

# Direct and downstream health effects of herbicides

Identification based on the US rollout of GM crops

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# Glyphosate and GM Crops

## Glyphosate

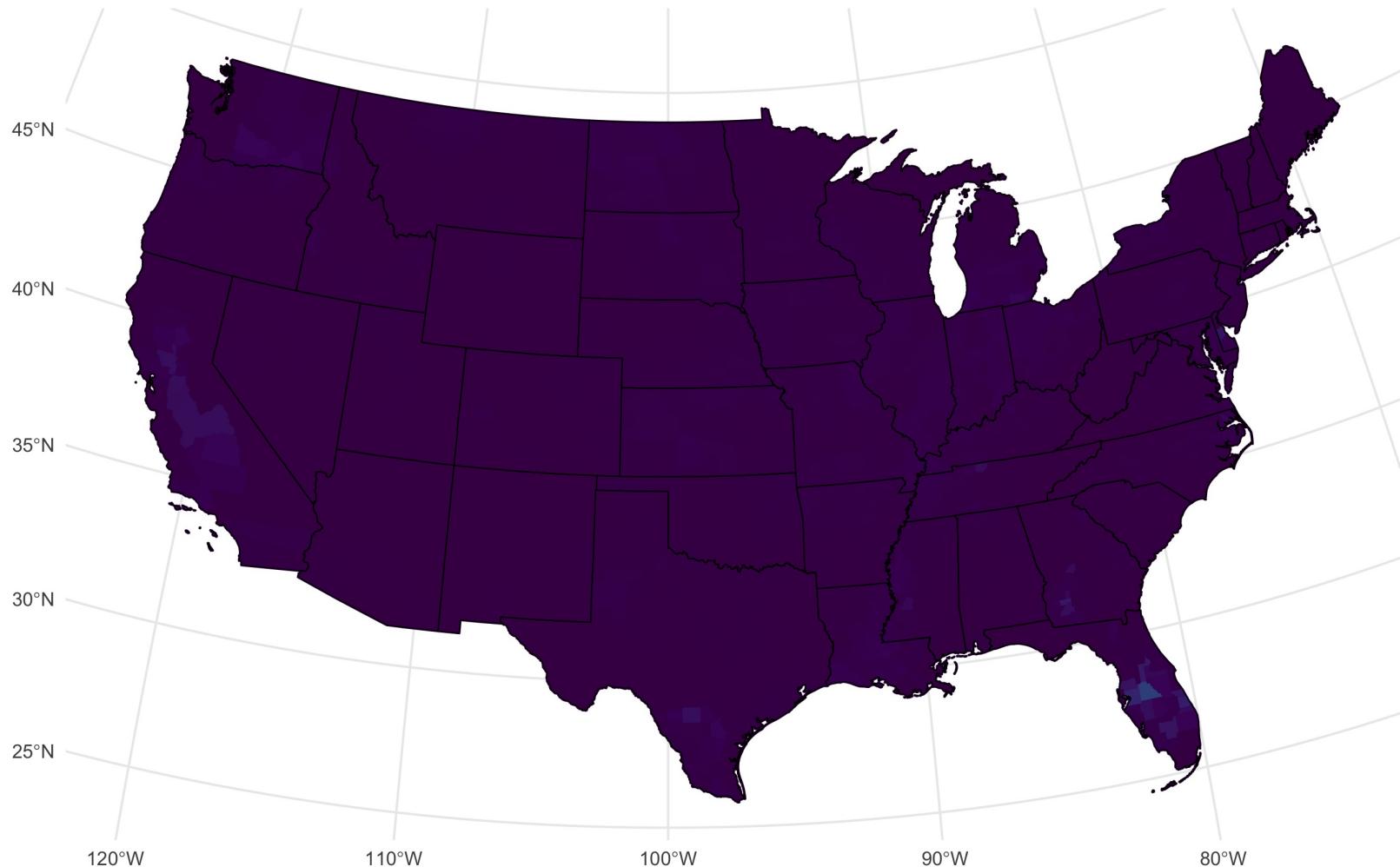
- Glyphosate (Roundup) is a weed killer developed by Monsanto in 1974
- It is **relatively less toxic** than other herbicides (DDT, paraquat, atrazine)
- Very water soluble

## Pairing with GM technology

- In the 1990's Monsanto introduced genetically modified (GM) crops that are **resistant to glyphosate**
- With GM seeds, farmers can spray their crops with glyphosate and kill all of the weeds, but not harm their crops

