

# 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

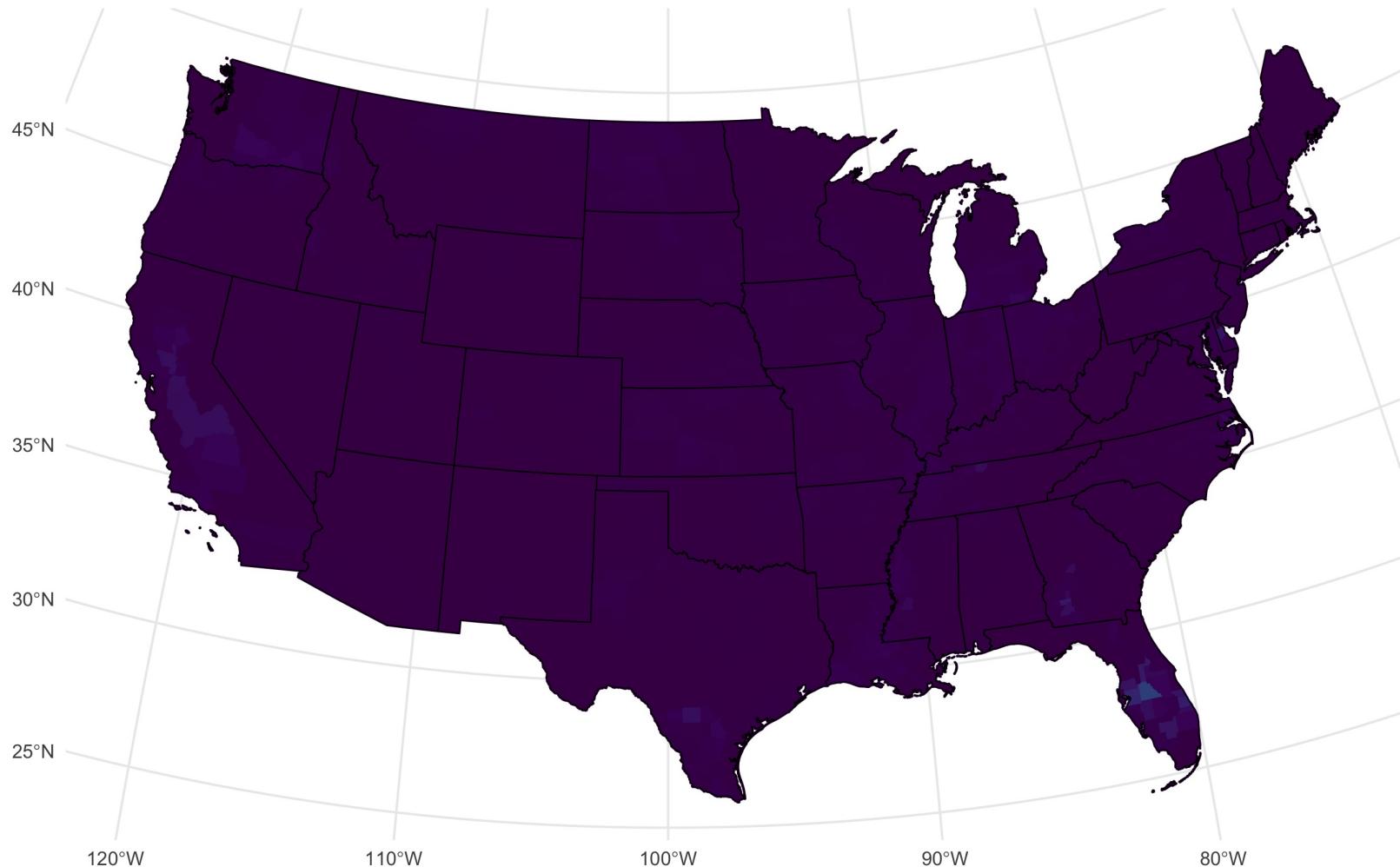
- Glyphosate (Roundup) is a weed killer developed by Monsanto in 1974
- It is **relatively less toxic** than other herbicides (DDT, paraquat, atrazine)
- Very water soluble

