



A Survey-Informed Evolutionary Opinion Dynamics Model of Political Activism with an Application to the 2022 Panamanian Protests

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Agenda

Introduction and Context

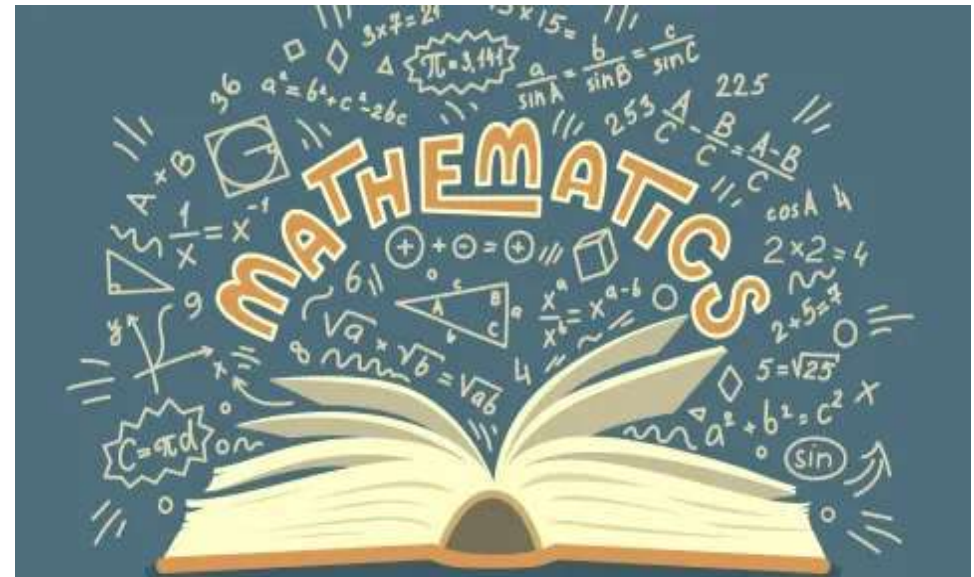
Relating Protests and Mathematics

The Conviction Moderated Model in Depth

The Conviction Moderated Model's Results

Revamping a Model with Real-World Data

A Survey Informed Model



Popular caricature of “Math Research”



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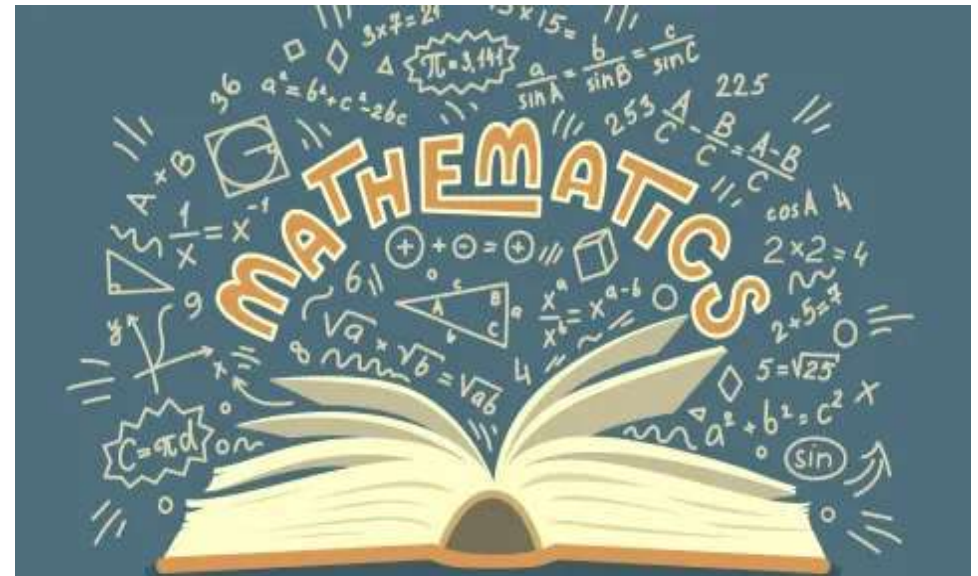
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Arturo F. Serrano Borrero Neukom Research Scholar

- Applied Math and Policy B.A. student from Panama at Dartmouth College
- Recipient of Mark C. Hansen and Nelson A. Rockefeller grants for undergraduate research
- Ongoing research in Panama's social activism since 2022
- Research interests include Evolutionary Game Theory, Sociophysics, Network Science, Mathematical Pedagogy, and Ehnomathematics





Olivia J. Chu

Neukom Postdoctoral Fellow

- Received Math B.A. at NYU and Quantitative Biology Ph.D. at Princeton
- Recipient of Neukom Post-Doctoral Fellowship in Mathematics and Sociology at Dartmouth College
- Research publications in evolutionary game theory (cooperation mechanisms in heterogeneous systems) and opinion dynamics (geospatial opinion dynamics in Ukraine)
- Additional areas of interest include Mathematical and Computational Biology and Evolutionary Dynamics