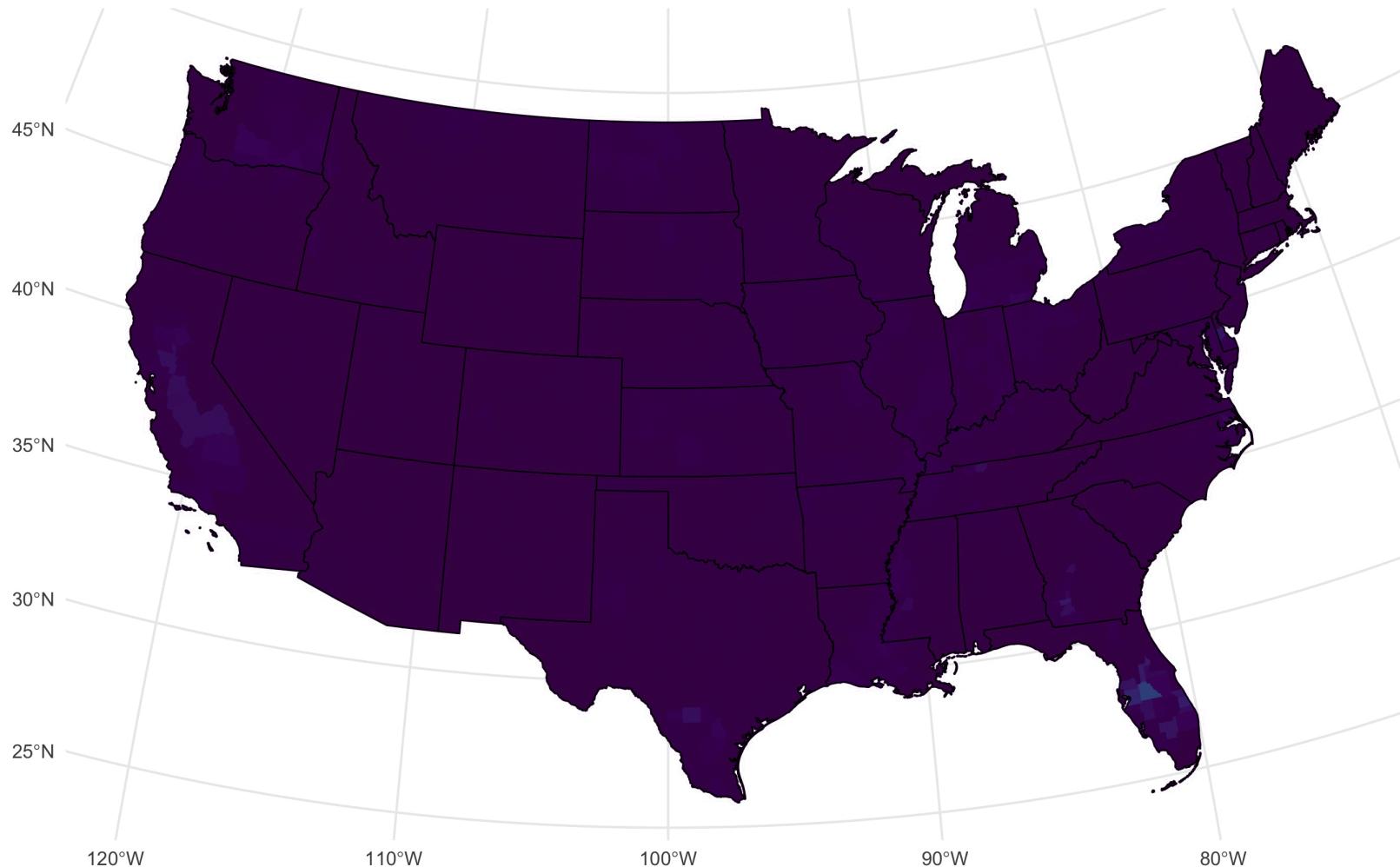
# Glyphosate in the US in 1992

**Glyphosate per square km in 1992**



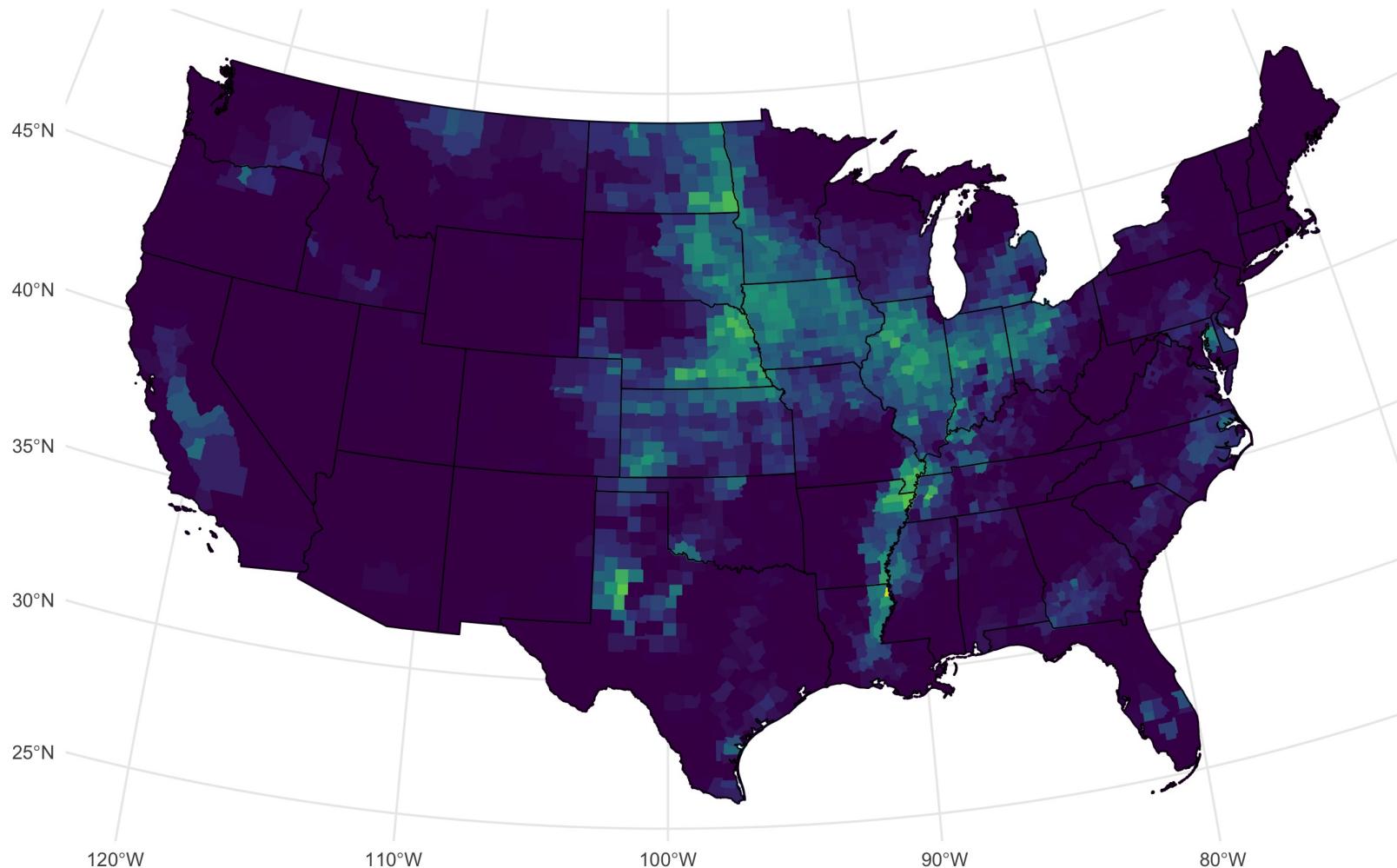
# Glyphosate in the US from 1992 to 2017

## Glyphosate per square km in 1992



# Glyphosate in the US in 2017

**Glyphosate per square km in 2017**



# Overview

**Research Question** Has the use of glyphosate due to the adoption of GM crops led to adverse health effects due to environmental exposure? Are there downstream spillovers?

**Methodology** Difference-in-differences comparing counties that are suitable for crops with GM varieties (corn, soy, and cotton), to those that are not; before and after the 1996 introduction of GM varieties.

**Data** We obtain county-level herbicide use from the USGS, birth certificate data from the NCHS, and crop suitability from the UN-GAEZ.

**Results** Corn-soy-cotton (CSC) counties show

- 1) Large increases in local glyphosate use
- 2) Decreases in birth weight relative to non-CSC counties
- 3) No statistically significant effect from upstream spraying

# Glyphosate and Health

- IARC (part of UN) said glyphosate is "likely carcinogenic" in 2015
- EPA says it is "safe at relevant doses"
- US court just ruled EPA must revisit this designation
- Camacho and Mejia (JHE 2017) and Dias et al (2019) show adverse effects on health from glyphosate in environment

The New York Times

## Weed Killer, Long Cleared, Is Doubted

 Give this article  



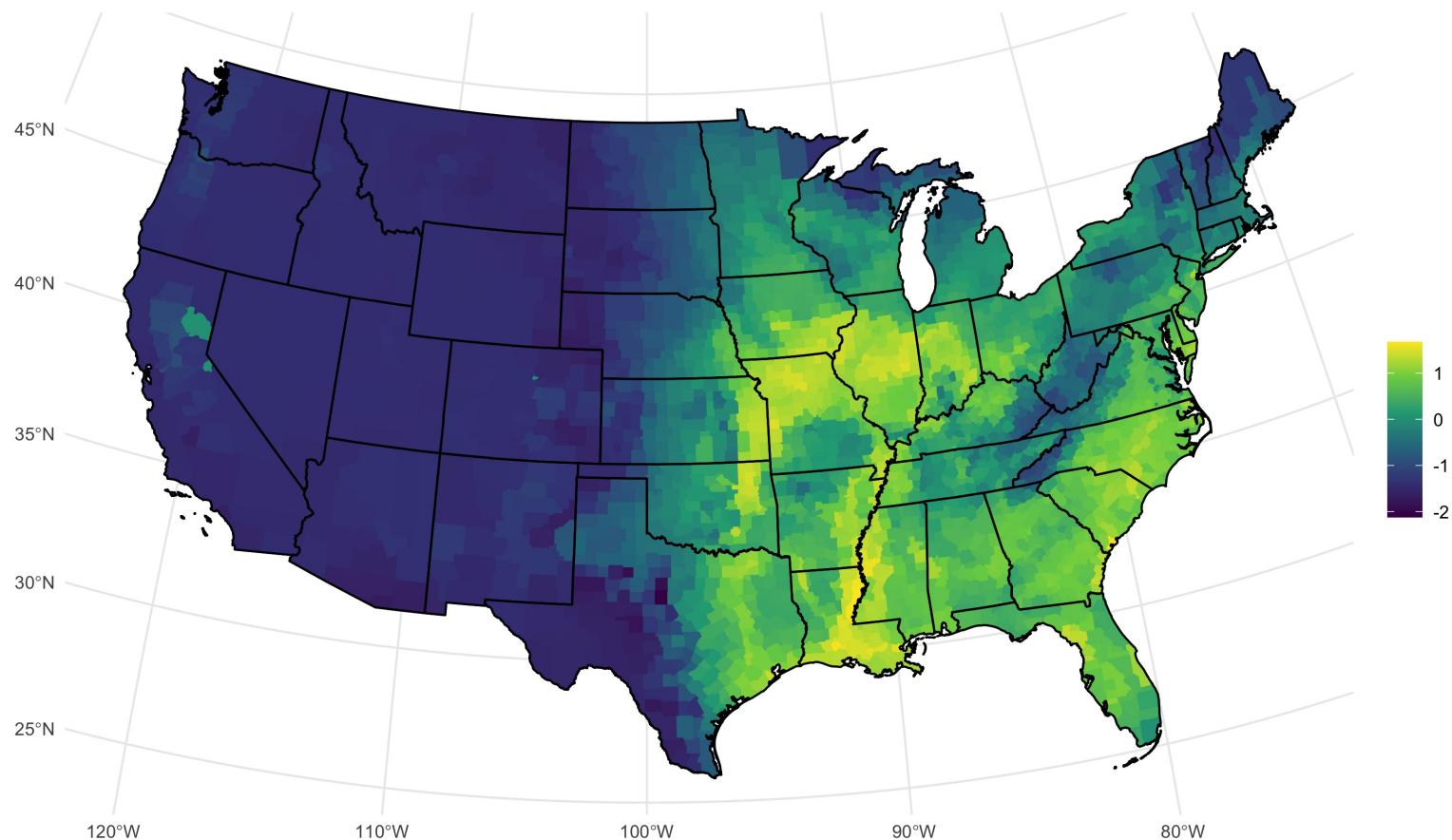
Glyphosate being sprayed on a field in Suffolk, England. Introduced in the 1970s, it is the most widely used herbicide in the world. Universal Images Group, via Getty Images

