

# Using Algorithms to Detect Gerrymandering and Improve Legislative Redistricting

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Joint work with many current and former Harvard undergraduate and graduate students  
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# Motivation

- Today's world for **quantitative social science**:
  - ① increasing availability of granular data
  - ② rapid methodological and technological advancement including AI
- Social scientists can and should solve problems of the real world!
- **Redistricting** as a major policy problem
- How can we use data and algorithms to evaluate redistricting plans?
  - traditional methods: comparison across states and time periods
  - confounded by state-specific political geography and rules
- Use of **simulation algorithms**
  - ① obtain a representative sample of redistricting plans under constraints
  - ② compare the enacted plan with this baseline distribution
- Technological solution to detecting gerrymandering
- Tool for analyzing and improving redistricting

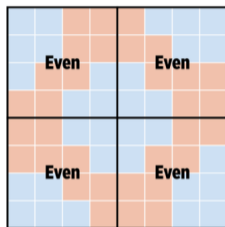


## Developing methodology and tools to analyze legislative redistricting.

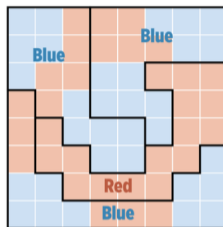
- What ALARM does:
  - ① develop efficient and flexible simulation algorithms
  - ② build open-source software packages for the entire workflow
  - ③ evaluate redistricting plans in the United States and elsewhere
- Goal: empower researchers, policy makers, data journalists, and citizen data scientists with powerful tools

# Redistricting Basics

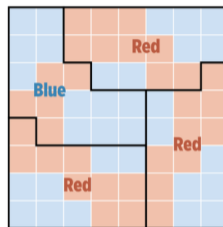
- Classic gerrymandering strategies: **packing** and **cracking**



**Even distribution**  
2 red, 2 blue



**Packing**  
1 red, 3 blue



**Cracking**  
3 red, 1 blue

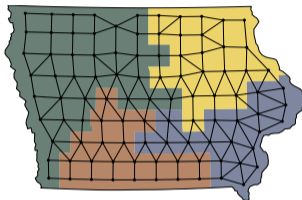
- What has changed:
  - availability of granular data
  - mapping software (e.g., Maptitude, Dave's Redistricting app)
- US Congressional redistricting
  - partisan gerrymandering: *Rucho v. Common Cause* (2019)
  - racial gerrymandering: *Louisiana v. Callais* (2026)

# Why Use Simulation Algorithm for Redistricting Evaluation?

- Traditional redistricting evaluation: comparison across states and over time
- Confounded by differences in political geography and redistricting rules
- Simulation-based redistricting evaluation
  - ① generate many **alternative plans** under a set of redistricting criteria
  - ② compare them with a proposed plan to evaluate its properties
- Benefits of simulation approach
  - ① can control for **state-specific** political geography and redistricting rules
  - ② **transparency** and ability to isolate a relevant factor
  - ③ mathematical properties  $\rightsquigarrow$  **representative sample** of alternative plans

# Redistricting Simulation (Fifield et al. (2020). *Journal of Computational & Graphical Statistics*)

- Redistricting as a balanced graph partition problem



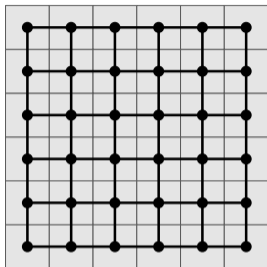
- Too many to enumerate
  - over 700 trillion ways to divide a  $9 \times 9$  grid into 9 equal sized districts
  - obtain a random (and representative) sample from the population of valid redistricting plans
- Target distribution

$$\pi(\xi) \propto \underbrace{\tau(\xi)^{\rho}}_{\text{compactness}} \times \underbrace{\exp(-J(\xi))}_{\text{custom constraints}} \times \underbrace{1_{\xi \text{ connected}}}_{\text{contiguity}} \times \underbrace{1_{\text{dev}(\xi) \leq D}}_{\text{equal population}}$$

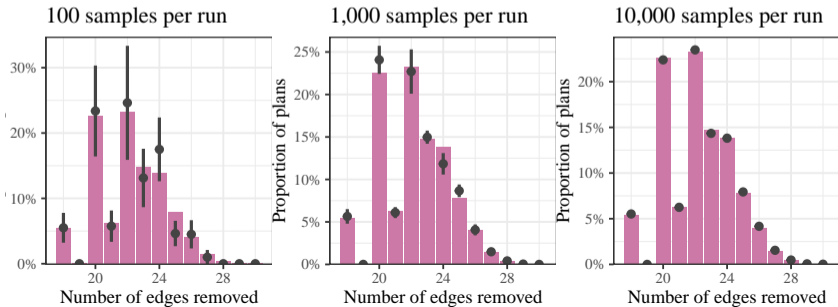
# Sequential Monte Carlo Algorithm (McCartan and Imai, 2023. *Annals of Applied Statistics*)