## 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 tolerance is not the only type of genetic modification

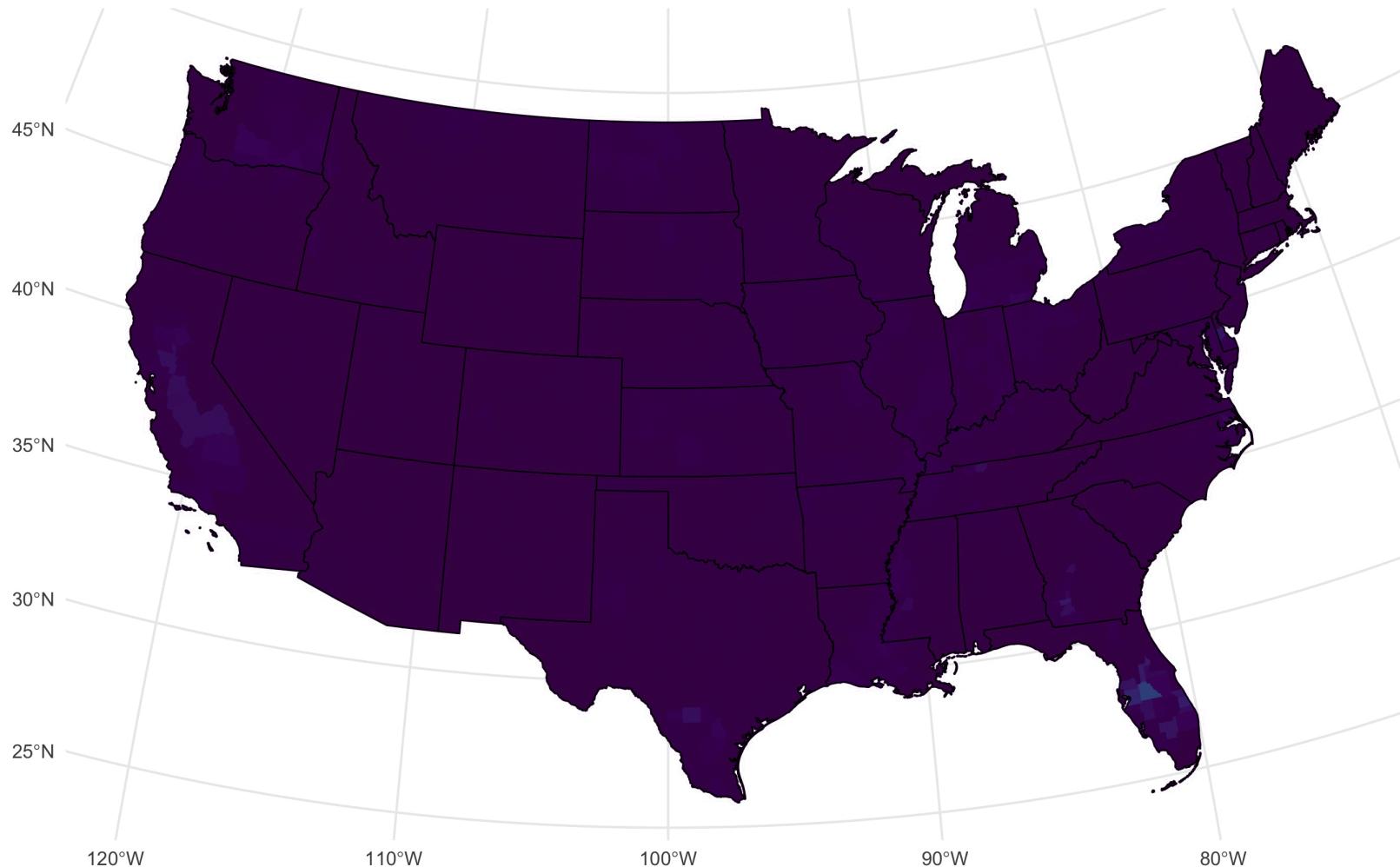
# Glyphosate in the US in 1992

**Glyphosate per square km in 1992**



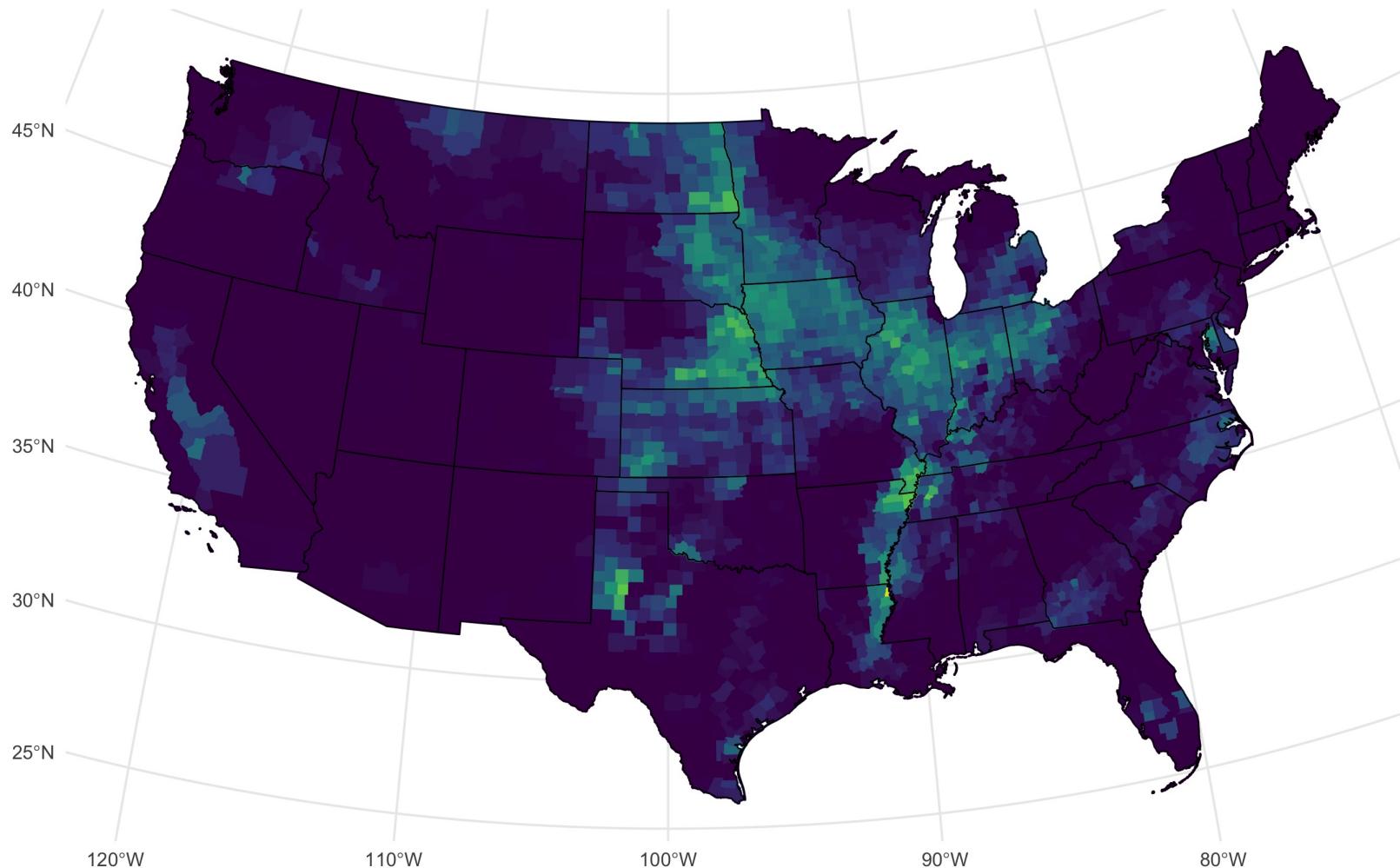
# Glyphosate in the US from 1992 to 2017

## 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  



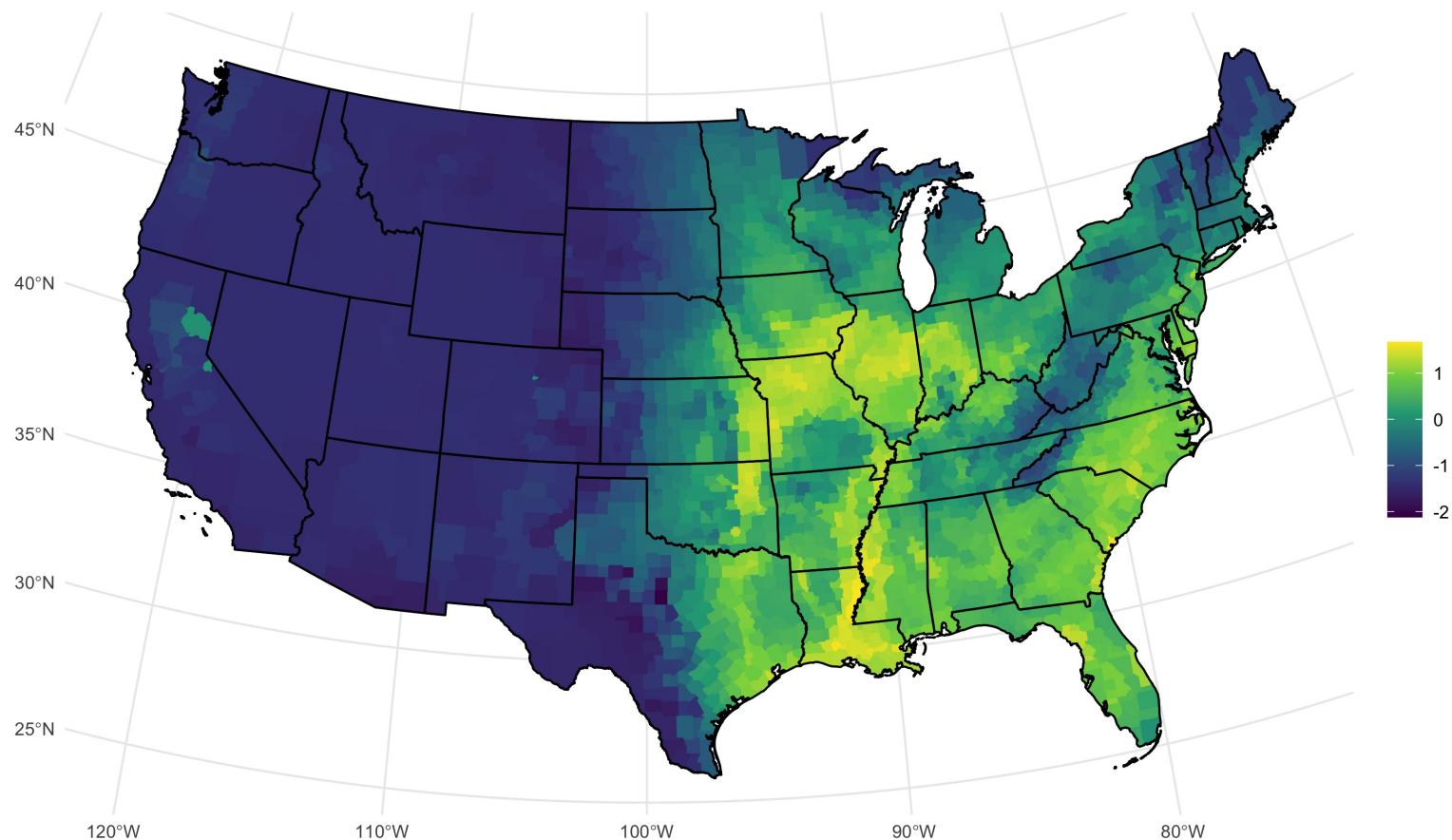
Glyphosate being sprayed on a field in Suffolk, England. Introduced in the 1970s, it is the most widely used herbicide in the world. Universal Images Group, via Getty Images

