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Don’t Farm So Close to Me: Have Externalities Associated with Weed Mobility Hastened the Emergence of Glyphosate-Resistant Weed Populations?

What are Glyphosate and Glyphosate-Resistant Weeds?

- Glyphosate, more commonly known as Round-Up, is a broad-spectrum herbicide that was invented in 1970.

- Glyphosate became the most used herbicide in US after introduction of crops that had been genetically modified to be Glyphosate-Resistant (GR) in 1996.

- However, glyphosate has become less effective in recent years with emergence of GR weeds.

Why does weed mobility matter?

- To some extent, the development of resistance may have been inevitable.
- However, some argue that weed mobility may have led growers to make decisions that hastened the development of resistance.
- Specifically, they argue that growers would be reluctant to take steps on their own to avoid resistance because their farms could still “end up infested with weeds from less-assiduous neighbors” (Nature, 2014).

Deals | Tue Mar 31, 2015 4:07pm EDT

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EPA will require weed-resistance restrictions on glyphosate herbicide

BY CAREY GILLAM

U.S. regulators will put new restrictions on the world's most widely used herbicide to help address the rapid expansion of weeds resistant to the chemical, Reuters has learned.

Objective

- This goal of this paper is to better understand whether weed mobility led growers to avoid taking steps that may have delayed the development of resistance.

- To achieve this goal, I utilize field-level data from over 5,000 soybean growers that was collected as part of the 2006 Agricultural Resource Management Survey.

Discussion Outline

1. Background and Economic Intuition
2. Empirical Strategies
3. Data
4. Estimation Results
5. Conclusions

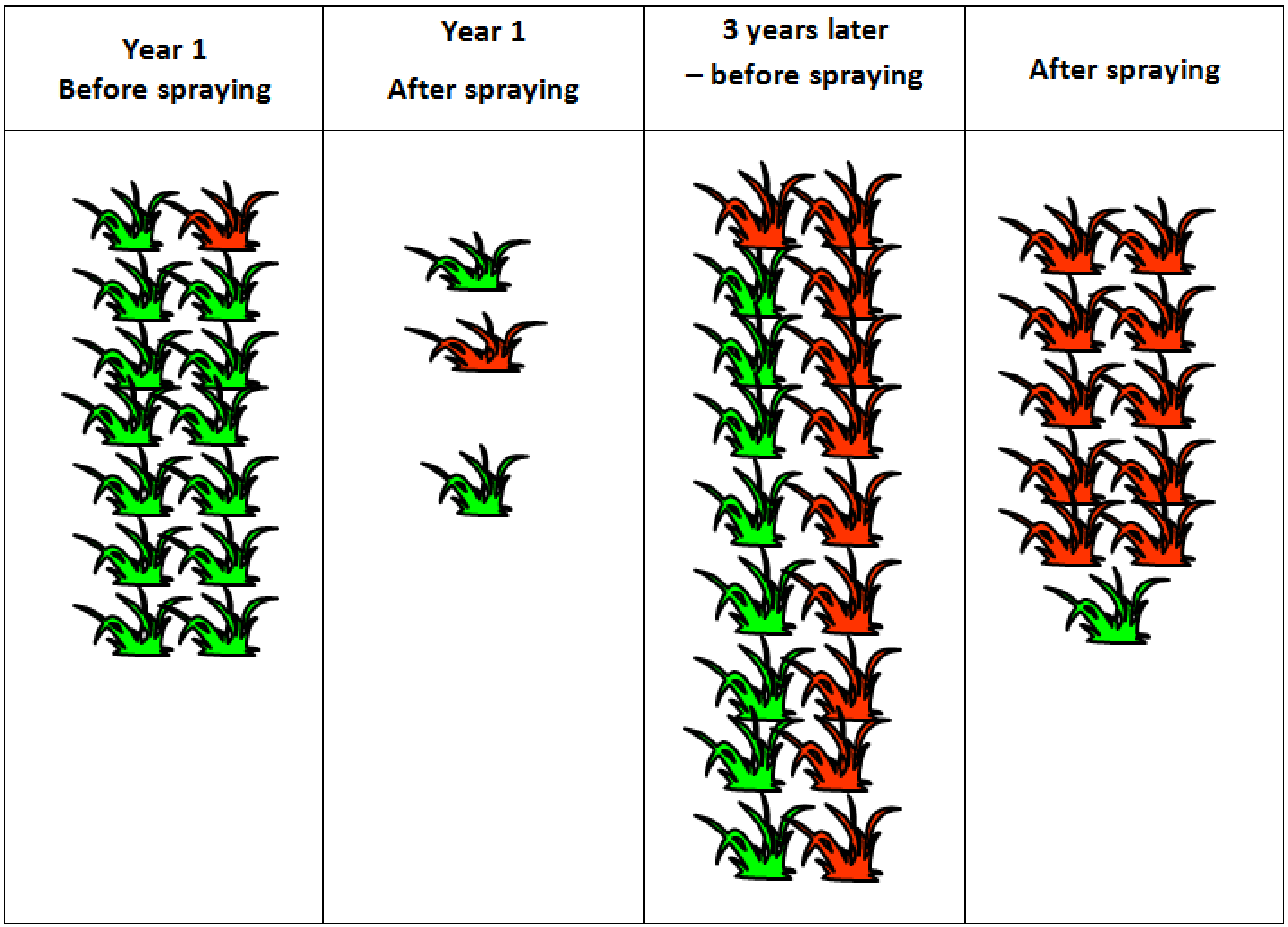
Emergence of GR weeds populations.

