Adverse Selection, Moral Hazard, and Grower Compliance with Bt Corn Refuge

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Overview of Presentation

- Motivate Bt Corn IRM Compliance Problem
- Describe Model Setup
- Develop principal-agent model to assess a fine program for Bt corn IRM compliance
- Endogenize technology fee (price of Bt corn), fine and audit rate
- Growers have private information for their Willingness to Pay (adverse selection) and Compliance Effort (moral hazard)
- Present empirical results

Background

- Bt Corn (maize) controls two major pests: European corn borer (ECB) and corn rootworm (CRW)
- Each estimated to cost about $1 billion annually in yield losses and control costs
- Bt corn: Maize engineered to contain DNA from bacterium *Bacillus thuringiensis* (Bt)
- Plant tissues express Bt toxin so that pests killed when eat/damage plants


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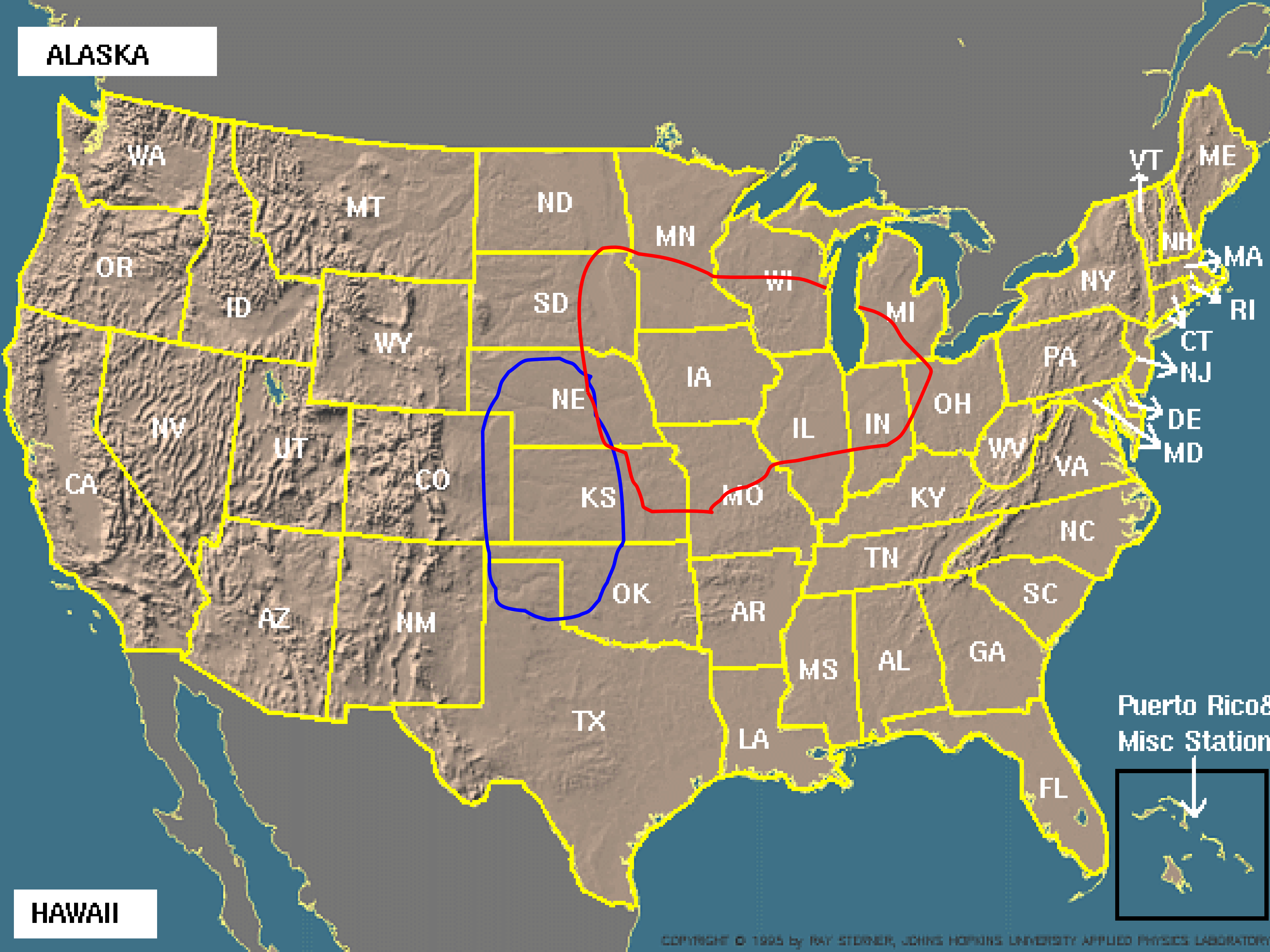
Background