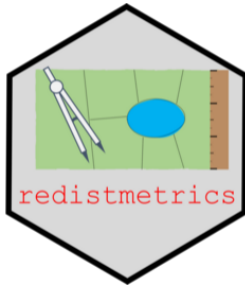
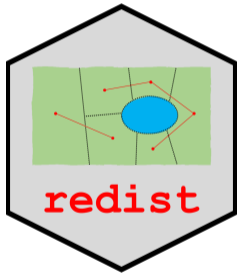
# Validation



- Divide a  $6 \times 6$  grid into 6 equal-sized districts
- Enumerate 451,206 plans (out of 356 billion)
- Compactness measure as a target statistic



# Free and Easy-to-Use Open-source Software Development



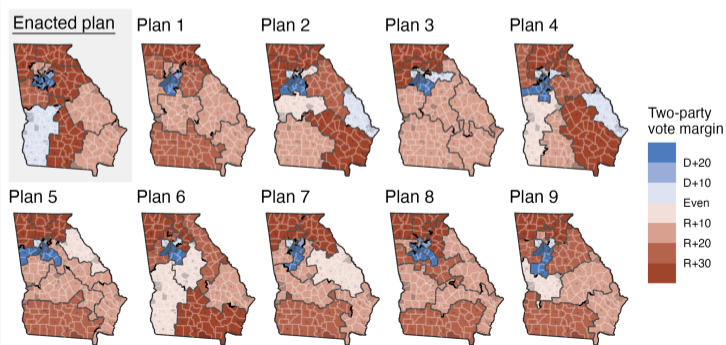


Comprehensive project to simulate alternative congressional redistricting plans for all fifty states.

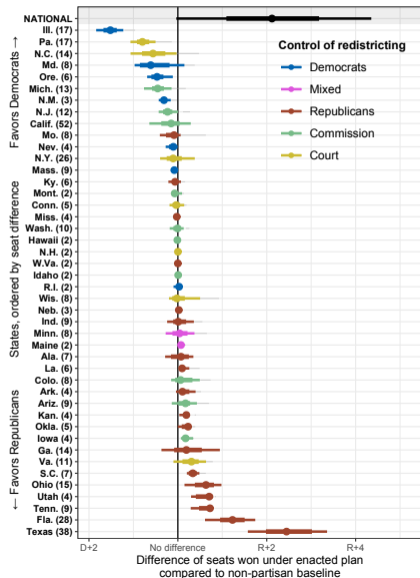
- tidied 2020 Census plus statewide election data from the VEST
- collect state-specific redistricting requirements
- construct algorithmic constraints based on these and traditional redistricting criteria
- simulated 5,000 nonpartisan plans
- code and data are available at Harvard Dataverse

## Example: Georgia

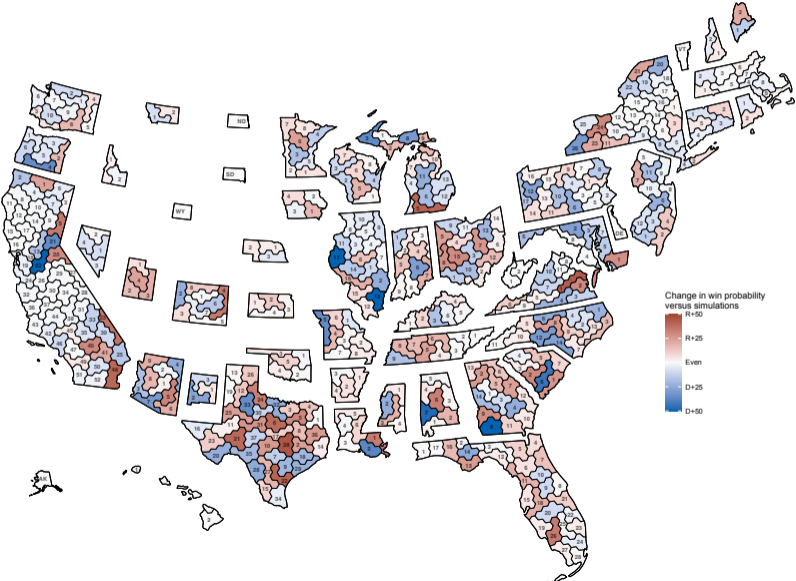
- House Legislative and Congressional Reapportionment Committee: districts must
  - be contiguous
  - have equal populations
  - be geographically compact
  - preserve county and municipality boundaries as much as possible
  - avoid the unnecessary pairing of incumbents
- Account for everything except incumbency constraint: VRA is tricky



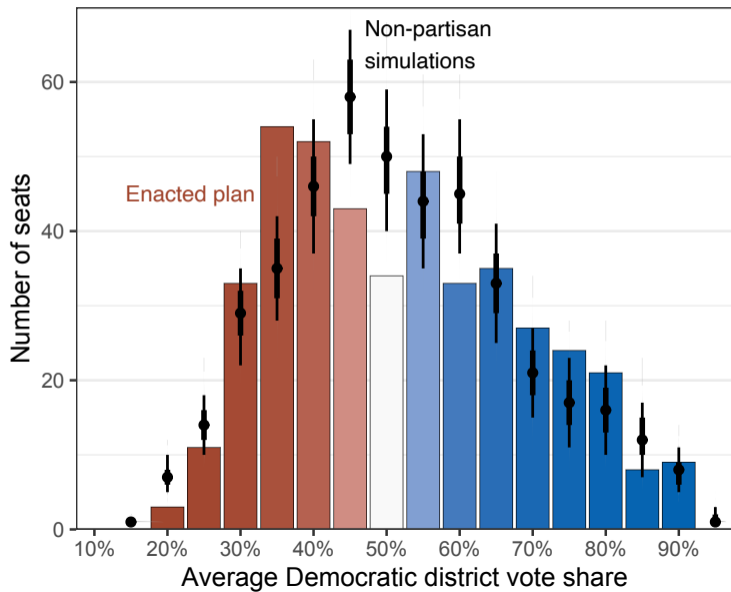
# Widespread Partisan Gerrymandering Cancels Nationally (Kenny et al. 2023. *PNAS*)



