Invasive Species Management: Border Enforcement, Location Theory, and Risk

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Previous Research on Economics of Invasive Species

- Research on prevention (and control) does not model the specifics of border enforcement (e.g., Horan et al. 2002; Jensen 2002; Olson & Roy 2005).
- No consideration of heterogeneity of importers or ports.
- No agent-based models (which are able to incorporate this heterogeneity).
- Though spatial analyses are becoming more common (Brown, Lynch, & Zilberman 2002, Barbier & Shogren 2002), they do not address border enforcement.

Previous Research on Economics of Invasive Species (cont.)

- McAusland and Costello (2004):
  - analyze the optimal mix of tariffs (rather than penalties) and inspection to control invasive species introductions,
  - find that at low levels of infectedness, optimal inspection increases as infectedness increases, while at high levels, this relationship is reversed,
  - consider one enforcement scenario only - infected goods barred from entry - which drives their findings on optimal inspections, and
  - do not consider multiple, heterogeneous ports.

Research Components

1. **Theoretical Model:** evaluates both intended & unintended importer response to different border enforcement regimes with a focus on firm-specific and port-specific attributes.
2. **Data:** APHIS import, inspection, & enforcement data.
3. **Agent Based Model (ABM):** based on theoretical model, spatial explicit, incorporates firm and port heterogeneity.
4. **Simulation Analysis:** will evaluate the welfare impacts of enforcement regimes for representative commodities.

Project Schedule

Institution/Major Tasks	2006			2007		
	Spring	Summer	Fall	Spring	Summer	Fall
UC Berkeley						
Theoretical analysis						
Data retrieval						
Consult with UA						
Consult with TAMU						
ABM policy analysis						
University of Alberta						
Develop ABM						
ABM policy analysis						
Texas A&M University						
Develop spatial damage function						

Data and Selection of Representative Commodities

- Data were retrieved from APHIS administered databases, our primary sources of data on shipments, country of origin, commodity, port-of-entry, interceptions, violations and disposition (action taken, e.g., entered, prohibited, fumigated, destroyed).
- Representative commodities and pests were selected based on preliminary data on disposition, pest interceptions, and interviews:
  - **Broccoli from Mexico**: flea beetle, Copitarsia worm
  - **Tomatoes & peppers, Netherlands**: Agromyzidae (Diptera).