- Glyphosate has gradually become less effective in many areas as GR weeds have emerged.

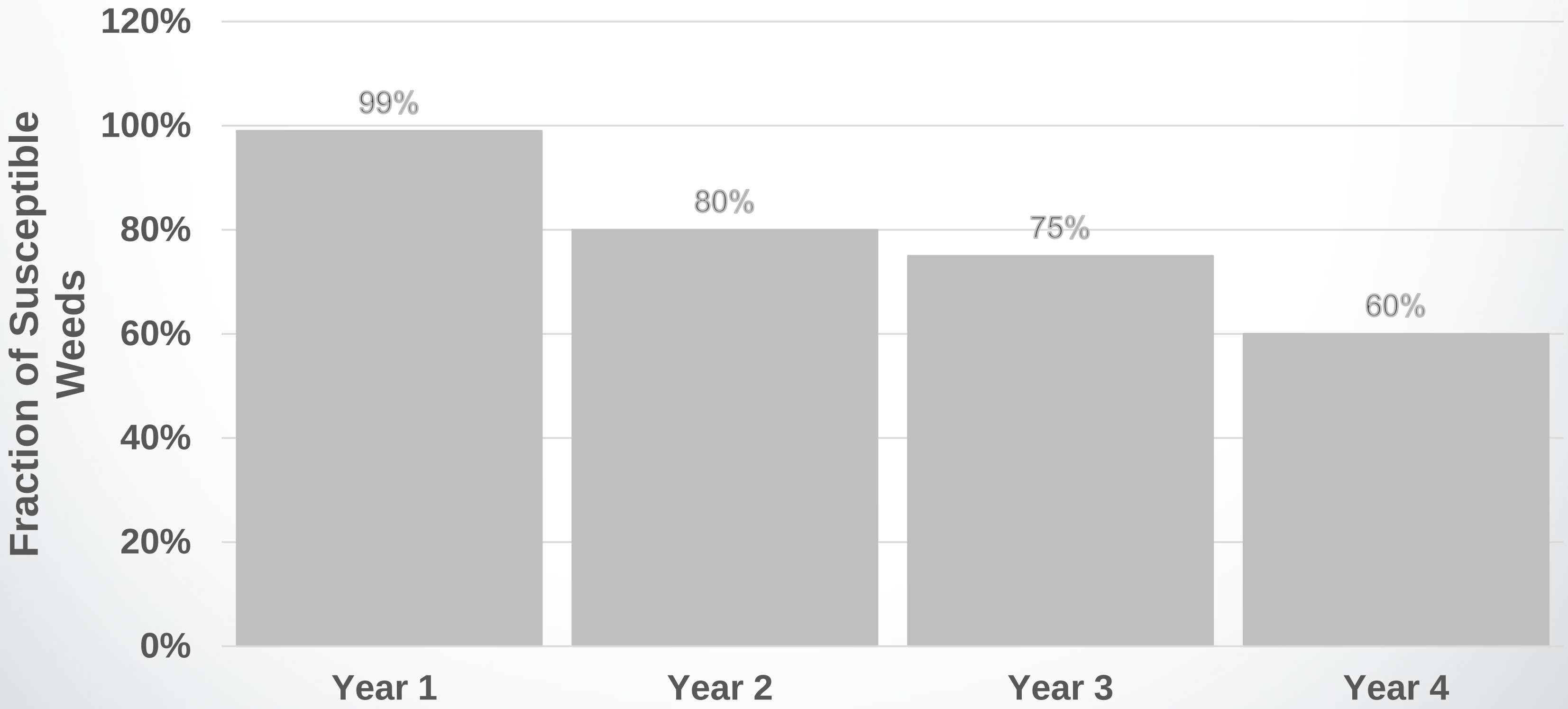
- This is because controlling weeds with glyphosate gives a reproductive advantage to weeds that are naturally resistant to glyphosate.

- Thus, overtime, the **susceptibility of the weed population to glyphosate is depleted** as GR weeds represent an increasing share of the weed population that farmers must control.