- Bt corn for ECB available since 1995
- Several "events" registered (MON 810, Bt 11, DBT 418, Event 176, CBH 351)
- YieldGard Corn Borer (MON 810/Bt 11) most popular Bt corn available
- YieldGard Rootworm (MON 863) for corn rootworm available in 2003
- Both YieldGard events available alone or stacked in the same hybrid (+ RR/HT)
- More companies releasing CRW Bt corn

USDA-NASS Adoption Data

	IR 2005	IR 2006	Stack 2005	Stack 2006
IL	25	24	5	19
IN	11	13	4	12
IA	35	32	11	18
KS	23	23	10	12
MI	15	16	5	10
MN	33	28	11	16
MO	37	38	6	7
NE	39	37	12	15
ND	21	29	15	20
OH	9	8	2	5
SD	30	20	22	34
TX	21	27	9	13
WI	22	22	6	10
US	26	25	9	15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Bt Maize in EU

- Spain: 60,000 ha (12%) in 2004, dropped in 2005 (weather), up again in 2006
- France: 1000 ha in 2005, 5000 ha 2006; likely higher due to undocumented imports from Spain (SW France has ECB pressure)
- Portugal: 750 ha in 2005
- Czech Republic: 1500 ha in 2006
- Germany: trials since 2004, 1000 ha in 2006 for commercial use

Resistance Problem

- Pests can develop resistance to Bt, especially the more regularly and exclusively it is used
- Documented resistance to Bt in field and lab for different species
- No documented cases of field resistance to Bt corn or Bt cotton

Resistance Regulation

- Bt crops registered by EPA under FIFRA as Plant Incorporated Protectants (PIP's)
- Under FIFRA, EPA can only register PIP's, not enforce regulations, but can impose registration requirements on registrants
- EPA requires Insect Resistance Management (IRM) plan for registration and requires registrants to enforce IRM plan
- EPA has not made similar requirements for other pest control methods

High Dose/Refuge IRM Strategy

- Bt corn must express a high dose (25 X LC99)
- Plant non-Bt corn refuge to generate non-exposed adults to mate with the few resistant adults from the Bt corn (500:1), and so to dilute the resistance gene in next generation
- **Refuge size requirement**
  - 20% for most of the Corn Belt
  - 40% if spraying for other pests
  - 50% in southern corn-cotton counties
- **Refuge proximity requirement**
  - within ½ mile

Compliance Problem for IRM

- Farmers have little incentive to voluntarily manage resistance by planting refuge
  - Refuge decreases profit in short run
  - Pest susceptibility treated as a common property resource: ”Tragedy of the Commons”
- Compliance surveys find a variety of compliance levels among farmers

- Annual Industry (ABSTC) Survey of farmers with more than 200 acres corn
  - In 2003, 92% met size requirement and 93% met distance requirement
  - In 2000, 87% met size requirement and 82% met distance requirement
  - Not report % satisfying both requirements
- CSPI, via Freedom of Information Act, obtained USDA 2002 crop acreage data
  - Farmers report Acres of corn and Acres Bt
  - Only able to evaluate **<u>size</u>** requirement
  - Found substantially less compliance

	% of Farms Planting Bt Corn		% of Bt Corn Acres	
State	Non-complying	w/ 100% Bt	Non-complying	w/ 100% Bt
IL	14%	9%	15%	7%
IN	11%	10%	13%	12%
IA	18%	13%	24%	14%
KS	33%	24%	34%	20%
MI	46%	38%	47%	33%
MN	18%	13%	25%	15%
NE	22%	14%	27%	14%
OH	38%	37%	56%	54%
SD	33%	21%	35%	19%
WI	18%	16%	28%	21%
10 Sts	21%	15%	26%	15%

				% within		% all Bt farms	
Acres Bt	Farms	Non-comply	100% Bt	Non-comply	100% Bt	Non-comply	100% Bt
≥ 200	56,150	7,090	3,720	13%	7%	8%	4%
< 200	37,380	12,620	10,300	34%	28%	13%	11%
All	93,530	19,710	14,020	21%	15%	21%	15%

				% within		% all Bt acres	
Acres Bt	Acres	Non-comply	100% Bt	Non-comply	100% Bt	Non-comply	100% Bt
≥ 200	14.15	3.36	1.81	24%	13%	21%	11%
< 200	2.01	0.85	0.66	42%	33%	5%	4%
All	16.15	4.21	2.47	26%	15%	26%	15%

Small farmers more likely violate size requirement

Large farmers have most non-complying acres (and more likely violate distance requirement)

- EPA (via FIFRA) required registrants to develop more aggressive compliance program in Dec. 2002, months before CSPI published its analysis
- Compliance Assurance Program
  - Randomly audit farmers for compliance
  - Non-complying farmers receive extra education and are guaranteed a compliance audit the next year
  - If farmer caught non-complying twice, banned from buying Bt
- Is the punishment is enforceable?
  - Registrants have licensed many seed companies
- Is the ban is an effective deterrent?
- **We examine a Fine Program as alternative**

Pertinence to EU

- Reducing genetic contamination of non-GMO crops the issue in EU, not IRM
- Coexistence requirements include a buffer strip planted around Bt maize
- This buffer also serves as a refuge to slow the development of resistance
- What are the incentive issues for EU growers of Bt maize and coexistence requirements?