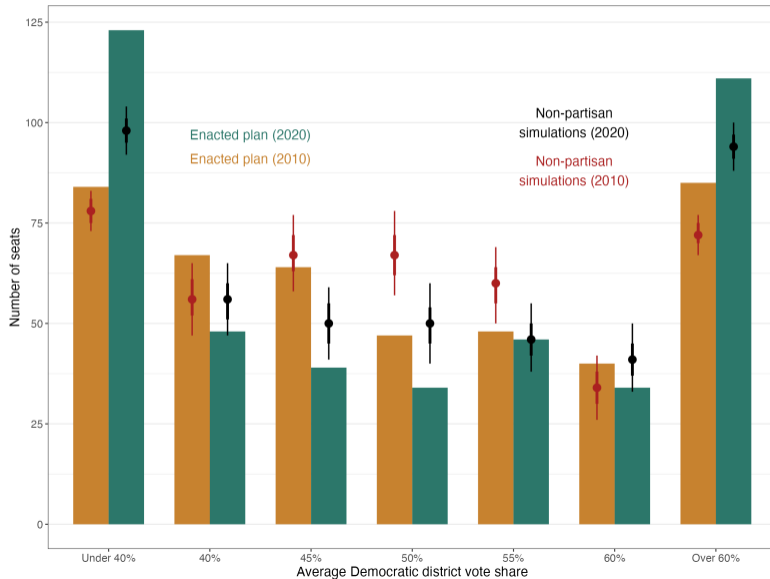
# Map of Partisan Gerrymandering



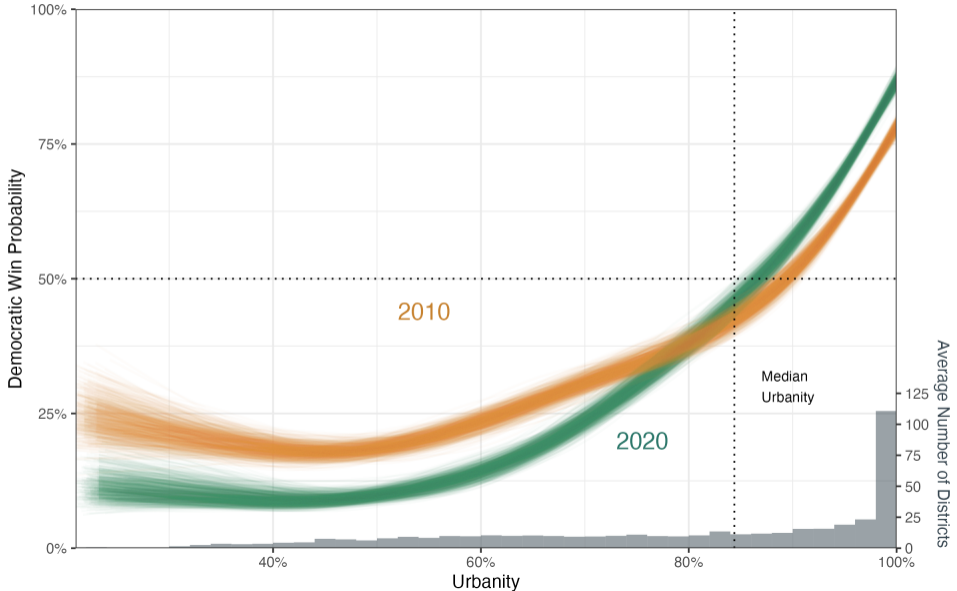
# Partisan Gerrymandering Reduces Competitiveness



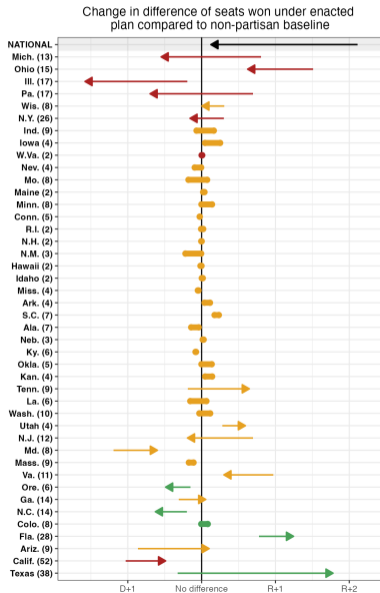
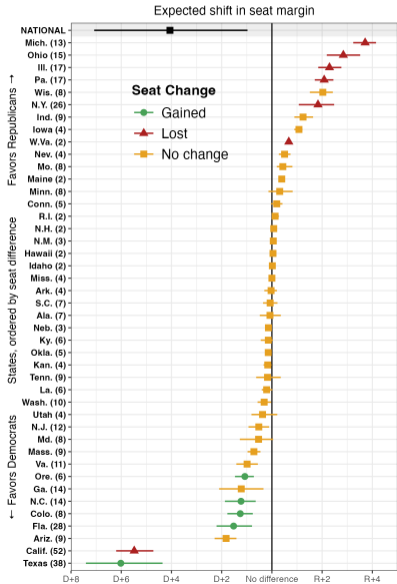
# Electoral Competitiveness Has Declined (Jasny et al. Working Paper)



