

Direct and downstream health effects of herbicides

Identification based on the US rollout of GM crops

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2022-07-02

Glyphosate and GM Crops

Glyphosate

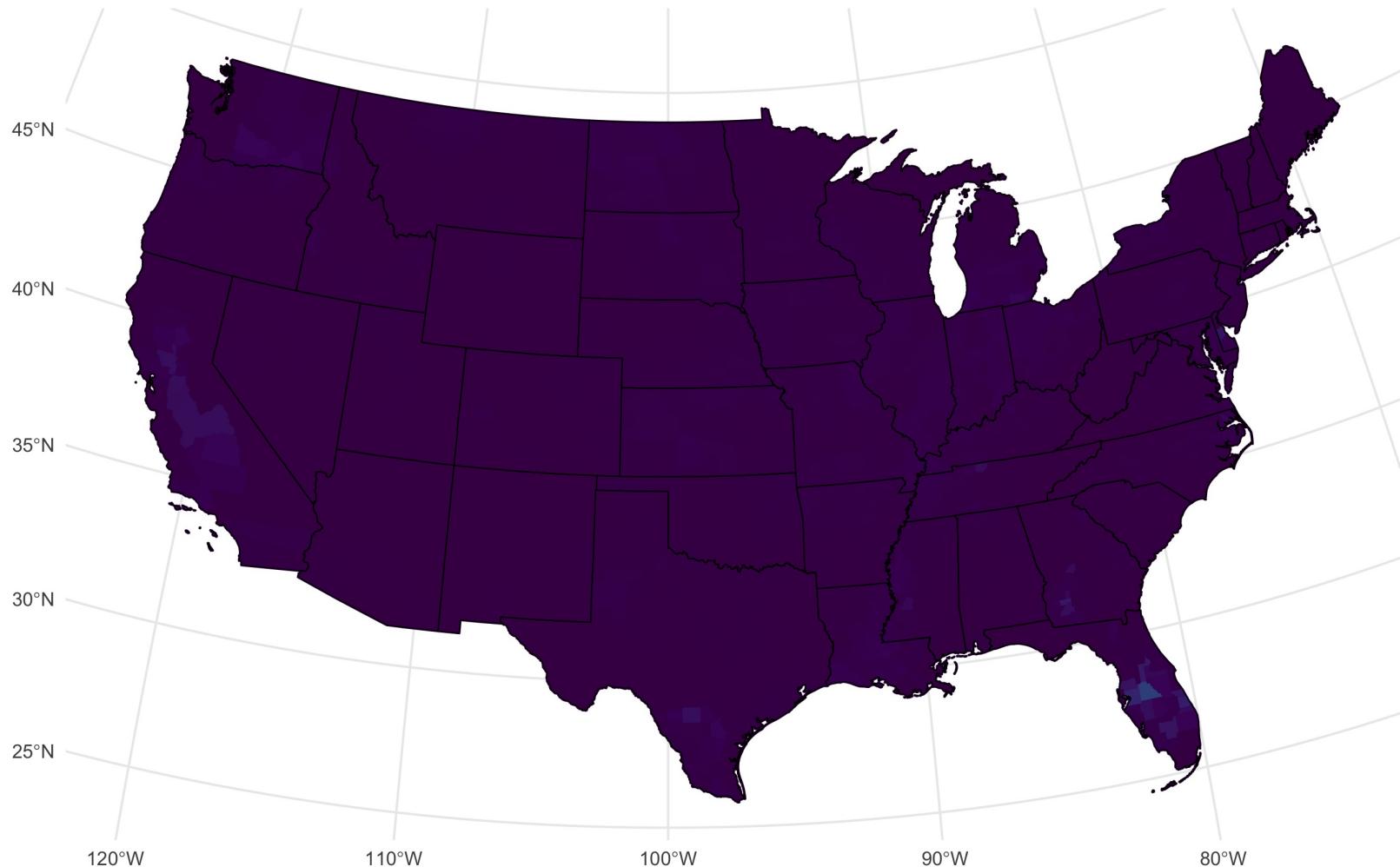
- Glyphosate (Roundup) is a weed killer developed by Monsanto in 1974
- It is **relatively less toxic** than other herbicides (DDT, paraquat, atrazine)
- Very water soluble

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 tolerance is not the only type of genetic modification