Fine Program Overview

- Growers register when they buy Bt corn, just as with current Grower Agreements
- Growers audited with probability α
- If audited and not complying (cheating on refuge requirement), grower pays the fine F (\$/ac)
- A non-complying grower pays the fine F with probability α and nothing with probability $(1 - \alpha)$
- Company chooses Bt corn technology fee T (price), the audit probability α, and the fine F

Timeline of Events

1. Company announces Bt corn price *T*, audit probability α, and fine *F*
2. Grower decides whether to buy Bt corn or conventional corn
3. Company audits those who buy Bt corn and imposes fines on growers not complying with refuge requirement

Model Overview

1. Define grower returns and then formulate participation and incentive compatibility constraints
2. Reformulate and describe constraints (Proposition 1 and 2 and Corollaries)
3. Formulate and describe company’s (principal’s) optimization problem
4. Note special case (Proposition 3)
5. Empirical Analysis

Model Setup

Grower returns ($/ac) for conventional corn

$$\pi_{CV} = py - K$$

p	non-random price of corn
y	random potential (pest free) yield
K	non-random production cost

Model Setup

Grower returns for planting all Bt corn

$$\pi_{bt} = py(1 + \lambda) - K$$

λ random yield gain for Bt corn

Grower returns with the Tech Fee T ($/ac)

$$= \pi_{bt} - T$$

Model Setup

Returns for a complying grower who plants required refuge ϕ_r

$$\pi_{cp} = \phi_r \pi_{cv} + (1 - \phi_r)\pi_{bt}$$

with the Tech Fee T

$$= \pi_{cp} - (1 - \phi_r)T$$

Model Setup

Grower's maximum per acre willingness to pay W (\$/ac) for Bt corn is private/hidden information

$$E[U(\pi_{cp} - W)] = E[U(\pi_{cv})]$$

Hidden information concerning W creates adverse selection when choosing T

Participation Constraint

$$E[U(\pi_{cp} - W)] \geq E[U(\pi_{cv})]$$

$$W \geq (1 - \phi_r)T$$

Buy Bt corn if WTP ≥ price

Model Setup

Hidden information concerning compliance effort (% refuge) creates moral hazard

Company uses the fine program to solve

Incentive Compatibility Constraint

$$E[U(\pi_{comply})] \geq E[U(\pi_{cheat})]$$

$$E[U(\pi_{cp} - (1-\phi_r)T)] \geq (1-\alpha)E[U(\pi_{Bt} - T)] + \alpha E[U(\pi_{Bt} - T - F)]$$

Propositions 1 and 2

If utility is continuous and strictly increases in income,

- The ICC can be expressed as $W \geq Z(\alpha, F, T)$, where $Z(\cdot)$ is a function depending on grower utility
- Distribution $G(W)$ "common knowledge"
- Using $G(W)$, the cdf of W, the constraints can be expressed as probabilities
- Probability of participation: $\beta = 1 - G((1 - \phi_r)T)$
- Probability of compliance: $\nu = 1 - G(Z(\alpha, F, T))$

