-0.054</td>
<td>0.045</td>
<td>0.22</td>
<td>-0.15</td>
<td>0.073</td>
<td>0.04</td>
</tr>
<tr>
<td>Cost</td>
<td>-0.021</td>
<td>0.0021</td>
<td>&lt;0.01</td>
<td>-0.027</td>
<td>0.0035</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>(\alpha_N)</td>
<td>-0.93</td>
<td>0.14</td>
<td>&lt;0.01</td>
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<td></td>
<td></td>
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<tr>
<td>(\alpha_B)</td>
<td>1.50</td>
<td>0.12</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**N** 2602

**LogL** -2926.61

**N** 961

**LogL** -543.18

*, **, and *** denote significant estimates at the 10, 5, and 1 percent levels, respectively.

All continuous variables, \(Othr\) and \(CCN\) are centered.
From the survey we find

Ranchers are:

• more likely to manage the higher the level of infestation
• more likely to manage weeds when their neighbors are
• more likely to manage weeds if not managing negatively impacts neighbors

In addition:

• size of ranching operation matters
• there are regional differences within the state
• share of family income from ranching impacts results
• type of weed matters

How do ranchers act in a multi-round experiment?
Experiment 2 (North West NM)

Ratio of Effort to Infestation
  = 0:   no effort
  = 1:   effort equals infestation level
  > 1:   effort > infestation level
EXP2: G3

Ratio of Effort to Infestation

<table>
<thead>
<tr>
<th>Part</th>
<th>Horizon</th>
<th>Acres</th>
<th>Herd</th>
<th>Graze</th>
<th>Yrs</th>
<th>Age</th>
<th>Gend</th>
<th>Educ.</th>
<th>Eth</th>
<th>Pol</th>
</tr>
</thead>
<tbody>
<tr>
<td>P7</td>
<td>10</td>
<td>&lt;50</td>
<td>20</td>
<td>Private</td>
<td>16</td>
<td>64</td>
<td>F</td>
<td>&lt;HS</td>
<td>Hisp</td>
<td>Rep</td>
</tr>
<tr>
<td>P8</td>
<td>5</td>
<td>&lt;50</td>
<td>10</td>
<td>Private</td>
<td>15</td>
<td>61</td>
<td>F</td>
<td>HS</td>
<td>Ang</td>
<td>Dem</td>
</tr>
<tr>
<td>P9</td>
<td>50</td>
<td>3160</td>
<td>200</td>
<td>Both</td>
<td>10</td>
<td>63</td>
<td>F</td>
<td>HS</td>
<td>Ang</td>
<td>Dem</td>
</tr>
<tr>
<td>P10</td>
<td>5</td>
<td>165</td>
<td>20</td>
<td>Private</td>
<td>35</td>
<td>67</td>
<td>F</td>
<td>&lt;HS</td>
<td>Ang</td>
<td>Rep</td>
</tr>
</tbody>
</table>

Round 6 reset infestation level
### SUMMARY

<table>
<thead>
<tr>
<th>Factor</th>
<th>Modeling</th>
<th>Survey</th>
<th>Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Action</td>
<td>Relatively Aggressive</td>
<td>Depends on level of infestation</td>
<td>Varies across participants</td>
</tr>
<tr>
<td>Neighbors’ Actions</td>
<td>If inaction, need to compensate</td>
<td>More likely to act if neighbor acts</td>
<td>Varies across participants</td>
</tr>
<tr>
<td>Strategy</td>
<td>Changes as problem changes</td>
<td>Impacted by infestation, neighbors, location, individual characteristics</td>
<td>Ranges from aggressive to free-riding</td>
</tr>
</tbody>
</table>
CONCLUSIONS

WEED MANAGEMENT PROGRAMS (PRE-ECONOMIC PROBLEM)

• education
• adaptable to heterogeneity
• menu of incentives

ONGOING WORK

• complete experimental analysis
• informed (from surveys and experiments) numerical modeling
• spatial variation
• uncertainty
• changing preferences
• changing characteristics
• group composition
• ….
THANK YOU

jchermak@unm.edu