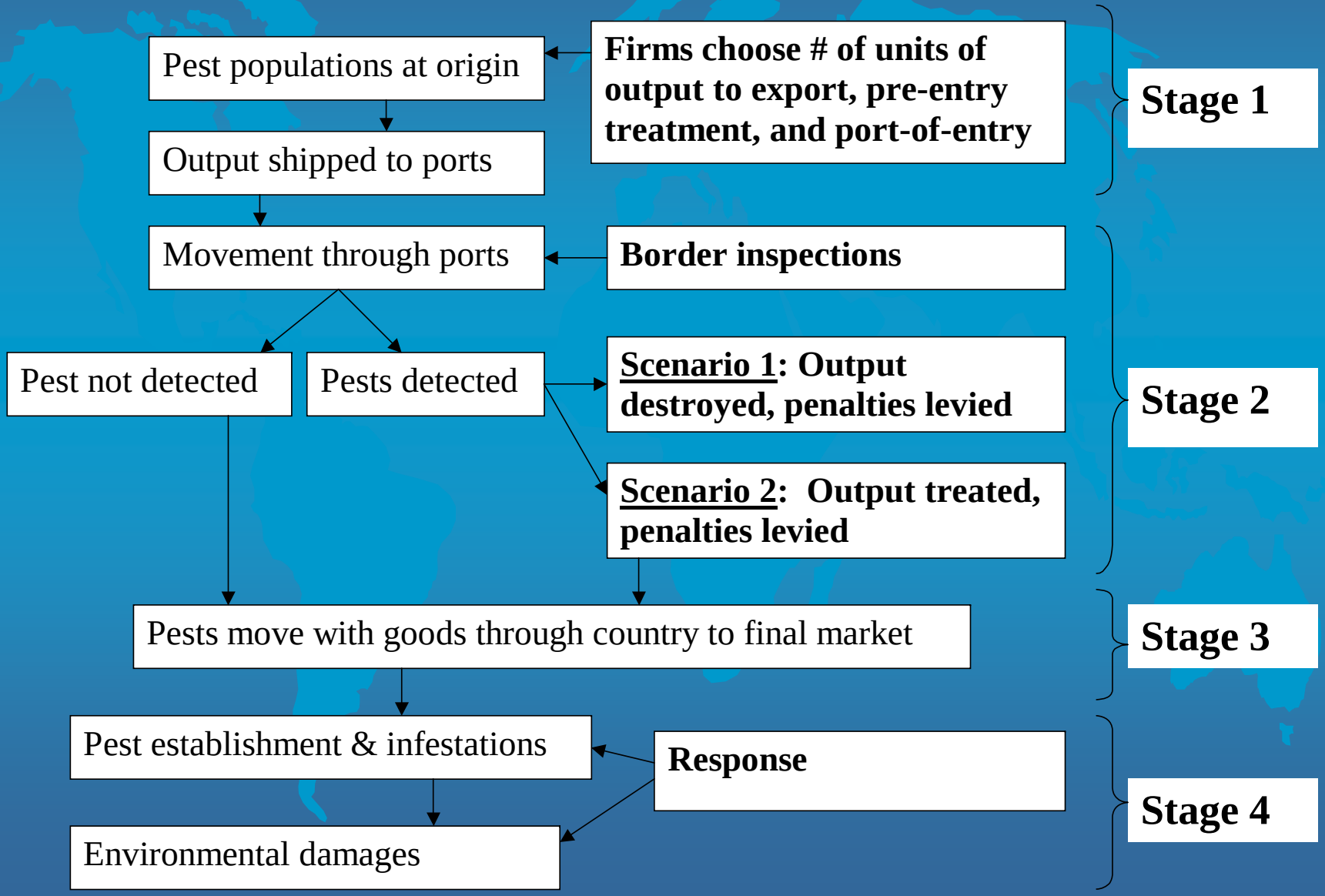
Theoretical Model

Assume:

- $i=1,..,I$ importing firms of a single commodity,
- Pest risk increases with i,
- Firms ship through $k=1,..,K$ ports of entry.

The model has four stages.

Model of Pest Populations & Movement, Importer Decisions, & Enforcement



Stage 1: Production, Initial Pest Exposure, Treatment & Shipment to Border

- An initial pest population, n_{ik}^{0}, increases with i.
- Firms choose:
  - k, to which port to ship,
  - y_{ik}, output, and
  - e^{0}_{ik}, per unit pre-entry treatment.
- After initial treatment, pest populations decline to $n_{ik}^{1} = n_{ik}^{0} g(e^{0}_{ik})$ where g is a kill function.
- Transportation costs from origin to border, τ_{ik}.
- Initial cost of production, $c_i(y_{ik})$.

Stage 2: Border Inspections, Enforcement & Treatment

- Port entry fees, ϕ_k, per unit of output.
- Inspection leads to discovery of $h(n_{ik}^1, w_k)y_{ik}$, where $h(n_{ik}^1, w_k)$ is a discovery function with per unit cost of inspection, w_k.

<u>Scenario 1. Shipments are destroyed</u>

The ith firm:

– supplies $s_{ik}^1=(1-h(n_{ik}^1, w_k))y_{ik}$, and

– pays a penalty of $t_k^1 h(n_{ik}^1, w_k)y_{ik}$.

Stage 2: Border Inspections, Enforcement, & Treatment (con't)

Scenario 2. Shipments are treated

The ith firm:

- supplies $s_{ik}^2 = y_{ik}$,
- pays a penalty of $t_k^2 h(n_{ik}^1, w_k) y_{ik}$, and
- pays treatment costs, $x_k h(n_{ik}^1, w_k) y_{ik}$.

Pest populations decline to $n_{ik}^2 = n_{ik}^1 g^2(x_k)$.

Stage 3: Shipment to Final Market

- l_k – per unit transportation cost from port to final market (analytically the same as a tariff).
- Import supply is sum of firms' output.
- Total supply = imported + domestic supply.
- Market equilibrium $\wp$ output price.
- Consumer surplus, domestic consumer surplus.

Stage 4: Environmental Damages

- $E(N,R)$
- N, pest population arriving on imported goods
- R, post-border, responsive treatment
- where: $\partial E / \partial N > 0, \partial E / \partial R < 0$.

Firm's Decision

Under scenario 1, for each port, the firm first solves:

$$\pi_{ik}^{1} = \max_{y_{ik}, e_{ik}^{0}} \left[\left\{ (pq_i - l_k)(1 - h(n_{ik}^{1}, w_k)) - t_k^{1} h(n_{ik}^{1}, w_k) - \phi_k - \tau_{ik} - e_{ik}^{0} \right\} y_{ik} - c_i(y_{ik}) \right]$$

Alternatively, under scenario 2:

$$\pi_{ik}^{2} = \max_{y_{ik}, e_{ik}^{0}} \left[\left\{ pq_i - (x_k + t_k^{2}) h(n_{ik}^{1}, w_k) - \phi_k - l_k - \tau_{ik} - e_{ik}^{0} \right\} y_{ik} - c_i(y_{ik}) \right]$$