By [Andrew Pollack](#)

March 27, 2015

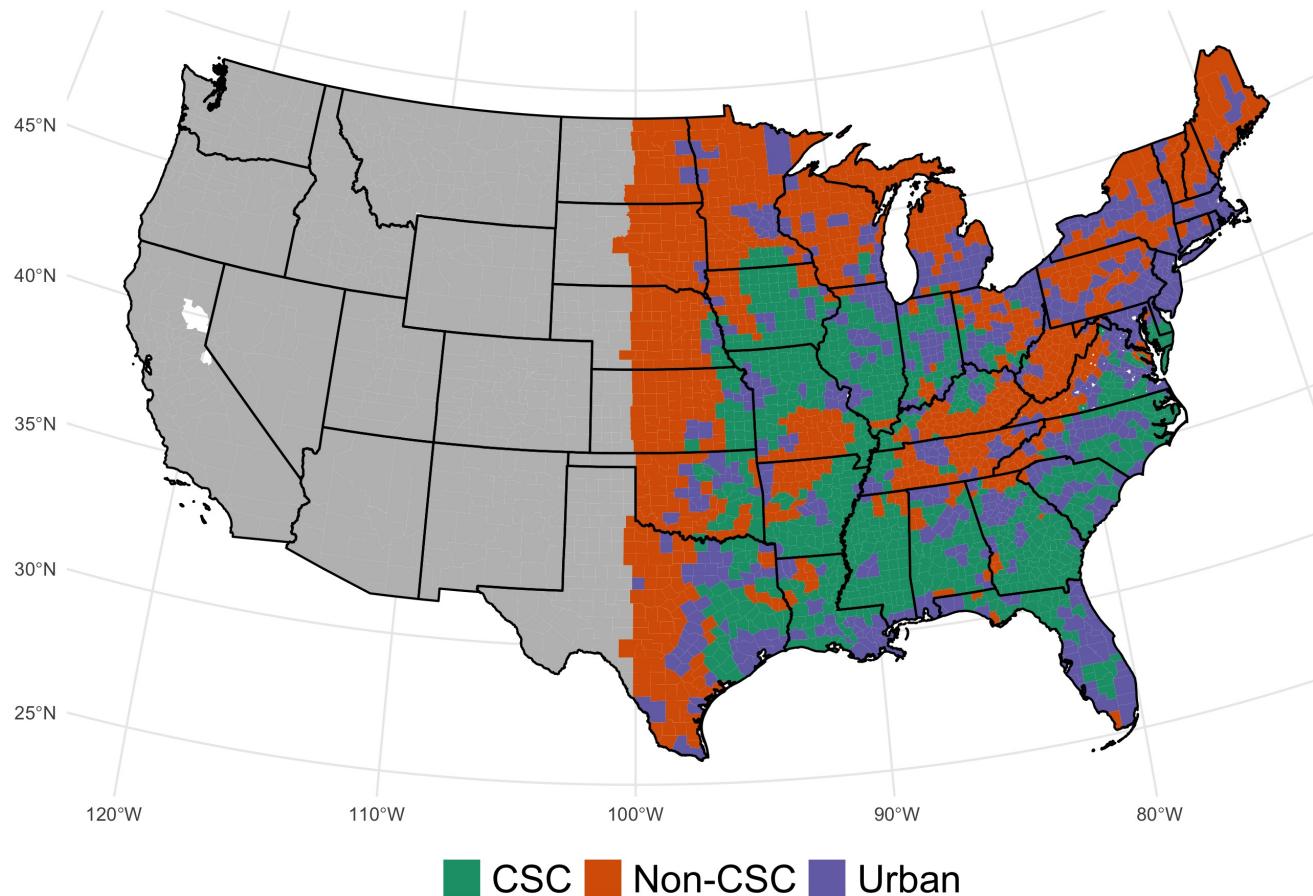
# GAEZ attainable yield

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



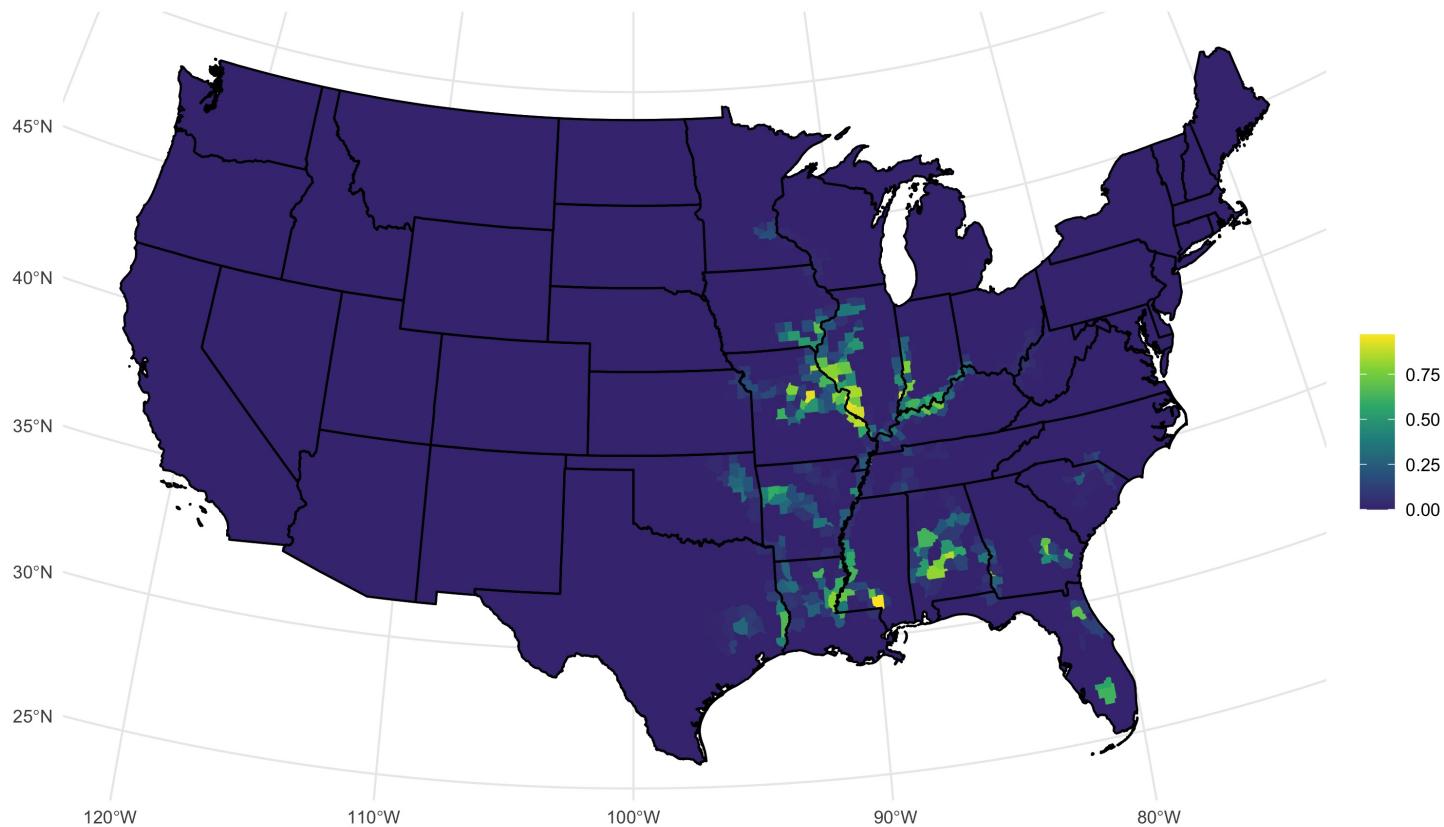
# CSC vs non-CSC Counties

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.

