Hierarchical Modeling and the Economics of Risk in IPM

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Goal Today

- Explain hierarchical modeling for economic analysis of pest-crop systems and IPM
- Overview how economists represent and compare risky systems and identify the preferred system

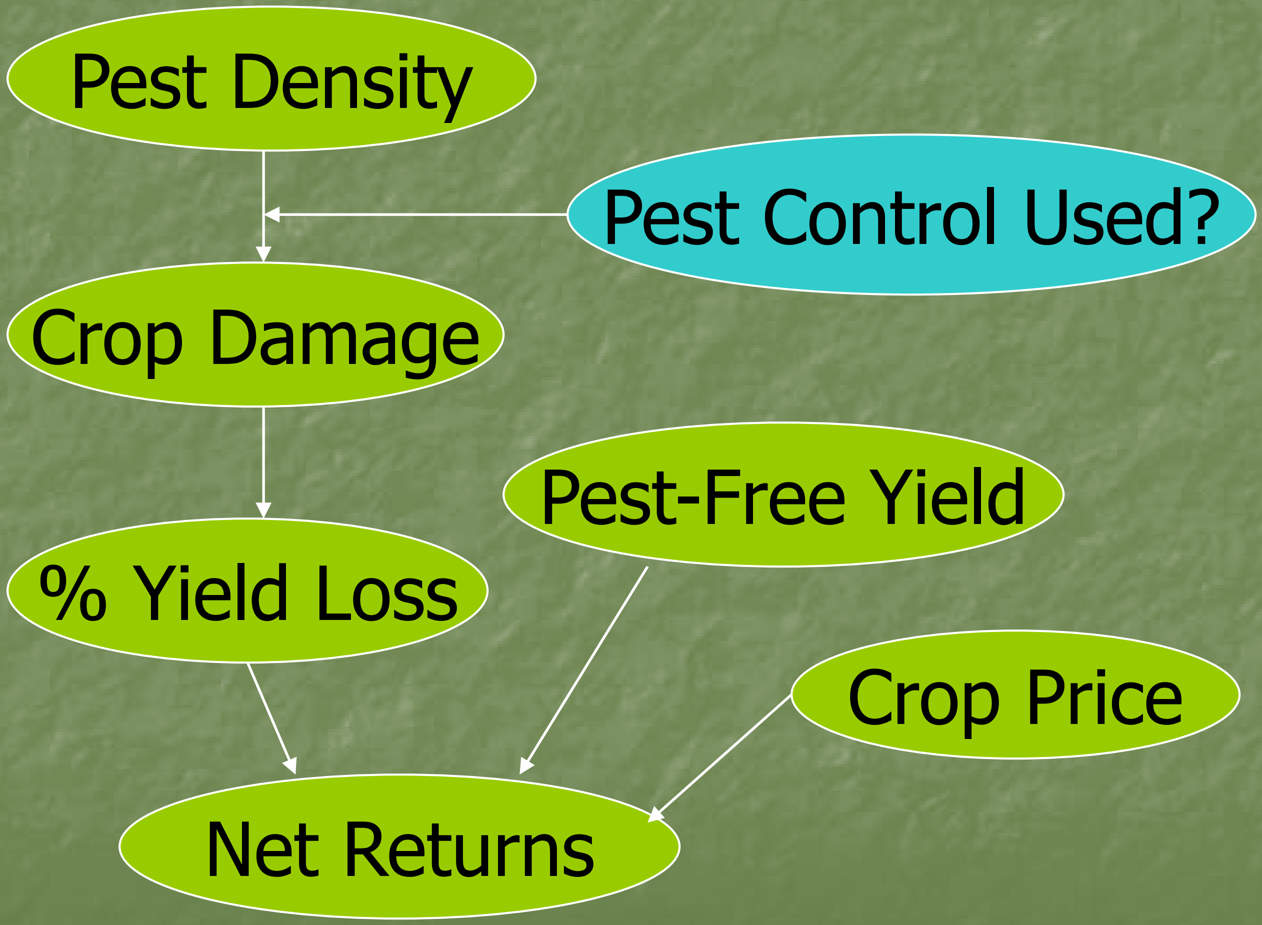
Hierarchical Modeling

- Purpose: To model the natural variability of the insect-crop system analyzing it
- Insect-crop system is highly variable
  - Pest population density, crop injury/damage for given pest density, crop loss for given injury/damage, control for given pest density
- Missing a key component of system if economic analysis ignores this variability

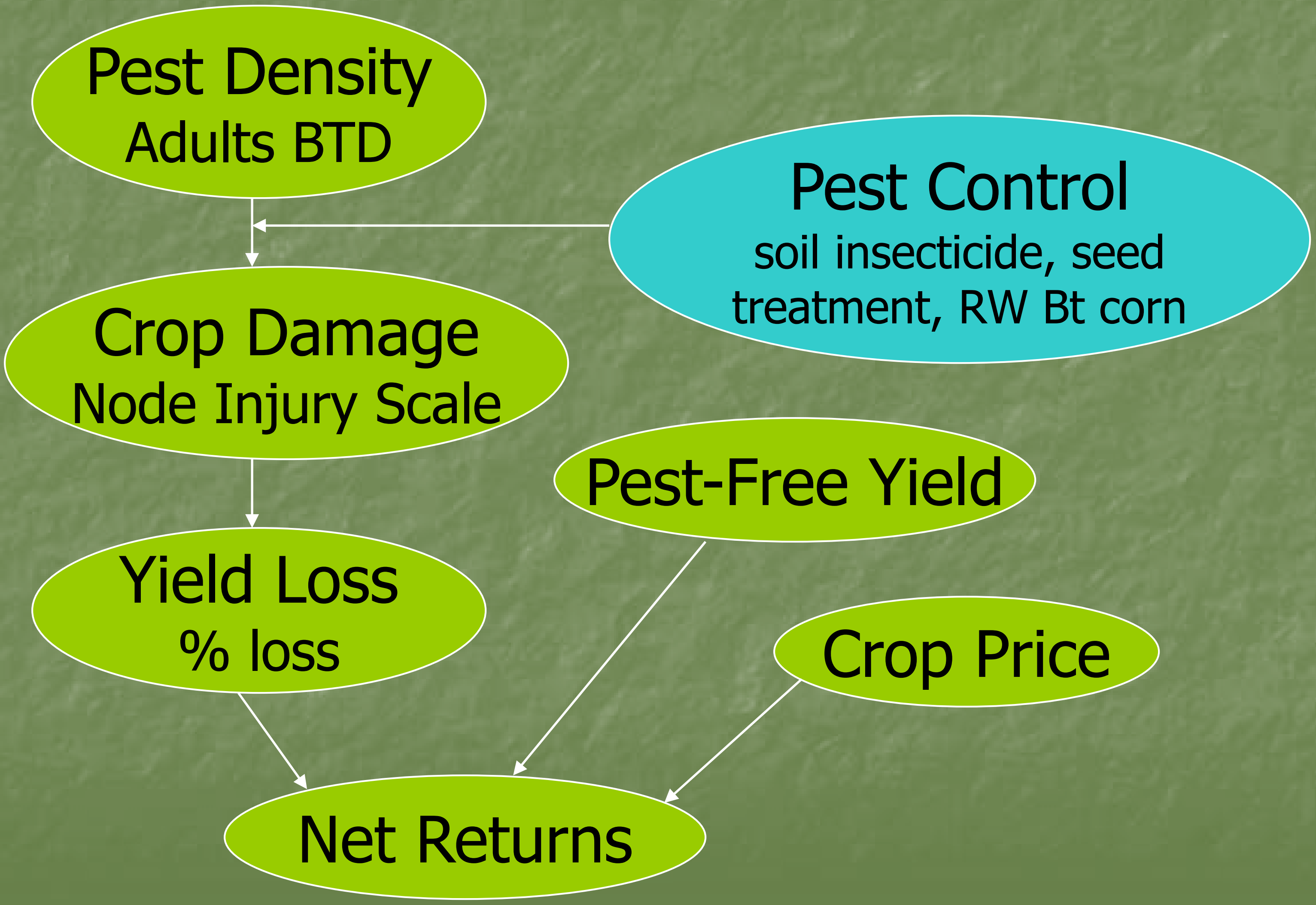
Hierarchical Modeling

- Treat variables as random and use linked conditional probability distributions
- pdf of a variable has parameters that depend (are conditional) on variables from another pdf, which has parameters that are conditional on variables from another pdf, … … …
- Final result: pdf for economic value that has much/most of the system's natural variability
- Key is having right the data to estimate the conditional probability distributions