The firm then chooses optimal port:

$$\Pi^{1}(i) = \underset{k}{Max} \left\{ \pi_{ik}^{1} \right\} \quad \text{or} \quad \Pi^{2}(i) = \underset{k}{Max} \left\{ \pi_{ik}^{2} \right\}$$

Social Welfare

$$sw^{scenario} = CS + PS_D + Envir.Damages + Inspection + Response$$

The social planner chooses optimal inspection, penalties and post border response for each scenario:

$$\max sw^{scenario}(y_{ik}^*, e_{ik}^{0*}, p^*; \square) =$$

$$\max_{w_k, t_k, , R} \int_0^{S_T(p^*)} [D(p) - p^*]ds + \int_0^{S_D(p^*)} [p^* - S_D(p)]ds - E(N,R) - \sum_{k=1}^{K}\sum_{i=1}^{I} w_k - R$$

then chooses optimal enforcement scenario :

$$\max SW = \underset{\substack{enforcement \\ scenario}}{MAX} \left\{ sw^1, sw^2 \right\} .$$

Preliminary Theoretical Results: Firm Response to Inspection

An increase in per unit inspection levels will lead to:

- an increase in pre-entry treatment if

$$\partial^2 h \big/ \partial n_{ik}^1 \partial w_k \geq 0$$

meaning the discovery function is either more responsive to changes in pest populations as inspection levels increase or unaffected by changes in inspection levels.

Preliminary Theoretical Results: Firm Response to Inspection (cont.)

An increase in inspection will also lead to:

- a reduction in output – an unintended response – if:

$$(pq_i - l_k + t_k)\left(\partial h \big/ \partial n_{ik}^{1} \; \partial n_{ik}^{1} \big/ \partial e_{ik}^{0} \right) \leq 1$$

meaning:

- price of output & penalties are relatively low,
- transportation costs high, or
- pre-entry treatment is relatively ineffective.

Preliminary Theoretical Results: Firm Response to Penalties v. Tariffs

Under both scenarios, an increase in **penalties** will lead to:

- an increase pre-entry treatment, and
- a reduction in output if : $(pq_i - l_k + t_k)\left(\partial h / \partial n_{ik}^{1} \; \partial n_{ik}^{1} / \partial e_{ik}^{0}\right) \leq 1$

An increase in the **tariff** will lead to:

- an ambiguous change in pre-entry treatment under scenario 1 with no change under scenario 2, and
- reduced output under scenario 2, and also under scenario 1 if :

$$(pq_i - l_k + t_k)\left(\partial h / \partial n_{ik}^{1} \; \partial n_{ik}^{1} / \partial e_{ik}^{0}\right) \geq 1$$

Preliminary Theoretical Results: Firm Heterogeneity in Pest Populations

An increase in initial pest population will lead to:

- increased levels of pre-entry treatment if:

$$\partial^2 n_{ik}^1 \Big/ \partial e_{ik}^0 \partial n_i^0 < 0$$

(the kill function gets more efficient as pest populations increase), and

- an increase or decrease in output depending on specific conditions.

Preliminary Theoretical Results: Port Choice

Obvious effects:

- A uniform increase in costs (e.g., tariffs, transport, port entry fees, treatment costs) across ports will not lead to port switching.
- An increase in costs at a single port will encourage importers to shift away from that port.

Preliminary Theoretical Results: Port Choice (cont.)

<u>Non-obvious effects</u>:

- A firm-specific change, such as a change in initial pest populations, can cause a shift between ports if:

$$\partial h / \partial n_{i1}^{1} \; \partial n_{i1}^{1} / \partial n_{i}^{0} \neq \partial h / \partial n_{i2}^{1} \; \partial n_{i1}^{1} / \partial n_{i}^{0} \quad \text{or} \quad \partial h / \partial n_{i1}^{1} \neq \partial h / \partial n_{i2}^{1}$$

- Similarly, a change inspection levels can cause a shift between ports if:

$$\partial h / \partial w_{1} \neq \partial h / \partial w_{2}$$

Preliminary Theoretical Results:
Scenario 1 (destroy) vs. Scenario 2 (treat)

- Under scenario 1, changes in inspection or initial pest populations lead to a greater output and pre-entry treatment response than under scenario 2 if:

$$(pq_i - l + t_k^1) > (x_k + t_k^2) \ .$$

- It is likely that under scenario 2, changes price, quality, transportation costs, tariffs, and port entry fees lead to a greater output response and lesser pre-entry treatment response than under scenario 1.

Alternative Enforcement Scenarios

Scenario 3:

- 3a. The unit where pests are discovered are destroyed,
- 3b. The remaining units are treated.