By [Andrew Pollack](#)

March 27, 2015

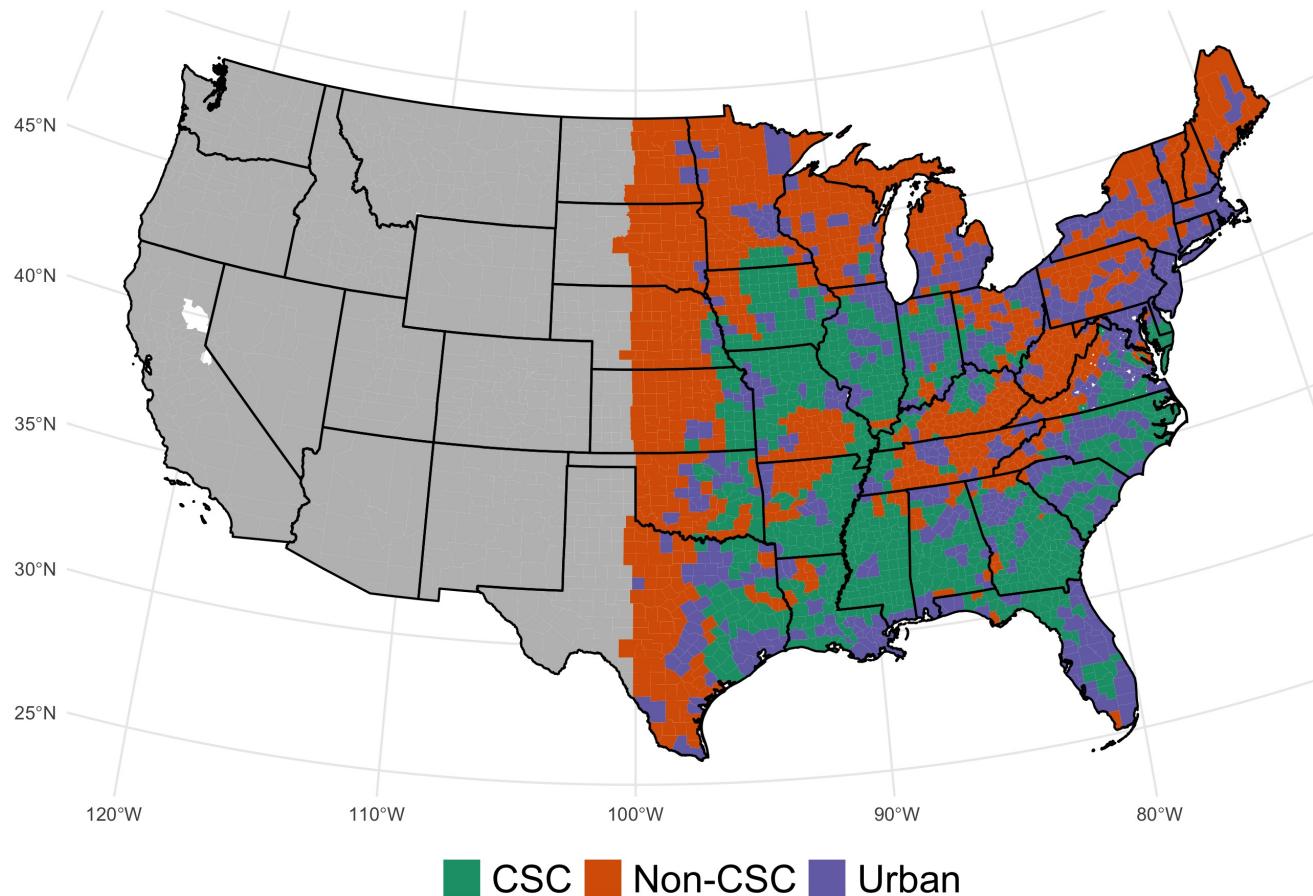
# GAEZ attainable yield

We standardize attainable yield for corn, soy, and cotton, then take the average across the three as a measure of suitability for GM crops.



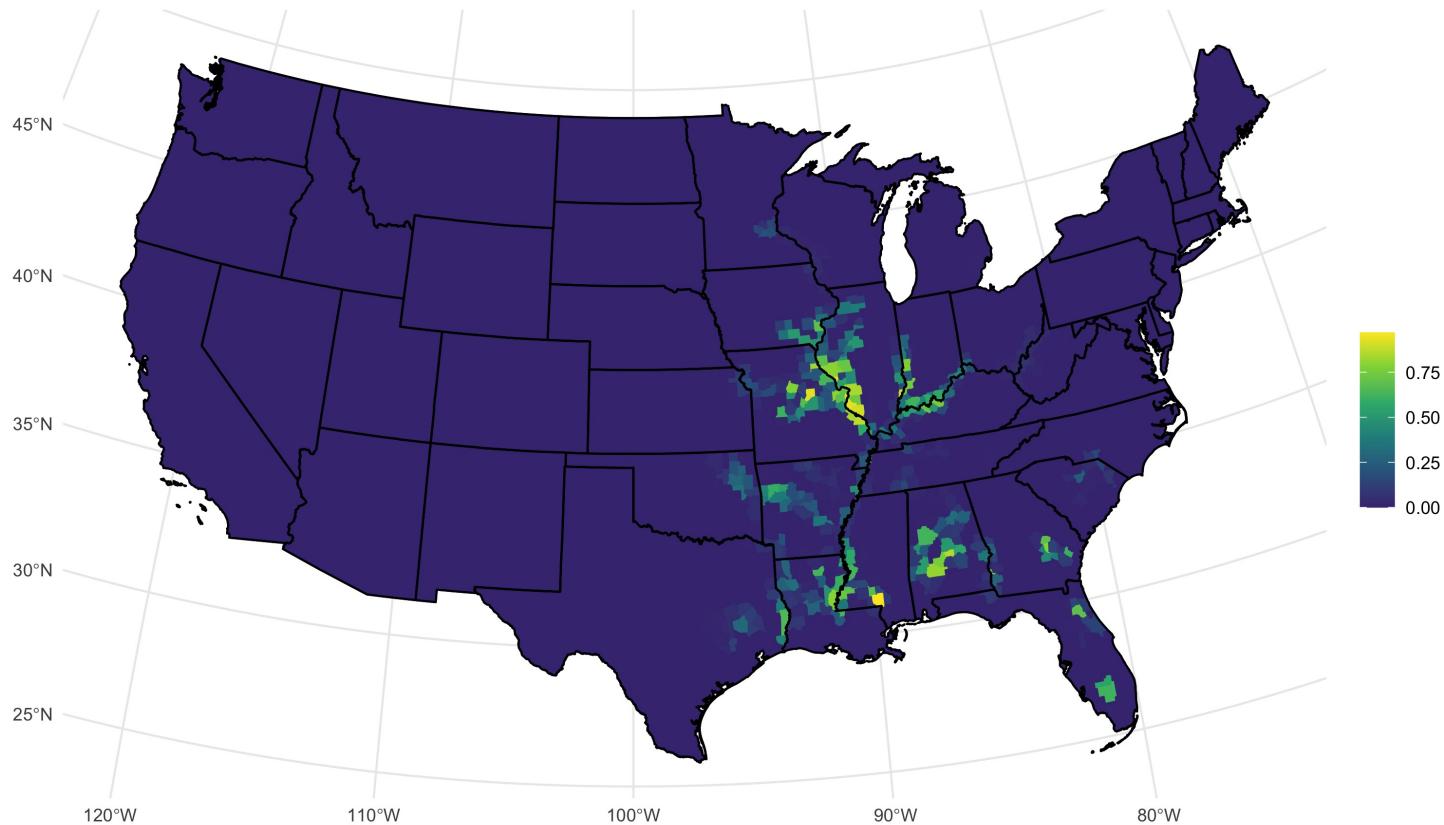
# CSC vs non-CSC Counties

Eastern, rural counties above median attainable yield for CSC are more likely to adopt GM and glyphosate.