Stylized Example



Corn Rootworm in Corn



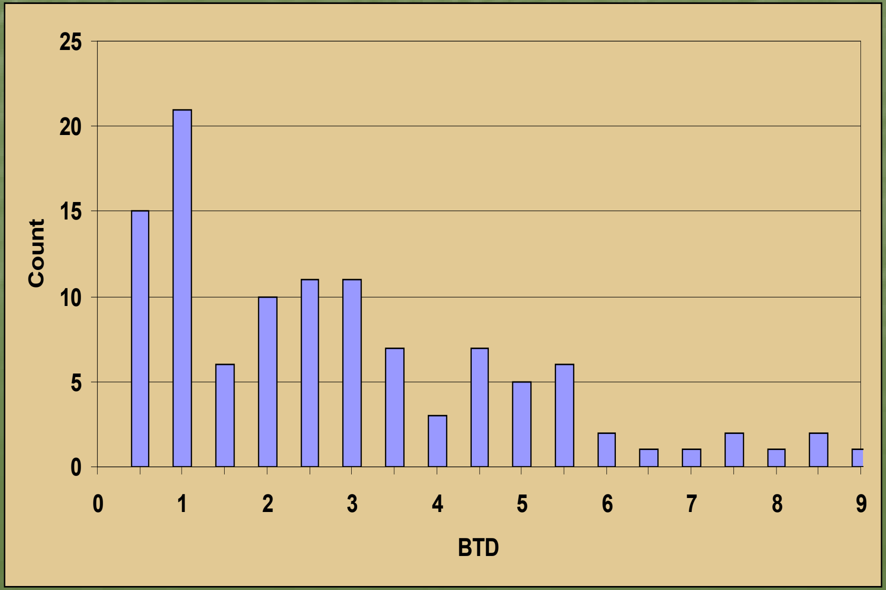
Pest Density: Adult beetles/trap/day

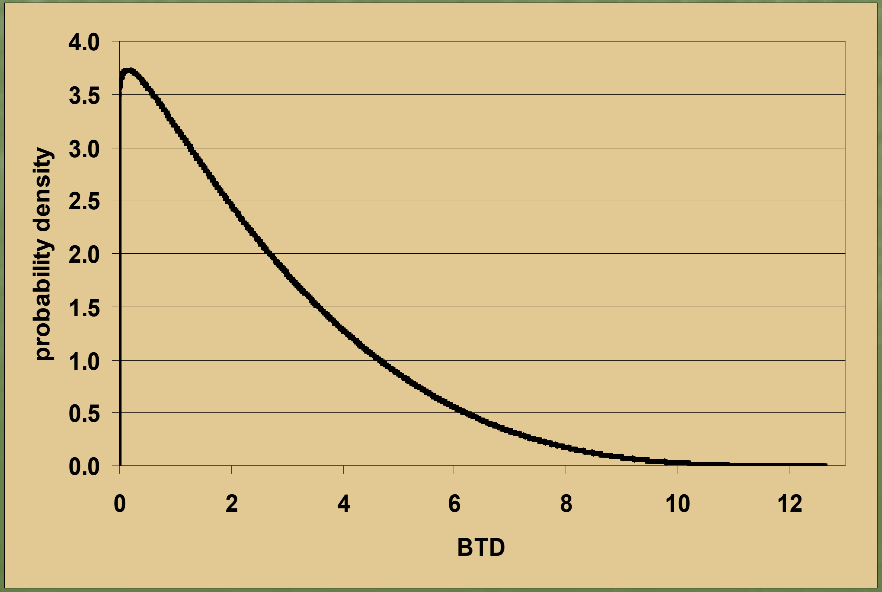
- Unconditional beta distribution
- Eileen Cullen's data from the Soybean Trapping Network in southern WI, 2003-2007

Year	N obs	Mean	St Dev	CV
2003	34	2.69	2.09	77.6%
2004	28	2.62	2.60	99.1%
2005	31	2.42	1.96	81.1%
2006	19	2.68	1.66	62.2%
2007	10	1.10	0.53	47.9%
All	122	2.47	2.06	83.5%

Pest Density: Adult beetles/trap/day

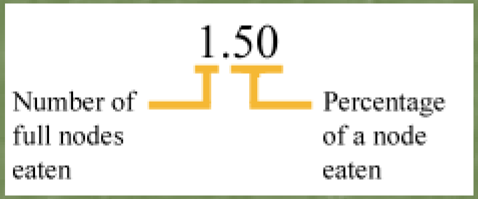
Parm	Estimate	Error	t-stat	P-value
mean	2.48	0.18	13.64	0.000
st dev	2.00	0.15	13.67	0.000
max	12.64	4.76	2.66	0.008





Crop Damage: Node Injury Scale

- Oleson et al. 2005. JEE 98(1):1-8
- Quantifies feeding damage on corn roots by corn rootworm larvae



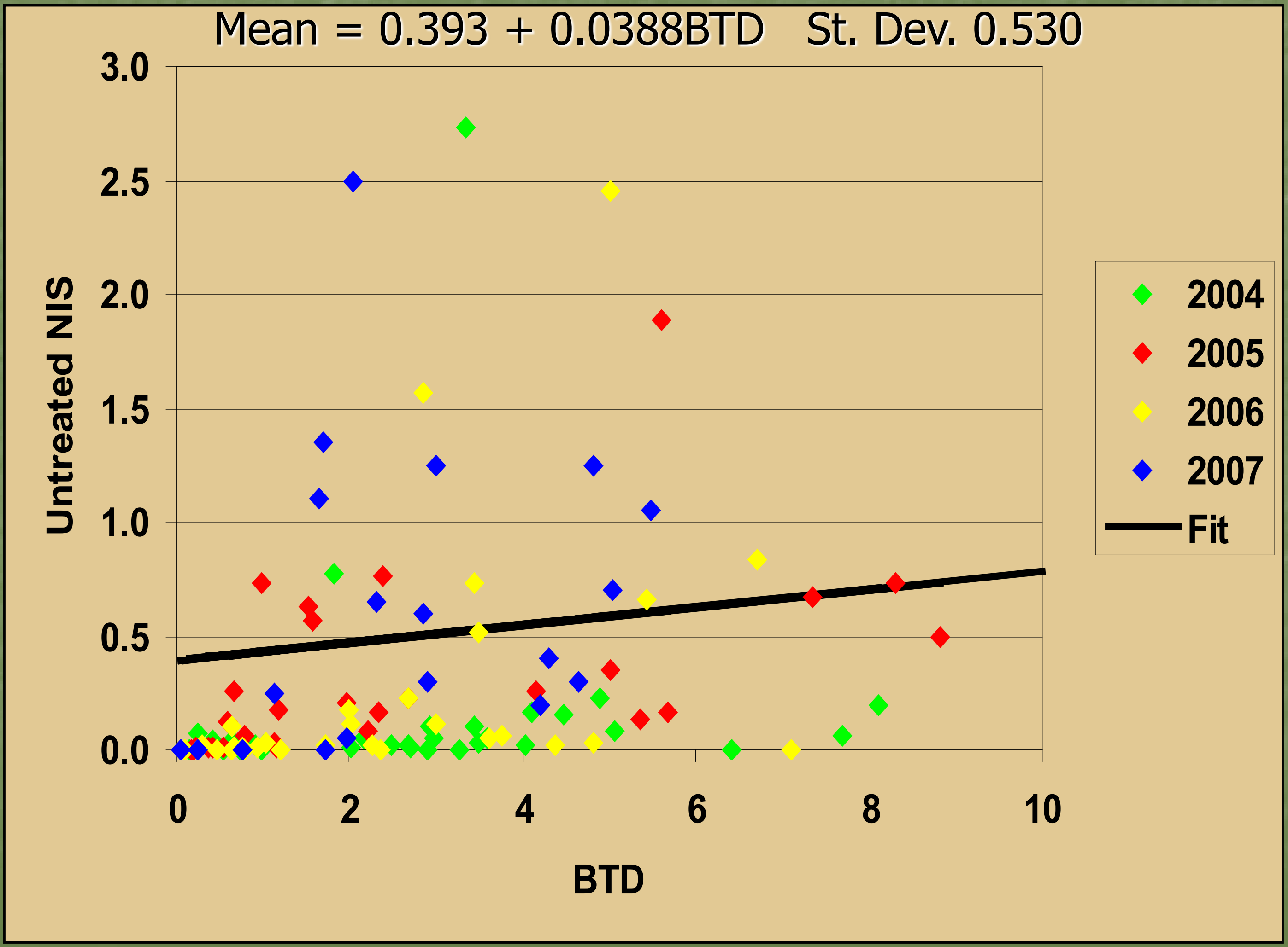
http://www.ent.iastate.edu/pest/rootworm/nodeinjury/nodeinjury.html

NIS	Description
0.0	No feeding damage (lowest score)
1.0	One node (circle of roots) or equivalent of an entire node eaten back to within approximately 1½ inches of stalk (soil line on 7th node)
2.0	Two complete nodes eaten
3.0	Three or more nodes eaten (highest score)

Crop Damage: Node Injury Scale

- Untreated NIS (NIS_0) conditional on previous summer's BTD
- Eileen Cullen's data from the Soybean Trapping Network (2003-2007)
- Conditional beta pdf estimated
  - Min 0 and max 3 set, then MLE conditional mean = $A_0 + A_1$BTD and constant st dev
  - A_0 = base level of damage even if observe BTD = 0

