# Market-Based Control of Invasive Species: *B. tabaci* in Arizona

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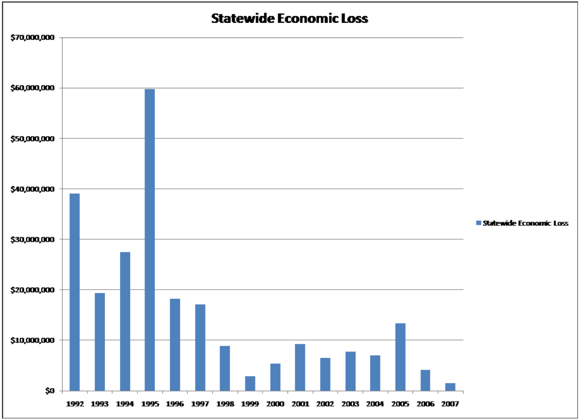
# Cost of Whitefly Infestation in Arizona




Source: ARS Estimates.

# Overview

- Research Problem
- Objectives
- Theory of Externality Regulation
- Economic Model
- Data Description
- Results and Discussion
- Conclusions and Implications

# Economic Cost of Invasive Insects

- Cost due to both control and yield loss
- 13% of crop production lost to insects in 2005
- 40% of insects are invasive
- $13.5 billion dollars
- Arizona Invasive Species Advisory Council (AISAC) est. by Gov. Napolitano
  - Loss only below $10.0 m annual due to lower cotton output
  - Important component of sustainability strategy
  - Economic imperative in Arizona to control whitefly

# An Infestation of B. tabaci...

# Whitefly Problem

- B-biotype vs Q-biotype
  - Multiphaguous
  - Adaptable to poor host conditions
  - Travels and breeds rapidly
  - Vector for many common plant viruses
  - Develops resistance quickly, increases egg production
- State initiative / budget problems
- Negative externality if not controlled privately
- Need for community-based regulation, or...
- Some system of taxes and / or permits
- How to design institutions / policies?

# Does the Market Fail?

- Two types of market failure:
  - Negative externality if not controlled privately
  - Weaker-link public good
- Need for community-based regulation, or...
- Some system of taxes and / or permits
- How to design institutions / policies?

# Objectives

- To determine which market-based control method is preferred for whitefly in Arizona

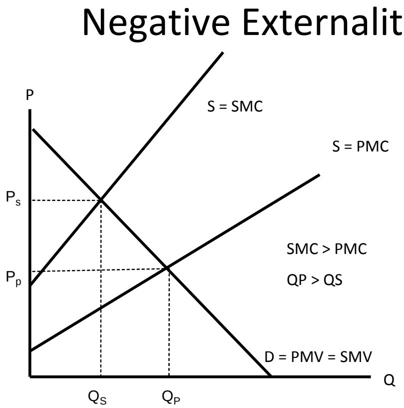
# Why Market-Based Solution?

1. Complexity of problem
2. Weaker-link public good nature of environment
3. Generate efficient outcome
4. Provide incentives to innovate

# Taxes versus Permits

- Taxes and Permits equivalent tools (Baumol and Oates, 1988)
- Weitzman (1974) shows taxes preferred under cost uncertainty
  - If MSB flat and MSC steep, then taxes preferred
  - If MSB steep and MSC flat, then permits preferred
- Taxes fix level of MSD, permits fix level of control
- Hoel and Karp (2001); Newell and Pizer (2003) in dynamic model
- Both prefer price-based regulation for pollution abatement (GHG)

# Static Analogy



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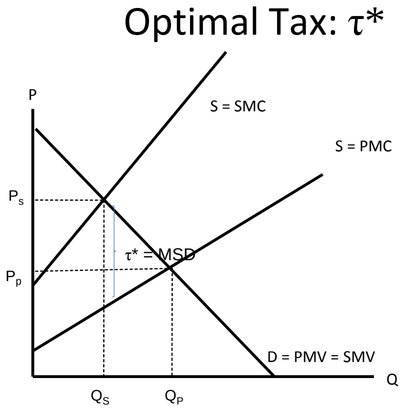
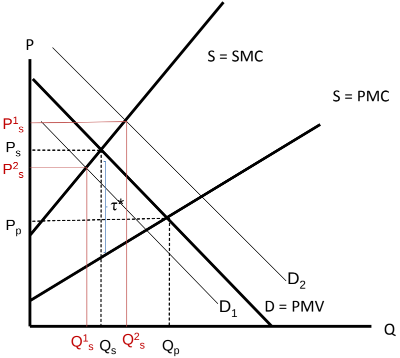