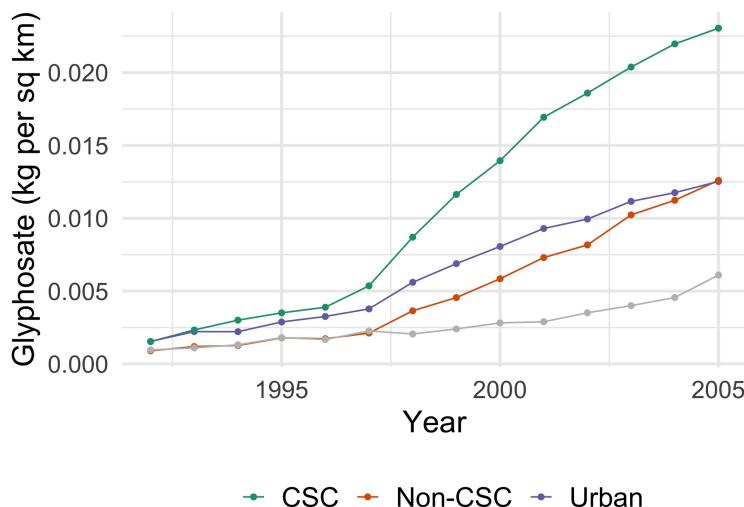
# Aggregating upstream CSC

Proportion of upstream counties that are CSC

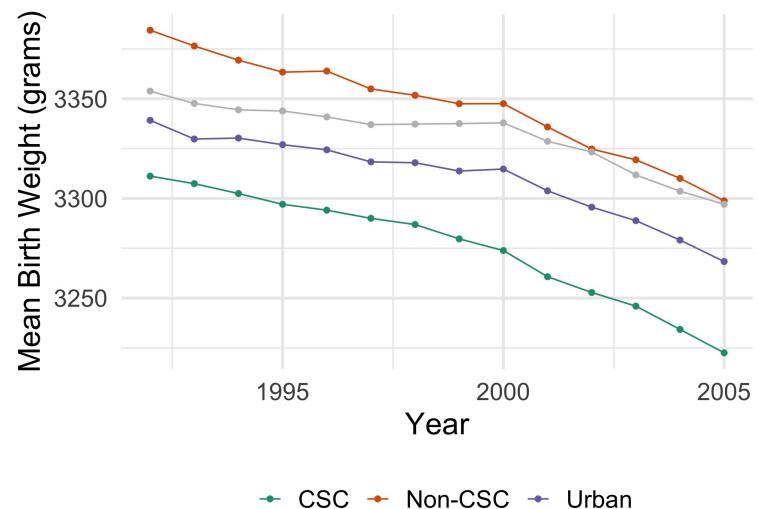


# Trends in glyphosate and births

## Glyphosate



## Median birth weight



# Methodology

# RF effect of GM on birth weight

How birth weights change in CSC after 1995 relative to non-CSC counties:

$$BW_{ijt} = \sum_{\tau \neq 1995} \left( \gamma_{\tau}^l GM_{j\tau}^{local} + \gamma_{\tau}^u GM_{j\tau}^{upstream} \right) + X'_{ijt} \delta + \alpha_j + \lambda_t + \varepsilon_{ijt}$$

- $GM_{j\tau}^{local}$  is an indicator for whether county  $j$  is CSC
- $GM_{j\tau}^{upstream}$  is the proportion watersheds upstream that are CSC

**Important:** Effect is calculated *relative* to whatever was going on in the pre-period (supposedly more toxic chemicals, more tilling).

## Parallel trends required for causality

If GM crops had not been introduced, then the difference in mean birth weight between CSC counties and non-CSC counties would have remained constant.

# Two-Stage Least Squares

- The effect of GM on health comes through glyphosate, not GM itself
- We're worried about bias if we estimated with OLS
- Use CSC interacted with year as an instrument glyphosate,  $G_{jt}$

$$G_{ijt} = \sum_{\tau \neq 1995} \theta_\tau GM_{j\tau}^{local} + X'_{ijt} \delta + \alpha_j + \lambda_t + u_{ijt}$$

$$BW_{ijt} = \beta \hat{G}_{ijt} + X'_{ijt} \eta + \alpha_j + \lambda_t + \epsilon_{ijt}$$

## Exclusion restriction required for causality

Our instruments, CSC dummy variable interacted with year, only affect birth weight through glyphosate, conditional on year and county fixed effects.

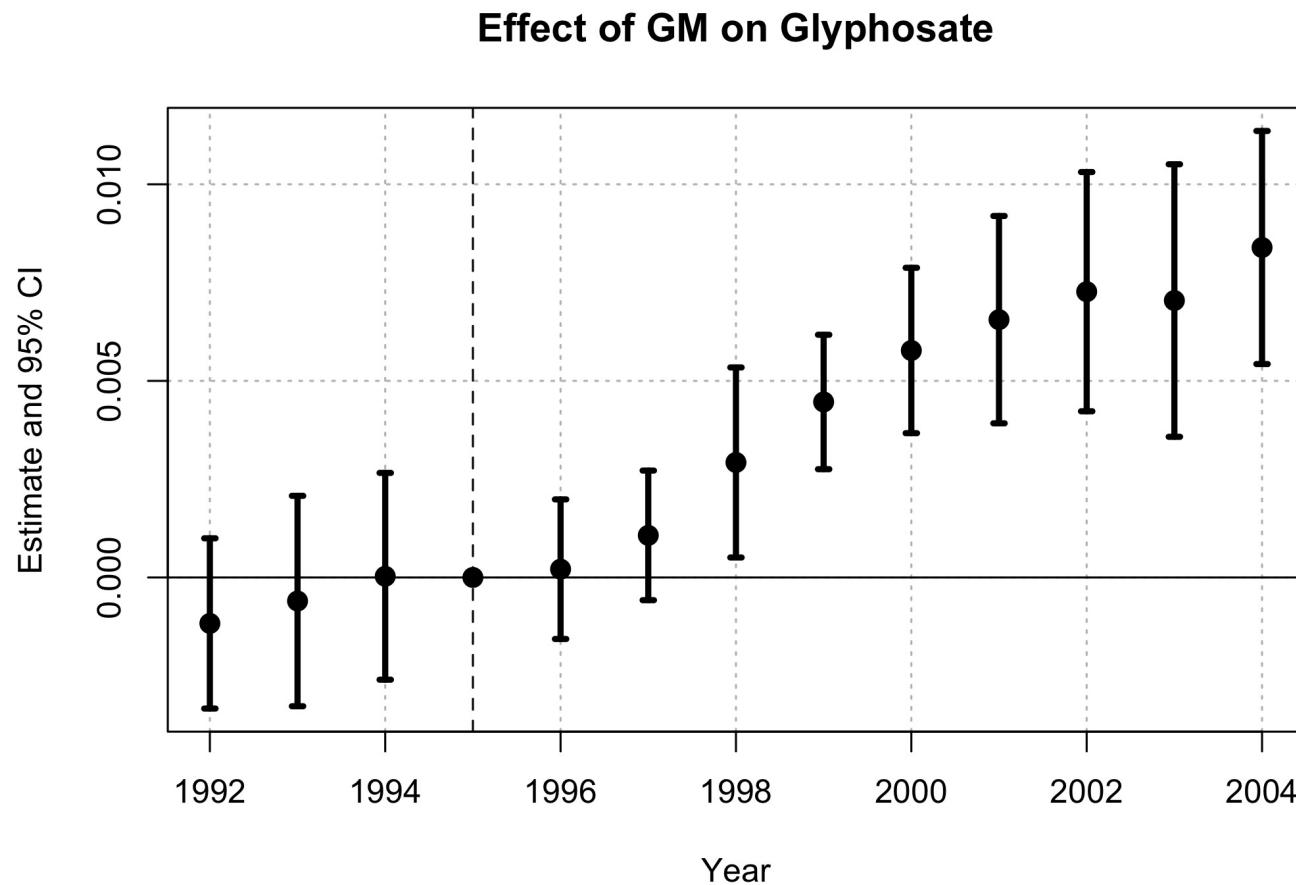
# Results

# First stage effect of GM on glyphosate

Going to plot the  $\theta_\tau$  coefficients from

$$G_{ijt} = \sum_{\tau \neq 1995} \theta_\tau GM_{j\tau}^{local} + X'_{ijt} \delta + \alpha_j + \lambda_t + u_{ijt}$$