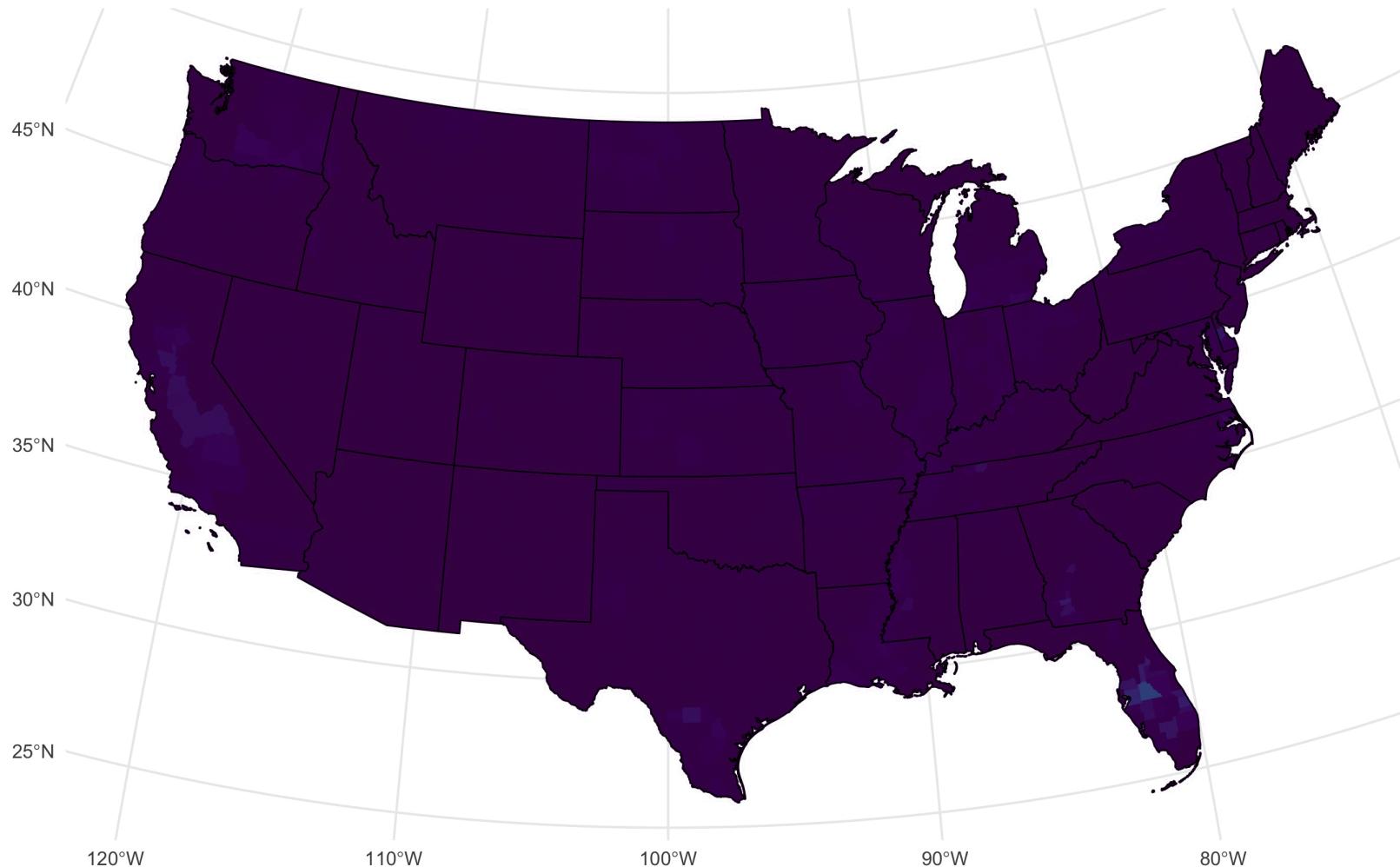
Glyphosate in the US in 1992

Glyphosate per square km in 1992



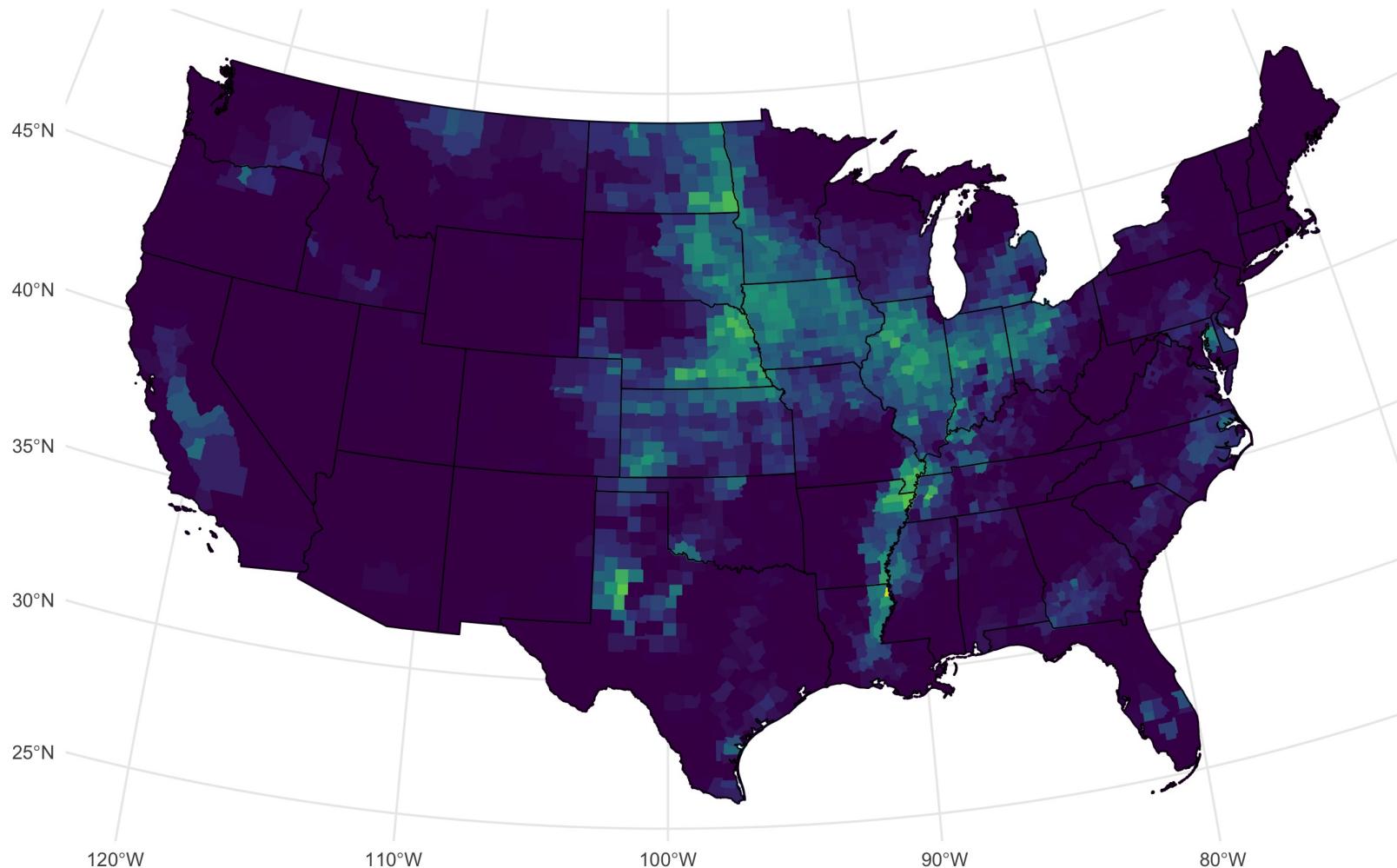
Glyphosate in the US from 1992 to 2017

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 last week that the 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  



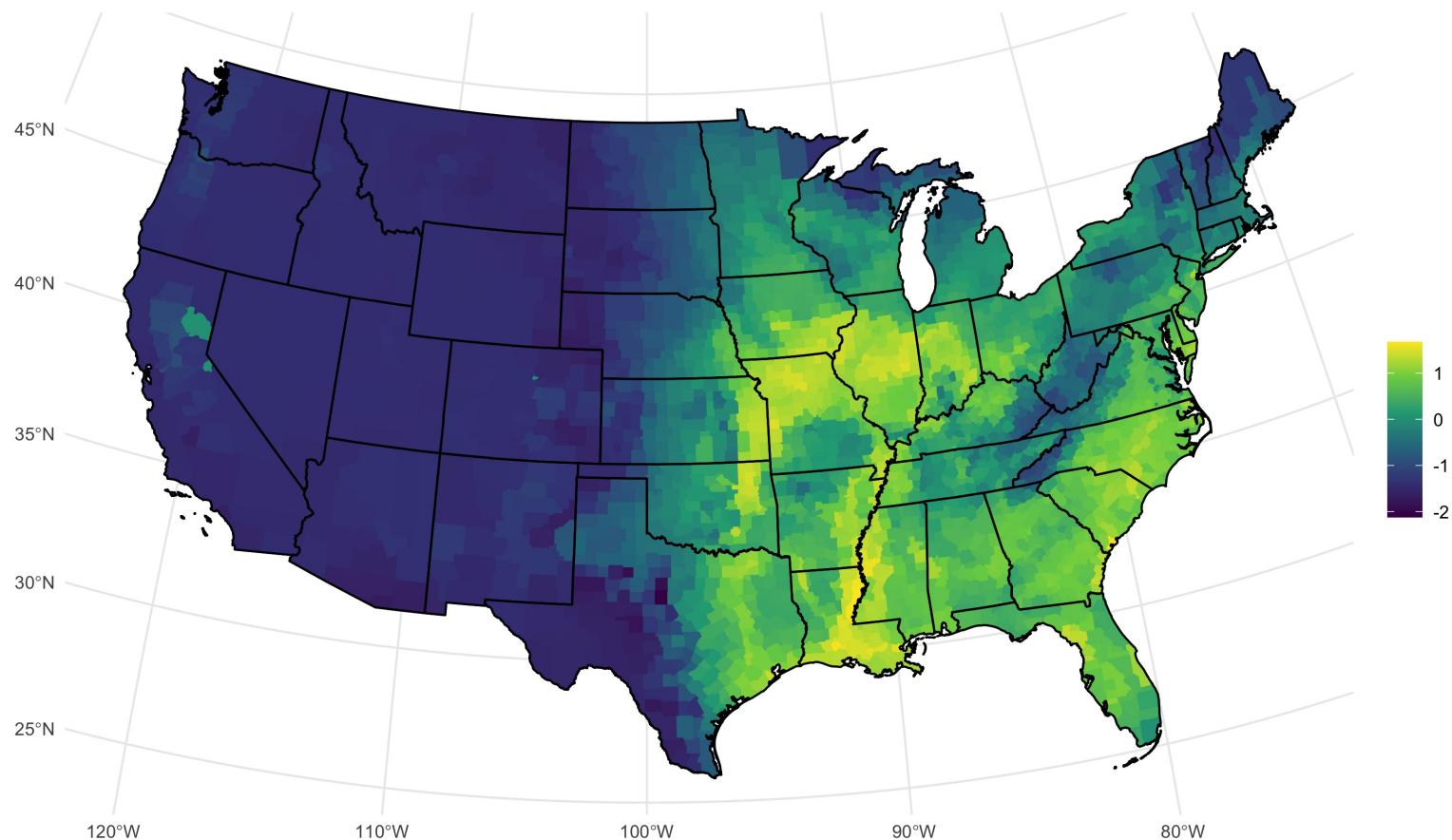
Glyphosate being sprayed on a field in Suffolk, England. Introduced in the 1970s, it is the most widely used herbicide in the world. Universal Images Group, via Getty Images