# Worsening Geographic Polarization Has Contributed to This

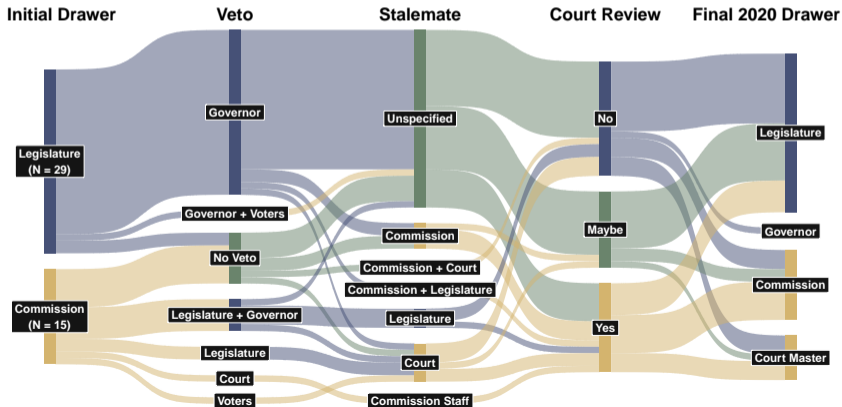


# Gerrymandering May be a Party's Response to Geographic Polarization

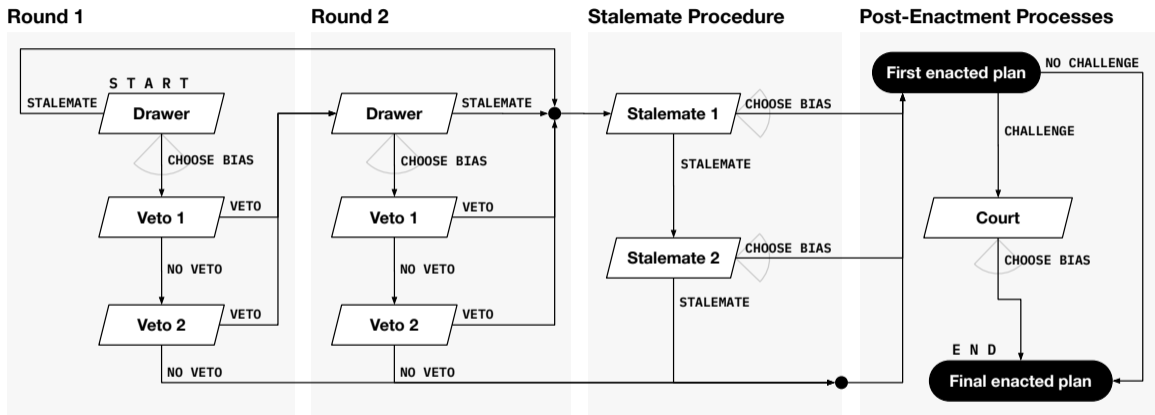


# Redistricting Reforms Reduce Gerrymandering (McCartan et al. Forthcoming. *APSR*)

- How should we reduce partisan gerrymandering?
  - nonpartisan and bipartisan commissions etc.
  - interventions by courts
  - veto by governor
- Methodological challenge: laboratories of democracy