Untreated NIS Conditional on BTD



Correlation

2004: 0.102

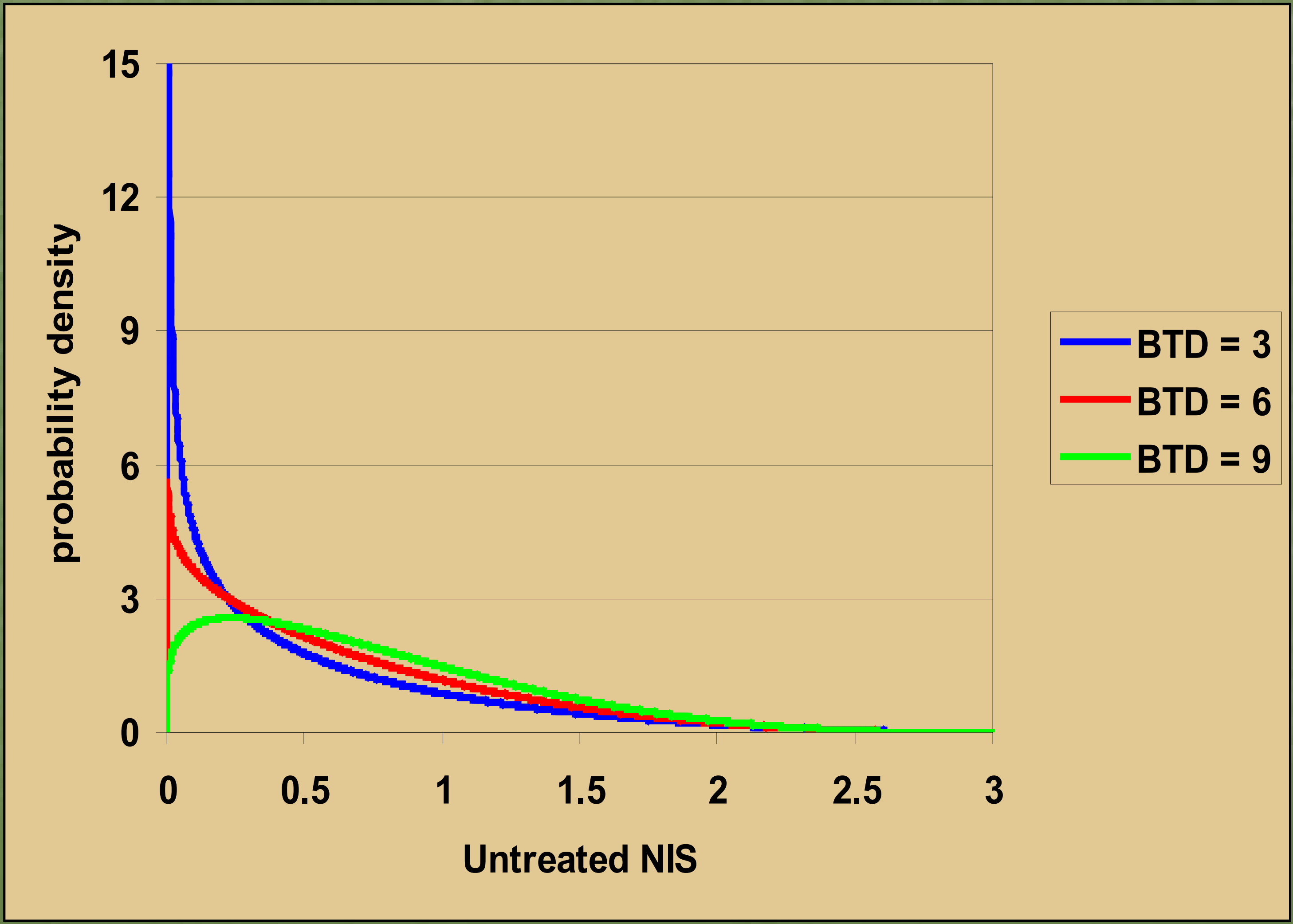
2005: 0.496

2006: 0.440

2007: 0.241

All: 0.292

Untreated NIS Conditional on BTD

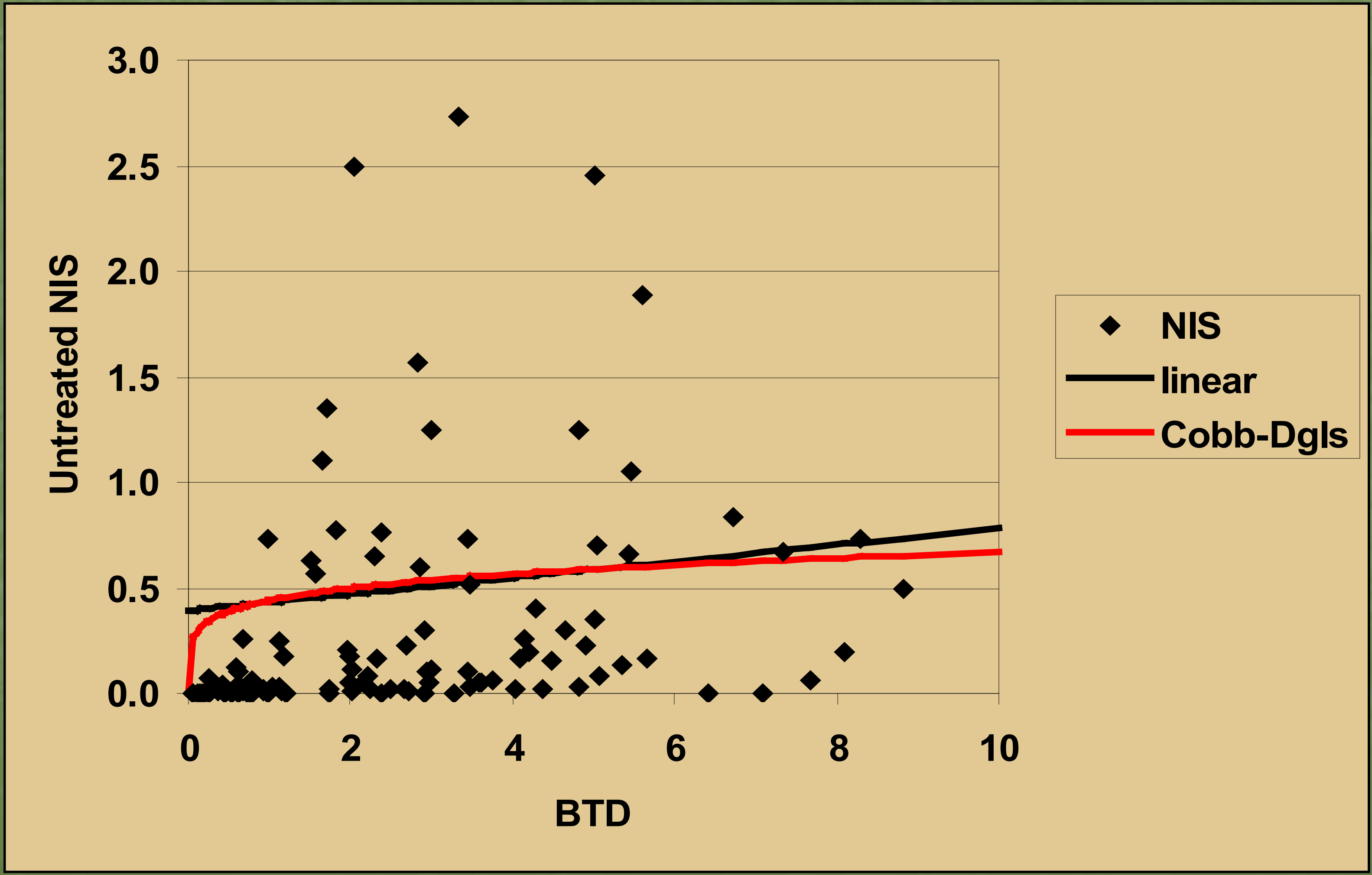


Mean
0.51
0.63
0.74

Untreated NIS: Estimation Results

Parm	Estimate	Error	t-statistic	P-value
Intercept	0.393	0.066	5.962	0.000
Slope	0.039	0.016	2.425	0.015
St Dev	0.530	0.052	10.106	0.000
LogL	-12.7248	Mean = $m_0 + m_1$*BTD		
Slope	0.440	0.058	7.547	0.000
Exponent	0.181	0.072	2.516	0.012
St Dev	0.533	0.052	10.193	0.000
LogL	-12.4867	Mean = $m_1 * BTD^{me}$		

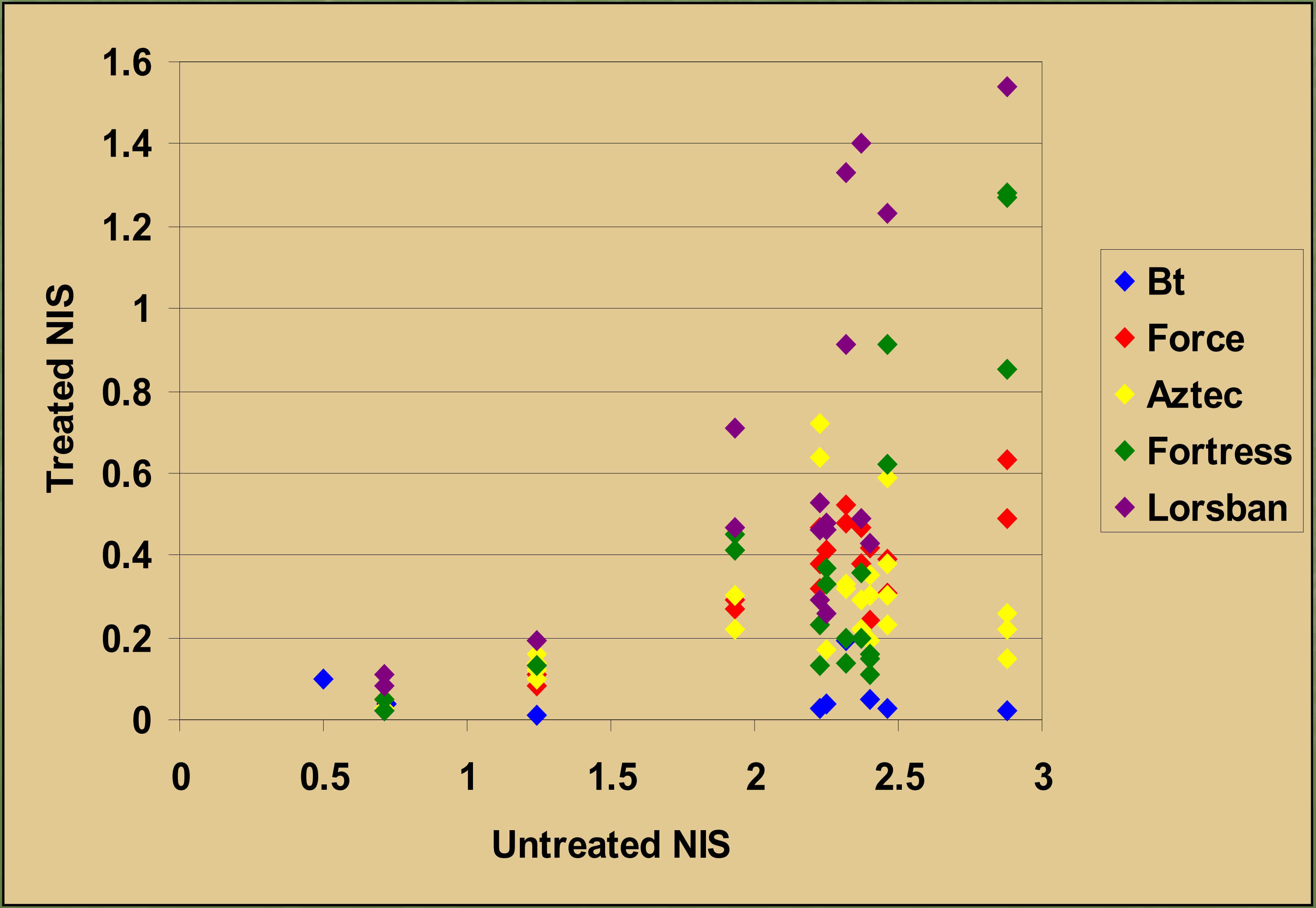
Untreated NIS
Linear vs Cobb-Douglas Mean