By [Andrew Pollack](#)

March 27, 2015

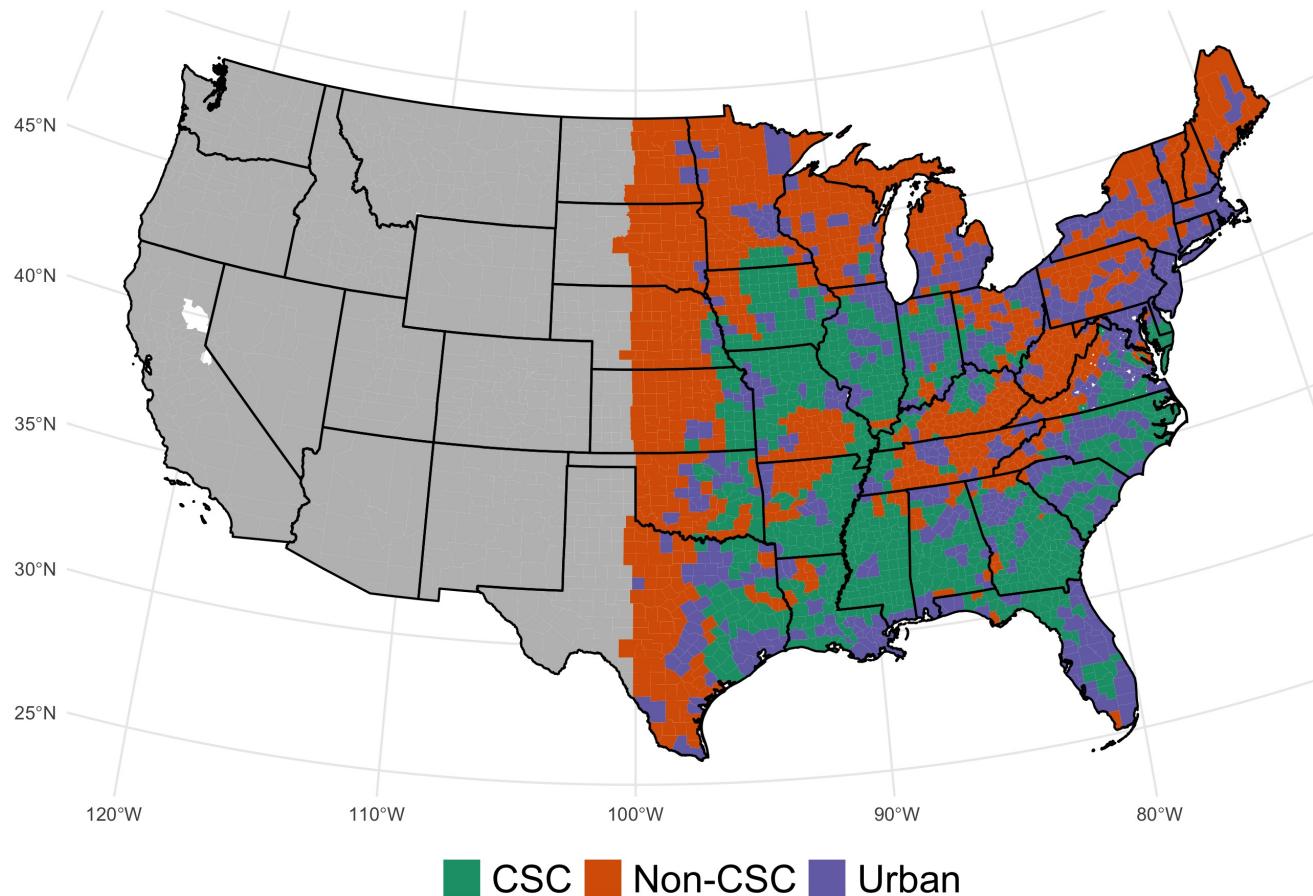
GAEZ attainable yield

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



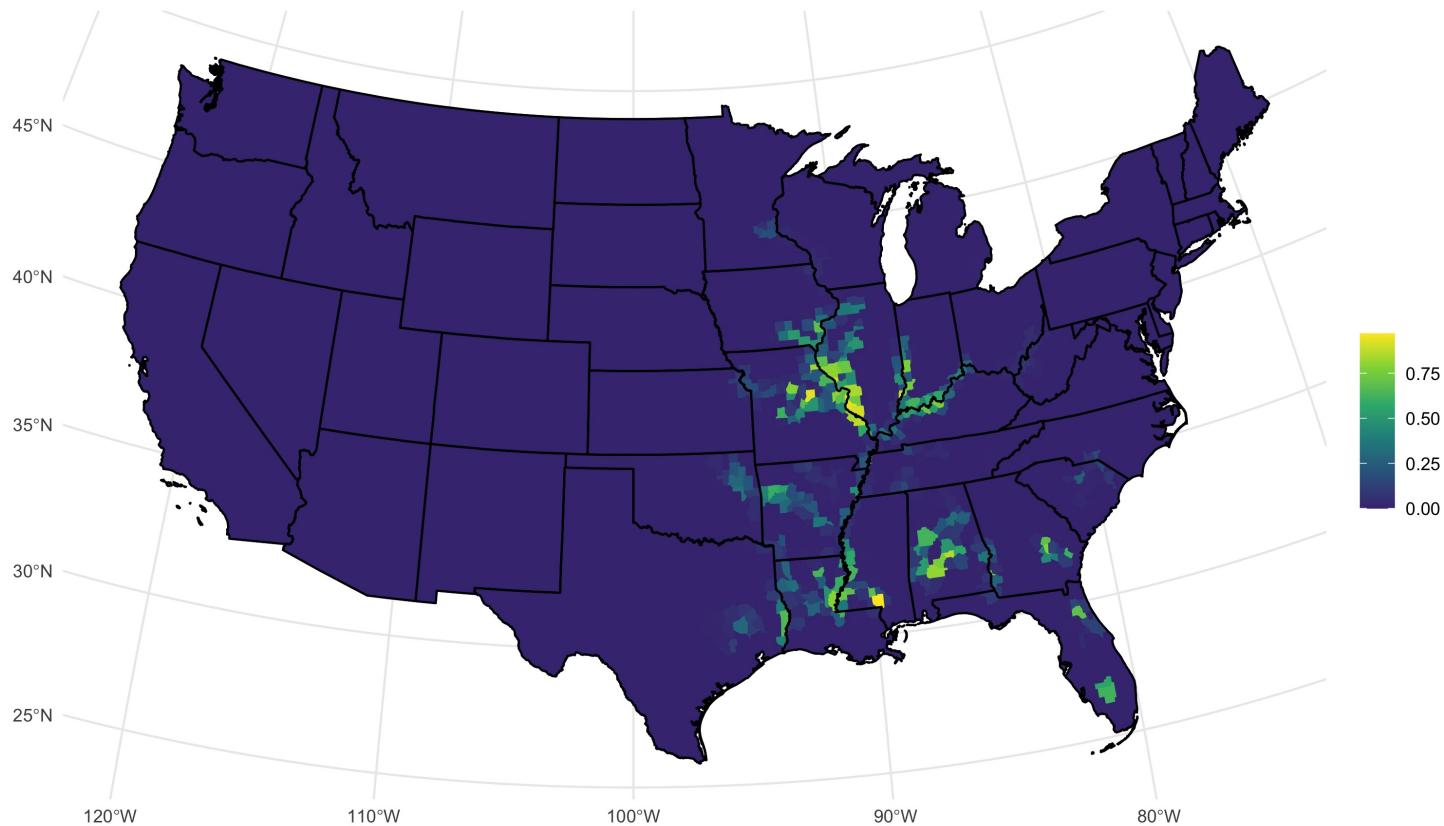
CSC vs non-CSC Counties

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



Aggregating upstream CSC

Proportion of upstream watersheds that are CSC



Methodology

RF effect of GM on birth weight

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

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

- $CSC_{j\tau}^{local}$ is an indicator for whether county j is CSC
- $CSC_{j\tau}^{upstream}$ 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 local and upstream CSC interacted with year as instruments for local glyphosate, G_{jt}^{local} , and upstream glyphosate $G_{jt}^{upstream}$

$$BW_{ijt} = \beta^l \hat{G}_{ijt}^{local} + \beta^u \hat{G}_{ijt}^{upstream} + X'_{ijt} \eta + \alpha_j + \lambda_t + \epsilon_{ijt}$$

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.