Propositions 1 and 2

- Participation (Rationality) constraint

  $W \geq (1 - \phi_r)T \;\rightarrow\; \beta = 1 - G((1 - \phi_r)T)$

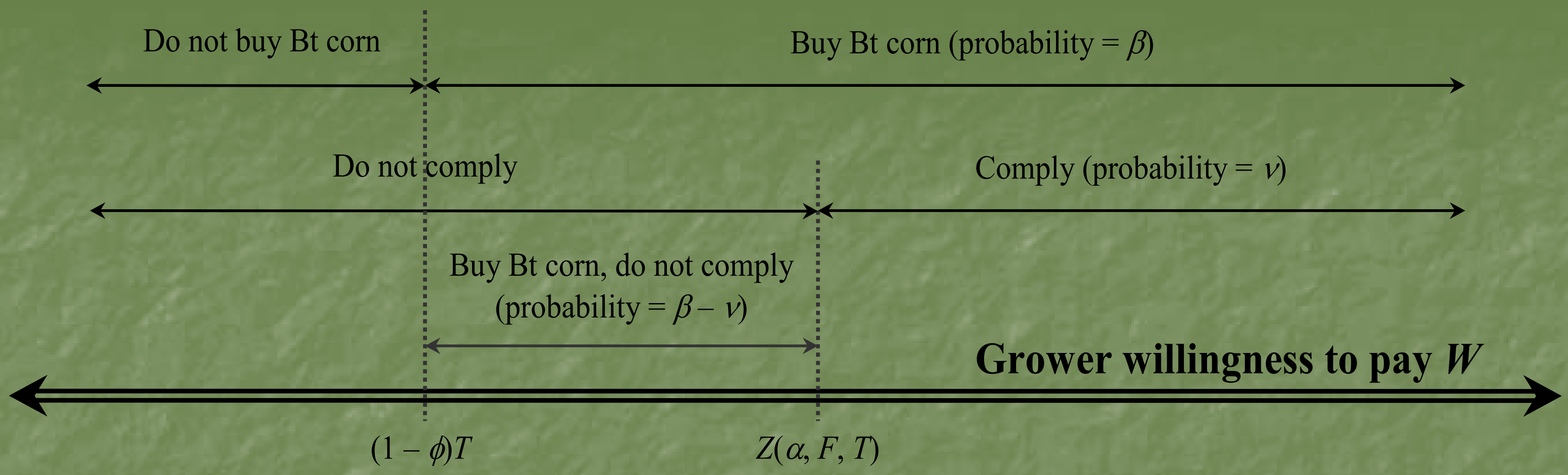
- Incentive compatibility constraint

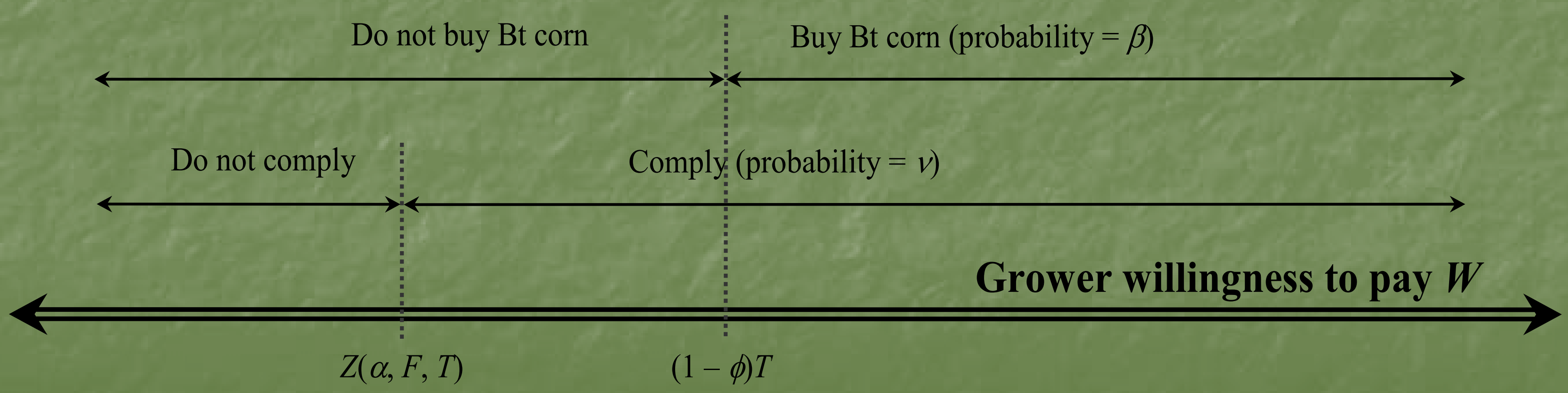
  $W \geq Z(\alpha,F,T) \rightarrow\; \nu = 1 - G(Z(\alpha,F,T))$

- Both put lower bound on W and which one binds implies different grower behavior

  $(1 - \phi_r)T < Z(\alpha,F,T) \rightarrow \beta > \nu$ (some buyers cheat)

  $(1 - \phi_r)T \,\varepsilon\square\, Z(\alpha,F,T) \rightarrow \nu \,\varepsilon\square\, \beta$ (all buyers comply)


Do not buy Bt corn
Buy Bt corn (probability = β)
Do not comply
Comply (probability = ν)
Buy Bt corn, do not comply
(probability = β – ν)
Grower willingness to pay W
(1 – ϕ)T
Z(α, F, T)


Do not buy Bt corn
Buy Bt corn (probability = β)
Do not comply
Comply (probability = ν)
Grower willingness to pay W
Z(α, F, T)
(1 – ϕ)T

Corollary 0

Probability of participation

$$\beta = 1 - G((1 - \phi_r)T)$$

- Decreases in technology fee T
  (i.e., downward sloping demand curve)
- Independent of fine F and audit probability α

Proposition 2/Corollary 1

Probability of compliance $\nu = 1 - G(Z(\alpha, F, T))$

- Non-decreasing in the audit probability α
- Non-decreasing in the fine F
- Non-decreasing (non-increasing) in technology fee T if