# Instrumental Variables

- 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 our controls.

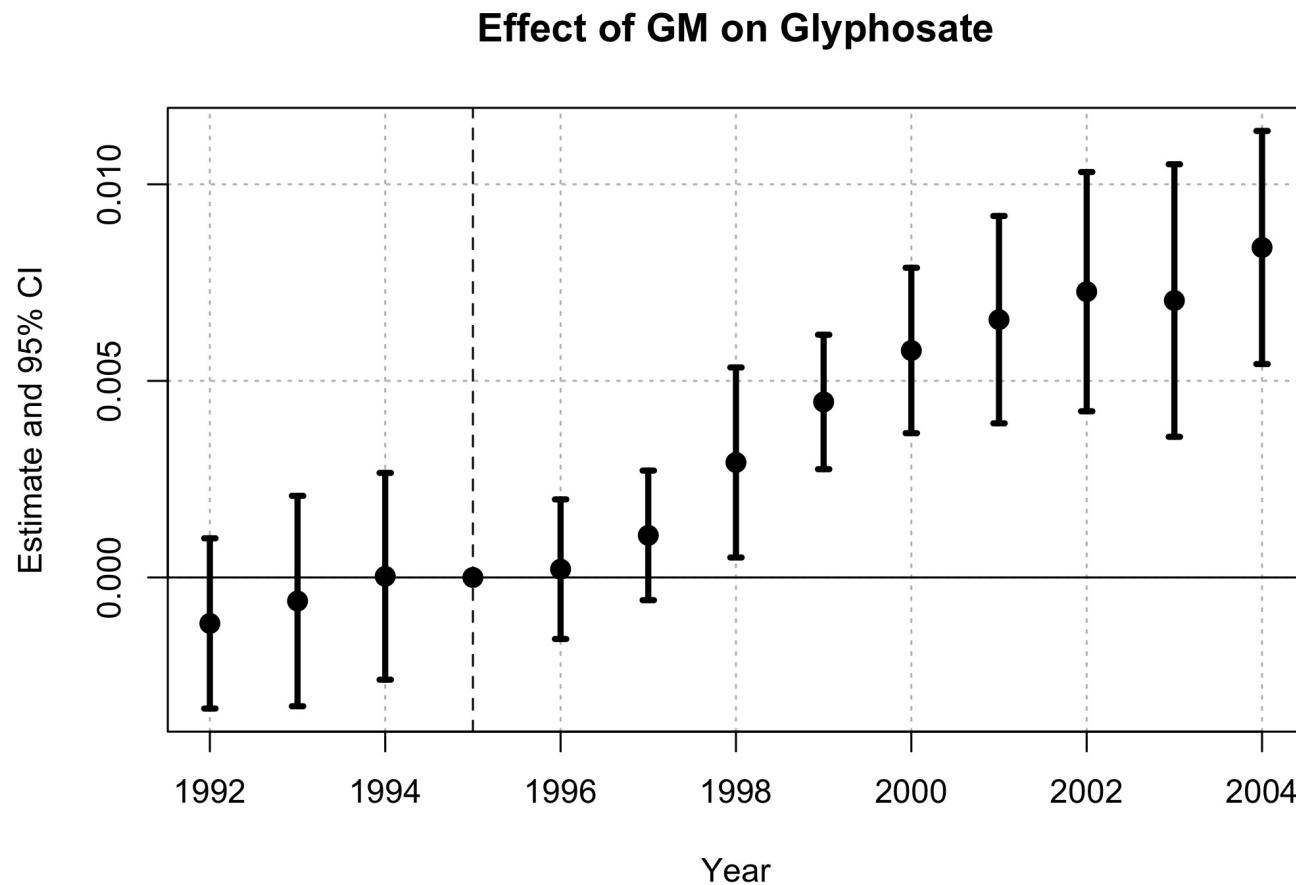
# Results

# First stage effect of GM on glyphosate

Going to plot the  $\theta_\tau$  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