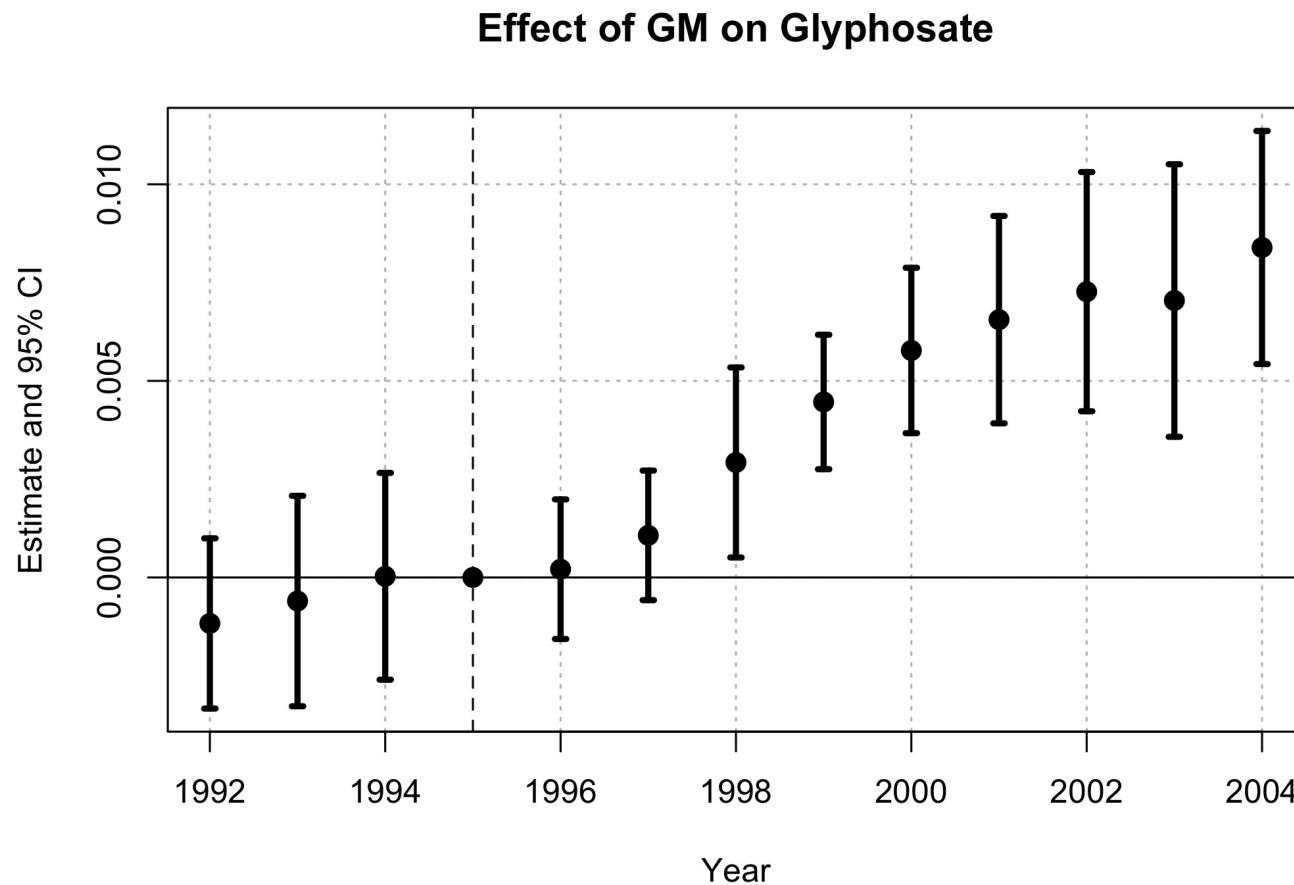
Results

First stage effect of GM on glyphosate

Going to plot the θ_τ coefficients from

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

First stage effect of GM on glyphosate



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

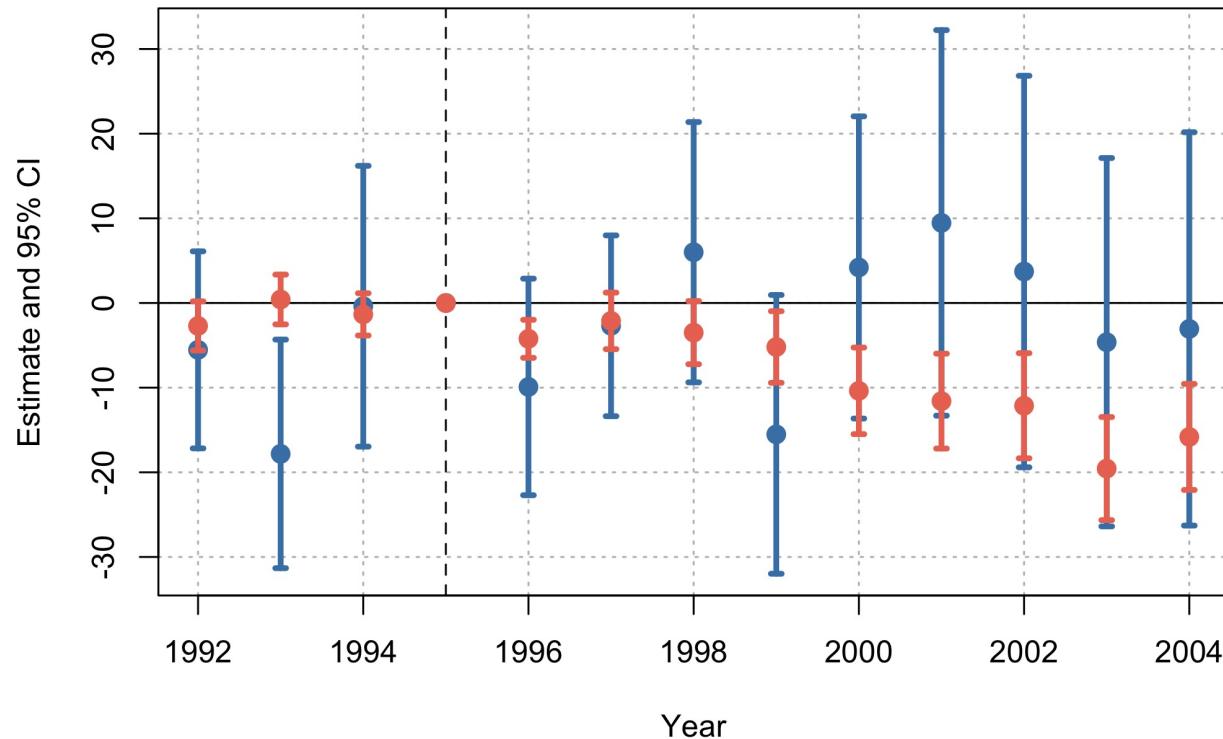
RF effect of GM on birth weight

Going to plot the γ_{τ}^l and γ_{τ}^u coefficients from

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

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
Local 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