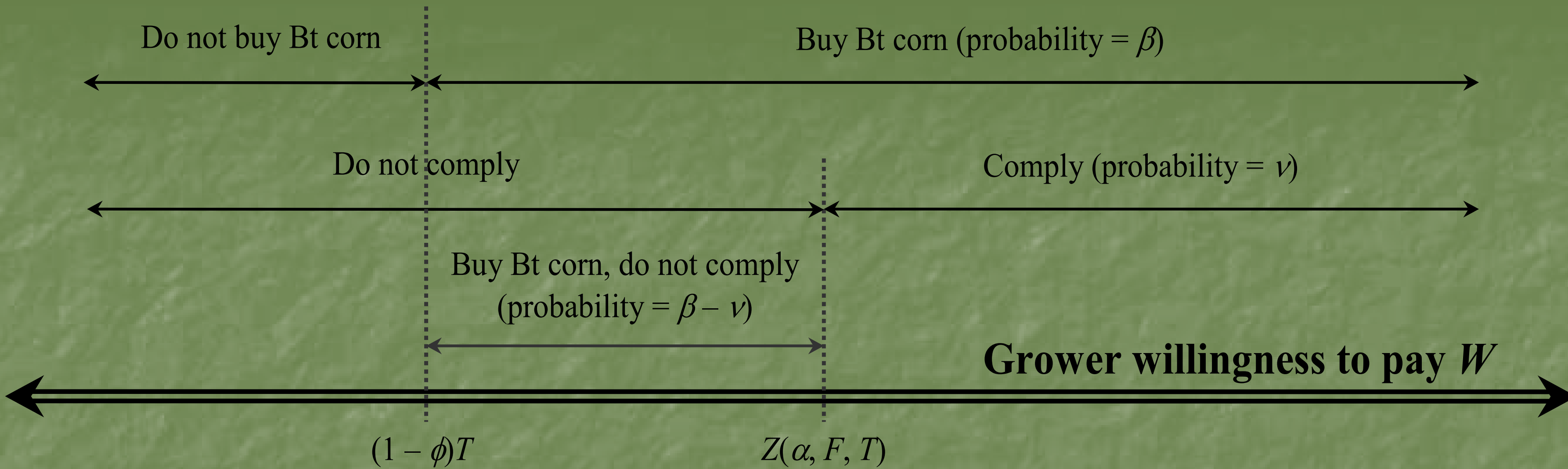
$$(1-\alpha)E[U'(\pi_{Bt} - T) + \alpha E[U'(\pi_{Bt} - T - F)]$$

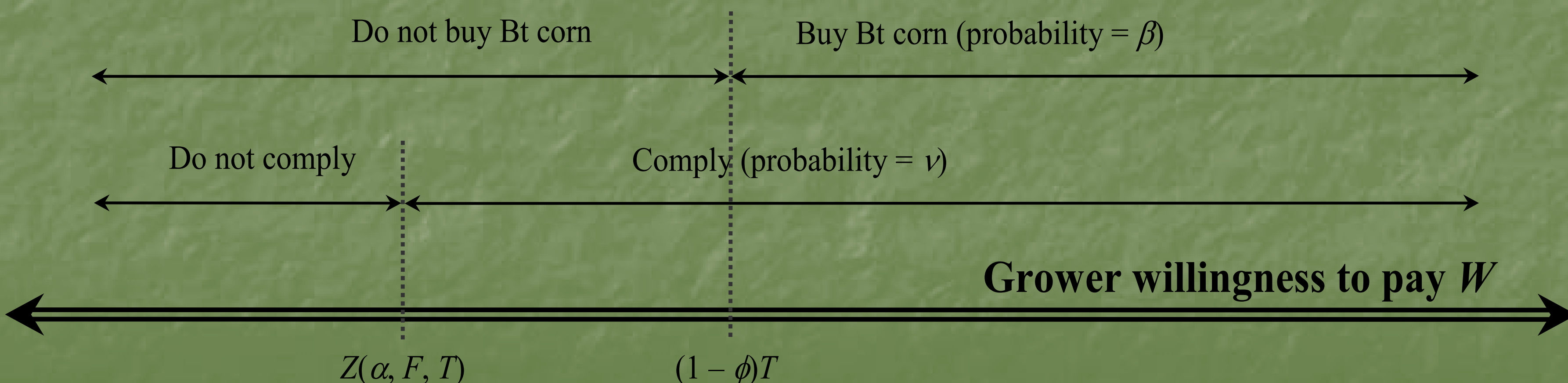
$$-(1-\phi_r)E[U'(\pi_{Bt} - (1-\phi_r)T - \phi_r(py\lambda)] > (<) 0$$

- Note: risk neutral or CARA utility $\rightarrow d\nu/dT \geq 0$

Company Problem

- Choose audit probability α, fine F, and technology fee T to maximize expected net revenue, subject to the participation and incentive compatibility constraints
- Company endogenizes both purchase and compliance probabilities
  - Pr[buy] = $\beta = 1 - G((1 - \phi_r)T)$
  - Pr[comply] = $\nu = 1 - G(Z(\alpha,F,T))$
- Which binds? $(1 - \phi_r)T <(>) Z(\alpha,F,T)$
- Creates two different functions