NIS conditional on Untreated NIS and control method

- Treated (NIS_t): beta density with conditional mean = $B_1 NIS_0$, conditional st. dev. = $S_1 NIS_0$, min = 0, max = NIS_0
  - Parameter B_1 varies by control method
  - No intercept and expect $B_1 < 1$ and $S_1 < 1$
  - Drive NIS_t to zero as NIS_0 goes to zero
- University rootworm insecticide trial data from 2002-2006 (U of IL, IA State, UW, etc.)
  - NIS for side-by-side plots, treated and untreated control, with trap crop planted previous year

Treated NIS vs Untreated NIS

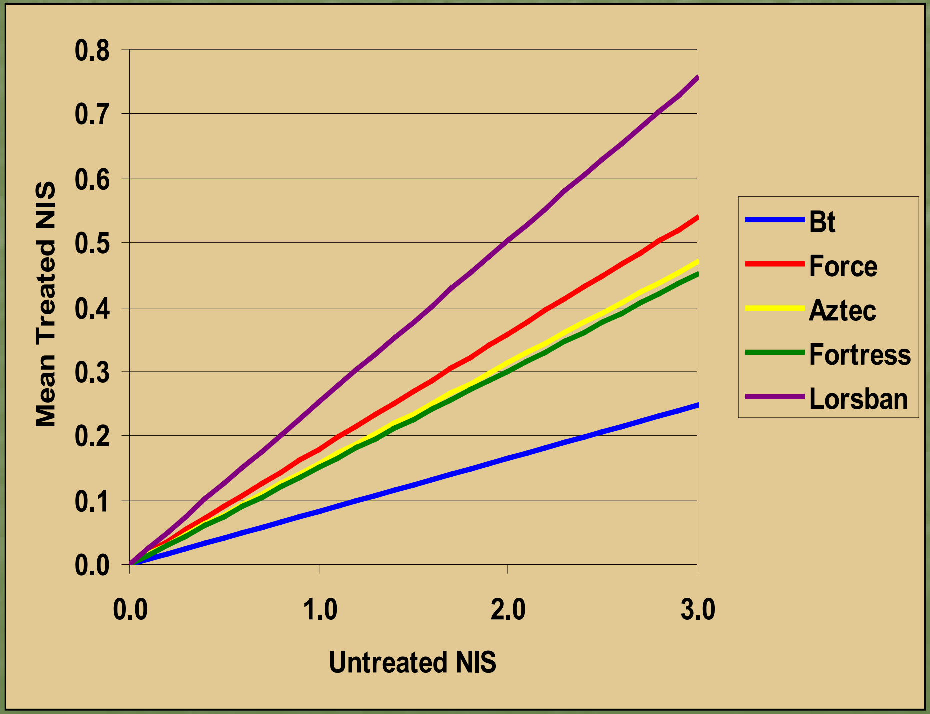


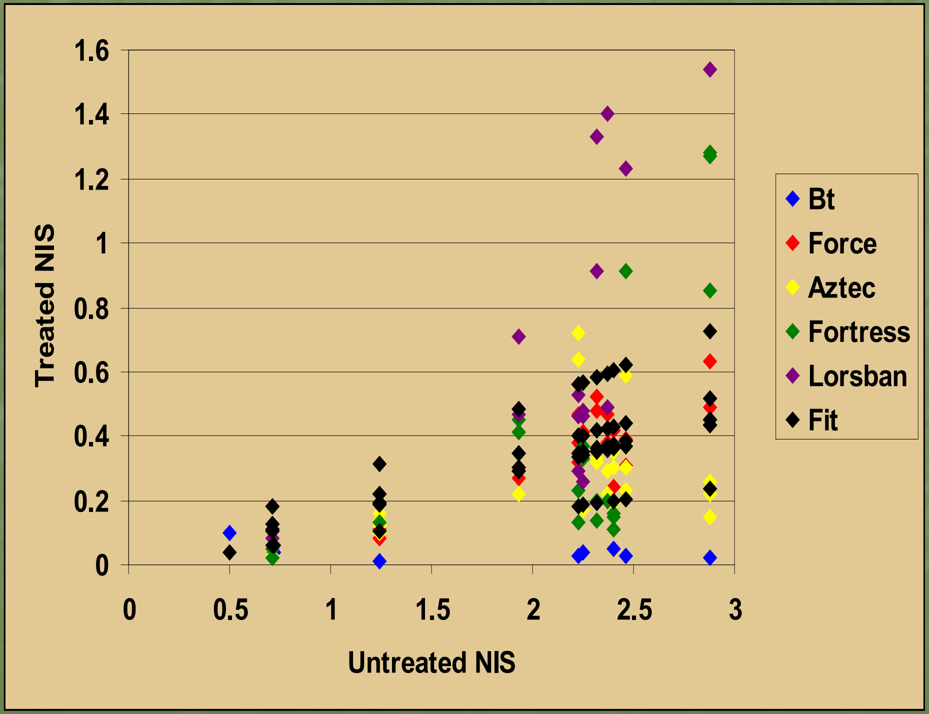
N obs
10
21
27
21
18

NIS conditional on Untreated NIS and control method

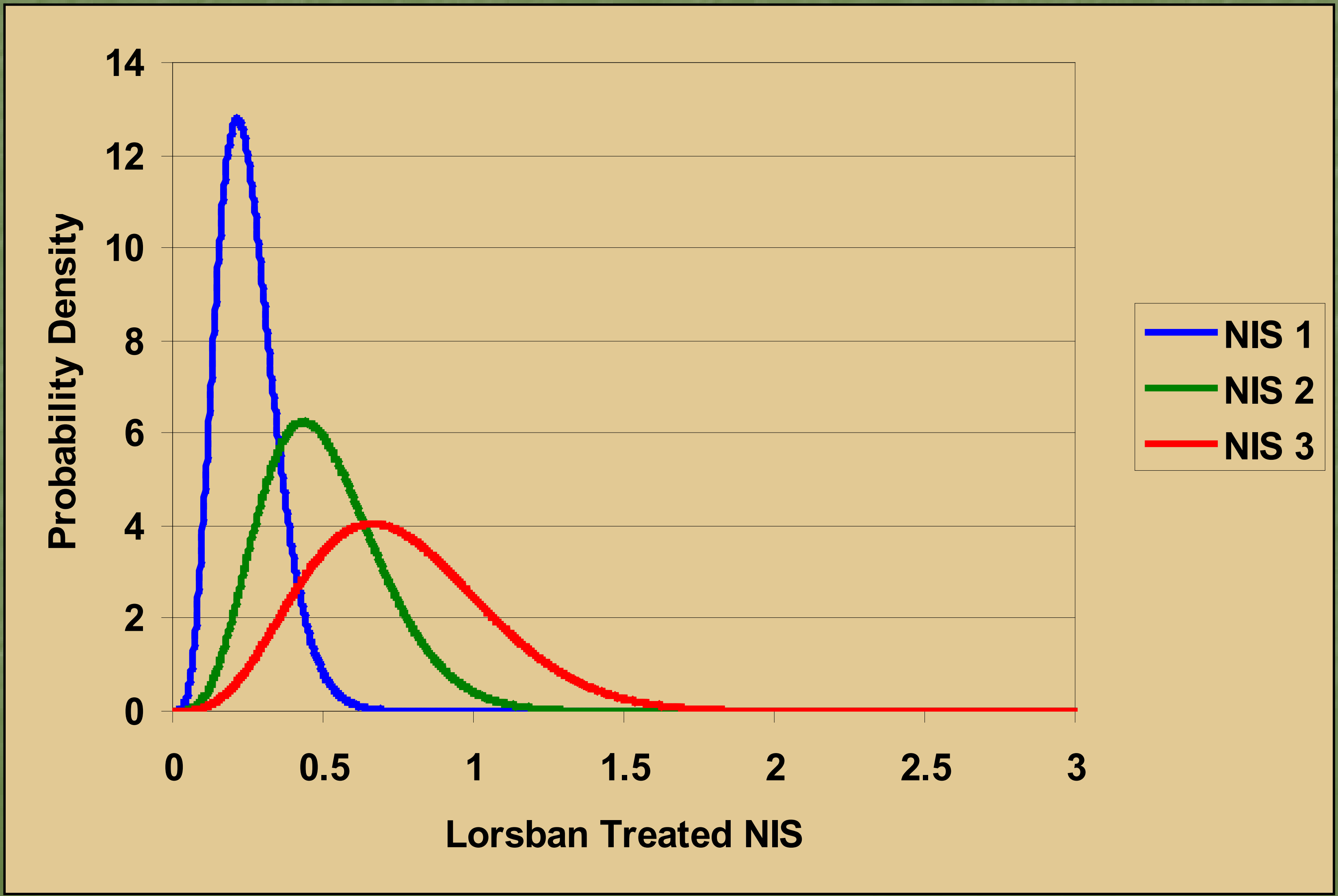
Parameter	est.	error	t-stat	p-val.
Bt (MON863 Cry 3Bb1)	0.082	0.014	5.73	0.000
Force (tefluthrin)	0.179	0.017	10.42	0.000
Aztec (tebupiriphos & cyfluthrin	0.156	0.015	10.60	0.000
Fortress (chlorethoxyfos)	0.151	0.018	8.50	0.000
Lorsban (chlorpyrifos)	0.252	0.023	11.04	0.000
S_1	0.098	0.008	12.23	0.000