# First stage effect of GM on glyphosate



CSC counties see **larger increase in glyphosate** than non-CSC counties

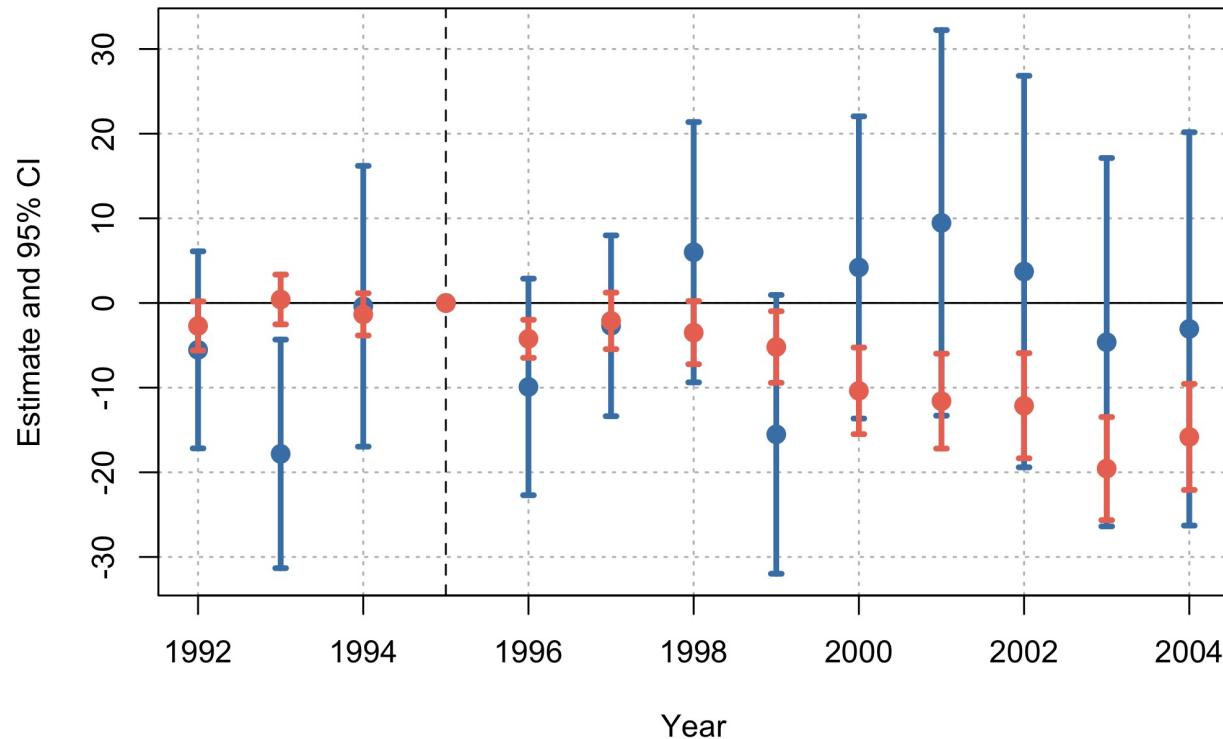
# RF effect of GM on birth weight

Going to plot the  $\gamma_{\tau}^l$  and  $\gamma_{\tau}^u$  coefficients from

$$BW_{ijt} = \sum_{\tau \neq 1995} \left( \gamma_{\tau}^l GM_{j\tau}^{local} + \gamma_{\tau}^u GM_{j\tau}^{upstream} \right) + X'_{jt} \delta + \alpha_j + \lambda_t + \varepsilon_{ijt}$$

# RF effect of GM on birth weight

Effect of local and upstream GM on Birth Weight



- Birth weight in CSC counties **decreases** relative to non-CSC counties
- CSC counties upstream have **no significant effect** on birth weight

# Second Stage estimates

Effect of Glyphosate on Birth Weight

	1	2	3
Glyph per sq-km	-1000*	-1221**	-1303+
	(388)	(394)	(601)
Mother Demographic Controls		X	
Other Herbicide Controls			X
1st Stage F-Stat	37150	34871	23641
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001			

Moving from the 50th to 90th percentile in glyphosate use in 2004 leads to a **35.2 to 56.6 gram decrease** or **1.2 to 2 ounce decrease** in birth weights.

# Conclusion

## GM technology altered herbicide use dramatically

- Farmers switched from many herbicides and mechanical tilling to glyphosate with GM varieties of crops
- Sign of health effect is unclear since other herbicides are more toxic than glyphosate, but GM enables more liberal use of glyphosate

## Evidence of adverse health effects from glyphosate

- Birth weights decrease in CSC counties relative to non-CSC counties after introduction of GM in 1996
- Results are robust to various specifications

## Implications for policy

- Results suggest we use more glyphosate than is socially optimal
- But the net effect on welfare depends on many factors, for future work!

# Thank you

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<https://www.emmettsaulnier.com/>