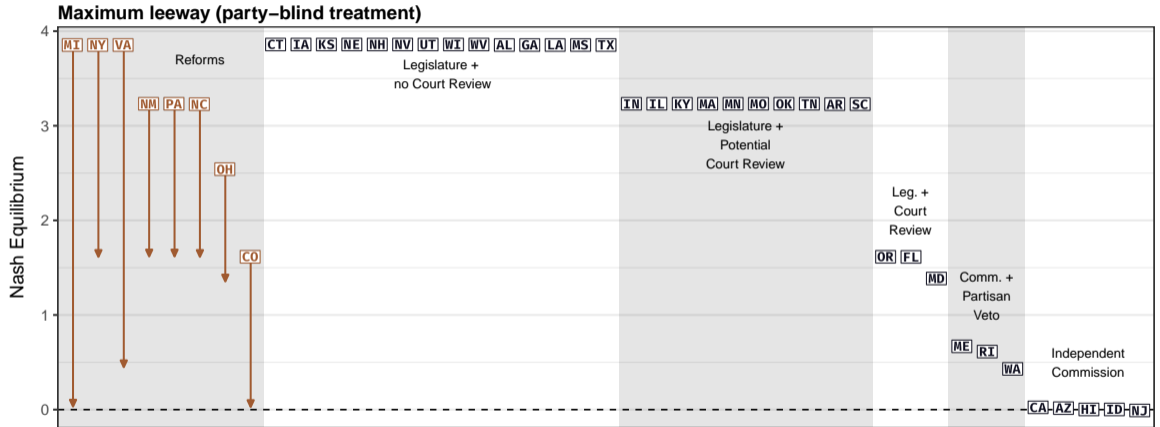


# Redistricting Game

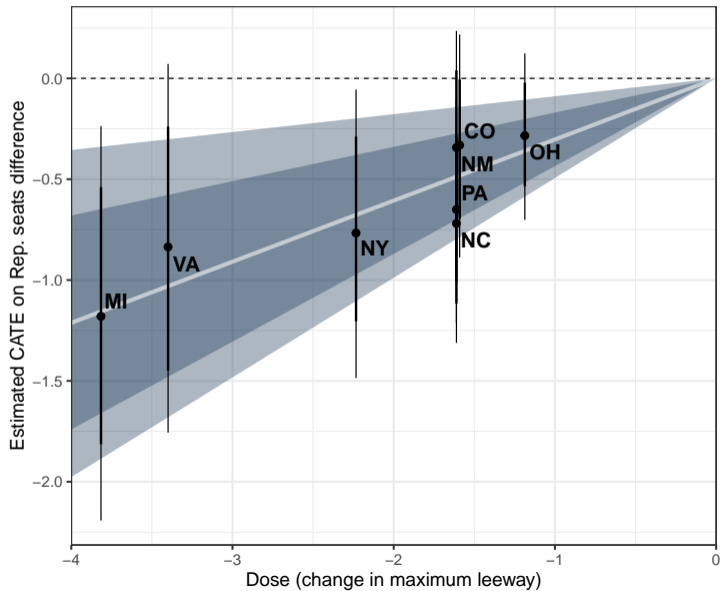


- Sequential zero-sum game characterized by 14 institutional features
- Nash equilibrium as a measure of “institutional leeway”

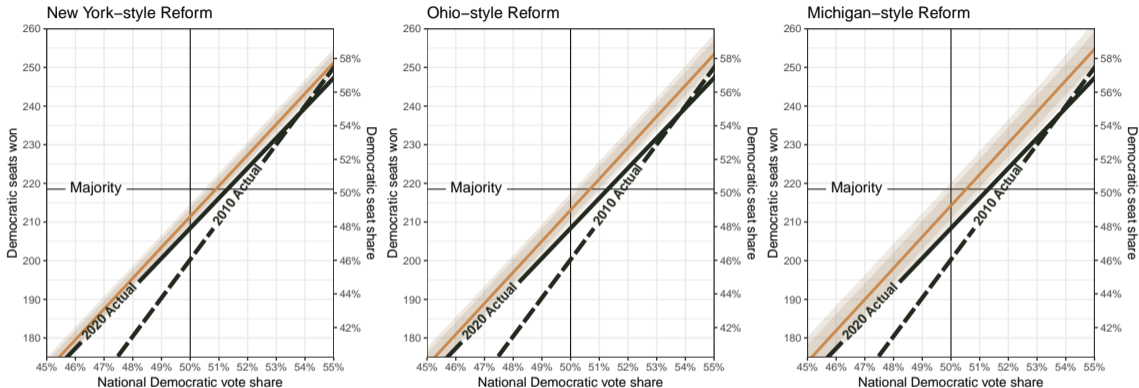
# Maximum Institutional Leeway



# Estimated Effects of Reform via Difference-in-Differences



# Commissions Can Reduce Partisan Bias

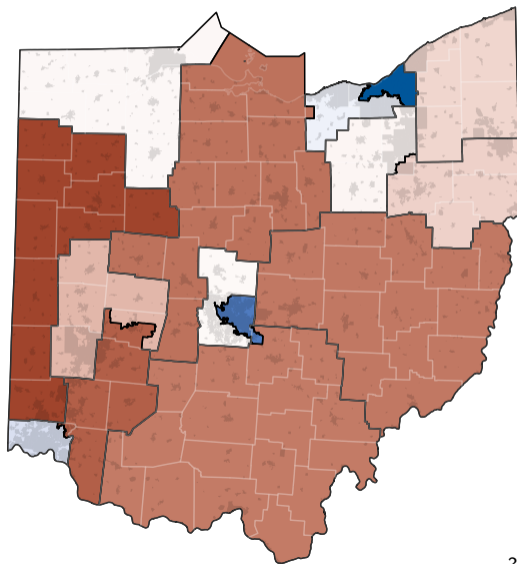
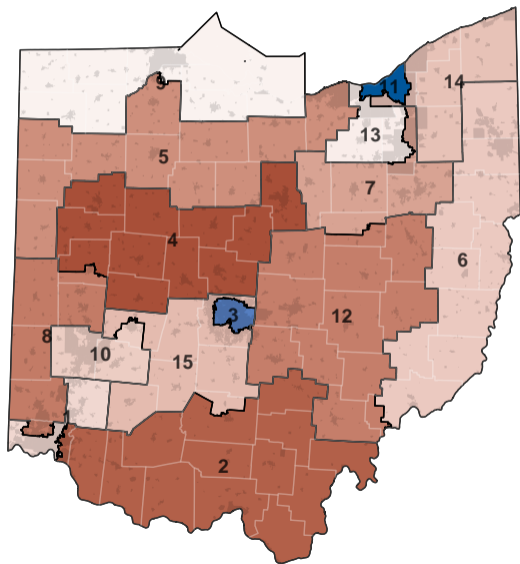