NIS conditional on Untreated NIS and control method

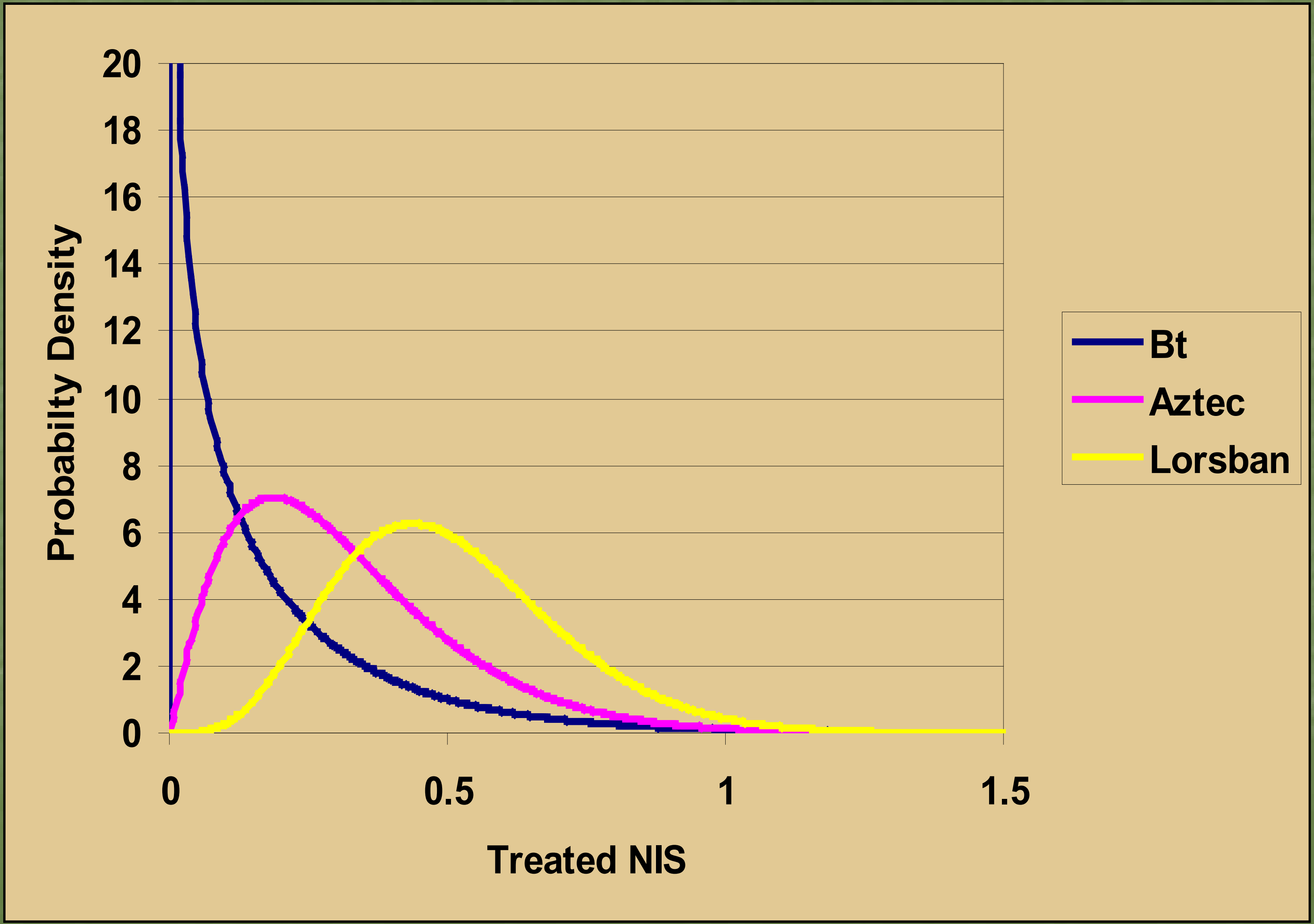




Effect of Untreated NIS



Effect of Control Method (NIS_0 = 1.5)



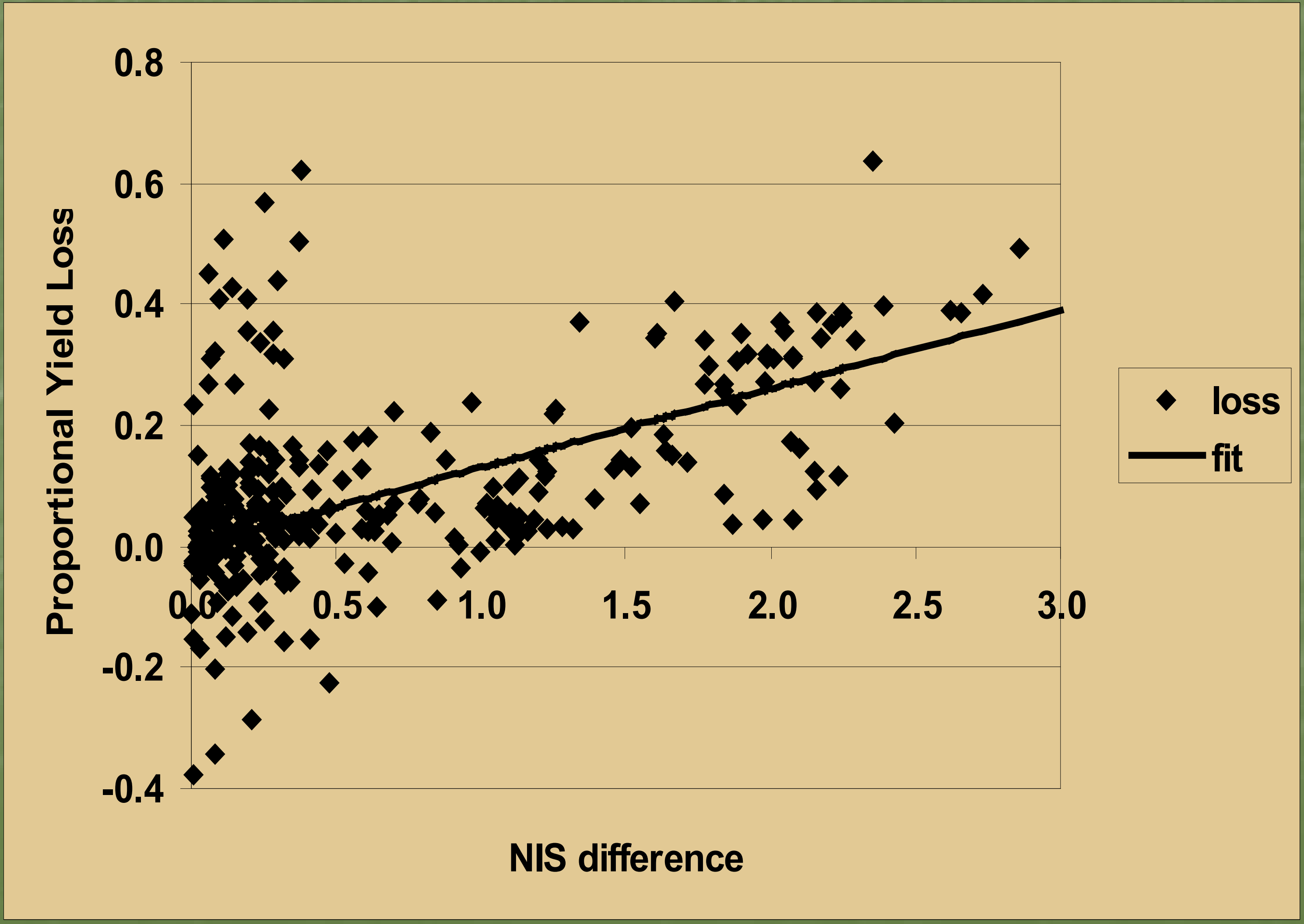
Proportional Yield Loss conditional on NIS difference

- No control method gives complete control (treated NIS $\neq 0$), so how determine the yield effect of rootworm control?
- Proportional yield loss conditional on the observed difference in the NIS
- Need NIS_a, NIS_b, $Yield_a$, and $Yield_b$ from plots in same location
- University rootworm insecticide trial data plus JEE publications (Oleson et al. 2005)
- Multiple pairings per location: if n treatments at a location, then have $n!/[2!(n-2)!]$ pairings