Emmett Saulnier

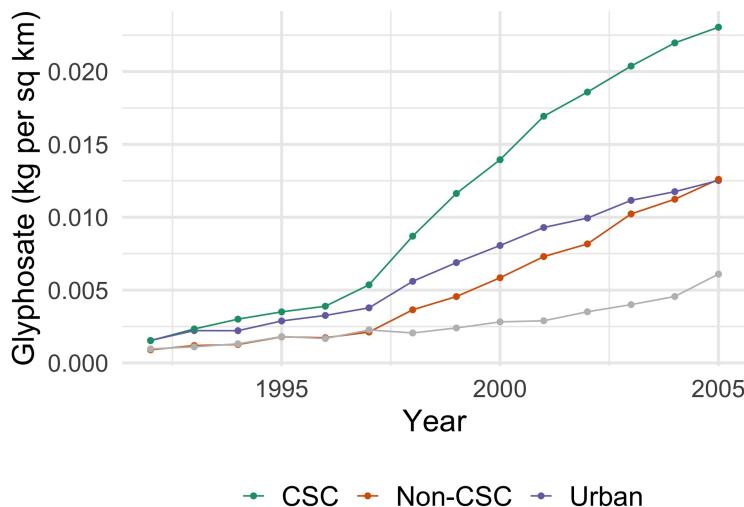
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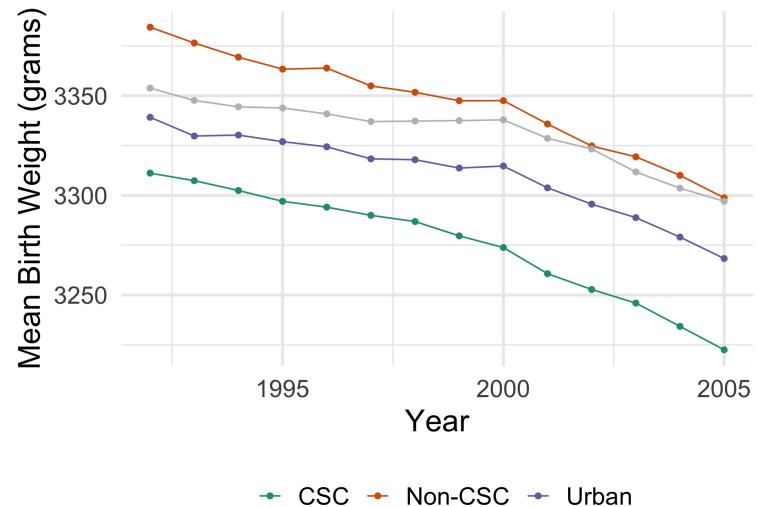
Appendix

Trends in glyphosate and birth weight

Glyphosate



Birth weight



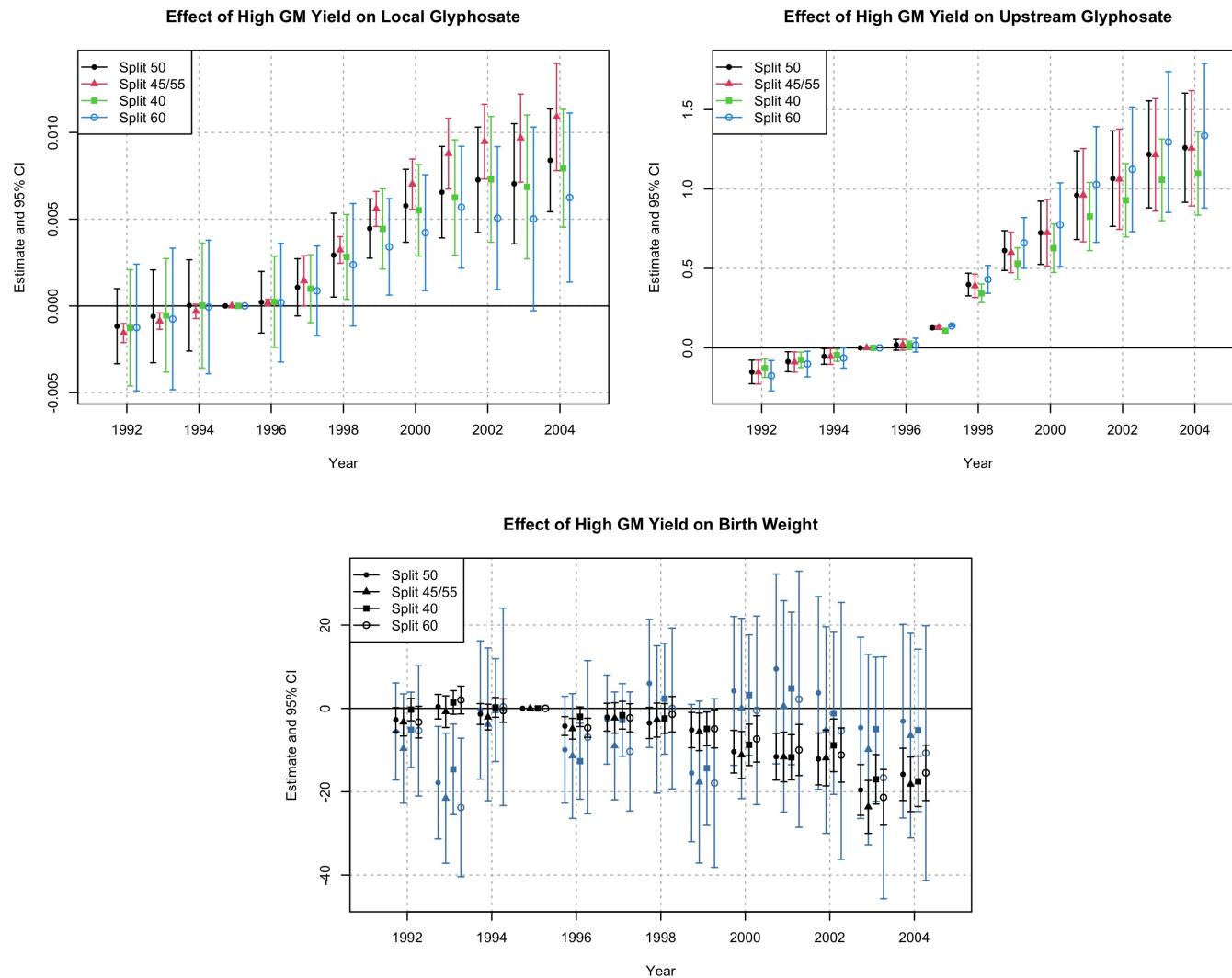
Balance table

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 ²)	2.59	3.09	1.29	1.46	2.25	3.72	1.05	1.49
Total Crop Area (km ²)	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