# Appendix

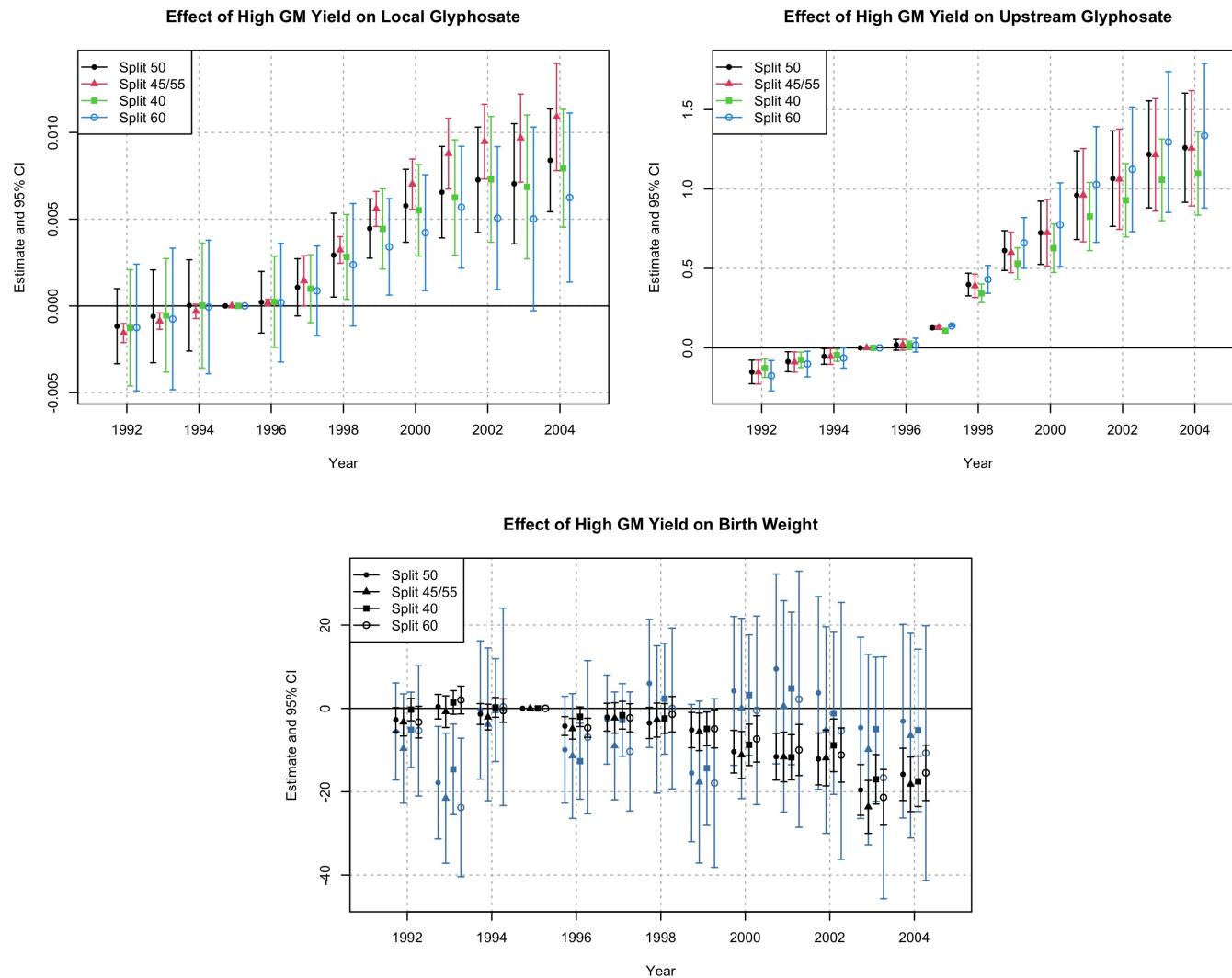
# Balance table

Variable	High GM Yield		Low GM Yield		Urban		West 100m	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Number of Counties	838	0	935	0	799	0	488	0
Birth Weight (g)	3345.69	81.89	3407.69	72.02	3386.99	59.69	3354.3	101.83
Pct Low Birth Weight	7.91	2.17	6.2	1.7	6.91	1.44	6.38	2.36
Percent Male	51.11	1.85	51.19	2.41	51.26	0.9	51.53	3.38
Infant Mortality	3.71	3.26	3.39	5.37	5.88	6.83	3.31	3.65
Total Births	346.85	286.17	301.63	300.42	3765.97	9079.14	328.33	1516.54
Glyphosate (g/km <sup>2</sup> )	2.59	3.09	1.29	1.46	2.25	3.72	1.05	1.49
Total Crop Area (km <sup>2</sup> )	354.49	414.88	351.65	490.9	243.35	386.54	337.28	478.71
Total Pop (1000's)	25.26	19.37	24.01	23.11	241.71	485.73	17.65	22.76
Percent Hispanic	1.39	2.81	3.32	11.31	5.25	10.07	12.42	17.54
Unemployment Rate	7.04	2.57	6.78	3.49	5.95	2.43	6.7	4.06
Pct Some HS Degree	35.95	8.91	32.86	10.49	24.99	8.22	25.48	8.83
Pct HS Degree	35.43	5.9	35.86	6.16	32.64	6.15	32.86	4.87
Pct Some College	18.32	4.29	19.8	5.26	24.46	5.12	26.98	5.07
Pct College Degree	10.3	3.58	11.48	4.64	17.92	7.83	14.68	5.72
Income per Capita	16.38	2.18	16.82	2.73	20.79	4.18	17.76	3.89

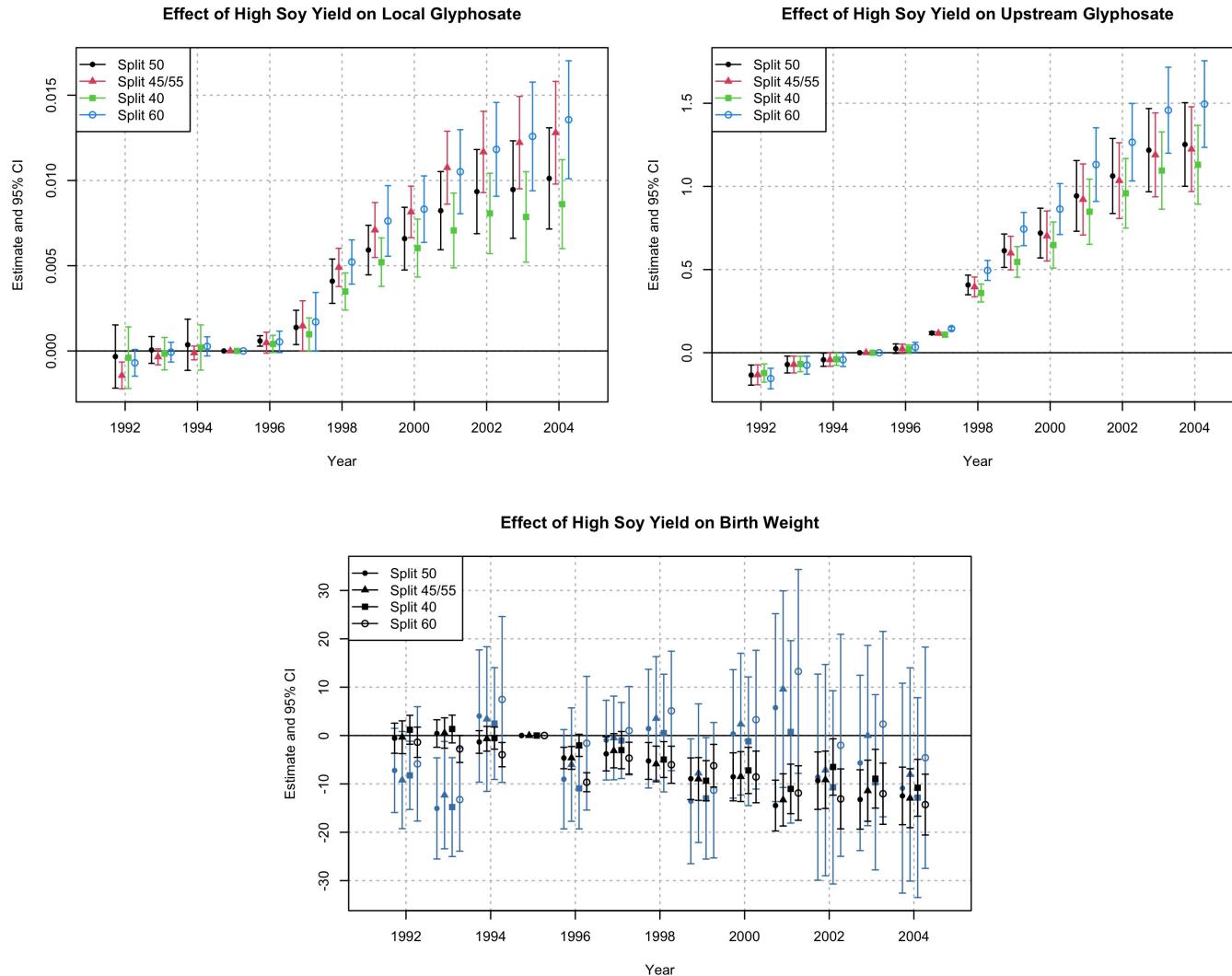
Means and standard deviations are calculated on county level averages between 1992 and 1995, which is the period prior to the release of GM crops.

# Robustness

# Robustness: Different splits

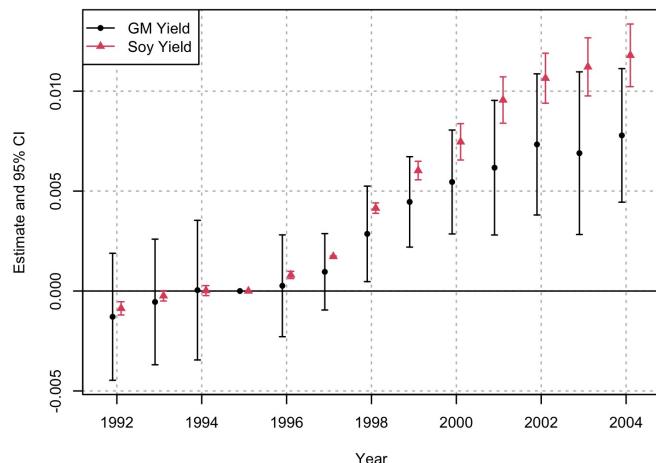


# Robustness: Soy Attainable Yield

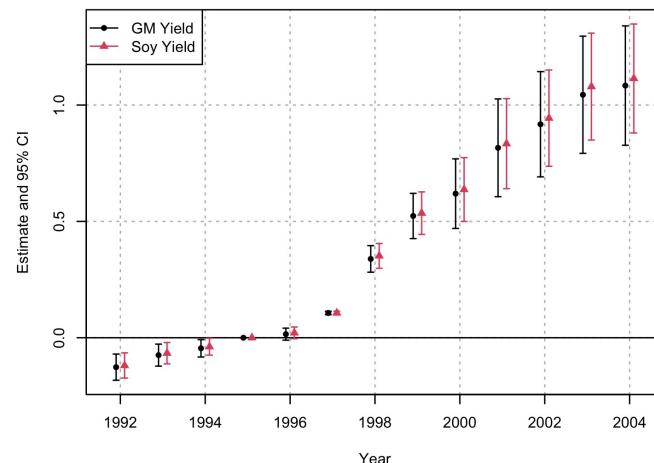


# Robustness: Entire country

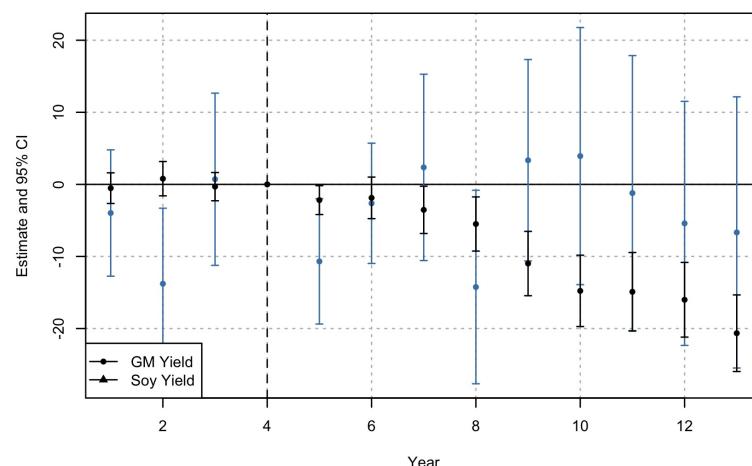
Effect of High Yield on Local Glyphosate, Entire Country