Proportional Yield Loss conditional on NIS difference

- If $NIS_a > NIS_b$, then $\Delta NIS = NIS_a - NIS_b$ and loss is $\lambda = (Y_b - Y_a)/Y_b$
- If $NIS_a < NIS_b$, then $\Delta NIS = NIS_b - NIS_a$ and loss is $\lambda = (Y_a - Y_b)/Y_a$
- ΔNIS always > 0, but λ not always > 0
- Conditional pdf: Normal distribution with $\mu = \mu_1 \Delta NIS$ and $\sigma = \sigma_0 + \sigma_1 \Delta NIS$
- If $\Delta NIS = 0$, then $\mu = 0$ and "noise" σ_0 causes the observed yield difference

Proportional Yield Loss conditional on NIS difference



σ_0	0.148
σ_1	-0.019
μ_1	0.130

Hierarchical Model Summary

1) Draw BTD
2) Use BTD to calculate conditional mean of NIS_0 and then draw NIS_0
3) Use NIS_0 to calculate conditional mean and st dev of NIS_{trt} and then draw NIS_{trt}
4) Calculate ΔNIS and conditional mean and st dev of loss, then draw loss
5) Draw yield and calculate net returns

Net Return to Control

- Returns without control
  - $R_0 = PY(1 - \lambda_0) - C$
- Returns with control
  - $R_{trt} = PY(1 - \lambda_{trt}) - C - C_{trt}$
- Net Benefit of Control
  - $R_{trt} - R_0 = PY(\lambda_0 - \lambda_{trt}) - C_{trt}$

Hierarchical Model Problems

- If specify a data-based multi-step hierarchical model, often no closed form expression exists for the pdf of some/all the intermediate and final variables
- What is pdf of NIS_0 ~ beta with a mean that is a linear function of BTD ~ beta?
- What is the pdf of net benefit to control?
- Must use Monte Carlo methods to analyze

Monte Carlo Methods

- Use computer programs to draw random variables in a linked fashion
- Draw sufficiently large number to get convergence to “true” pdf
- Excel with 1,000 draws to illustrate for today’s presentation

Economics of Risk in IPM

- Current simulations assume blanket treatment (always use control)
- IPM: make decision to use control a function of drawn BTD
  - If BTD $\geq$ T, returns = R_{trt}
  - If BTD < T, returns = R_0
- 3 returns to compare: R_0, R_{trt}, and R_{ipm}
- How do you compare systems when returns or net benefit is random?

Economics of Risk in IPM

- This problem is what economists call “risk”
  - When decisions have random outcomes
- Economics (& other fields) have methods and criteria for comparing random systems to decide which is “best”
- Quick review today using IPM in cabbage
  - Mitchell and Hutchison (2008) “Decision making and economic risk in IPM”

Representing Risky Systems

- Three elements needed
  - Actions: Apply insecticide, Adopt IPM
  - Events/States of Nature with Probabilities: Rainy, Low pest pressure
  - Outcomes: Insecticide washed off, IPM prevents unneeded applications
- Represent with decision trees, payoff matrices or statistical functions
  - All are equivalent representations

Cabbage IPM Case Study

- Cabbage looper (*Trichoplusia ni*) in cabbage (*Brassica oleracea*)
  - Mitchell and Hutchison (2008) Book Chapter
- Based on Minnesota cabbage IPM 1998-2001 case study
  - Hutchison et al. 2006ab; Burkness & Hutchison 2008

Payoff Matrix

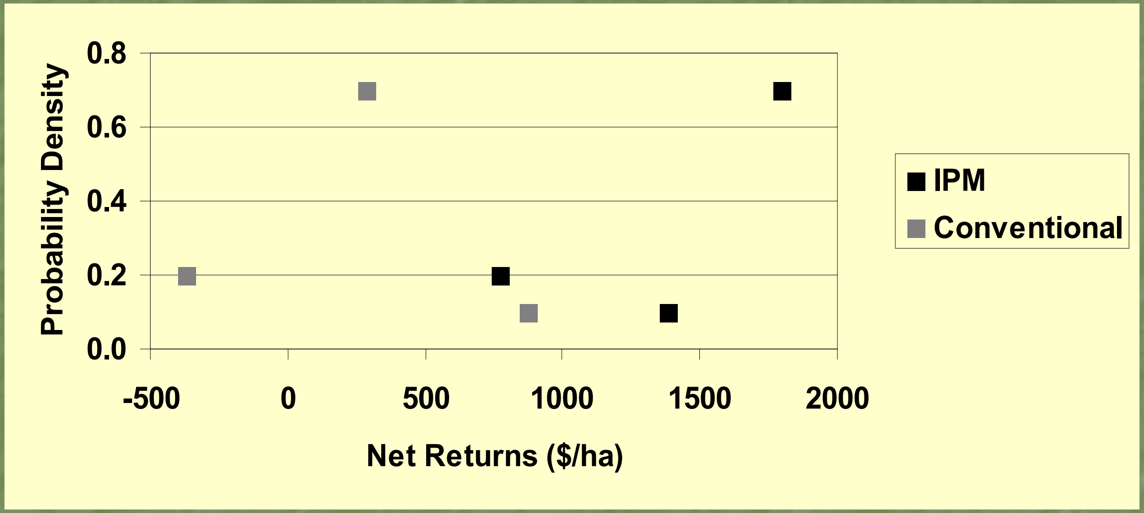
Event or State of Nature		------ Action to choose ------	
Pest intensity (*T. ni*) (# sprays)	Probability	Biologically-Based IPM	Conventional System
Low (1-2 sprays)	0.70	1795	285
Moderate (3-4 sprays)	0.20	775	-366
High (> 5 sprays)	0.10	1381	871

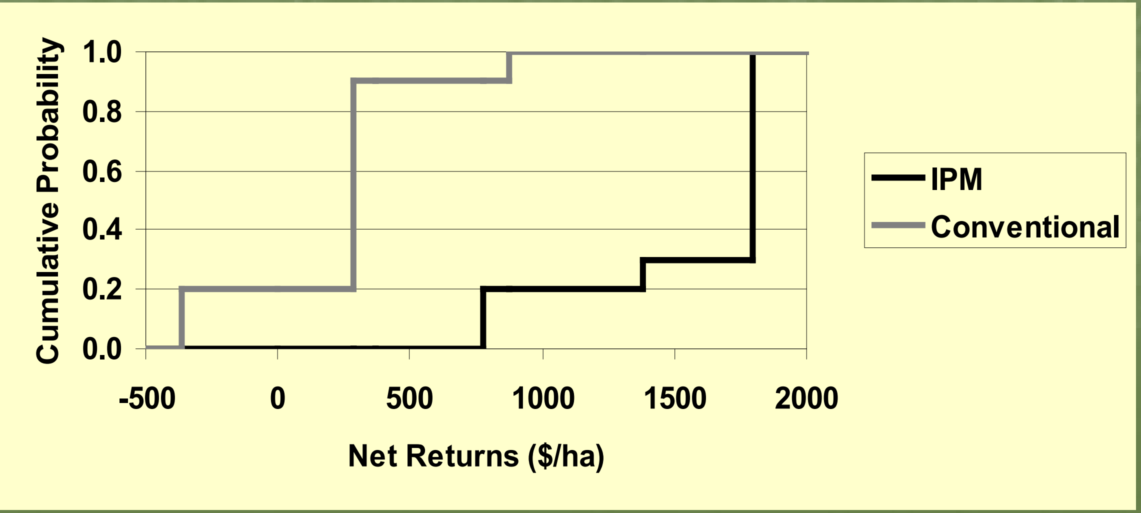
Subjective probabilities based on expert opinion of cabbage IPM specialist

Decision Tree

Action (Pest Management System)	Event (Pest Intensity)	Probability (Subjective)	Outcome (Net Returns $US /ha)
IPM	Low	0.70	1795
	Moderate	0.20	775
	High	0.10	1381
Conventional	Low	0.70	285
	Moderate	0.20	-366
	High	0.10	871

Statistical Functions (pdf and cdf change with action)