- New York: nonpartisan map-drawer with several veto points
- Ohio: legislature drawn map with partisan and bipartisan veto points
- Michigan: nonpartisan commission with no partisan veto points and potential court review

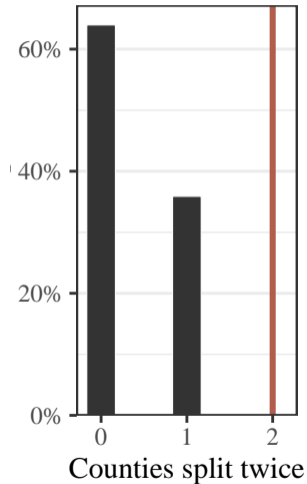
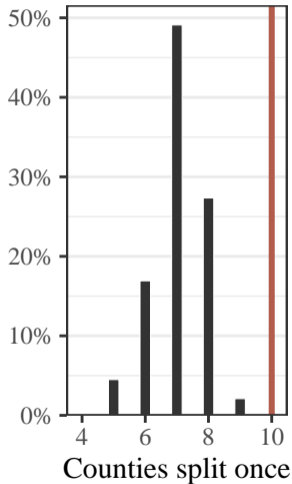
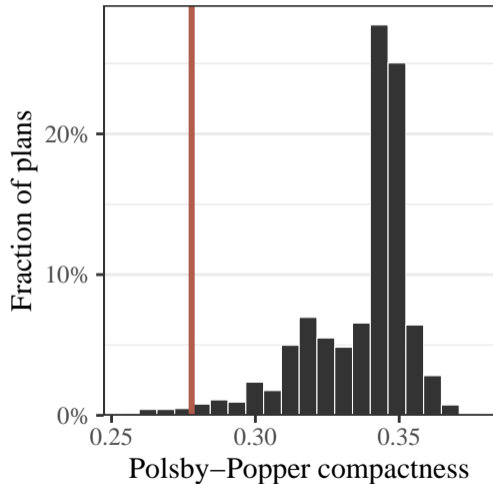
## Application in the Court: Ohio Congressional Redistricting

- Previously 16 districts: 4 Democrats and 12 Republicans
- After 2020 Census, the number of seats is reduced to 15 districts
- 2018 Ohio voters passed the constitutional amendment
- I served as an expert witness for Relators: *League of Women Voters of Ohio et al. v. Ohio Redistricting Commission, et al.*
- Simulation analysis
  - 5,000 alternative plans
  - contiguous and compact districts
  - compliant with the Voting Rights Act (Cleveland)
  - Section 2(B)(5): out of Ohio's 88 counties,
    - at least 65 counties should not be split
    - no more than 18 counties can be split no more than once
    - no more than 5 counties can be split no more than twice

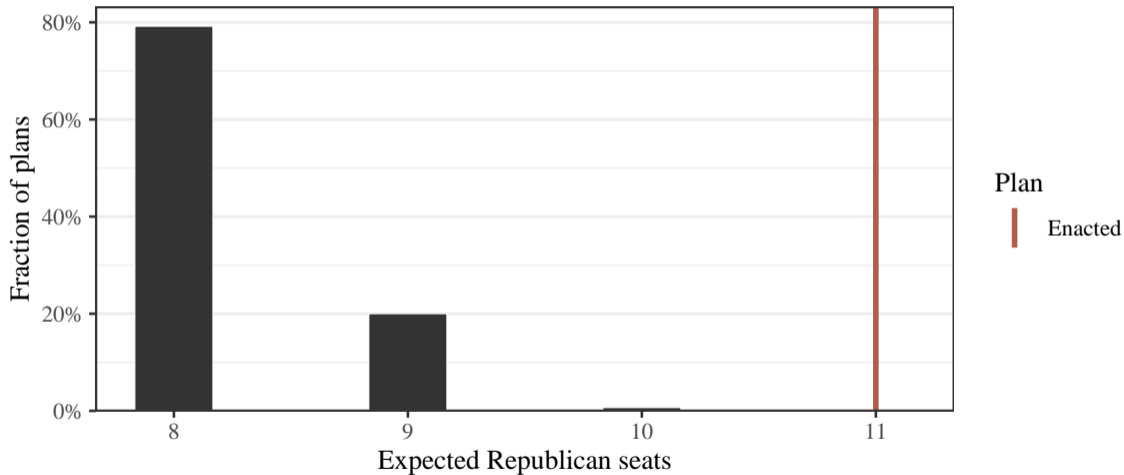
## The Enacted and Example Simulated Plans



