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Insecticide Use, Resistance, and the Billion-Dollar Bug:
Evidence from Farmers' Management of US Corn Fields

Jonathan McFadden, USDA Economic Research Service, jonathan.mcfadden@usda.gov
Seth Wechsler, USDA Economic Research Service, seth.wechsler@usda.gov
Samuel Williamson, USDA Animal Plant and Health Inspection Service, samuel.williamson2@usda.gov

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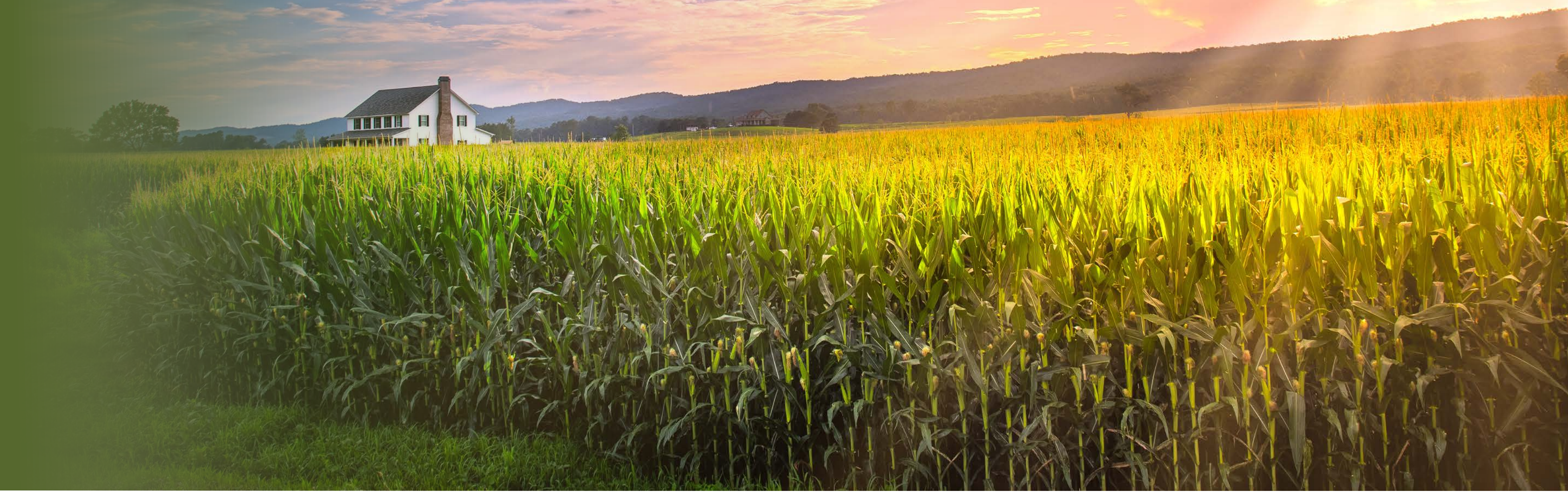

Insecticide Use, Resistance, and the Billion-Dollar Bug: Evidence from Farmers' Management of US Corn Fields

Jonathan McFadden and Seth Wechsler, USDA, Economic Research Service; and Samuel Williamson USDA, Animal and Plant Health Inspection Service

Introduction

- **Rootworms** are historically one of the most destructive corn pests in the United States.
- Genetically engineered, rootworm resistant **(Bt-CRW)** corn varieties (first commercialized in 2003) are an effective, economical alternative to conventional insecticides.
- Heavy use of Bt-CRW corn has raised concerns about **resistance** to Cry proteins developing in rootworm populations.
  - 2009: First documented cases of field-evolved resistance in Iowa.
  - Over time, resistance has been observed in localized populations of rootworms in Iowa, Minnesota, North Dakota, and Texas.
  - Entomologists characterize rootworm resistance as a regional problem, not a national one.

Photos: Anthony Zukoff, Kansas State University

Project Overview

Research questions

1. How does Bt-CRW adoption affect corn yields and insecticide use?
2. Has the marginal productivity of Bt-CRW seeds changed in areas where resistance has been identified?

Main contributions

- Extends past work focused on detecting and quantifying rootworm resistance by:
  - Exploring whether rootworm resistance is present on a **regional** rather than national basis (specifically, in areas where resistance has been documented by extension specialists and entomologists, i.e., Iowa and Minnesota)
  - Leveraging **sub-additivity** of pricing for GE seed traits for econometric identification
  - Expanding study period to include 2016 (alongside 2005 and 2010)

Farmer's Profit Maximization Problem

The farmer's objective is to maximize expected profits per acre:

$$\max_{\substack{I,H\geq 0;\\ Bt,HT\in\{0,1\}}} \quad E[PY - p_I I - p_H H - p^{Bt}(HT)Bt - p^{HT}(Bt)HT]$$

$$\text{s.t. } Y = \Upsilon G_R G_W \exp(\varepsilon),$$

$$G_R = \exp(-\exp(\ln(Z_R) - aI - bBt))$$

where P is the price of corn, Y are yields, I is a label rate application of soil insecticide, p_I is the price of soil insecticides, H is a label rate application of herbicides, p_H is the price of herbicides, $p^{Bt}(HT)$ is the premium paid for seeds with Bt-CRW traits, $p^{HT}(Bt)$ is the premium paid for seeds with HT traits, Bt and HT are indicators of genetically engineered (GE) seed use, ε reflects uncertainty, α reflects the effectiveness of soil insecticides, and b reflects the effectiveness of Bt-CRW seeds.