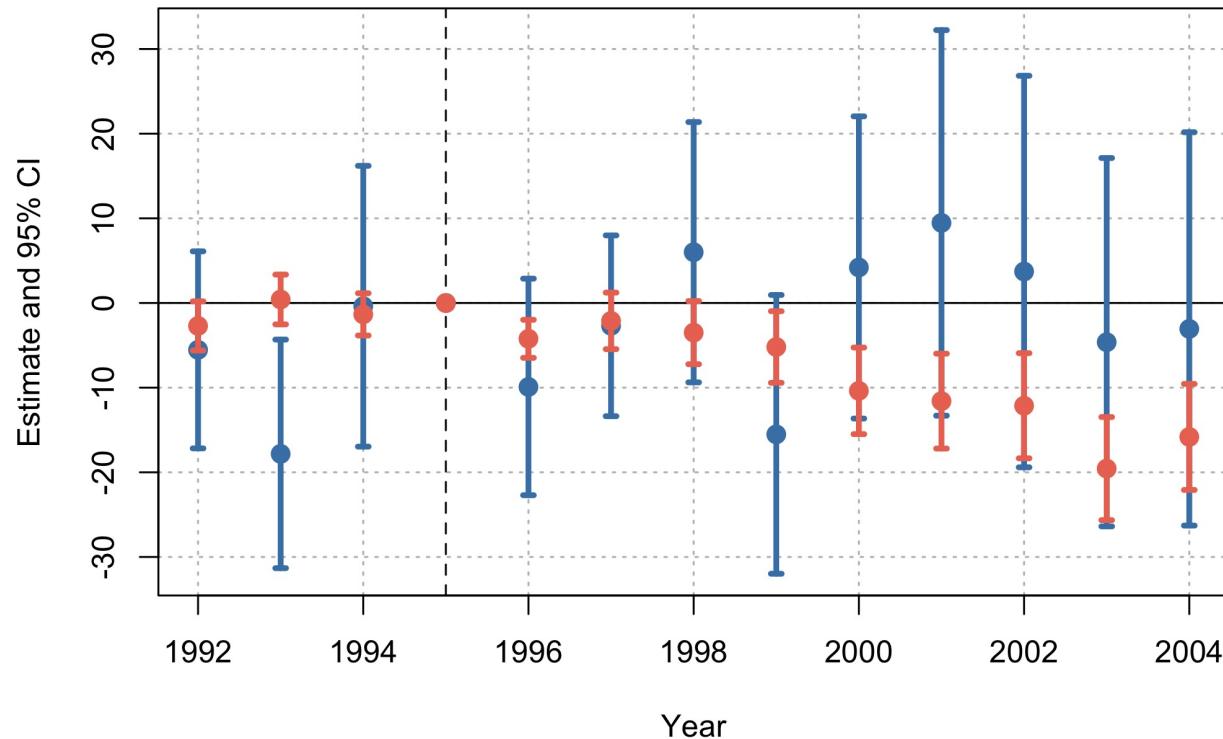
# RF effect of GM on birth weight

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

# Instrumental variables 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

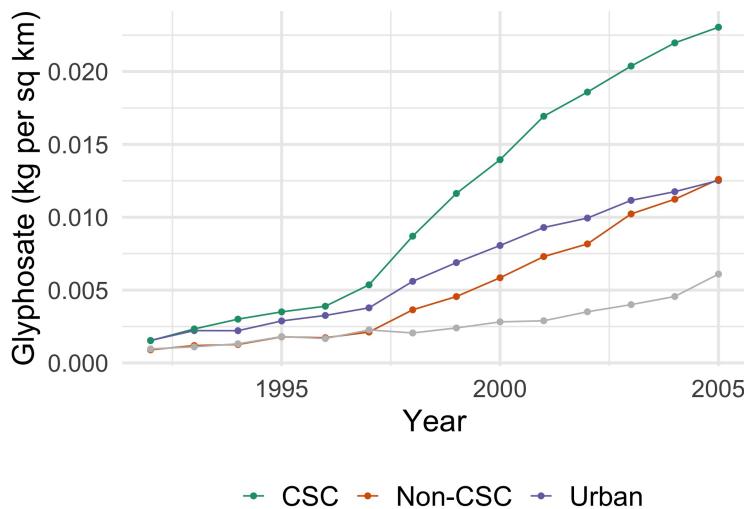
[emmetts@uoregon.edu](mailto:emmetts@uoregon.edu)

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

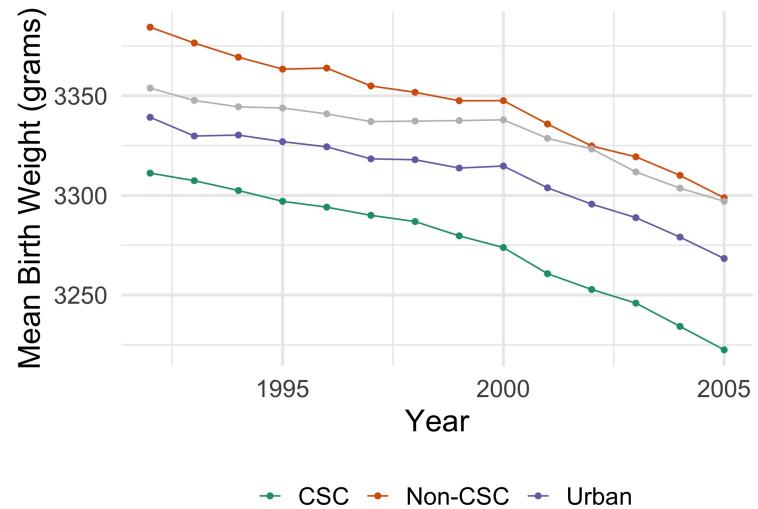
# Appendix

# Trends in glyphosate and birth weight

## Glyphosate



## Birth weight



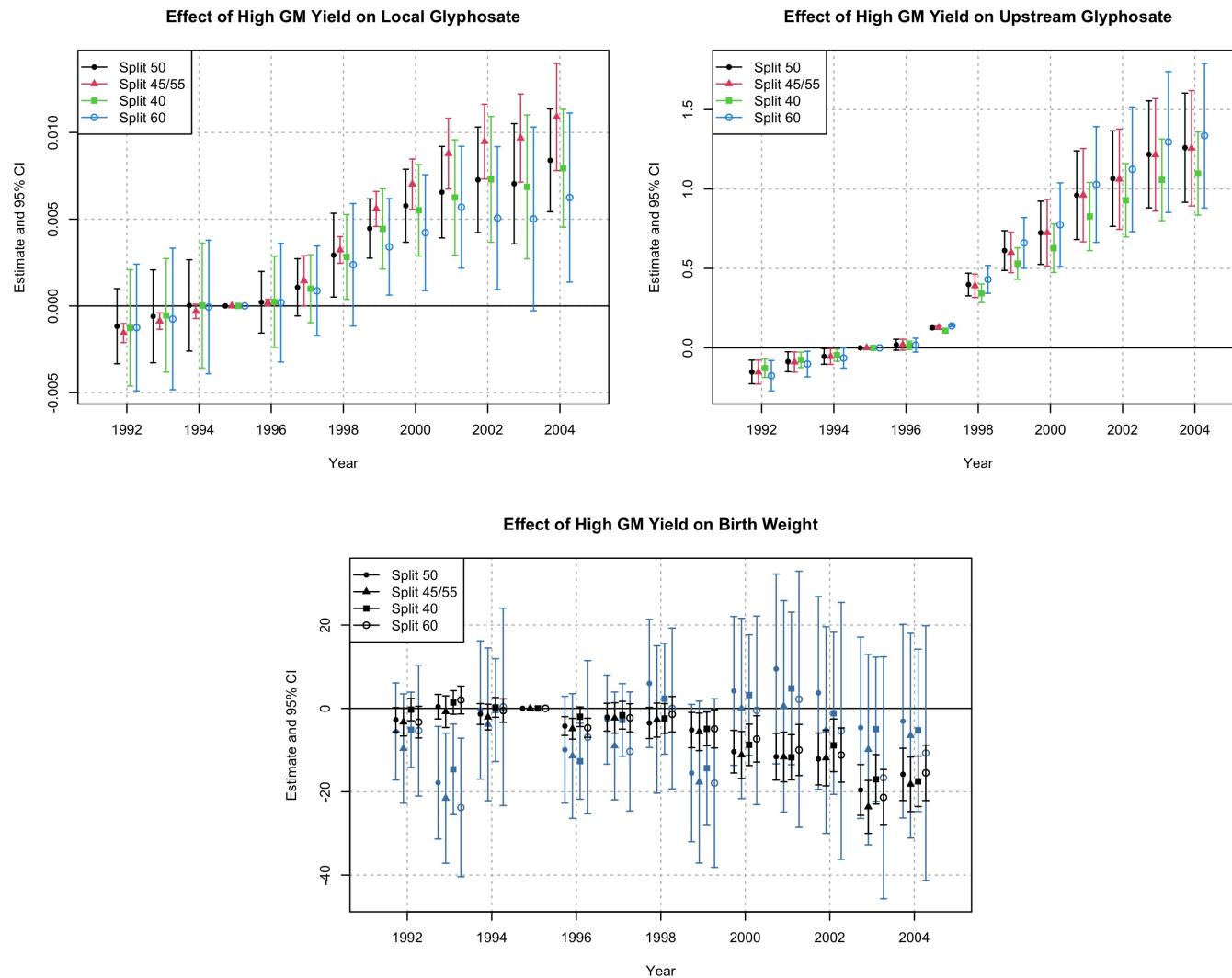
# Balance table

| 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 <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    |