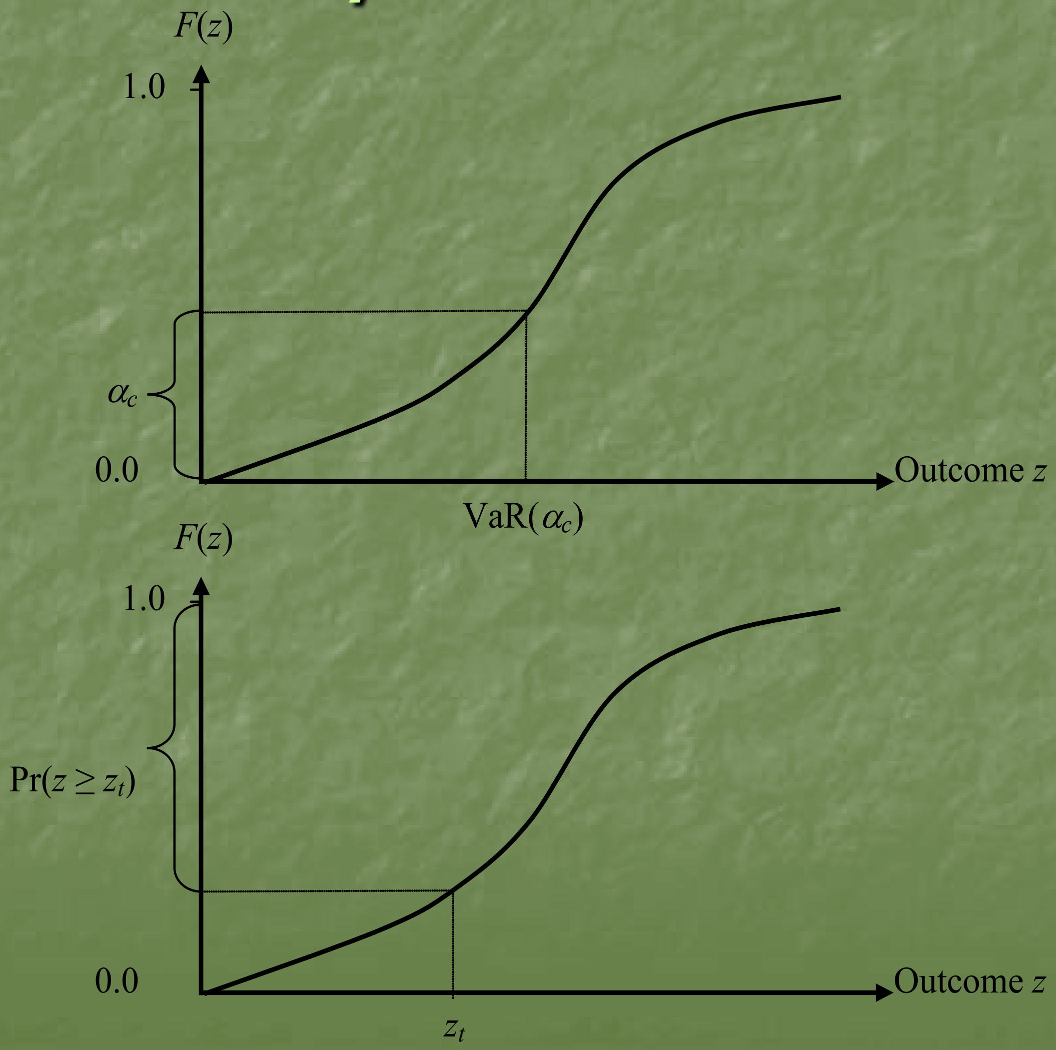




Measuring Risky Systems

- Central Tendency: Mean, Median, Mode
  - But what about variability?
- Variability/Spread/Dispersion
  - Variance/Standard Deviation
  - Coefficient of Variation: σ/μ
  - Return-Risk Ratio (Sharpe Ratio): μ/σ
- Asymmetry or "Downside Risk"
  - Skewness
  - Returns for critical probabilities (Value at Risk VaR)
  - Probabilities of key events (Break-Even Probability)

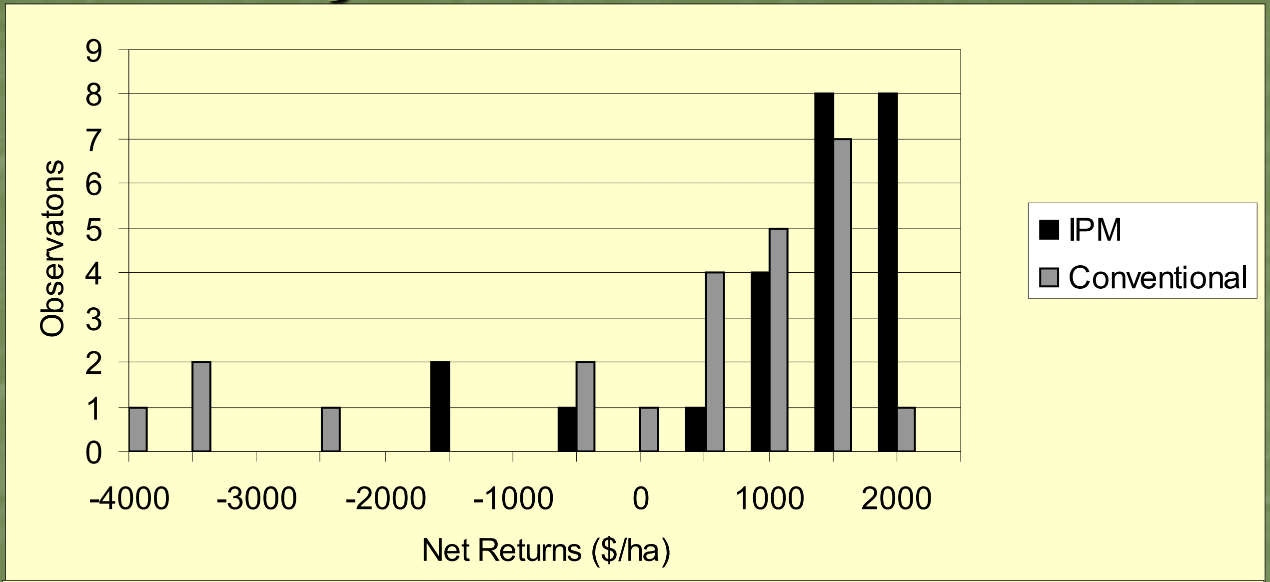
Value at Risk and Probability of Critical Outcome

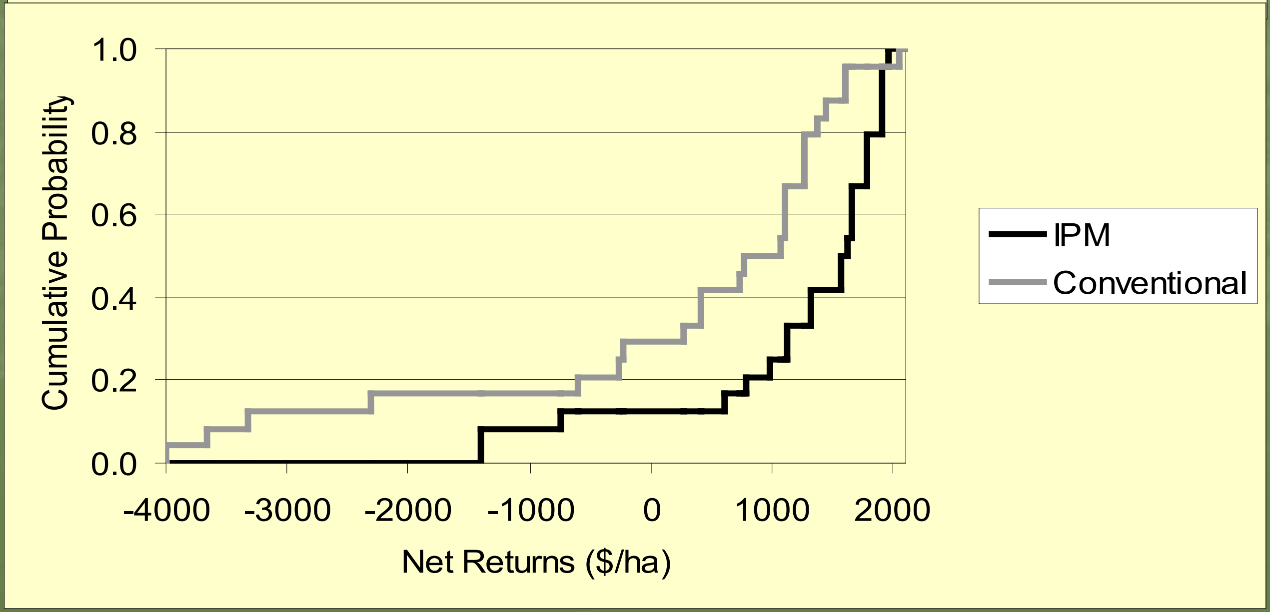


Probabilities

- Subjective: what the decision maker thinks based on beliefs and experience
  - Often based on expert opinion
- Objective: based on collected data
- Cabbage case study
  - 24 observations (6 fields x 4 years)
  - Smoother plots than in previous figures

Cabbage Case Study
Objective Probabilities





Measures of Risk
Cabbage IPM Case Study

	Subjective Probabilities		Objective Probabilities	
Measure	IPM	Conventional	IPM	Conventional
Mean	1550	213	1177	186
Median	1795	285	1560	771
Mode	1795	285	1896	1107 & 1272
Standard Deviation	406	338	970	1709
Coefficient of Variation	0.26	1.58	0.82	9.20
Return-Risk Ratio	3.81	0.63	1.21	0.11
Break Even Probability	1.0	0.8	0.88	0.71
Probability of $1000/ha	0.8	0.0	0.75	0.50

Comparing Risky Systems

- How to choose between risky systems?
  - Need a criterion to combine with one of these representations of risk to make decision
- Many criteria exist, quickly overview some commonly used in ag & pest management

Decision-Making Criteria
Risk Neutral

- Choose system to maximize mean returns
  - “Risk neutral” because indifferent to variability
    1) μ = \$10/ac with σ = \$5/ac
    2) μ = \$10/ac with σ = \$50/ac
  - These equivalent with this criterion, but most would choose the first system (“risk averse”)

Decision-Making Criteria Safety First

- Minimize probability returns fall below a critical level
  - Places no value on mean
- Maximize mean returns, subject to ensuring a specific probability that a certain minimum return is achieved
  - Max μ s.t. Pr(Returns > \$100/ha) $\geq$ 5%
- Useful for limited income farmers such as in developing nations

Decision-Making Criteria Tradeoff Mean and Variability

- Most people willing to tradeoff between mean and variability
  - Buy insurance because indemnities reduce variability of returns, though premiums reduce mean returns
- Preference (or Utility) function to formalize this trading off between risk and returns

Certainty Equivalent and Risk Premium

- Certainty Equivalent: non-random return that makes person indifferent between taking risky return and this certain return
  - Certain return that is equivalent for a person to the risky return
- Risk Premium: Mean Return minus the Certainty Equivalent
  - How much the person discounts the risk return because of the risk

Risk Preferences/Utility Functions

- Takes each outcome and converts it into benefit measure after accounting for risk
- Mean-Variance: $U(R) = \mu_R - \beta\sigma_R^2$
- Mean-St Dev: $U(R) = \mu_R - \beta\sigma_R$ Mean-St
  - U(R) is the certainty equivalent
  - $\beta\sigma$ or $\beta\sigma^2$ is the risk premium
  - β is the personal parameter determining their tradeoff between risk and returns