# Static Analogy

## Demand Uncertainty: Tax



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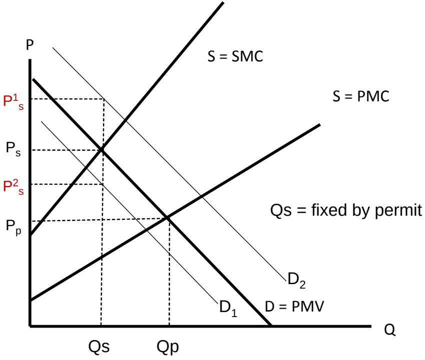
## Demand Uncertainty: Permits



# Spatial-Temporal Problem

- Invasive species case fundamentally different
- Uncertainty in arrival and dispersion
- Uncertainty on MSB side, not MSC
- Spatial movement adds dimension of uncertainty
- Hypothesis: quantity-based regulation preferred for invasive species

# Spatial Externality

- Each location represents one grower
- Each location provides host habitat
- Grower doesn’t take into account insects that migrate
- Migration raises costs for neighbors
- Total population growth faster with migration
- Weaker-link public good problem

# Social Planner's Objective

- Socially-optimal control:

$$V^s = \underset{x_{st}}{Max} \int_0^\infty e^{-\delta t} \sum_{s \in \theta} [(p_t - c_{st}) y(b_{st}) - D(ND_s(b_{1t}, b_{2t}, ..., b_{St})) - k(b_{st}, x_{st})] dt$$

- $p_t$ = cotton price,
- $c_{st}$ = marginal cost of production at location $s$, time $t$,
- $y_{st}$ = cotton yield,
- $b_{st}$ = insect population,
- $D()$ = external damage function,
- $k$ = control cost function,

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# Equations of Motion

- Subject to:

$$\frac{\partial b_{st}}{\partial t} = g_{st}(b_{st}) + ND_s(b_{1t}, b_{2t}, ..., b_{St}) - x_{st}$$

- $g_{st}$ = growth function:

$$g_{st}(b_{st}) = r_s b_{st}(1 - b_{st}/K_s),$$

- $ND_s$ = net dispersion function for location $s$,

$$ND_s(b_{1t}, b_{2t}, ..., b_{St}) = \sum_{j=1}^{S} d_{js} b_{jt},$$

- $d_{js}$ = net dispersion from $j$ to $s$,
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- Spatial-temporal model of Sanchirico and Wilen (2005, 2008)

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# Dispersion Coefficients

- Elements of dispersion matrix $(d_{sj})$ estimated with Fick's Law
- Fick's Law:

$$b_{st} = b_{s_0 t_0} \left( \frac{e^{-q^2/4Gt}}{2\sqrt{\pi G t}} \right)$$

- $G$ = dispersion rate,
- $q$ = Euclidean distance between locations,
- $b_{s_0 t_0}$ = starting value at location $s$ and time $t$
- Implies insects normally distributed at time $t$ and distance $q$
- Allow $d_{sj}$ to be random to reflect uncertainty in movement

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# Firm's Objective

- Privately-optimal control:

$$V^p = \underset{x_{st}}{Max} \int_0^{\infty} e^{-\delta t}[(p_t - c_{st})y(b_{st}) - k(b_{st}, x_{st})]dt$$

- Not additive over spatial locations
- Include elements that reflect policy tools:
  - Tax: $\tau_{st}(ND_s)$ = location-specific tax = MSB - MSC,
  - Permit Price: $\pi_{st}(ND_s)$ = solve for permit price with fixed $b_{st}$

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# Planner's Problem

- Population levels:

$$b^*_{st} = (K_s/r_s)(x_{st} - \sum_{j \neq s} d_{st} b_{jt} - d_{ss} - 1)$$

- Control level:

$$x^*_{st} = (1/k_{xb})(((p_t - c_{st})y_b - \sum_j D'(ND_{bj}) - k_b + k_x(r_s(1 - b_{st}/K_s - r_s(b_{st}/K_s) + \delta + \sum_j d_{sj}) + k_{xb}(r_s b_{st}(1 - b_{st}/K_s) + \sum_{j \neq s} d_{sj} b_{st})$$