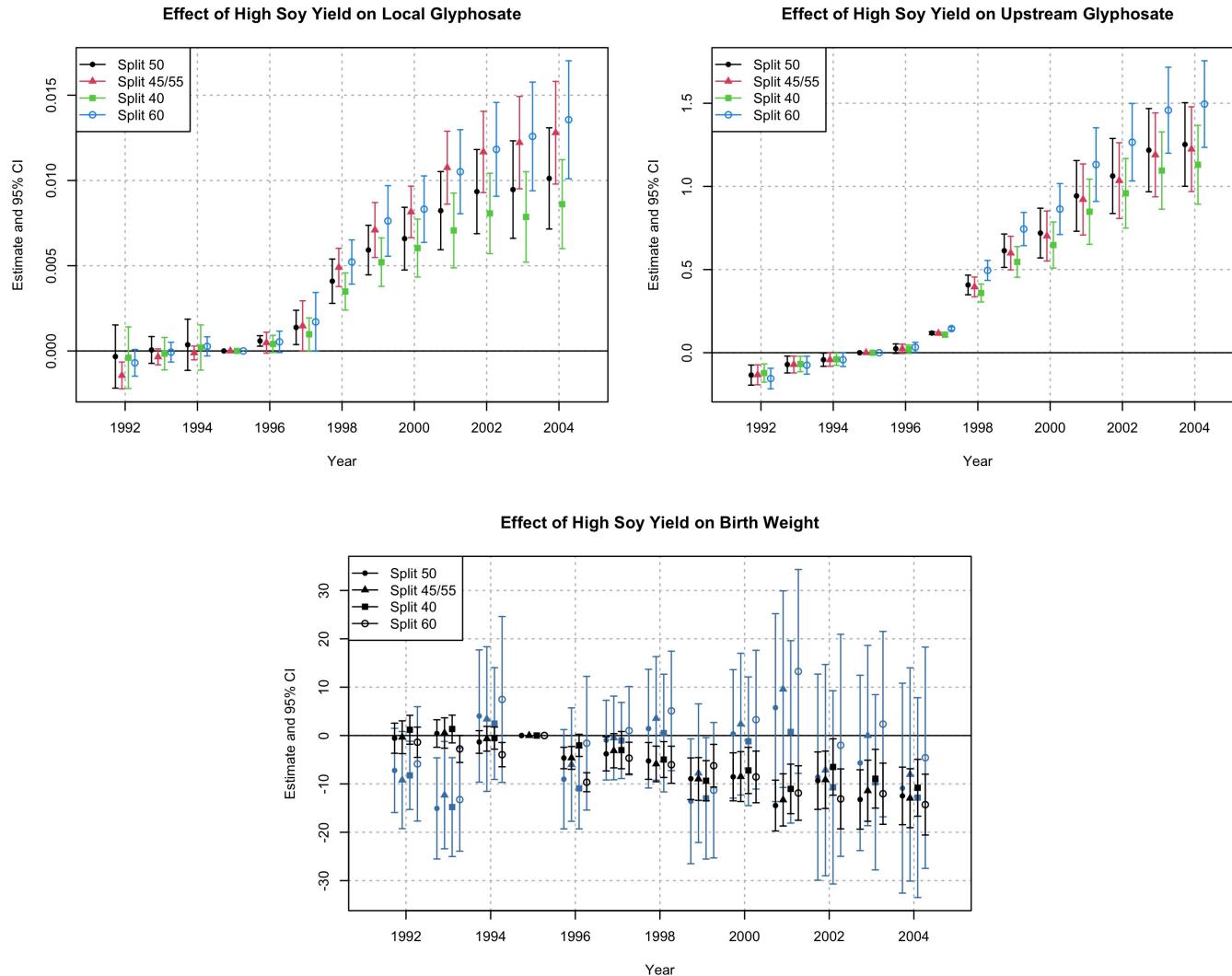
Means and standard deviations are calculated on county level averages between 1992 and 1995, which is the period prior to the release of GM crops.

# Robustness

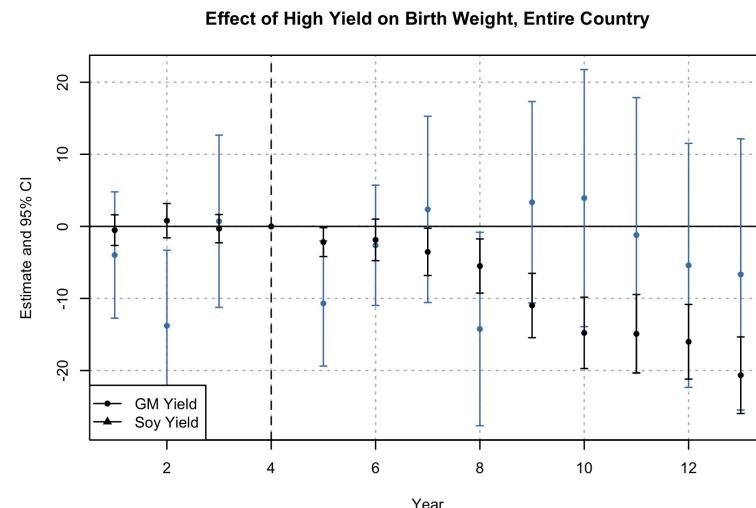
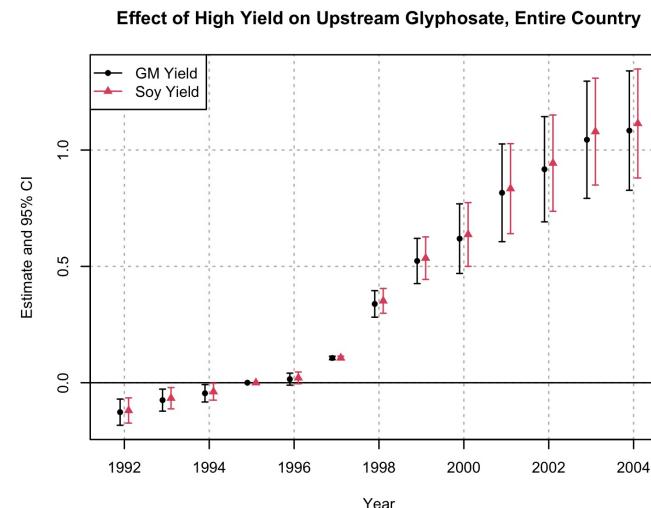
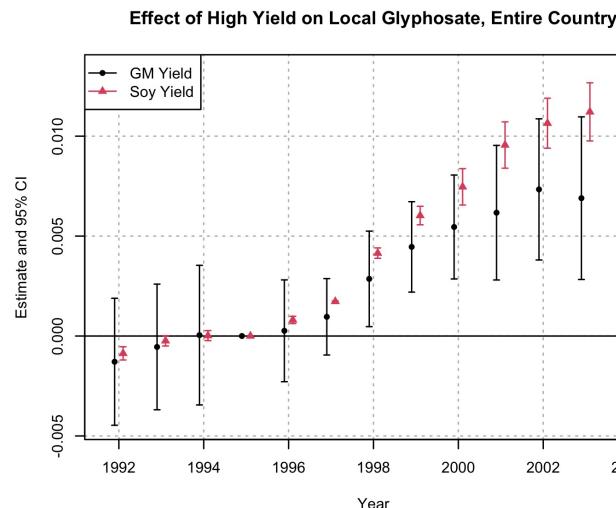
# Robustness: Different splits