# Compactness and Administrative Boundary Splits

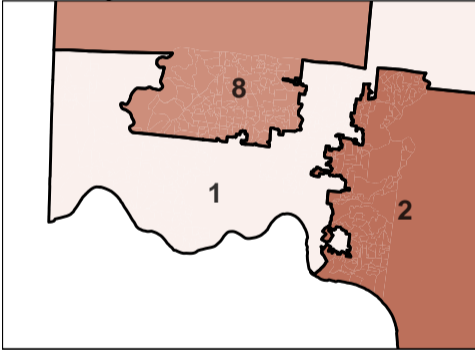


## Expected Number of Republican Seats

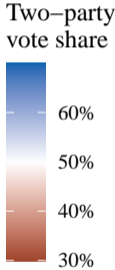
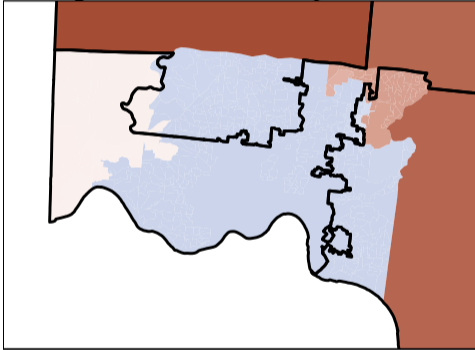


# Cracking: Hamilton County (Cincinnati Area)

Enacted plan

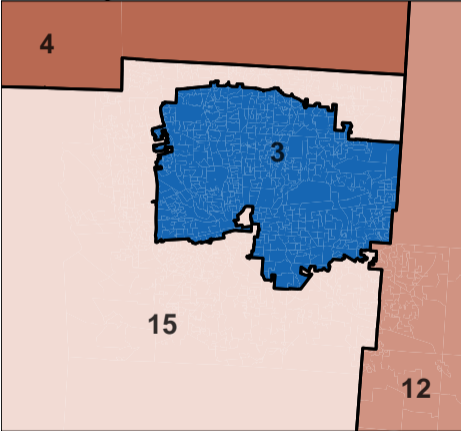


Average across simulated plans

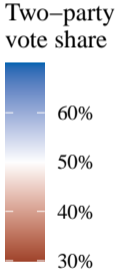
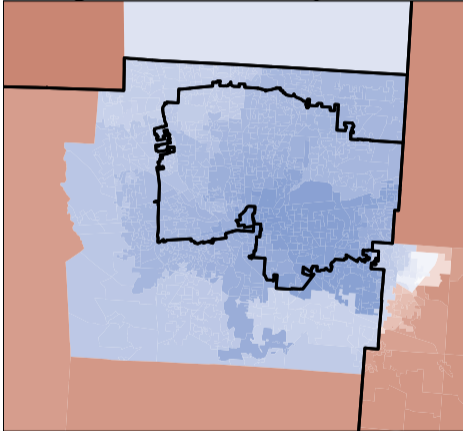


# Packing: Franklin County (Columbus Area)

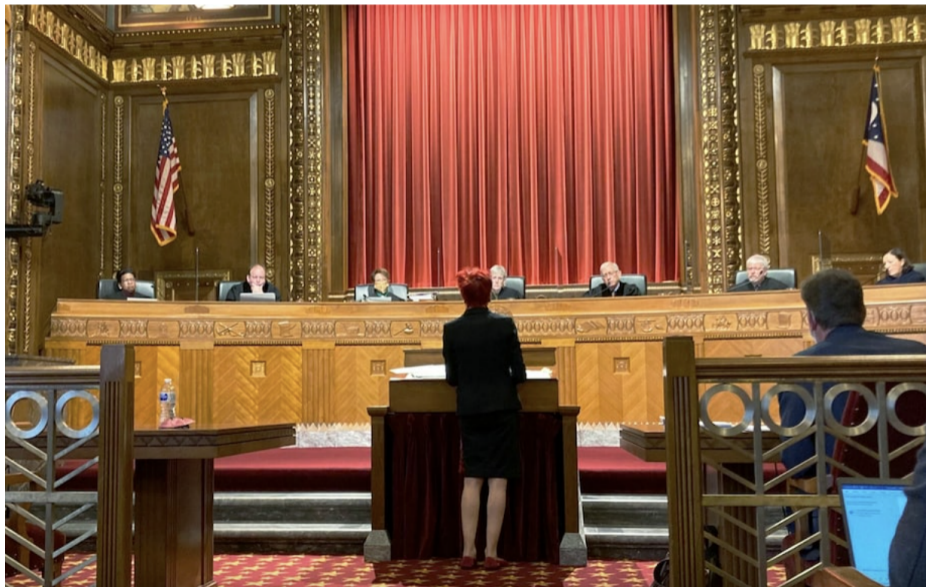
Enacted plan



Average across simulated plans



## Ohio Supreme Court Strikes Down the Enacted Map



## The Court Opinion

*Id.* at Section 1(C)(3)(a). The above evidence, particularly Dr. Imai's conclusion that the enacted plan will result in, on average, 2.8 more Republican seats than are warranted, shows that the General Assembly's decision to shift what could have been—under a neutral application of Article XIX—Democratic-leaning areas into competitive districts, i.e., districts that give the Republican Party's candidates a better chance of winning than they would otherwise have had in a more compactly drawn district, resulted in a plan that unduly favors the Republican Party and unduly disfavors the Democratic Party.