Do not buy Bt corn
Buy Bt corn (probability = β)
Do not comply
Comply (probability = ν)
Buy Bt corn, do not comply
(probability = $\beta - \nu$)
Grower willingness to pay W
$(1-\phi)T$
$Z(\alpha, F, T)$


Do not buy Bt corn
Buy Bt corn (probability = β)
Do not comply
Comply (probability = ν)
Grower willingness to pay W
$Z(\alpha, F, T)$
$(1-\phi)T$

Company Problem

- Company returns are sum of net revenue from sales and fine collection
- If $(1-\phi_r)T < Z(\alpha, F, T)$, $\beta > v$

$$\max_{\alpha, F, T} \; (\beta - v\phi_r)(T-c) + (\beta - v)\alpha F - \beta k(\alpha)$$

- Expected net sales revenue $(\beta - v\phi_r)(T-c)$
- Expected fine revenue $(\beta - v)\alpha F$
- Expected monitoring cost $\beta k(\alpha)$

Company Problem

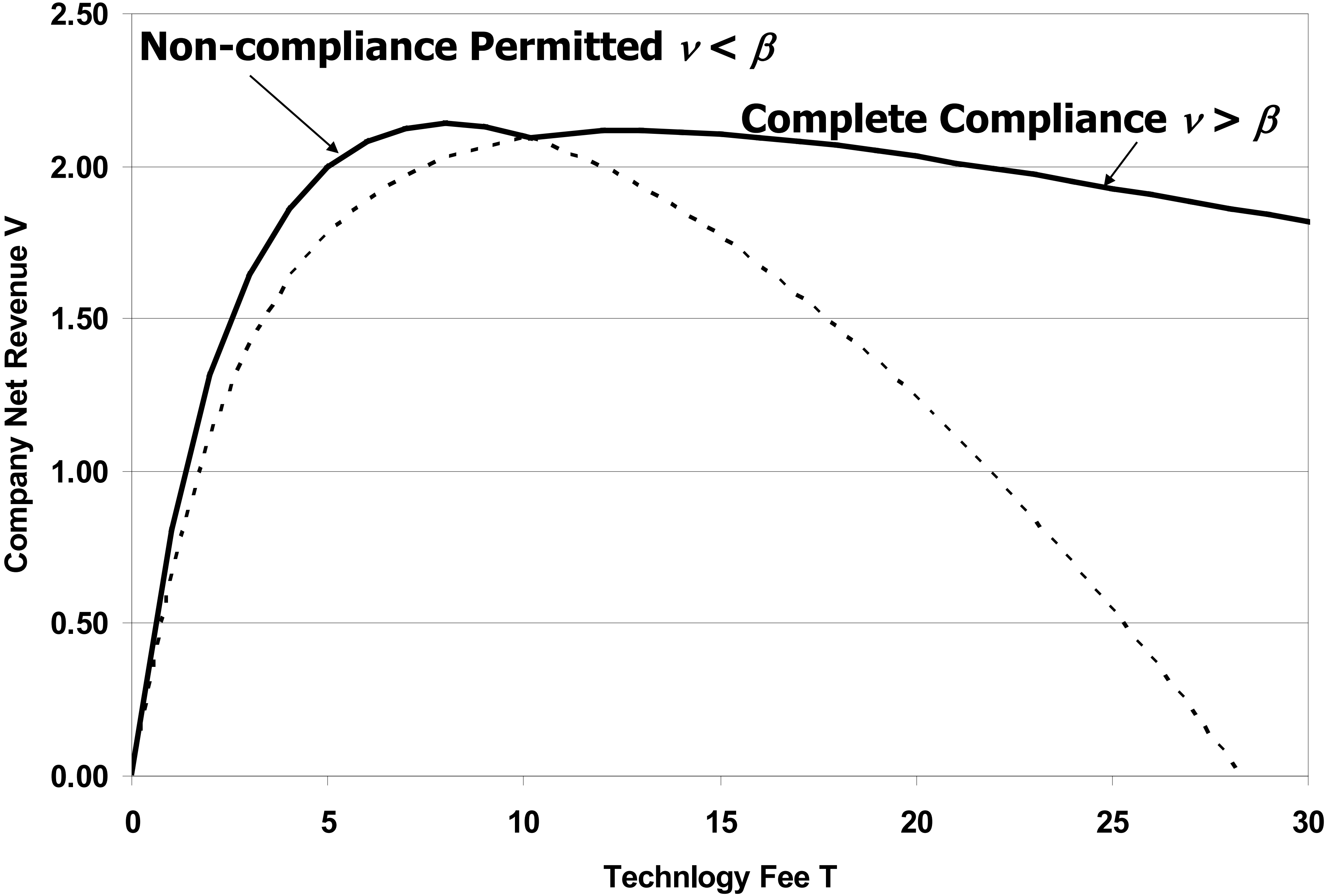
- If $(1 - \phi_r)T > Z(\alpha, F, T)$, $\beta > \nu$
- All growers who buy comply, so $\nu = \beta$