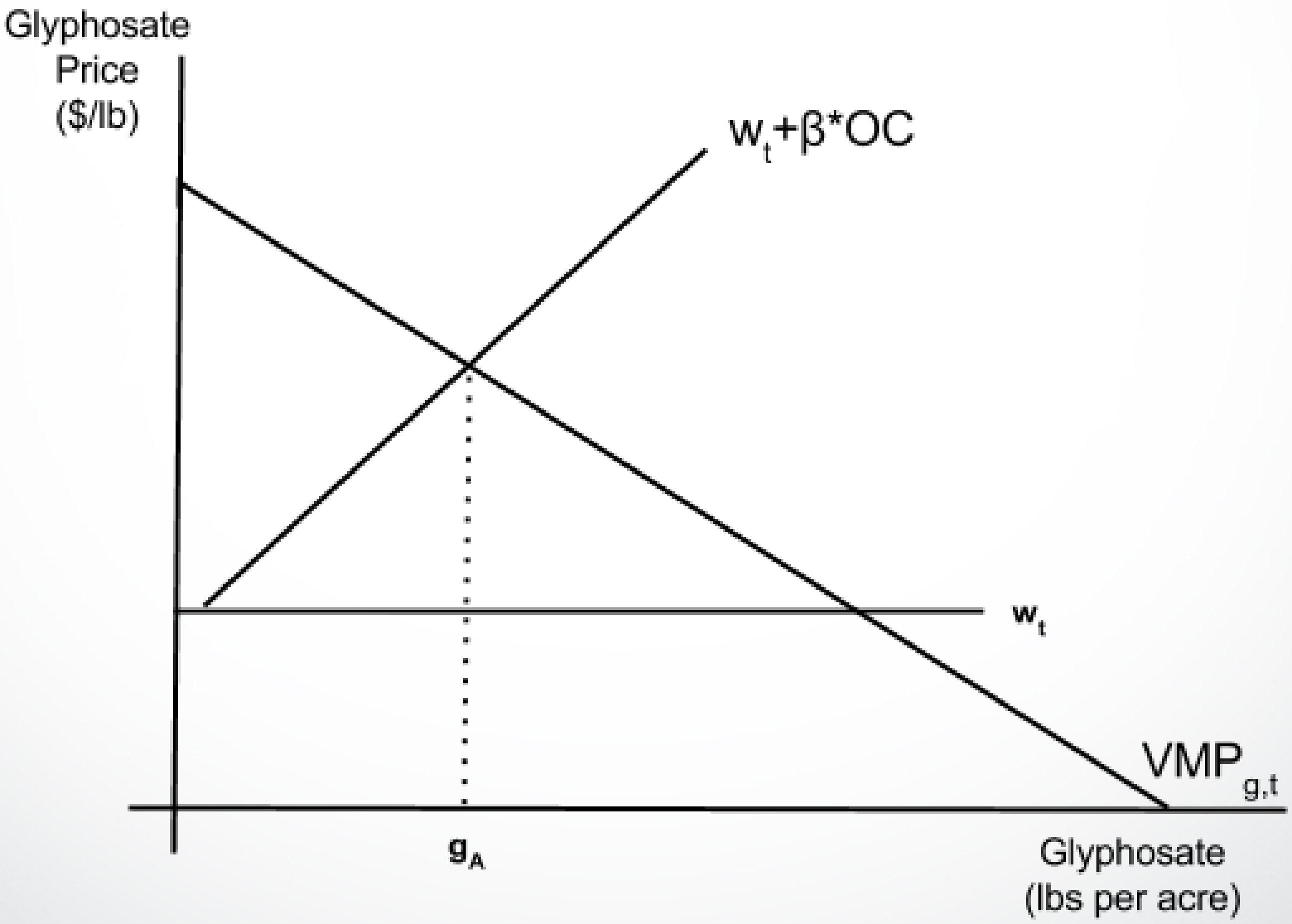
Glyphosate use gives GR weeds reproductive advantage.



Fraction of susceptible weeds falls over time.



Model susceptibility as depletable resource.