## Supreme Court: *Alexander v. South Carolina NAACP*.

- South Carolina racial gerrymandering case
- Served as an expert witness for the plaintiffs
- Used simulation to provide evidence that a disproportionately large number of Black voters are packed into District 6
- Federal district court ruled in favor of NAACP
- South Carolina directly appealed to the Supreme Court
- The Supreme Court reversed the federal district court's decision:

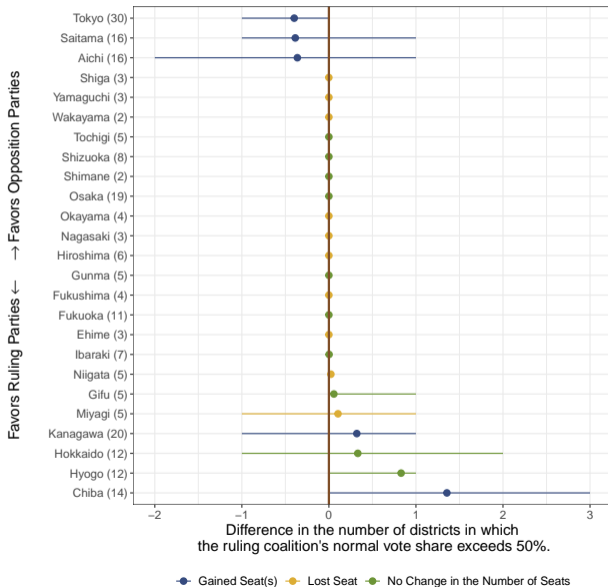
*The Challengers' inference is flawed because Dr. Imai's models failed to consider partisanship. [...] Dr. Imai's algorithm produced maps without requiring that District 1 comply with the legislature's asserted aim of ensuring that District 1 remain a relatively safe Republican seat.*

## Beyond US Redistricting: Japan (Miyazaki et al. Working paper)

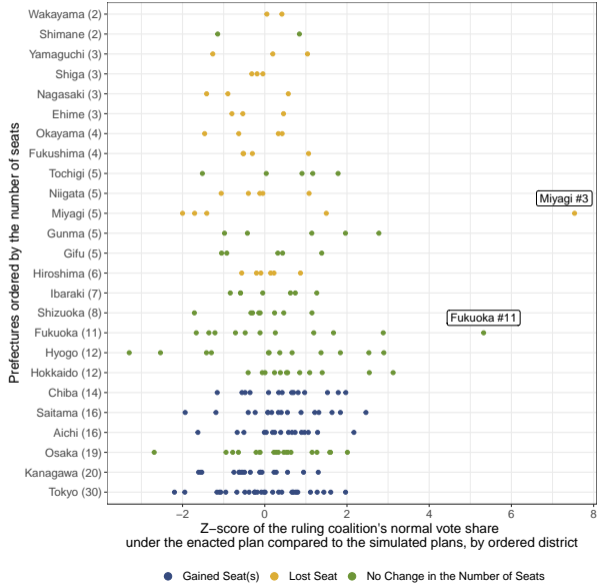
- Non-partisan commission  $\rightsquigarrow$  no partisan bias?
- Potential sources of partisan bias
  - members are appointed by the prime minister and approved by the Diet
  - governors are invited to provide their opinions
  
- 2020 Japanese redistricting
  - redistricting in 25 prefectures out of 47
  - largest redistricting in the history



# Little Partisan Bias at the Prefecture Level



# Some but Relatively Little Partisan Bias at the District Level

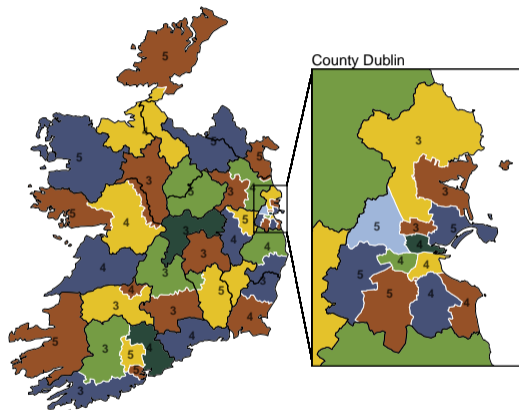


# Ireland Redistricting (O'Sullivan et al. *Working paper*)

- Ongoing collaboration with the Irish Electoral Commission



- Dáil Éireann (Lower House) redistricting
  - multimember district: 3, 4, or 5 seats per district
  - 171–181 seats in total



- We generalized our algorithm to handle multimember districts

## Concluding Remarks

- Redistricting matters
  - fair representation and policy outcomes
  - competitiveness of districts and responsiveness
  - geographic polarization
- How should we stop gerrymandering?
  - independent commissions
  - electoral reforms
- Role of academic experts
  - testimony to courts and legislatures
  - collaboration with non-partisan groups and commissions
- Ongoing work
  - analysis of Congressional redistricting in 1990 and 2000
  - analysis of State House and Senate redistricting
  - communities of interest
  - redistricting in other countries