Deriving the Soil Insecticide Demand Function

- The solution to the farmer's maximization problem indicates that the derived demand function for soil insecticides is:

$$I^* = \frac{1}{a}\left[Z + \ln\left(\frac{aPE[Y]}{p_I}\right) - bBt_i\right]$$

- Comparative statics:
  - Insecticide use increases as pest pressure and expected revenue rises (e.g., $\partial I^*/\partial PE[Y] > 0$)
  - Insecticide use decreases as insecticide prices rise and if Bt seeds are used (e.g., $\partial I^*/\partial p_I < 0$, $\partial I^*/\partial Bt < 0$)
  - Crucially, insecticide use also increases as Bt-CRW efficacy decreases (i.e., $\partial I^*/\partial b < 0$). So, ceteris paribus, there should be more soil insecticide use in areas where resistance is present (i.e., where b is lower).

Empirical Approach

- We reparametrize the derived demand function such that:

$$I^* = \beta_0 + \beta_1 Z + \beta_2 \ln\left(\frac{PE[Y]}{p_I}\right) + \beta_3 Bt_i.$$

- We estimate the parameters of this demand function by estimating a tobit model using survey data collected in 2005, 2010, and 2016.
- We use a variety of soil characteristics and climatic variables as proxies for the intensity of rootworm pressure.
- We test whether the magnitude of β_3 is lower in areas where rootworm resistance has been documented.
- We account for the endogeneity of Bt-CRW seed use, expected yields, and soil insecticide prices (which depend on row spacing decisions) in the soil insecticide demand function by modelling these equations simultaneously.
  - The structural model suggests that HT-seed use decisions enter the soil insecticide demand function indirectly, via Bt-CRW seeds use decisions. So, we constrain the correlation between residuals of the HT-seed use and soil insecticide use equation to zero.

Data

Table 1

Select summary statistics, Corn Production Practices and Costs Report, Agricultural Resource Management Survey

Variable	Unit	2005	2010	2016
Yield goal	bushels/acre	158	170	182
Average yield loss from untreated rootworms	bushels/acre	16.25	17.25	21.91
Corn rotation in prior year	percent of growers	88%	72%	72%
Percent using Bt-CRW seeds	percent of growers	10%	56%	60%
Percent using insecticides	percent of growers	14%	7%	5%
Average insecticide use	percent of label rate	13%	6%	4%
Corn productivity index	NA	51%	49%	48%
Observations	unweighted growers	1,167	1,327	1,081

Source: Phase II of the USDA's Agricultural Resource Management Survey (ARMS), 2005, 2010, and 2016. Oregon State's Prism Climate Data, The USDA, Natural Resources Conservation Service's (NRCS) Soil Data and National Crop Commodity Datasets.

Data (continued)

The dataset contains 3,575 field-level observations for farms located in Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin.

While approximately 14 percent of corn farmers applied soil insecticides in 2005, only 7 percent applied soil insecticides in 2010, and only 5 percent in 2016.

Insecticides have different potencies. Therefore, each application was converted into an equivalent dosage of Lorsban 15. Implicitly, this assumes that each insecticide is equally effective when applied at the label rate.

Table 2

Insecticide use by BT-CRW users has trended upward in Iowa and Minnesota, while decreasing in other States

	Average application rate[1]		Percent of Bt-CRW users applying insecticides		Average soil insecticide use[1]	
Year	Other States	Resistance region	Other States	Resistance region	Other States	Resistance region
2005	91%	62%	11%	3%	10%	2%
2010	80%	89%	10%	6%	8%	6%
2016	71%	64%	2%	4%	2%	3%

[1]Percent of label rate.

Source: Phase II of the USDA's Agricultural Resource Management Survey (ARMS), 2005, 2010, and 2016.

- Entomologists have identified field-evolved resistance to Bt-CRW seeds in Iowa and Minnesota (i.e. the resistance region).
- Average insecticide use has decreased in these states but trended upwards in other Midwest corn growing states.
- This is consistent with how our theoretical model predicts we would observe farmers behaving if resistance was developing.