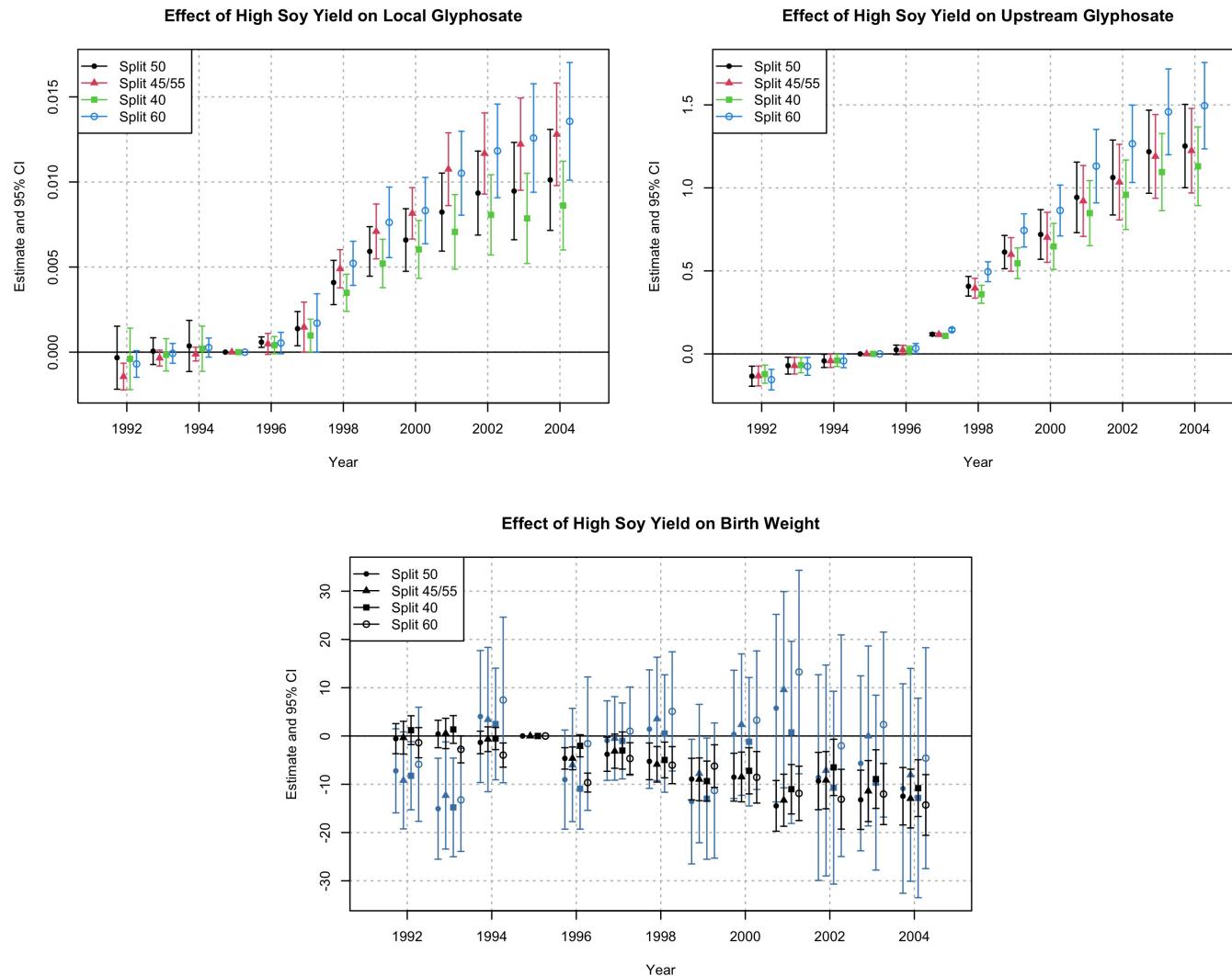
Means and standard deviations are calculated on county level averages between 1992 and 1995, which is the period prior to the release of GM crops.