Scenario 4:

- 4a. Penalties are based on the number of discovered units,
- 4b. All units are treated

Implications

- Firms consider the tradeoffs associated with costs and benefits associated with location - inspection intensity or port entry fees versus distance to port-of-entry and final market.
- Different types of firms will weigh these tradeoffs differently.
- High risk firms are likely to select ports that are perceived to be low-enforcement ports, perhaps forfeiting distance.
- High risk firms are likely to choose low-enforcement ports rather than pre-entry treatment.

Implications (cont.)

- Low risk firms are likely to value transportation cost savings versus enforcement.
- Increased enforcement (higher inspection intensity) may not result in reduced pest risk.
- Scenario 1 (destroy) is likely to be optimal when response costs and potential damages are high, and consumer surplus impacts are low.
- Scenario 2 (treat) is likely to be optimal when response costs are low, potential damages are low, and consumer surplus impacts are high.

Further Questions to Address with Theoretical Analysis

- What are the specific conditions under which scenario 1 (destroy) is an optimal choice over scenario 2 (treat)?
- How do socially optimal enforcement and response change with changes in model parameters?
- What are the implications of different assumptions concerning risk (e.g., uncertain pest populations, prices)?
- Given importer response, how should gov't decision makers allocate inspection effort across different types of ports?
- What are options for firm-specific enforcement?

Agent Based Modeling

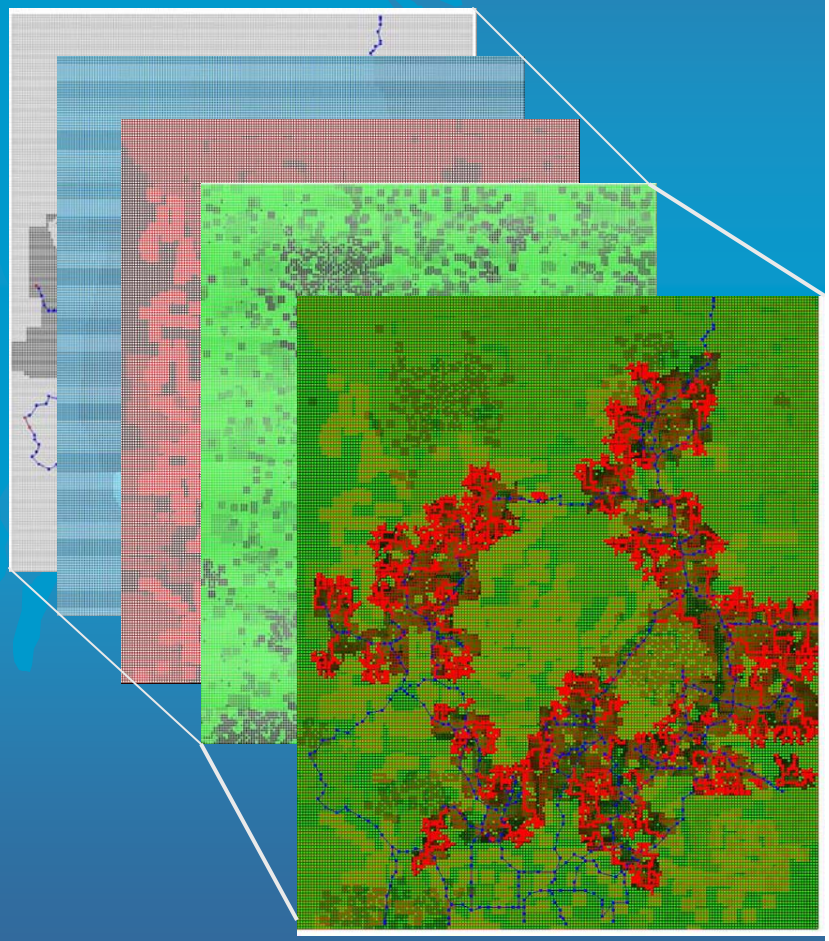
- Computational simulation of individual classes written in object-oriented programming.
- Model of complex systems of interactions between autonomous agents.
- Tracks system level dynamics emergent from autonomous individual actions.

Spatially Explicit Agent Based Models

Agents
- Importers
- Regulators
- Pests, etc.

Landscape
- Roads, cities, boundaries
- Natural features
- Native animal populations
- Locations of affected industries (ag, fisheries, etc.)

Dynamic
- Event sequencing
- Interaction rules
- Stochastic events



Agent Based Modeling

- U. of Alberta personnel working collaboratively with Berkeley researchers on analytical model design and Texas A&M researchers on spatial modeling of invasive damage on key crops.
- APHIS data will provide benchmark values to calibrate the port-specific and commodity/country of origin-specific parameters.

Policy Evaluation

- The ABM will evaluate and rank inspection and enforcement schemes for imports of a single commodity across different types of importers and ports-of-entry.