# Robustness: Soy Attainable Yield



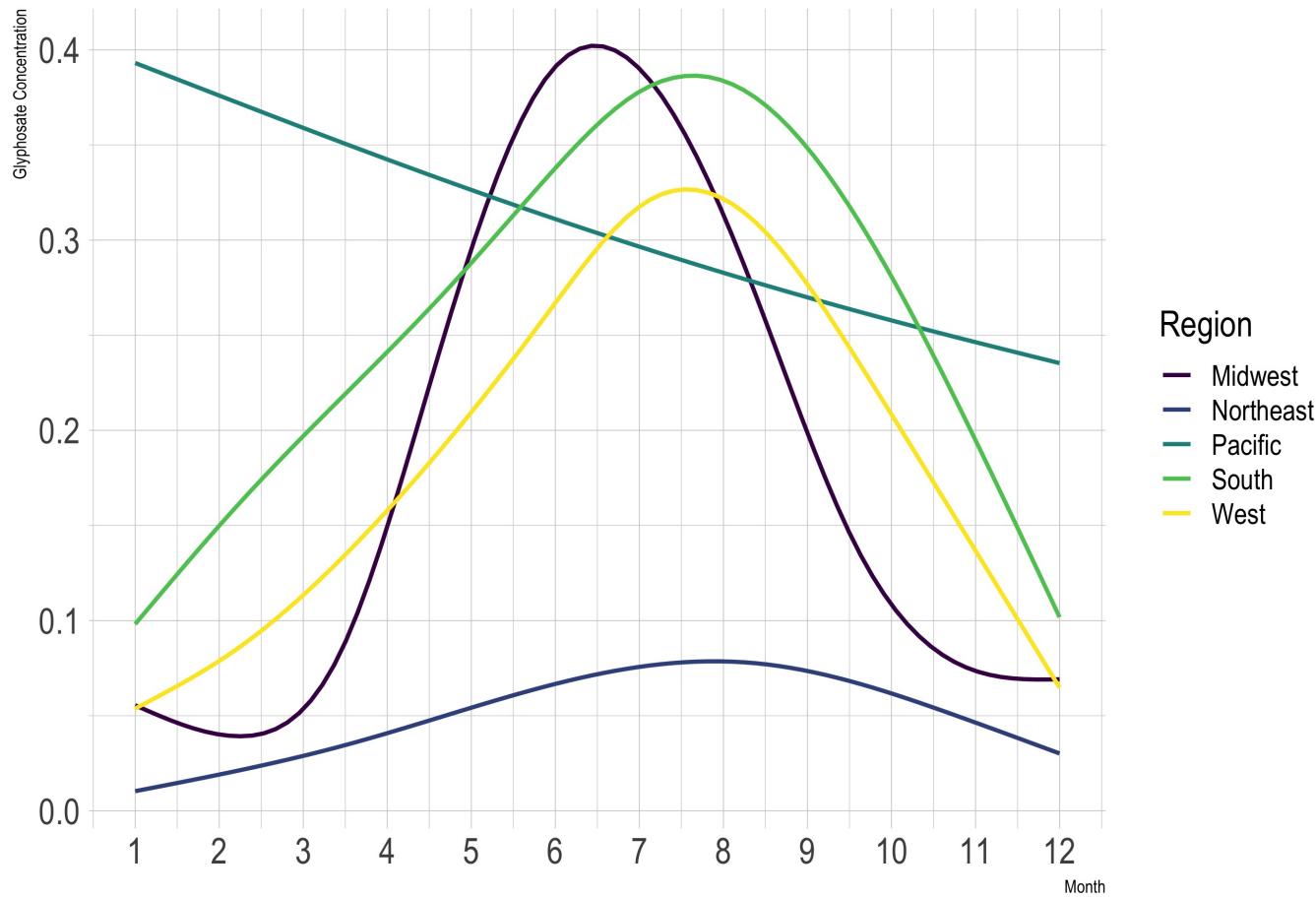
# Robustness: Entire country



# Upstream vs Local Effects

# Glyphosate in water

## Concentration of Glyphosate in Water



# Upstream vs Local Effects

## What is the exposure mechanism?

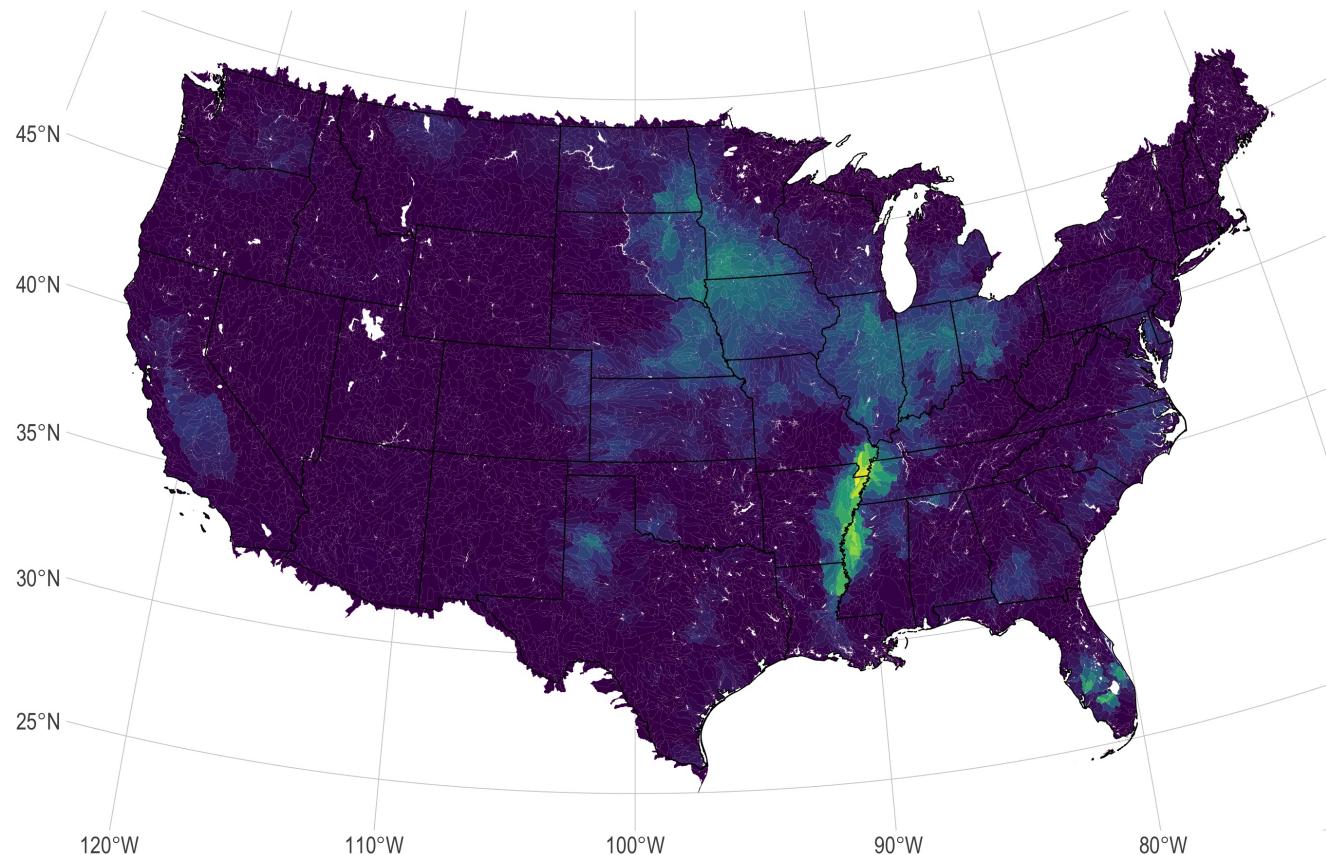
- **Direct:** Occupational exposure during/after spraying
- **Drift:** Glyphosate particles blown around by the wind
- **Water:** Glyphosate particles dissolve into water and contaminate surface or ground water