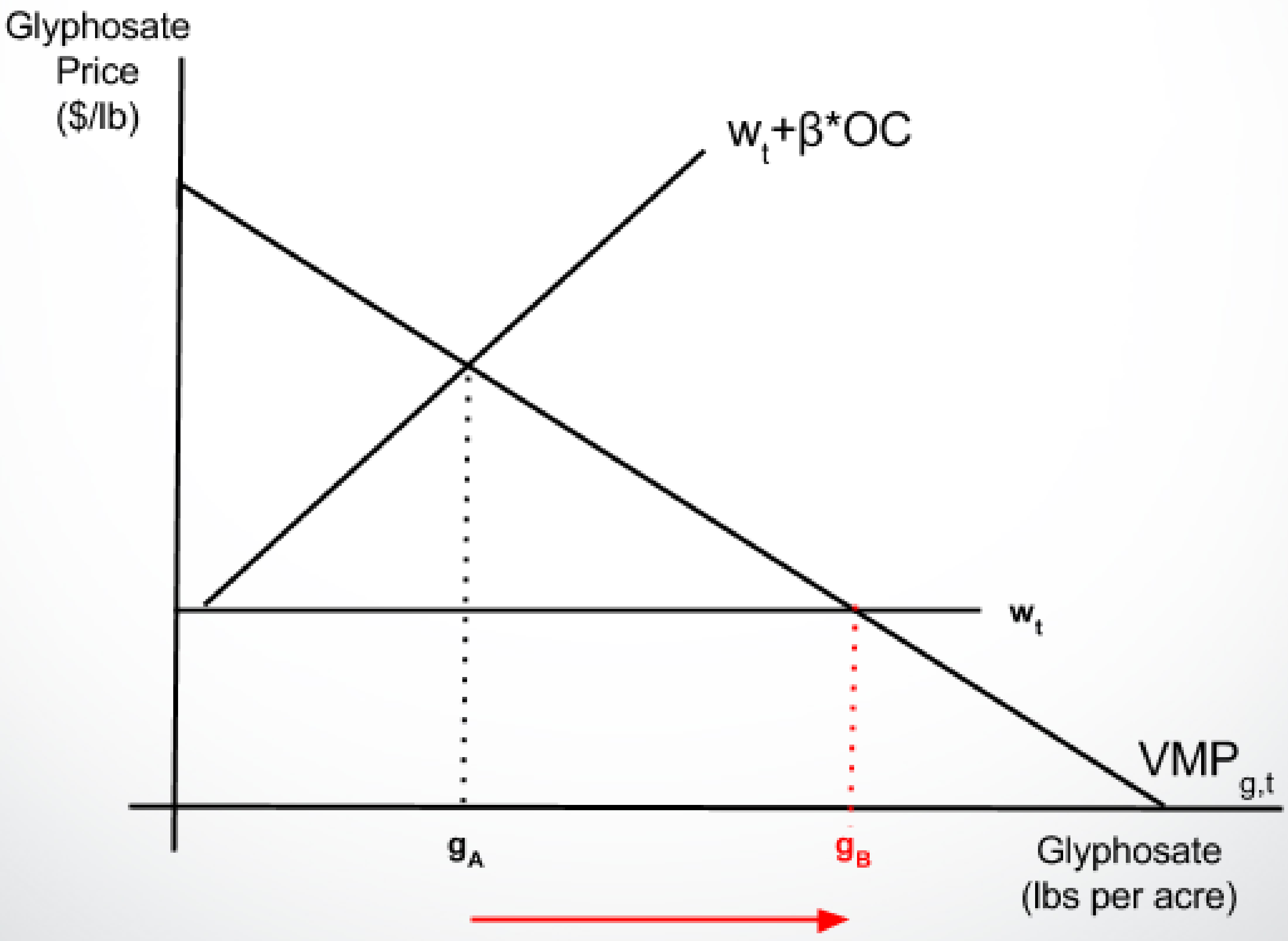
Weed mobility changes everything.

- **If weeds are highly mobile** across a set of closely located farms, this implies that these **farmers collectively face a shared weed population**.

- As a result, how quickly this population's vulnerability to glyphosate is depleted will depend on how much glyphosate is applied by ALL farmers in that area.

- Thus, in this situation, glyphosate susceptibility can be considered a common property resource (Clark and Carlson, 1990).

Encourages overuse of glyphosate.



Weeds are mobile, but has this led to overuse of glyphosate?

- There is evidence that weeds are mobile. The *Conyza Canadensis* plant a.k.a horseweed can travel up to 547 yards on the wind alone (Dauer *et al.*, 2007).

- However, it is not obvious that this level of weed mobility has led to the overuse of glyphosate.
  - Does distance between farms?
  - Could informal agreements could be reached?

No recent studies have tried to answer this question.

- Only Clark and Carlson (1990) has tried to determine if there were common property resource problems associated with herbicides.

- They found no evidence of common-property resource characteristics associated with aggregate herbicide use.

- Purpose of this study is to fill the gap in the literature. **I identify two empirical strategies to answer this question.**

Empirical Strategy 1: Structural Approach

- Test whether growers are myopic (as in common property regiment where β=0) or forward-looking.

- Grower's Problem:

$$\underset{\{G_t\}}{\text{Maximize}} \quad \pi_t = \sum_{i=0}^{\infty} \beta^i [f(G_{t+i}, S_{t+i}) - wG_{t+i}]$$

$$\text{Subject to} \qquad S_t - S_{t-1} = \varphi - \delta G_{t-1}$$

Derive and estimate Euler Equation then test model restriction.

- *Estimate model for forward-looking growers*
- $G_t = \beta_0 + \beta_1 G_{t+1} + \beta_2 G_{t-1} + \beta_3 w_{t+1} + \beta_4 w_t + \beta_5 w_{t-1} + u_t$

- *Estimate model for myopic growers* (β=0)
- $G_t = \alpha_0 + \alpha_1 G_{t-1} + \alpha_2 w_t + \alpha_3 w_{t-1} + \varepsilon_t$

- *Test model restrictions*

Empirical Strategy 2: Reduced form approach

- Recognize that problems associated with weed mobility are worse in areas where there are more farms per acre (high density). Why?
  1. Weeds have less distance to travel, making it more likely growers share a common weed population.

  2. More farmers may increase cost of coordinating weed management activities.

- This suggests the following testable implication:

$$H_{null}: \frac{\partial g_{it}}{\partial D} = 0$$

$$H_{alt}: \frac{\partial g_{it}}{\partial D} > 0$$

Empirical Strategy 2: Estimation

- In order to estimate the partial effect of interest, I estimate the demand for glyphosate using a single-equation approach.