First Stage Results

- **Yield goals** are higher when soils are highly productive, corn prices are high, and soil insecticide prices are low.
- **Row spacing** tends to be wider in states where insecticide prices are higher.
- **Bt and HT trait adoption** is higher on fields where corn is in continuous rotation.
- Generally, there are strong, relevant exclusion restrictions and/or binding restrictions suggested by the theoretical model. In other words, the second stage of this model is identified.

Table 3

Reduced form models of potentially endogenous variables

	(OLS) ln(Yield goal)	(OLS) ln(Lineal feet)	(Bivariate probit) Bt-CRW	HT
Instruments				
Highly-erodible soil	-0.04***	0.002	-0.14	0.13
Soil productivity	0.24***	-0.003	0.06	-0.83***
ln(Corn price)	0.83***	0.047	0.06	-0.20
ln(Force 3G price)	-0.06	-0.092***	0.22	-0.14
Other variables				
2010	0.10***	-0.019	1.54***	1.38***
2016	0.06***	0.014**	1.46***	1.62***
ln(Farm size)	0.03***	0.020***	0.10***	0.05
Expected yield loss	0.001	-0.001	0.02**	0.01
Soil pH	0.09***	-0.0002	0.35***	0.17*
Corn lag	-0.01	-0.018***	0.55***	0.17*
Resistance state	0.05***	-0.003	0.18**	0.37***
Growing Degree Days	0.0001	-0.0001	0.004***	0.01***
Precipitation	0.05*	-0.015	0.76***	1.06***
Growing Degree Days × Precip	0.0001*	0.00001	-0.001***	-0.001***
Silt	0.01***	-0.002***	-0.02**	-0.02*
Sand	0.003***	-0.001**	-0.02**	-0.01
Constant	2.68***	2.968***	-8.88***	-9.31***
Rho	-	-	0.32***	
Number of observations	3,575	3,575	3,575	

* p < 0.10, ** p < .05, *** p < .01.

Note: Standard errors were jackknifed to account for the complexity of the survey design.

Source: Authors' estimates.

Reduced Form Results

- Bt-CRW seeds reduced insecticide use in 2005, 2010, and 2016.
- Results suggest that latent pest pressure is higher on field where Bt-CRW seeds are used (i.e., controlling for endogeneity is important).
- The magnitude of the parameter estimates suggest that Bt-CRW seeds were less effective in Iowa and Minnesota in 2010 and 2016.
  - Point estimates not statistically significant, however (potentially due to jackknifed standard errors).

	(1) No Restrictions, No End. Correct.	(2) Restrictions, No End. Correct.	(3) Restrictions, End. Correct.
Variables that affect the efficacy of Bt-CRW			
Single trait Bt-CRW in 2005	-0.67*	-0.73	-1.58
Single trait Bt-CRW in 2005 × Resistance Region	-0.37	-0.36	-0.33
Single trait Bt-CRW in 2010	-0.21	-0.22	-1.04
Single trait Bt-CRW in 2010 × Resistance Region	0.79	0.75**	0.75**
Single trait Bt-CRW in 2016	-1.16**	-1.16	-1.98*
Single trait Bt-CRW in 2016 × Resistance Region	0.99	1.00*	.99*
Pyramided Bt-CRW Seeds	-1.14**	-1.14	1.97*
Variables that affect pest pressure			
Constant	-12.09*	-12.34***	-14.14***
Expected yield loss	0.06***	0.06***	0.06***
Soil pH	0.27	0.31*	0.39**
ln(farm size)	0.30***	0.31***	0.33***
2010	-1.52**	-1.95***	-1.55**
2016	-1.67***	-2.06***	-1.66**
Corn lag	0.42**	0.42**	0.55**
Corn lag × Bt-CRW lag	-0.29	-0.28	-0.28
Resistance region	-0.53*	-0.51**	-0.47**
Growing degree days	0.00	0.003	0.00*
Precipitation	1.02***	1.03***	1.22***
Precipitation × growing degree days	0.00***	-0.001***	0.00***
Pct sand (county avg)	-0.03**	-0.03***	-0.04***
Pct silt (county avg)	-0.02	-0.02	-0.02
Other variables			
ln(Corn price)	0.37	1.43**	1.45**
ln(Yield goal)	1.67***	1.43**	1.45**
ln(Force 3G price)	-0.52	1.43**	1.45**
ln(Lineal feet)	-1.43*	1.43**	1.45**
Number of observations	3,575	3,575	3,575

* p < 0.10, ** p < .05, *** p < .01

Note: standard errors were jackknifed to account for the complexity of the survey design.

Source: Authors' estimates.

Discussion and Next Steps

- Preliminary results suggest that Bt-CRW seeds may be less effective in regions where resistance has been documented.
- Future work includes exploring alternative estimation approaches and
  - Bootstrapping
  - Bayesian approaches

Photo: Simerjeet Virk, University of Georgia

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Contact Information:
Jonathan McFadden: jonathan.mcfadden@usda.gov
Seth Wechsler: seth.wechsler@usda.gov
Samuel Williamson: samuel.williamson2@usda.gov

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