- Multiplier:

$$\lambda^*_{st} = (1/\delta)(((p_t - c_{st})y_b - \sum_j D'(ND_{bj}) - k_b + k_x(g_b + ND_b + \delta) - \sum_{j \neq s} k_x d_{sj}$$

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# Net Benefits

- Follow Newell and Pizer (2003) in comparing tax / permit results
- Difference in expected net benefits:

$$\Delta_t = E[V^p_{t,tax}] - E[V^p_{t,permit}]$$

- Conduct Monte Carlo simulation over random $d_{sj}$ values
- Conduct sensitivity analysis with respect to:
  - $\partial y_{st}/\partial b_{st}$ = slope of MSB function,
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# Whitefly Spatial Data

- ARS-USDA insecticide trial data
- Brawley, CA experimental plot: 5 x 5 grid
- 13 weeks in 1994, 13 weeks in 1995
- Estimate elements of Fick's Law / Growth with MLE
- Solve for steady-state values of: $x_{st}$,$b_{st}$, $\lambda_{st}$ and $\pi_{st}$
- We use 3 x 3 sub-grid to simplify problem

# Social vs Private Solution

**Table 1. Base-Case Solution: Social and Private Optima**

| Social Optimal | | | | Private Optimal | | | |
|---|---|---|---|---|---|---|---|
| $x^s(1,1)$ | 4.000 | $b^s(1,1)$ | 6.687 | $x^p(1,1)$ | 4.960 | $b^p(1,1)$ | 10.095 |
| $x^s(1,2)$ | 3.876 | $b^s(1,2)$ | 6.366 | $x^p(1,2)$ | 4.800 | $b^p(1,2)$ | 9.759 |
| $x^s(1,3)$ | 3.420 | $b^s(1,3)$ | 5.814 | $x^p(1,3)$ | 4.240 | $b^p(1,3)$ | 8.900 |

- Results show steady-state solutions in social / private optimum
- Values below observed values
- Social lower than private

# Taxes versus Permits

**Table 2. Value of Net Benefit Under Taxes and Permits**

| | $V^p$ | $\sigma$ | Min | Max | t-ratio |
|---|---|---|---|---|---|
| Taxes | 742.38 | 89.45 | 636.30 | 964.96 | -16.351 |
| Permits | 1,524.90 | 478.57 | 794.36 | 2,304.00 | |

- Permits preferred to taxes in invasive species case
- Opposite to GHG regulation example of Newell and Pizer (2003)

# Comparative Dynamics

**Table 3. Effect of Slope of MSB on Taxes vs Permits**

| | Tax | | Permits | |
|---|---|---|---|---|
| $y_b$ | $V^p$ | $\sigma_{V^p}$ | $V^p$ | $\sigma_{V^p}$ |
| 2.500 | 527.06 | 55.64 | 1,532.20 | 573.42 |
| 3.500 | 634.58 | 71.42 | 1,533.60 | 531.17 |
| *4.656* | *742.38* | *89.45* | *1,524.90* | *478.57* |
| 5.500 | 809.53 | 102.53 | 1,510.70 | 440.18 |
| 6.500 | 876.01 | 118.06 | 1,483.80 | 396.41 |

- Steeper MSB favors taxes
- Opposite to emissions control example

# Comparative Dynamics

**Table 4. Effect of Slope of MSC on Taxes vs Permits**

| | Tax | | Permits | |
|---|---|---|---|---|
| $k_x$ | $V^p$ | $\sigma_{V^p}$ | $V^p$ | $\sigma_{V^p}$ |
| 0.050 | 553.00 | 71.67 | 913.49 | 280.58 |
| 0.075 | 636.20 | 79.92 | 1,151.30 | 358.27 |
| 0.*101* | *742.38* | *89.45* | *1,524.90* | *478.57* |
| 0.125 | 855.17 | 96.27 | 2,016.30 | 639.64 |
| 0.150 | 982.36 | 100.94 | 2,697.70 | 865.82 |

- Steeper MSC favors permits
- Again, opposite to emissions problem

# Conclusions

- Permits preferred to taxes for whitefly control in AZ
- Conditions opposite to emissions abatement case:
  - Steeper MSB favors taxes
  - Steeper MSC favors permits
- Opposite conditions from emissions case
- Possible to design quantity-based whitefly regulation
- Community-based initiatives consistent with model