- Specifically, I assume glyphosate application (G) is a function of the following:
  - Density of Glyphosate Using Farmers
  - Source of Information on Herbicide Use
  - Weather conditions
  - Production Practices
  - Region

Empirical Strategy 2: Model to estimate

- Equations to be estimated using OLS

Model 1: $G_i = \beta_0 + \beta_1 D_i + \beta_2 D_i^2 + \ \alpha Weather_i + \gamma Production_i + \theta Region_i + u_i$

Where:

- G_i = grower i's post-emergence glyphosate application rate (lbs. per acre),
- D_i = density or the number of farms per 1,000 acres in the county containing grower i,
- $Weather_i$ = spring temperature and precipitation in the county containing grower i,
- $Production_i$= production practices of grower i,
- $Region_i$=USDA Ag production Region containing grower I,

Empirical Strategy: Hypothesis Test

- Hypothesis to be tested

$$\mathrm{H_{null}}: \frac{\partial \mathrm{G}}{\partial D} = (\beta_1 + 2\beta_2 D_i) = 0$$

$$\mathrm{H_{alt}}: \frac{\partial \mathrm{G}}{\partial D} = (\beta_1 + 2\beta_2 D_i) > 0$$

Data: Sources

- Cross-Sectional data on glyphosate application & other grower production practices characteristics were obtained at field-level for U.S. Soybean Growers from 2006 USDA Agricultural Resource Management Survey.

- This dataset was chosen because…
  1. Easier to argue growers are informed about consequences of glyphosate over use, and

  2. Less technological heterogeneity.

Data - Sources

- **Neighbor Density (Farms per acre):** Obtained obtained from the 2007 U.S. Agricultural Census at the county-level.
  - This essentially assumes that each county faces a single, separate weed population. Hard to say if this is true.
- **Weather Controls:** Spring temperature and precipitation estimated using weather-station level data obtained from the National Climate Data Center from its Global Historical Climatology Network (GHCN) Monthly database.

Descriptive Statistics (2,258 Observations)

Variable (units)	Mean	St Dev	Min	Max
Neighbor Density (Farms per 1,000 Acre)	1.87	0.88	0.19	5.95
Total Glyphosate Application (lbs. er acre)	1.33	0.56	0.12	3.00
Soybean Farm Size (Acres)	723.2	840.7	6	11,900
Mean Monthly Temperature, Spring (°C)	18.38	4.03	8.35	28.23
Total Precipitation, Spring (millimeters)	12.93	3.61	5.12	27.76
Neighbor(s) Primary Source for Pest Info	0.02	0.16	0.00	1.00
Neighbor(s) Primary Source for Pest Info	0.21	0.41	0.00	1.00
Neighbor(s) Primary Source for Pest Info	0.21	.41	0.00	1.00

Empirical Results

OLS Estimates (2,258 Observations)

Variables	(1)		(2)		(3)	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std Err.
Dependent Variable: Glyphosate Application Rate (lbs. per acre)						
Density	-0.139**	0.054	-0.132**	0.059	-0.127**	0.056
$Density^2$	0.026**	0.011	0.024**	0.012	0.024**	0.012
Weather Controls	Excluded		Included		Included	
Info Controls	Excluded		Excluded		Included	
Reg. Dummies	Included		Included		Included	
Adjusted R^2	0.036		0.038		0.045	