## Estimate upstream glyphosate

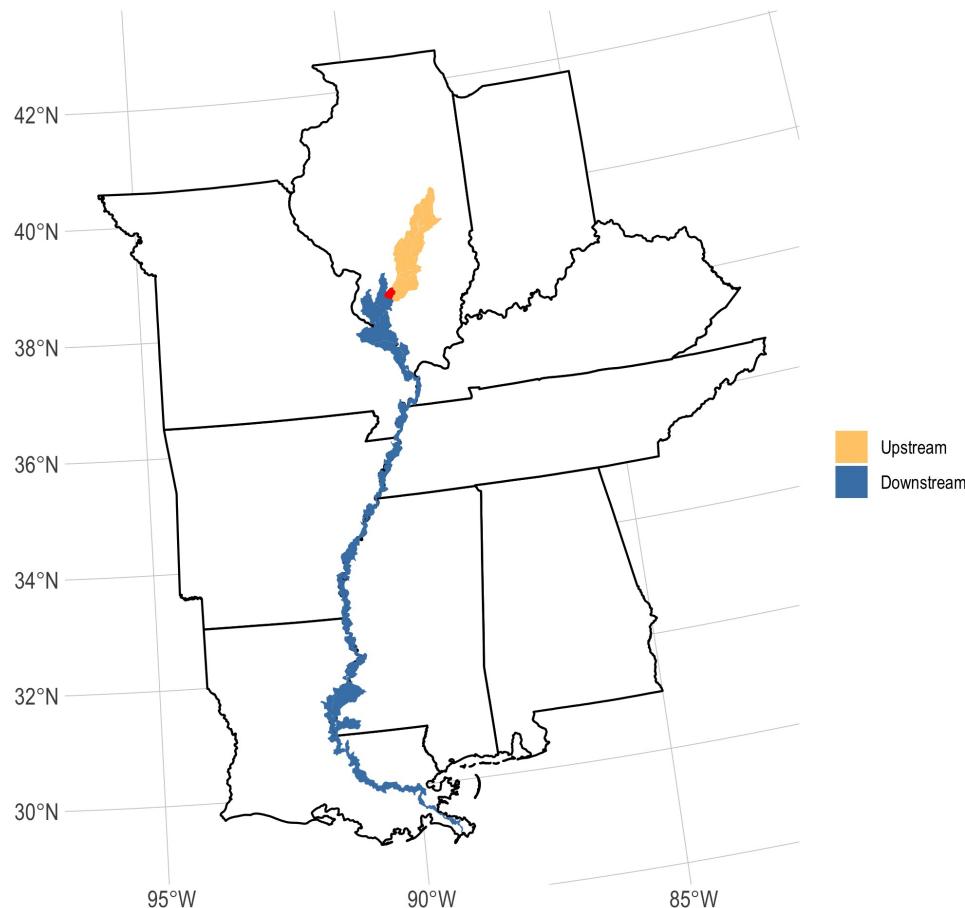
- Link counties with a spatial water model
- Aggregate upstream and downstream spraying
- Also aggregate first stage predictions from exogenous regressors

# Disaggregating to watersheds

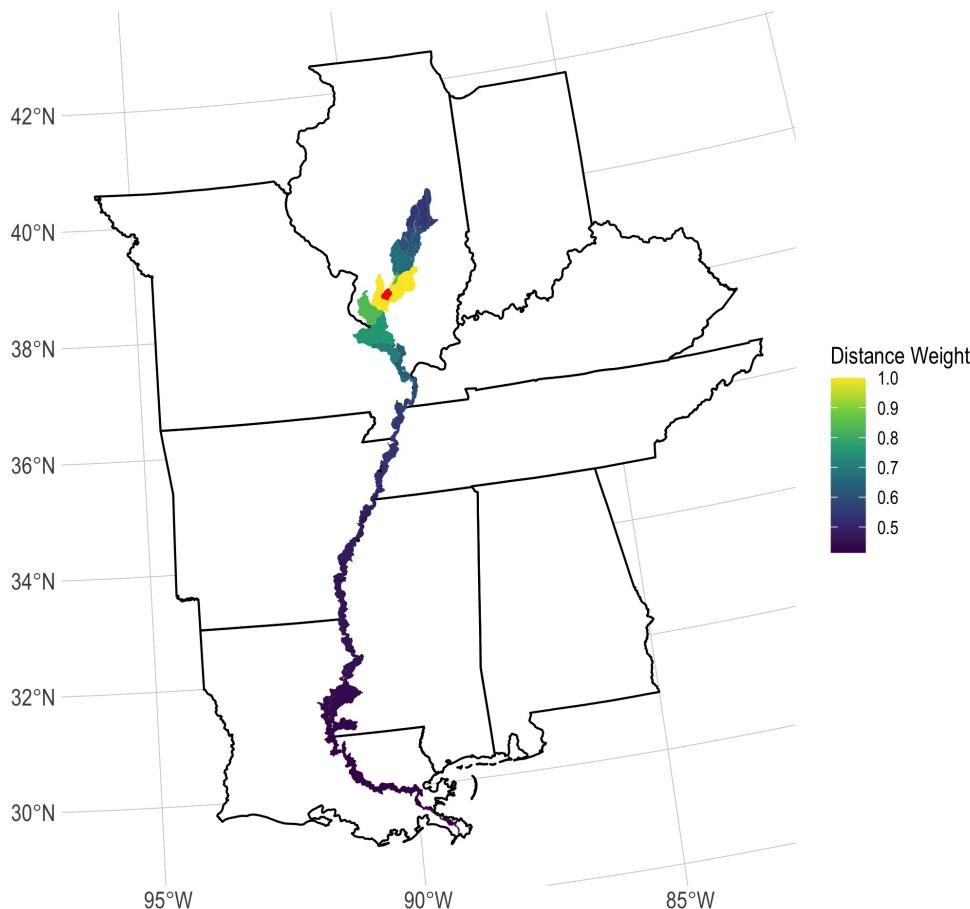
**Area weighted glyphosate by watershed in 2006**



# Aggregating upstream glyphosate



# Distance weighting



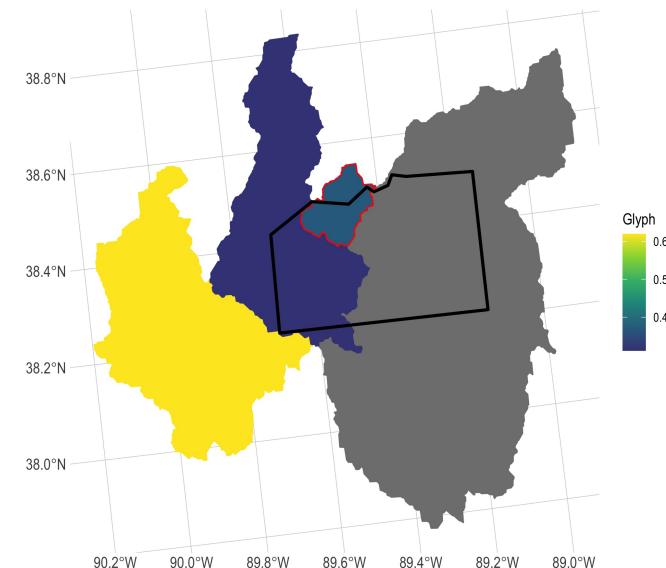
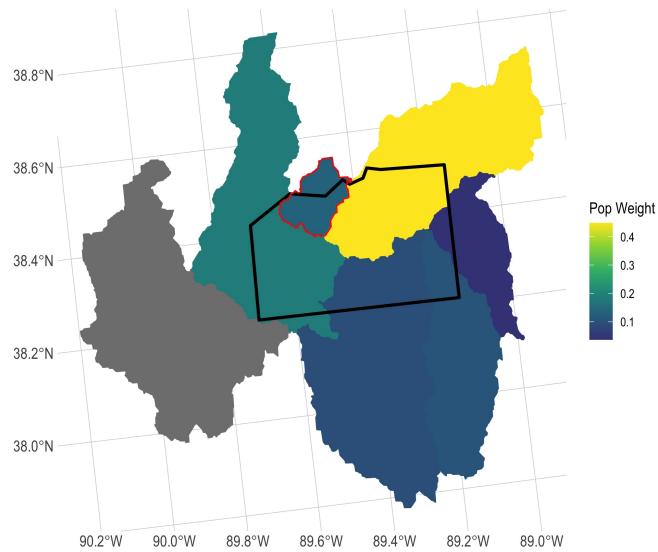
# Upstream Glyphosate

Upstream Glyphosate in 2006



# Adding population weights

Example: Washington County, IL



# Aggregating to county level

