Insect Derivatives: Managing Insect Risk with Financial Instruments

Timothy J. Richards, ASU

James Eaves, U. Laval

Valerie Fournier, U. Laval

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Overview

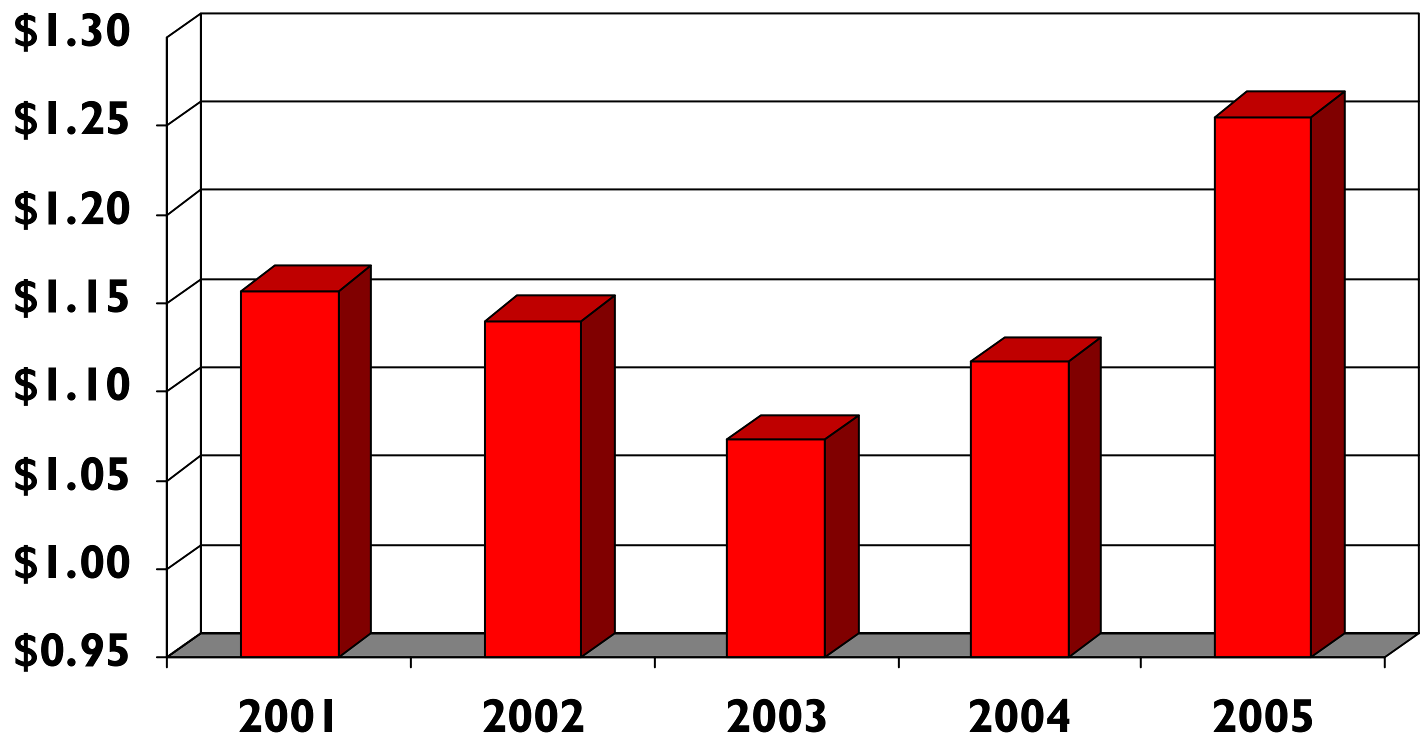
- Description of the Problem
- Objectives
- Bioeconometric Model of Insect Growth
- Dervative Pricing Model
- Simulation Model / Visual Basic
- Conclusions and Future Research

Economic Damage from Invasive Insect Species

- Pimentel, Zuniga, and Morrison (2005)
  - Crop loss due to insects at 33%
  - Value of loss is $33.0 billion
  - 40% of insect species are invasive
  - $13.5 billion loss, including control, in 2001
- Crop insurance not good alternative for many insect-sensitive crops
  - Fruits
  - Vegetables

Cotton Losses to Insects ($ b)

source: M. Williams, Mississippi State U.



Need for market-based method of managing invasive-insect risk

Objectives

- Define and design derivative contract
- Create pricing model for derivative
- Estimate spatio-temporal model of insect growth process
- Estimate damage function in AZ cotton
- Simulate effectiveness of derivatives in managing financial risk

Today

- Focus on two parts:
  - Spatio-temporal model
  - Simulation model
- Richards, et al (2006 AFR) describe temporal model:
  - Growth
  - Damage
  - Simulation

Spatio-Temporal Model

- Three phases of growth:
  1. Arrival
  2. Establishment
  3. Spread
- Model is a synthesis of:
  1. Bioeconometrics
  2. Spatial econometrics (linear and non-linear)

Linear Spatio-Temporal

- Linear model from Anselin (1988):

$$B(s,t) = WB(s,t) + \beta X \quad + v(s,t)$$

$$v(s,t) = Mv(s,t) + \varepsilon$$

- Where:

  B(s,t) = adult insects at point s, time t
  W = spatio-temporal weight matrix
  M = spatio-temporal weight matrix
  Weights are inverse Euclidean distance

Linear Spatio-Temporal…

- Disaggregate W as in Pace, et al (2000)

$$B(s, t) = \varphi_S SB(s, t) + \varphi_T TB(s, t) + \varphi_{ST} STB(s, t) + u(s, t)$$

- Where parameters are spatial and temporal lag effects

Non-Linear Spatio-Temporal

- Non-linear over space and time:

$$B(s,\ t) = f(\theta \mid S, T, X) + \xi(s,\ t)$$
$$\xi(s,\ t) = h(\Omega \mid S, T) + \mu$$

- Non-linear term is sum of:
  - Temporal growth (exponential)
  - Spatial dispersion (Fick's Law)

Non-linear…

- Exponential part:

$$B^t(s_0 t) = \left(\frac{K}{1 + de^{Tk}} \right) + X\beta$$

- Fick's Law part:

$$B^s(s, t_0) = \left(\frac{B(s_0, t_0) e^{-(Sk)^2/4\gamma Tk}}{2\sqrt{\pi\gamma Tk}} \right)$$

Estimation Strategy

- Combine linear and non-linear models
- Estimate with GMM
- Recover error process
- Estimate with MLE
- Preferred process is:
  - Mean reverting
  - Geometric Brownian Motion
  - Poisson jump terms

Option Pricing Model

- Risk Neutral Valuation (Monte Carlo)
  - Forecast Q-Wiener process for error
  - Forecast mean process
  - Multiply by tick-rate
  - Discount to present at risk free rate
- Call option valuation formula:

$$C(s,t) = e^{-rt} \int_{x}^{\infty} f(B(s,t))(B(s,t) - x)\,dB(s,t)$$

Simulation Model

- Profit equation:

$$\pi_g = py_g - C(c_g, F)$$

- Damage Function:

$$\ln(y_{g,t}) = \beta_0 + \beta_1 \ln(B_{g,t}) + \beta_2 \ln(c_{g,t}) + \beta_3 D94 + \varepsilon_{g,t}$$

- Risk Premium:

$$R(\pi_g) = E[\pi_g] - CE(\pi_g) = E[\pi_g] - ((1-\rho)E[U_g])^{1/(1-\rho)}$$

Data

- Experimental field-trial data from ARS
  - Western Cotton Research Lab in Phoenix
  - Data gathered at Brawley, CA
- *Bemisia Tabaci* (whitefly) in cotton
  - 21 weeks in 1994, 18 weeks in 1995
  - 25 plots, 5x5 Latin Square design
  - 5 treatments (1=control, 5=intensive)
  - Adult count from plant sample

Data…

- Yield data gathered at harvest
- Other variables include CDD (NOAA)
- Representative farm financial data:
  - U.C. Davis cost of production study
  - Prices from 2004
  - Control costs set at sample average

B. Tabaci Call Option Prices (X = 5 adults, t = 1 month)

	1	2	3	4	5
1	8.832	8.266	6.694	4.475	2.053
2	8.289	7.718	6.201	4.087	1.771
3	6.701	6.224	4.921	3.009	0.987
4	4.466	4.095	3.008	1.480	0.082
5	2.043	1.758	0.967	0.076	0.000

B. Tabaci Call Option Prices (X = 5 adults, t = 3 months)

	1	2	3	4	5
1	20.438	20.106	19.051	17.405	15.345
2	20.059	19.743	18.728	17.122	15.063
3	19.041	18.737	17.757	16.209	14.235
4	17.447	17.112	16.237	14.793	12.957
5	15.306	15.040	14.217	12.921	11.229

Option Pricing Results

- Option prices fall away from (1,1) start
- Difference between (1,1) and (5,5) shrinks over time
- Option "chain" is an "option grid"
- Can buy spreads and straddles over length and width of option grid

Bug Option Hedge: Temporal

		$\rho = 0.1$	$\rho = 0.5$	$\rho = 0.9$
	Sharpe Ratio	1.43	1.43	1.43
No Hedge	VaR (5%)	-$6.23	-$6.23	-$6.23
	CE	$51.22	$44.24	$21.55
	Sharpe Ratio	2.96	2.96	2.96
Full Hedge	VaR (5%)	$32.06	$32.06	$32.06
	CE	$52.28	$52.28	$52.28

Bug Option Hedge: Spatial

		ρ = 0.1	ρ = 0.5	ρ = 0.9
	Sharpe Ratio	1.37	1.37	1.37
No Hedge	VaR (5%)	-$34.03	-$34.03	-$34.03
	CE	$54.57	$38.73	$5.49
	Sharpe Ratio	2.89	2.89	2.89
Full Hedge	VaR (5%)	$32.06	$32.06	$32.06
	CE	$52.04	$51.35	$50.37

Conclusions

- Possible to create simple Bug Option pricing model
- Insects evolve in spatio-temporal way
- Financial risk can be reduced by hedging
- Spatial hedging reduces basis risk
- No moral hazard if counted at experiment station