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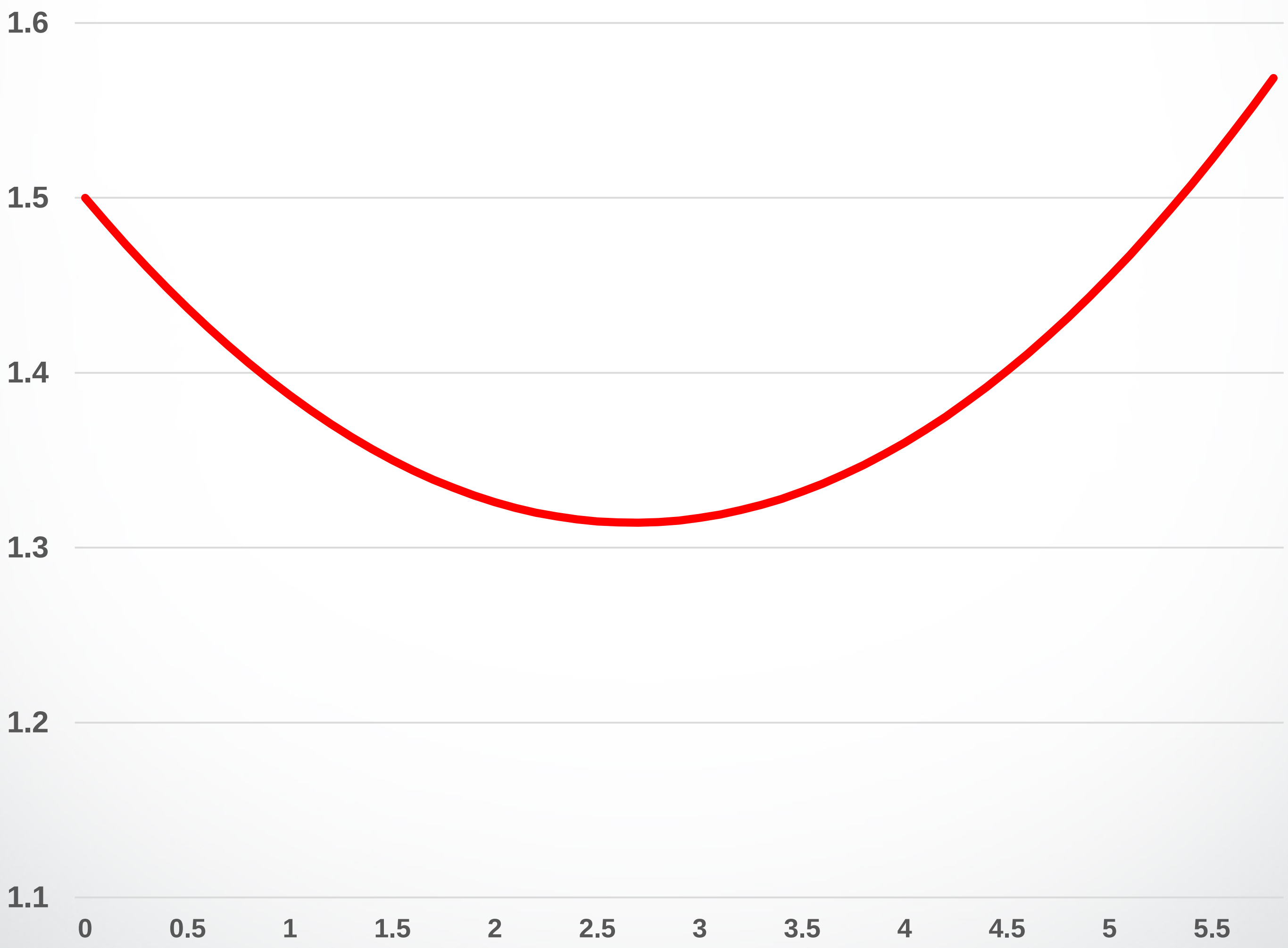
Predicted Glyphosate Application Rate



Testing Partial Effect of Neighbor Density on Glyphosate Application Rate

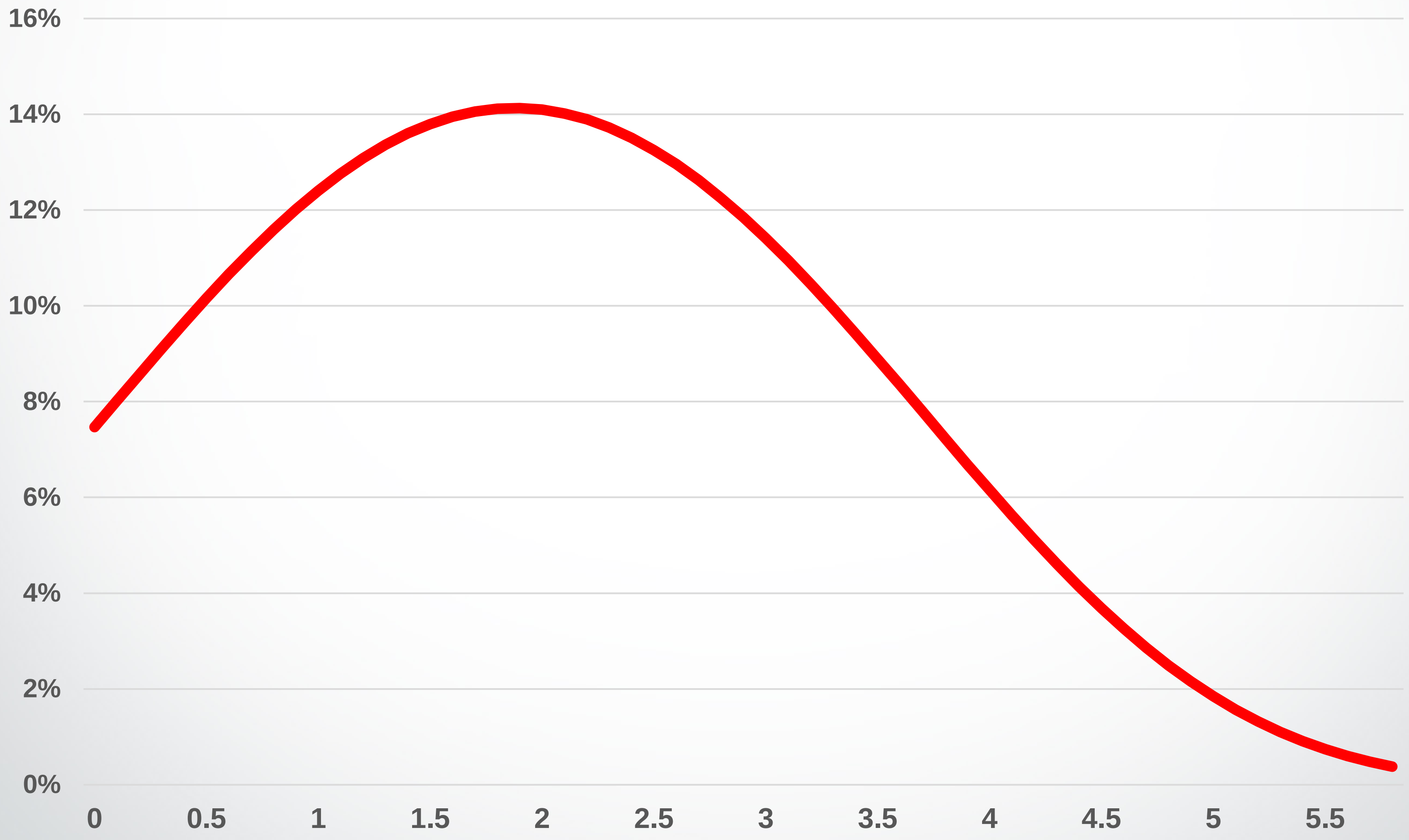
Neighbor Density	$\boldsymbol{\beta_1 + 2\beta_2 N_i}$	Standard Error	T-Stat	One-Sided 5% Critical Value
Minimum (0.191)	-0.132	0.052	-2.55	1.645
1	-0.079	0.034	-2.30	1.645
2	-0.031	0.018	-1.69	1.645
3	-0.009	0.031	-0.30	1.645
4	0.064	0.044	1.46	1.645
5	0.113	0.066	1.70	1.645
Maximum (5.951)	0.169	0.088	1.91	1.645