Effect of High Yield on Upstream Glyphosate, Entire Country



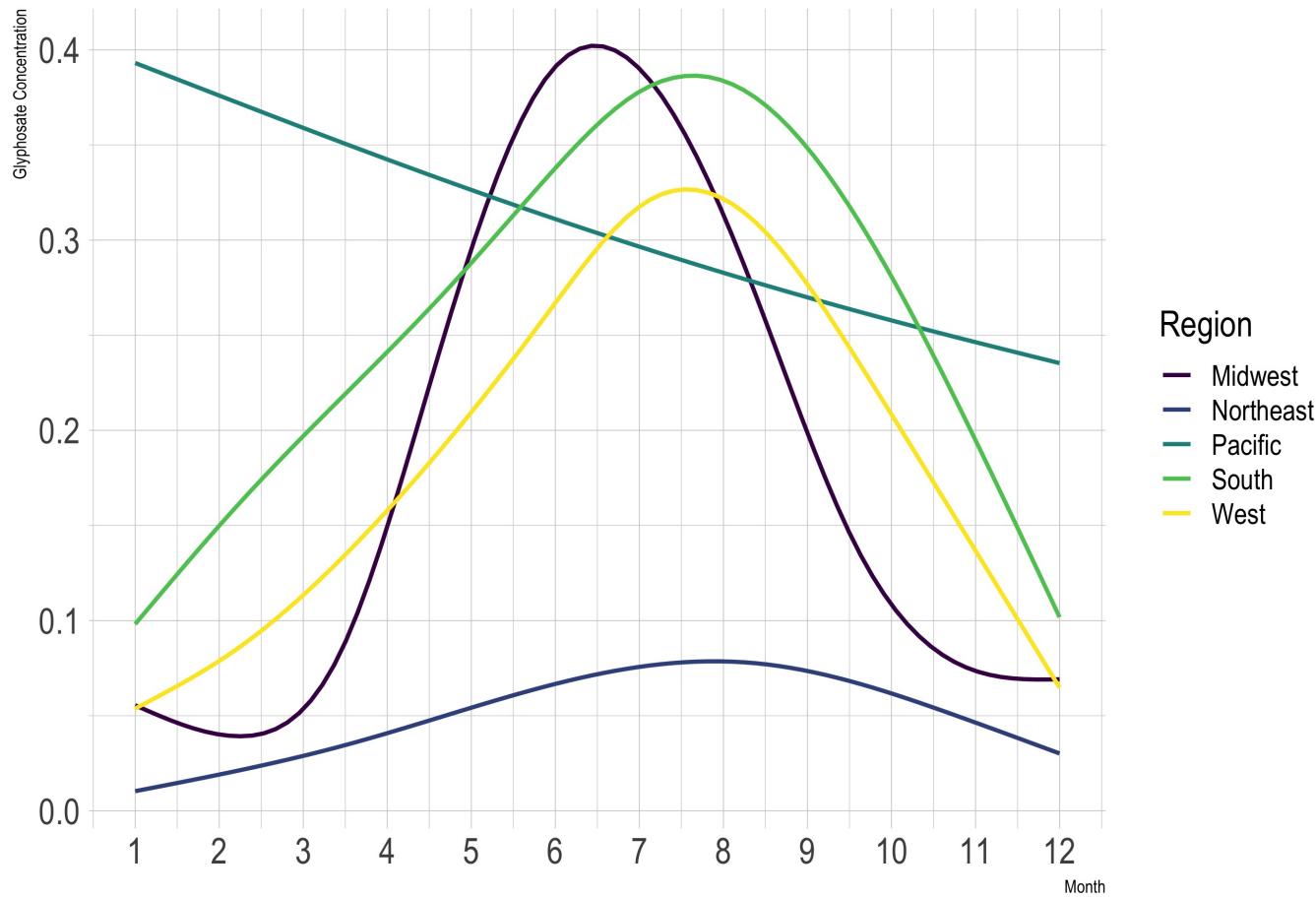
Effect of High Yield on Birth Weight, Entire Country



# Upstream vs Local Effects

# Glyphosate in water

## Concentration of Glyphosate in Water



# Upstream vs Local Effects

## What is the exposure mechanism?

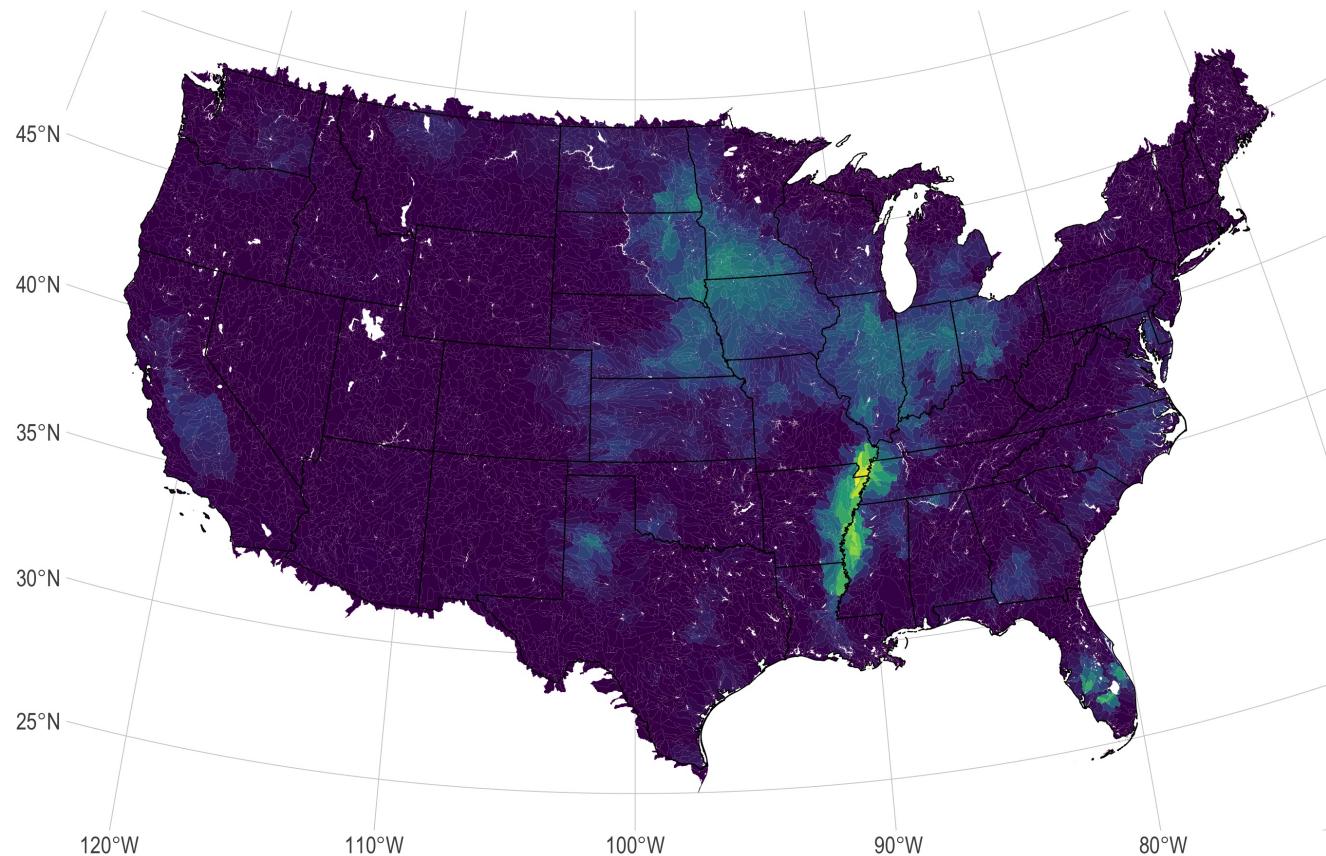
- **Direct:** Occupational exposure during/after spraying
- **Drift:** Glyphosate particles blown around by the wind
- **Water:** Glyphosate particles dissolve into water and contaminate surface or ground water