Robustness

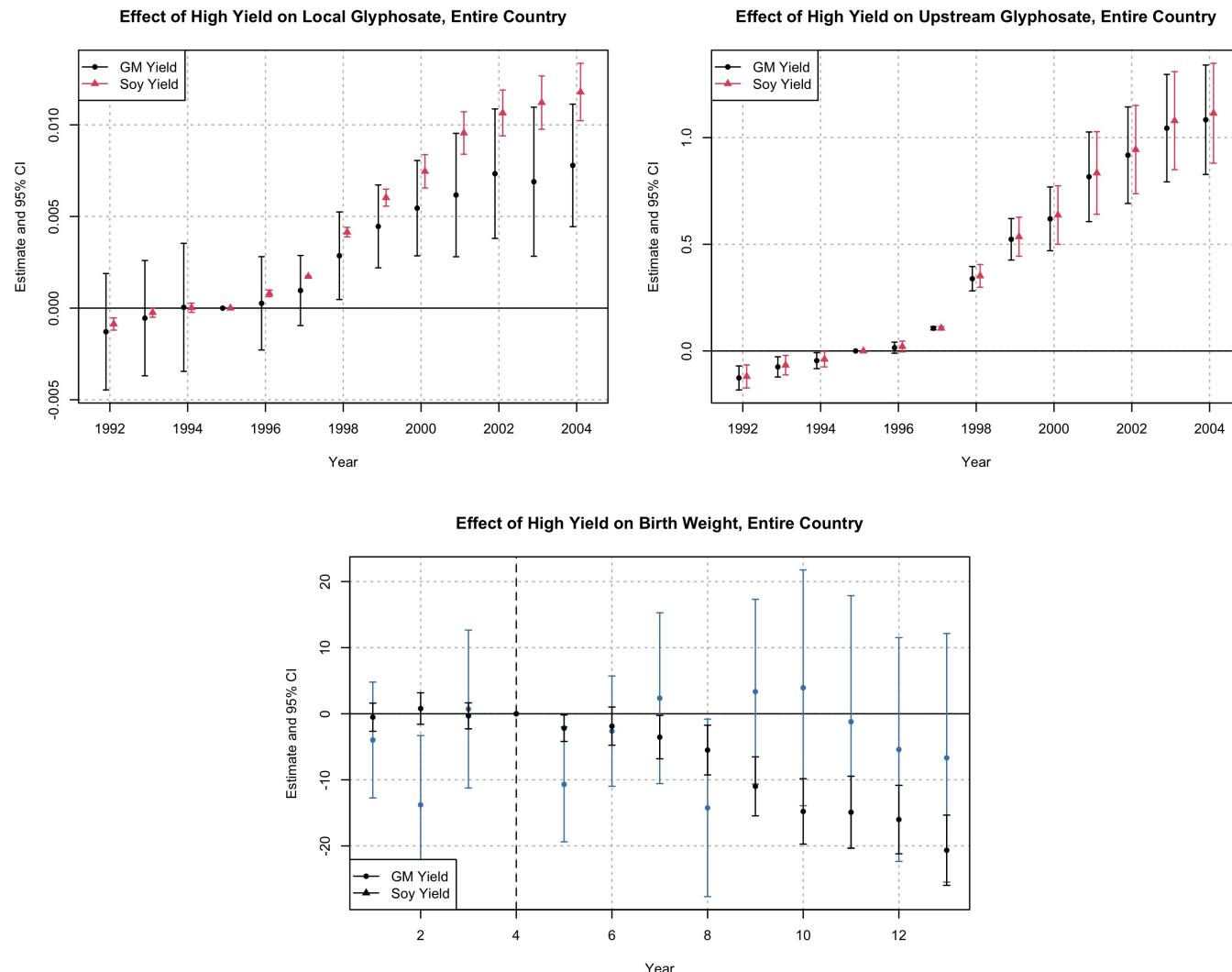
Robustness: Different splits



Robustness: Soy Attainable Yield



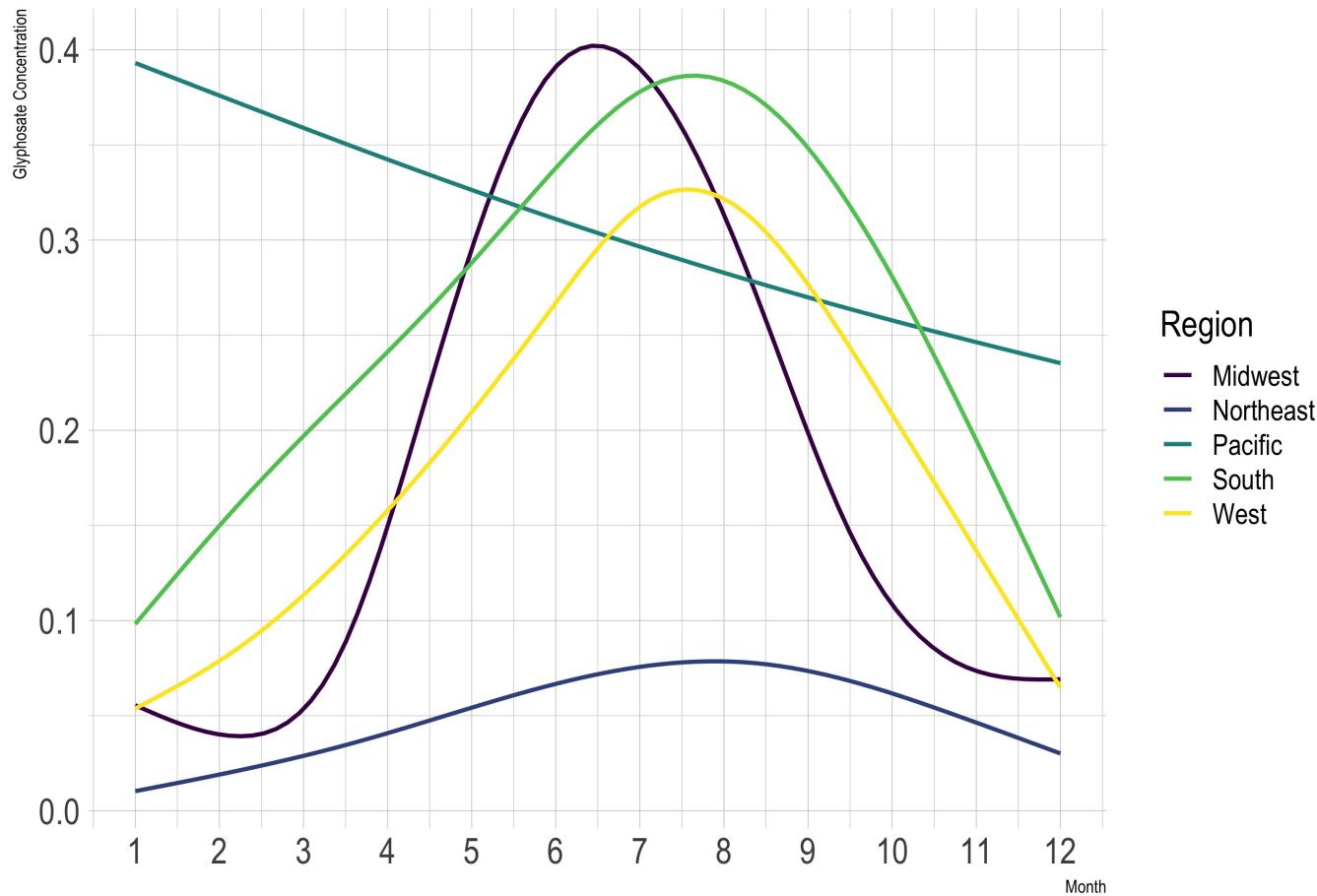
Robustness: Entire country



Upstream vs Local Effects

Glyphosate in water

Concentration of Glyphosate in Water



Upstream vs Local Effects

What is the exposure mechanism?

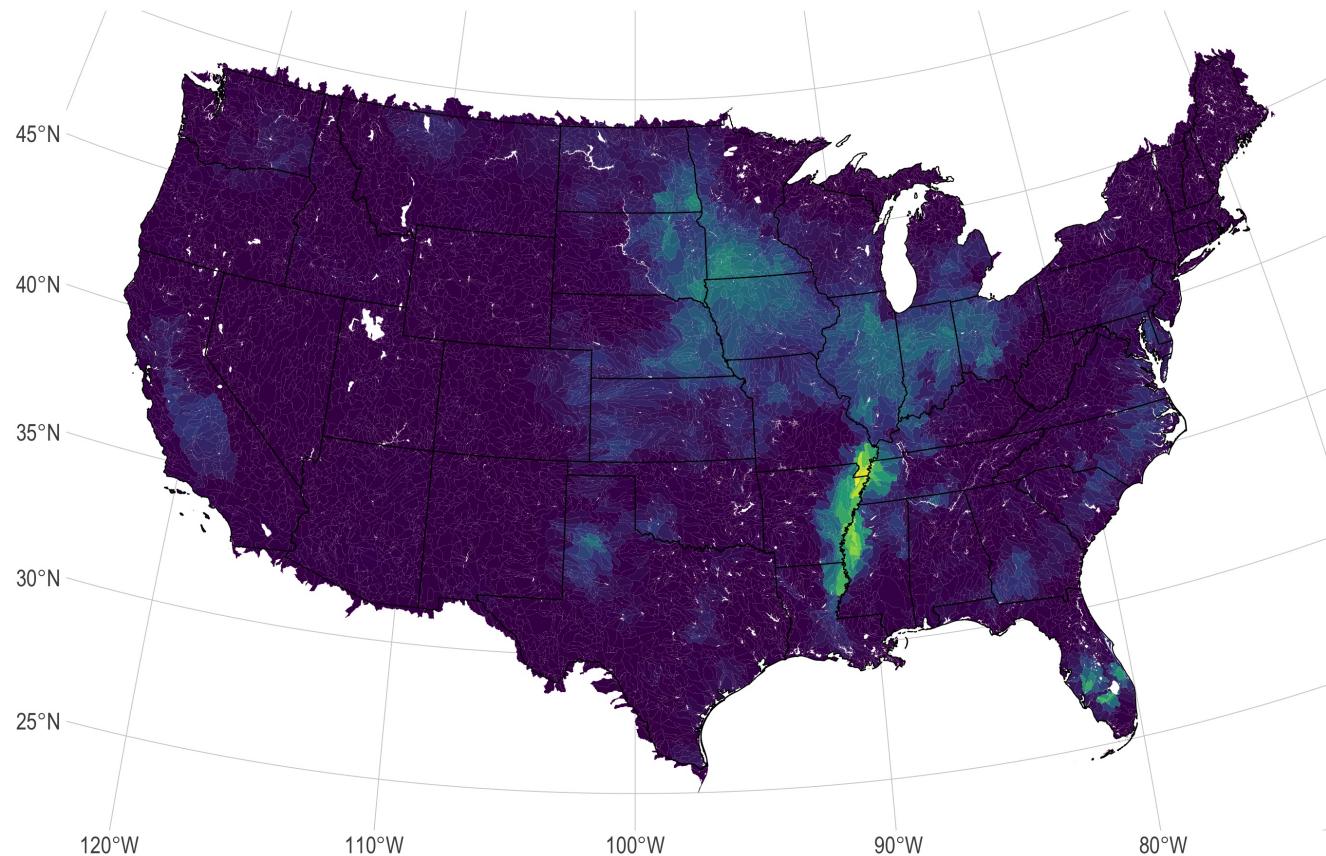
- **Direct:** Occupational exposure during/after spraying
- **Drift:** Glyphosate particles blown around by the wind
- **Water:** Glyphosate particles dissolve into water and contaminate surface or ground water