Note: Standard errors were computed for each partial effect by centering and re-estimating the model for each density.

Probit Estimates (2,258 Observations)

Variables	(1)		(2)		(3)	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std Err.
Dependent Variable: Grower use herbicides with multiple-MOAs (1=Yes, 0=No)?						
Density	0.391*	0.205	0.394*	0.206	0.495***	0.215
Density^2	-0.104**	0.021	-0.105**	0.020	-0.118**	0.047
Size Controls	Excluded		Included		Included	
Weather Controls	Excluded		Included		Included	
Info Controls	Excluded		Excluded		Included	
Reg. Dummies	Included		Included		Included	

Predicted probability of using herbicides with multiple mechanisms of action



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Conclusions

Conclusions

- A I do not find evidence that the emergence of glyphosate resistance was the result of a national “tragedy of the commons” problem.

- According to the base model, a higher neighbor density actually has a negative effect on the glyphosate application rate until the density reaches 2.7 farms per 1,000 acres, only after which does the effect becomes positive.

Conclusions - Alternative Explanations

- Alternative Explanation #1 – Growers may be attracted to areas that simply have fewer weeds and therefore have to apply less glyphosate.
  - If this were true and weed mobility were still issue, you would expect that growers in more populated areas would still be less likely to use pesticides with multiple modes of action. This is not what I find.
- Alternative Explanation #2 – Growers in more populated areas may benefit from knowledge spillovers that make them more likely to adopt IPM practices.