Risk Preferences/Utility Functions

- Constant Absolute Risk Aversion
  - $U(R) = 1 - \exp(-\alpha R)$
  - α = coefficient of absolute risk aversion
- Constant Relative Risk Aversion
  - $U(R) = R^{1-\rho}$ ($\rho < 1$), $U(R) = -R^{1-\rho}$ ($\rho > 1$), and $U(R) = \ln(R)$ ($\rho = 1$)
  - ρ = coefficient of relative risk aversion
- Others exist that I'm not mentioning

Cabbage IPM Case Study Certainty Equivalents ($/ac)

	Subjective Probabilities		Objective Probabilities	
Criterion	IPM	Conventional	IPM	Conventional
Mean-Variance (β = 0.0005)	1467	156	706	-1274
CARA (α = 0.0001)	1541	208	1127	28
CRRA (ρ = 1.2)	1461	*	*	*

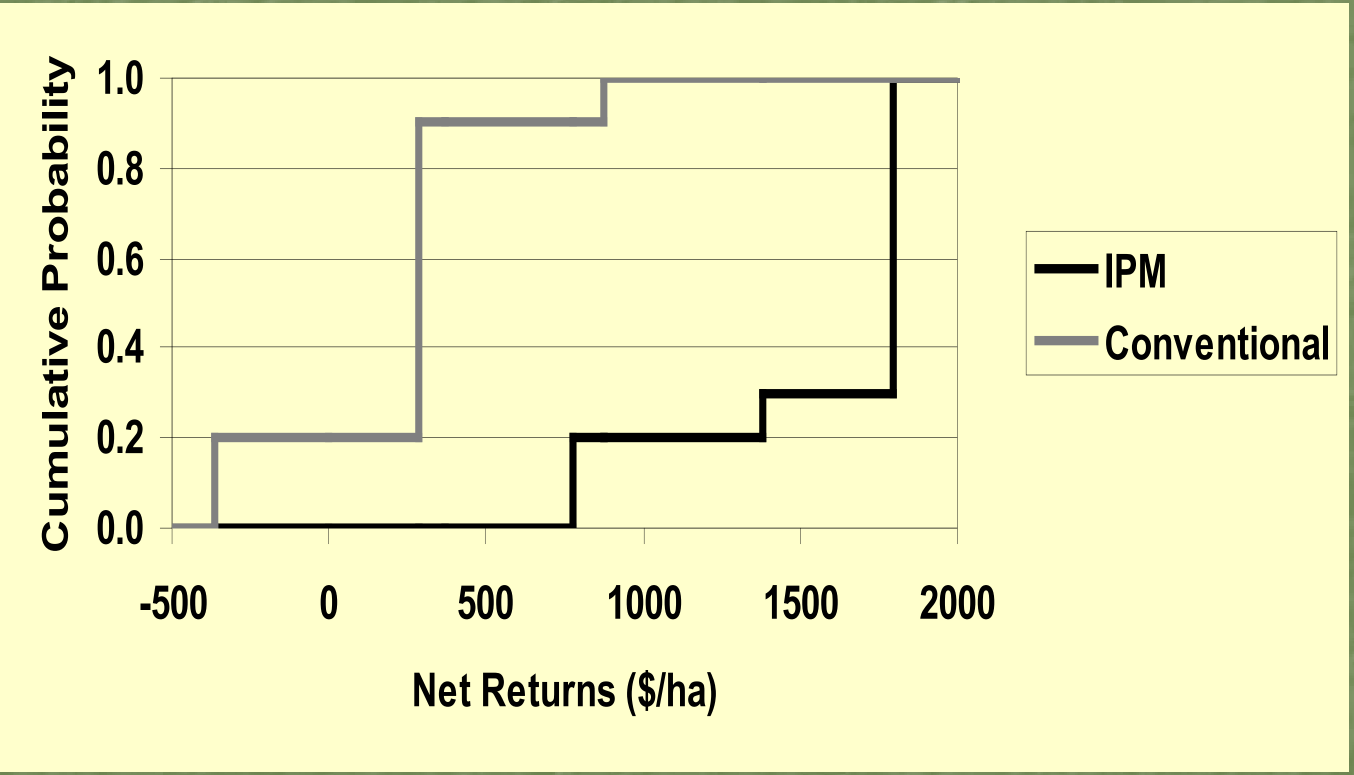
*CRRA preferences not defined for negative returns outcomes

Decision-Making Criteria Stochastic Dominance

- Assume little structure for utility function and still rank risky systems in some cases using cdf
- First Oder Stochastic Dominance
  - If $F_a(R) \leq F_b(R)$ for all R, then R_a preferred to R_b if $U' > 0$ (prefer more to less)
- Second Order Stochastic Dominance
  - R_a preferred to R_b if $U'' < 0$ (risk averse) and

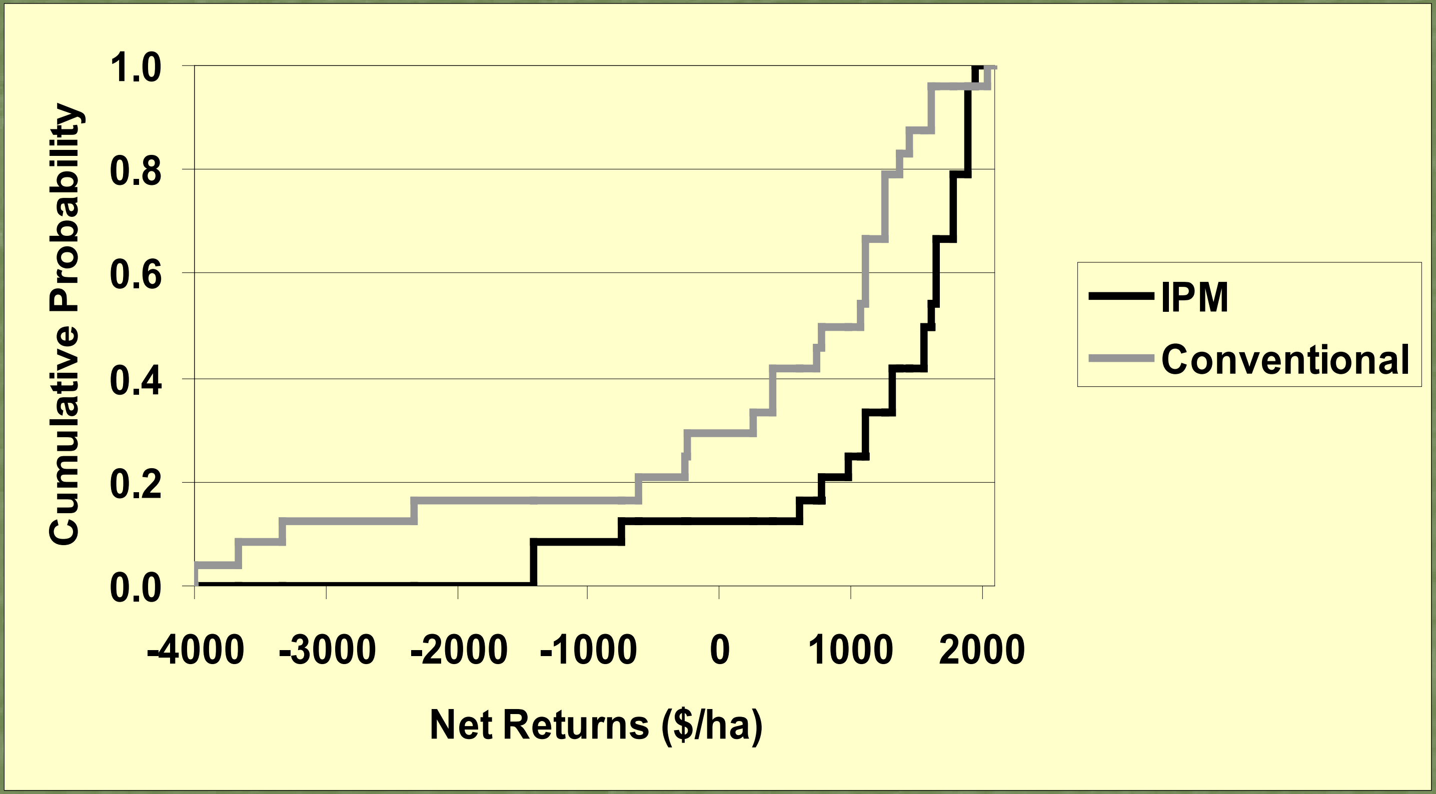
$$\int_{R_{\min}}^{R^*} F_b(R) - F_a(R)dR \geq 0, \ \forall R_{\min} \leq R^* \leq R_{\max}$$

IPM FOSD's Conventional pest control when using subjective probabilities



$$F_{ipm}(R) \leq F_{conv}(R)$$

IPM SOSD's Conventional pest control when using objective probabilities



$$\int_{R_{\min}}^{R^*} F_{conv}(R) - F_{ipm}(R)\,dR \geq 0,\ \forall R_{\min} \leq R^* \leq R_{\max}$$

Summary

- Illustrated Hierarchical Modeling as way to include natural variability in the analysis of pest-crop systems
  - Example: western corn rootworm in corn
  - Still need to add in IPM component and apply decision making criteria to derive optimal IPM thresholds and estimate the value of IPM

Summary

- Overviewed how economists represent and compare risky systems
  - Illustrated with cabbage IPM case study of cabbage looper
  - Representing risky systems
  - Measures of risk
  - Decision-making criteria to choose system