Estimate upstream glyphosate

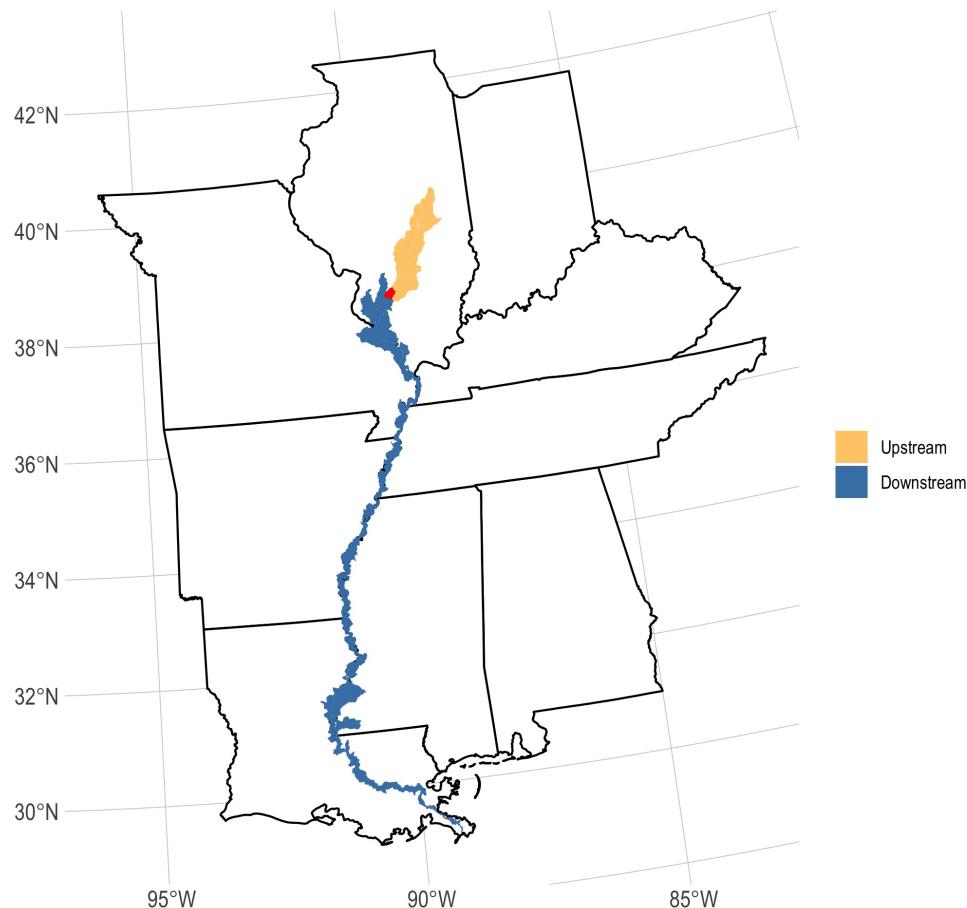
- Link counties with a spatial water model
- Aggregate upstream and downstream spraying
- Also aggregate first stage predictions from exogenous regressors

Disaggregating to watersheds

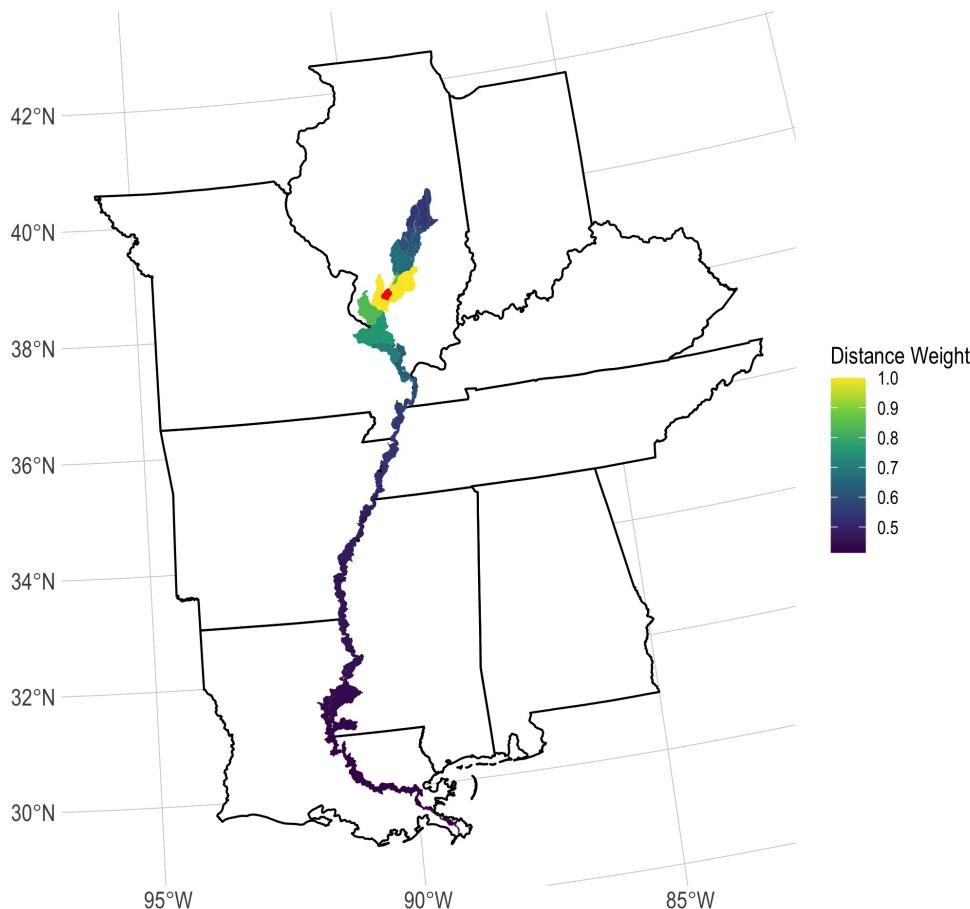
Area weighted glyphosate by watershed in 2006



Aggregating upstream glyphosate



Distance weighting



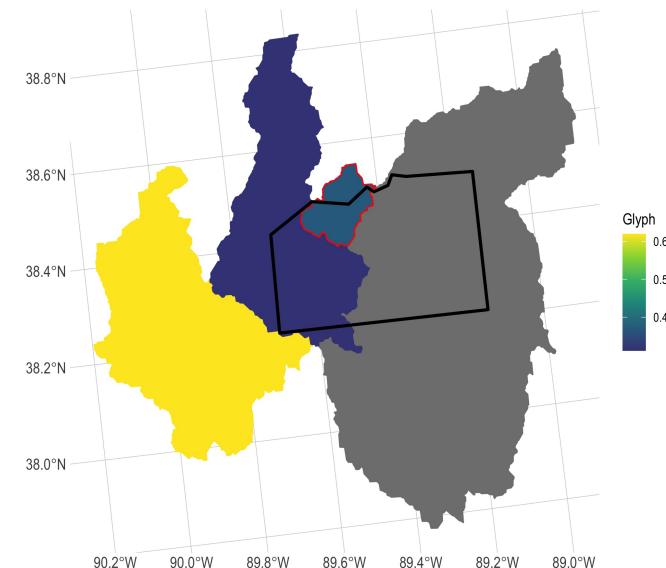
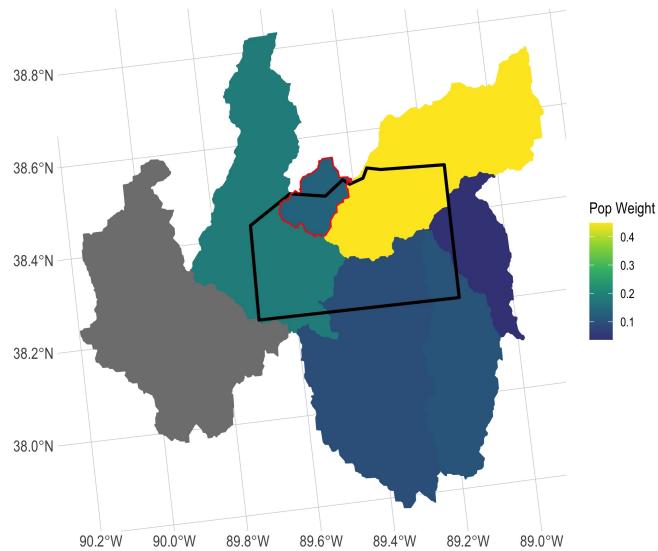
Upstream Glyphosate

Upstream Glyphosate in 2006



Adding population weights

Example: Washington County, IL



Aggregating to county level