$$\max_{\alpha, F, T} \beta(1 - \phi_r)(T - c) - \beta k(\alpha)$$

- Expected net sales revenue $\beta(1 - \phi_r)(T - c)$
- Expected fine revenue = 0
- Still have to monitor and threaten fine for incentive compatibility, but $k'(\alpha)$ defines α^* then set F so that $(1 - \phi_r)T > Z(\alpha, F, T)$ holds

Optimization

- The company/principal maximizes the upper envelope of the two functions
- Various relationships possible depending on the parameters c, $G(\cdot)$, λ, $U(\cdot)$, ϕ_n, etc.
- Both functions concave, so separately maximize each and compare solutions



Non-compliance Permitted $\nu < \beta$
Complete Compliance $\nu > \beta$
Company Net Revenue V
Technlogy Fee T
0.00
0.50
1.00
1.50
2.00
2.50
0
5
10
15
20
25
30

Proposition 3

If growers are risk neutral, the optimization problem separates

- $k'(\alpha) = 0$ defines the optimal audit rate $\alpha*$, regardless of $G(W)$, the distribution of grower willingness to pay
- The principal's objective need only be optimized with respect to F and T, treating α as a parameter defined by $k'(\alpha) = 0$

Model Summary

- Conceptually, a solution (α, F, T) exists for the company's optimization problem
- Analytically tractable solutions exist with uniform $G(W)$ and risk neutral grower
- Special cases (risk neutral or CARA utility) imply simpler optimization problem
- More realistic distributions for W require numerical methods to find solution

Empirical Analysis

- Parameterize the model for Rock County Wisconsin and corn rootworm Bt corn
- Prime Wisconsin corn-soybean area with new invasion of rotation resistant western corn rootworm and new Bt corn available
- Grower survey data (Langrock and Hurley) for similar Minnesota location

Grower Returns

- $\pi_{cv} = py - K$
  - p = \$2.25/bu, K = \$200/ac
  - y random: beta distribution, mean = 150 bu/ac, CV = 30%, min = 0, max = 240
- $\pi_{bt} = py(1 + \lambda) - K$
  - λ random: beta distribution, mean 3%, 5%, 7%, CV = 100%, min 0, max 1
  - y and λ independent

Grower Preferences

- CARA Utility: $U(\pi) = 1 - \exp(-R\pi)$
  - $R = 0.005174$ so risk premium 25% of $E[\pi]$
- Effort = proportion of refuge planted
  - Comply $\phi = \phi_r$ or Not Comply $\phi = 0$
- Grower willingness to pay pdf $G(W)$
  - Based on survey of Langrock and Hurley
  - $G(W)$ = lognormal, mean = \$8.59/ac, standard deviation = \$20.60/ac

Company Returns

- Marginal cost of Bt corn vs conventional corn $c = 0, 3, 6$
- Define $k(\alpha)$ so $k'(\alpha) = 0$ defines reasonable α^*, since this defines optimal α^* if $\beta > \nu$ or if risk neutral grower
- Calibrate with hybrid seed corn certification

1. $k(\alpha)$ so $k'(\alpha) = 0$ defines $\alpha = 0.04$
2. Average cost = \$1.20/ac at $\alpha = 0.04$
3. 25% cost increase if audit rate doubles

- $k(\alpha) = 1.5 - 15\alpha + 187.5\alpha^2$

No Compliance Program

	$E[\lambda]$	c	T	α	F	β	ν	cheat	V
Risk Neutral	3%	0	8.05	--	--	31.5%	24.6%	22.0%	2.14
		3	19.70	--	--	12.9%	12.9%	0.0%	1.73
	5%	0	9.60	--	--	27.1%	13.7%	49.6%	2.34
		3	14.06	--	--	18.8%	14.7%	22.0%	1.75
	7%	0	10.53	--	--	24.9%	8.7%	65.0%	2.44
		3	15.58	--	--	16.9%	9.3%	44.9%	1.89
		6	19.73	--	--	12.9%	9.8%	24.2%	1.50
Risk Averse	3%	0	12.82	--	--	20.6%	20.6%	0.0%	2.12
		3	19.70	--	--	12.9%	12.9%	0.0%	1.73
	5%	0	8.92	--	--	28.9%	18.0%	37.8%	2.26
		3	19.70	--	--	12.9%	12.9%	0.0%	1.73
	7%	0	9.87	--	--	26.4%	12.1%	54.1%	2.37
		3	14.49	--	--	18.2%	13.0%	28.6%	1.79
		6	26.02	--	--	9.2%	9.2%	0.0%	1.47