Feedback

References

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Appendix

Testing Partial Effect of Neighbor Density on Glyphosate Application Rate

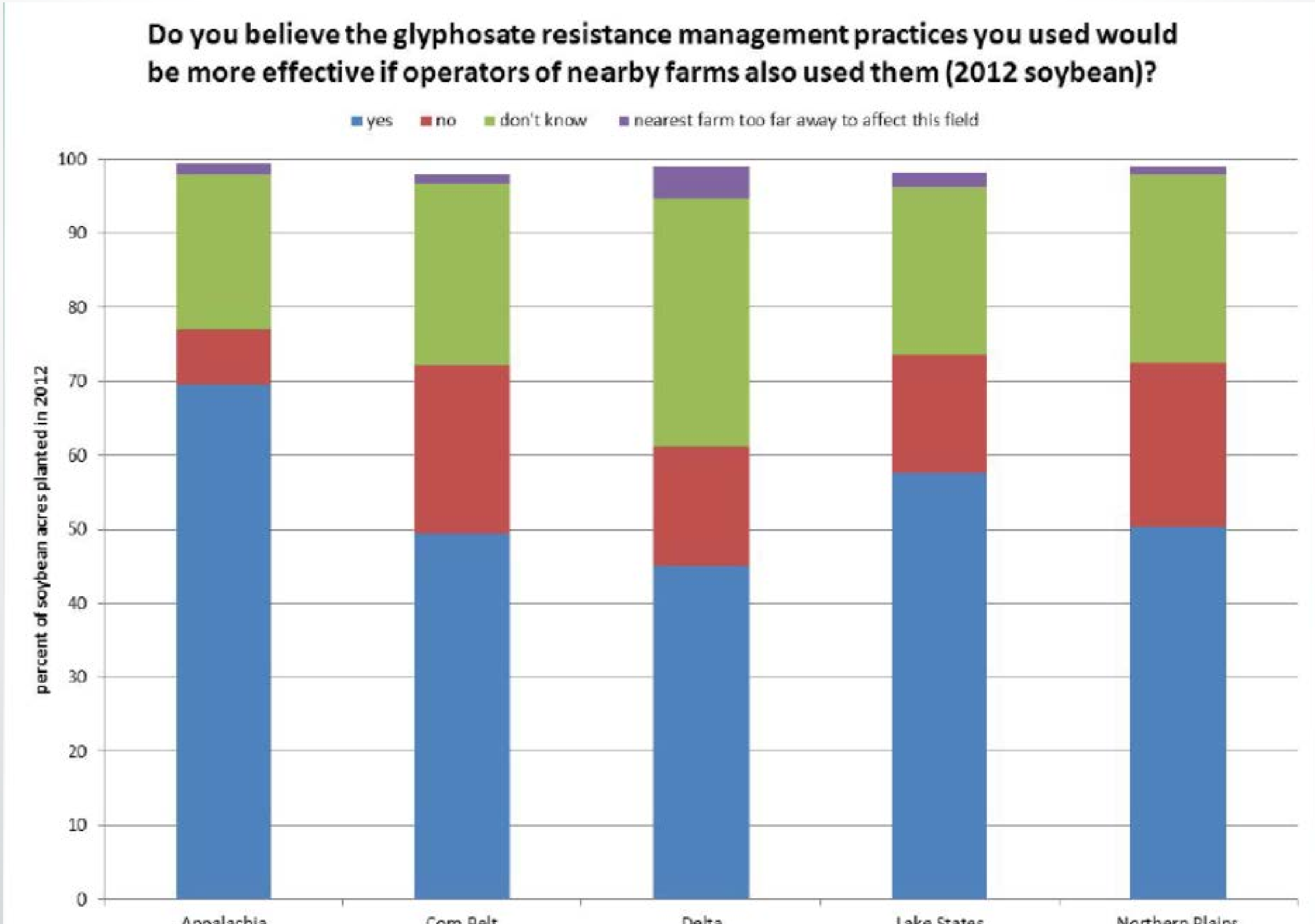
Neighbor Density	$\beta_1 + 2\beta_2 N_i$	Standard Error	T-Stat	One-Sided 5% Critical Value
Minimum (0.191)	-0.132	0.052	-2.55	1.645
Lower Quartile (1.210)	-0.078	0.030	-2.60	1.645
Median (1.859)	-0.044	0.019	-2.25	1.645
Upper Quartile (2.425)	-0.015	0.018	-0.85	1.645
Maximum (5.951)	0.169	0.088	1.91	1.645

Note: Standard errors were computed for each partial effect by centering and re-estimating the model for each density.

3.0 Data for Structural Approach

- **State-level Glyphosate Application Rates:** Agricultural Resource Management Survey (ARMS). Data used for 1996-2002 for soybean growers.

- **Output and Input Price Data:** mean price farmers paid for glyphosate across the U.S. between 1990 and 2002 were obtained from Agricultural Chemical Usage Report. Data on mean prices for soybeans received by farmers were obtained for each state and each year between 1990 and 2002 from the USDA's annual commodity cost and returns report.


Do you believe the glyphosate resistance management practices you used would be more effective if operators of nearby farms also used them (2012 soybean)?
yes
no
don't know
nearest farm too far away to affect this field
percent of soybean acres planted in 2012
0
10
20
30
40
50
60
70
80
90
100
Appalachia
Corn Belt
Delta
Lake States
Northern Plains

OLS Estimates Model 2 (2,258 Observations)

Variables	(1)		(2)		(3)	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Dependent Variable: Glyphosate Application Rate (lbs. per acre)						
N	-0.229***	0.069	-0.216***	0.071	-0.231**	0.070
N^2	0.043***	0.013	0.039**	0.015	0.044**	0.016
NxApp	0.294**	0.119	0.262**	0.121	0.270**	0.120
N^2xApp	-0.052**	0.024	-0.046*	0.025	-0.050**	0.025
Weather Controls	Excluded		Included		Included	
Production Controls	Excluded		Excluded		Included	
Regional Dummies	Included		Included		Included	
Adjusted R^2	0.039		0.041		0.052	

Game Theoretic Model

- Individual grower's application decision in Symmetric Nash Equilibrium is represented by:
- $$\frac{pY_1\phi W_0}{\frac{g_1}{g^{max}}e} = q + \beta\left(\frac{pY_2\phi W_0 \ln\left(\frac{\phi W_0\left(pY_2 - \ln\left(\frac{ng_1}{G^{stock}}e\right)\right)}{q}\right)}{ng_1}\right)$$

Game Theoretic Model (cont.)

- As number of growers increases, the present value of the opportunity cost next period declines
- $$\lim_{n\to\infty}(q) = \lim_{n\to\infty}\left(\frac{pY_1\phi W_0}{\frac{g_1}{g^{max}}e}\right) + \lim_{n\to\infty}\left(\beta\frac{pY_2 bW_0 \ln\left(\frac{\phi W_0\left(pY_2 - \ln\left(\frac{ng_1}{G^{stock}}e\right)\right)}{q}\right)}{ng_1}\right)$$
- In the limit it disappears and grower makes decision based only on maximizing current period profits:

$$\frac{pY_1\phi W_0}{\frac{g_1}{g^{max}}e} = q$$