## Estimate upstream glyphosate

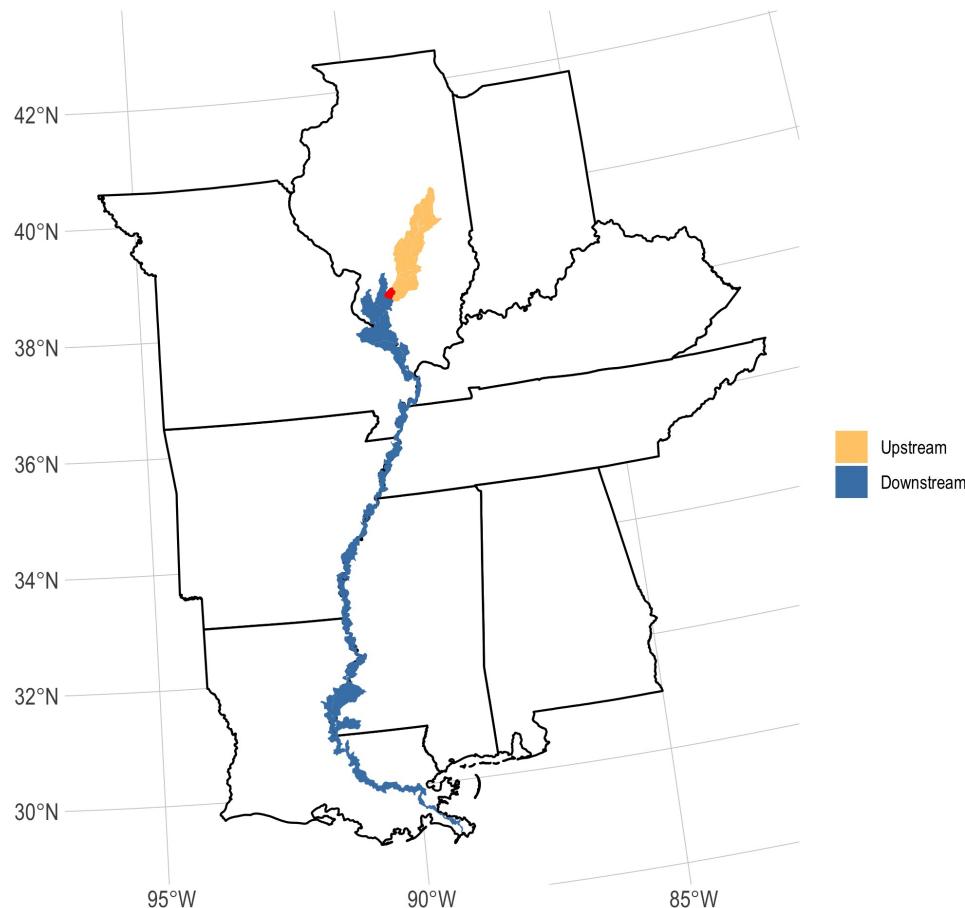
- Link counties with a spatial water model
- Aggregate upstream and downstream spraying
- Also aggregate first stage predictions from exogenous regressors

# Disaggregating to watersheds

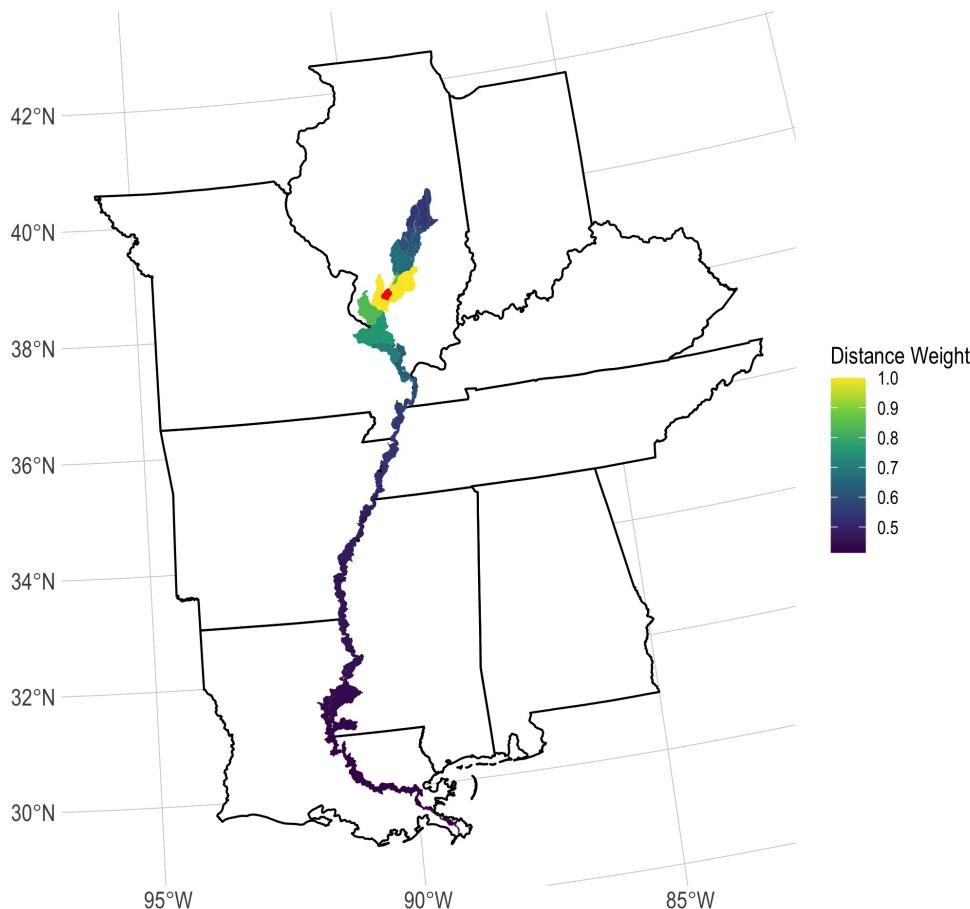
**Area weighted glyphosate by watershed in 2006**



# Aggregating upstream glyphosate



# Distance weighting



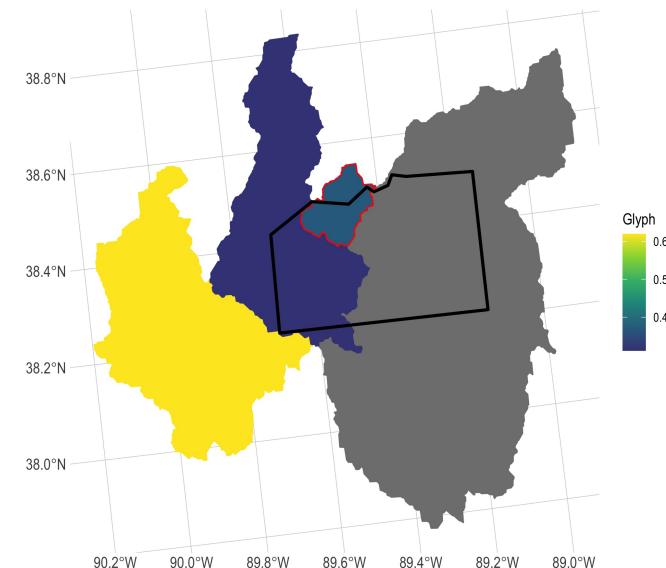
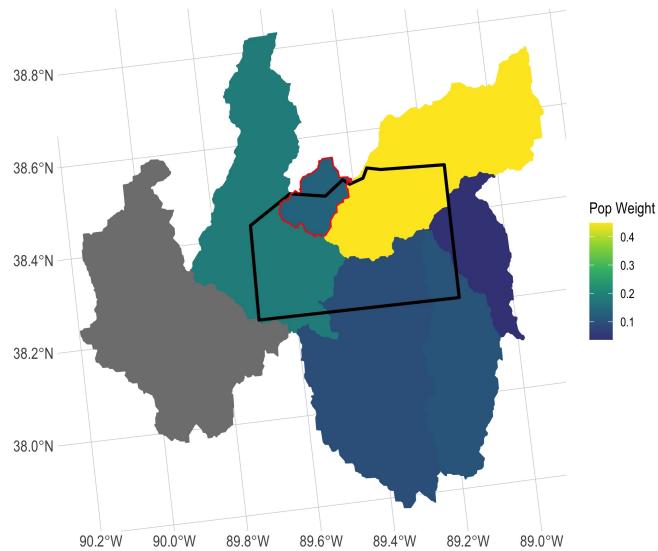
# Upstream Glyphosate

Upstream Glyphosate in 2006



# Adding population weights

Example: Washington County, IL



# Aggregating to county level