Results with No Program

- Current tech fee about \$20/ac, which consistent for T^* with c = \$3-\$6/ac
- "Peak Switching" occurs
  - In some cases, no cheating occurs
  - In some cases, cheating ranges 22%-65%
- Risk aversion can cause peak switching, (increases T^*), else decreases T^*
- Risk aversion reduces cheating and company returns
- Marginal cost c and expected loss E[λ] increase T^*

Fine revenue capped at monitoring cost

	E[λ]	c	T	α	F	β	ν	cheat	V
Risk Neutral	3%	0	16.36	4.0%	--	16.0%	16.0%	0.0%	1.90
		3	22.91	4.0%	--	10.8%	10.8%	0.0%	1.59
	5%	0	16.36	4.0%	--	16.0%	16.0%	0.0%	1.90
		3	22.91	4.0%	--	10.8%	10.8%	0.0%	1.59
	7%	0	16.36	4.0%	--	16.0%	16.0%	0.0%	1.90
		3	22.91	4.0%	--	10.8%	10.8%	0.0%	1.59
		6	29.04	4.0%	--	7.9%	7.9%	0.0%	1.36
Risk Averse	3%	0	16.36	4.0%	--	16.0%	16.0%	0.0%	1.90
		3	22.91	4.0%	--	10.8%	10.8%	0.0%	1.59
	5%	0	5.85	4.8%	62.18	40.1%	23.8%	40.6%	2.07
		3	22.91	4.0%	--	10.8%	10.8%	0.0%	1.59
	7%	0	8.79	4.7%	51.91	29.3%	14.8%	49.6%	2.31
		3	10.01	5.0%	67.14	26.1%	16.6%	36.3%	1.60
		6	29.04	4.0%	--	7.9%	7.9%	0.0%	1.36

Results with fine revenue cap

- Optimal audit rate α* gravitates to 4% to minimize monitoring costs
- Cap generally causes a "peak shift" to complete compliance with higher tech fees and lower participation
- Eliminates non-compliance, but reduces company revenue and grower use of technology
- Exceptions: low tech fee (high β) and fine $F*$ of \$50-\$70/ac, with lots of cheating (36%-50%)

No fine revenue cap

	$E[\lambda]$	c	T	α	F	β	ν	cheat	V
Risk Neutral	3%	0	16.36	4.0%	0	16.0%	16.0%	0.0%	1.90
		3	22.91	4.0%	0	10.8%	10.8%	0.0%	1.59
	5%	0	0.10	4.0%	293.84	99.6%	37.3%	62.6%	6.22
		3	0.14	4.0%	296.43	99.3%	37.9%	61.8%	3.46
		0	0.07	4.0%	431.05	99.8%	31.4%	68.6%	10.67
	7%	3	0.07	4.0%	433.74	99.8%	31.8%	68.1%	9.36
		6	0.10	4.0%	436.10	99.6%	32.2%	67.7%	5.07
Risk Averse	3%	0	16.36	4.0%	0	16.0%	16.0%	0.0%	1.90
		3	22.91	4.0%	0	10.8%	10.8%	0.0%	1.59
	5%	0	0.25	7.2%	93.94	97.9%	38.6%	60.6%	2.88
		3	22.91	4.0%	0	10.8%	10.8%	0.0%	1.59
		0	0.14	8.7%	109.41	99.3%	32.6%	67.2%	4.87
	7%	3	0.30	8.6%	110.69	97.1%	32.9%	66.1%	2.12
		6	29.04	4.0%	0	7.9%	7.9%	0.0%	1.36

Results with no fine revenue cap

- Two regimes are optimal depending on parameters
- Higher tech fee with complete compliance
  - Eliminates non-compliance, but reduces company revenue and grower access to Bt
- Very low tech fee with cheating 60%-70%
  - Give Bt away so 100% adoption
  - Become fine collection company with much higher returns: high fines with lots of cheating

Discussion/Summary of Empirics

- Inspection-Fine program may work if Compliance Assurance Program not sufficient
- Must impose cap on company fine revenue, otherwise create perverse incentives
- Current Compliance Assurance Program similar to capped fine revenue case
  - Company monitors, but collects no fines
  - Tech fee increased, 100% compliance, lower adoption/participation
- Before imposing Inspection-Fine, let's see how Compliance Assurance Program performs

What's Next?

- Welfare analysis
  - Monopoly and IRM restrict supply, implying welfare loss
  - Cheating offsets these welfare losses
  - To identify social optimum, must determine social gain from preserving pest susceptibility
- Unify grower willingness to pay and utility
  - Joint distribution $G(W,R)$ implies $U(\pi|R)$
  - Estimate with same survey in manner akin to Love and Bucola 1991; Saha et al. 1994