Our Opportunity: Funded Summer Research in Mathematics and Political Attitudes

- Professor Daniel Rockmore (Neukom Institute) connected us to explore both data-driven and abstract modeling of Latin American political systems and attitudes over the summer of 2022
- Our research was funded by the Undergraduate Advicing and Research Office at Dartmouth College



One of our data sources: The World Justice Project

Panamanian Protests of 2022: Panama's First Multi-Cohort Social Protests in Decades



Bocas del Toro



Guna Yala



Ngäbe Buglé



Herrera



Panamá



Darién

Key Features of the Panama Protests of 2022



Typical Panamanian Protest

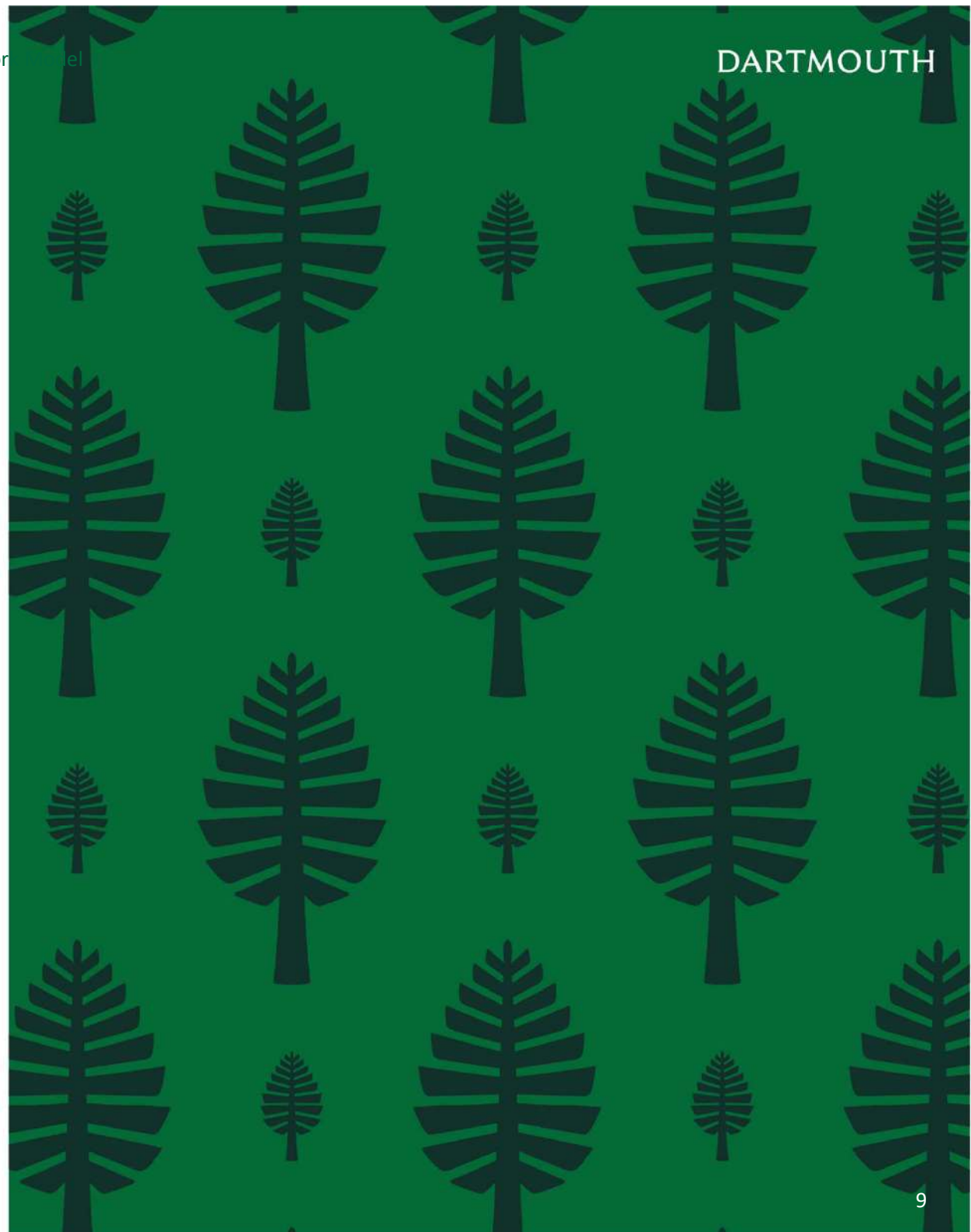
The COVID-19 pandemic and the Cortizo government brought about major changes in political attitudes, political behaviors, and social structure:

- Political attitudes: tendency towards negativity and toxicity; more nuanced discussion of corruption; growing frustration with cost of living and indigenous rights abuses
- Political behaviors: more frequent political discussion among semi-isolated inner circles; politicization of everyday life and decision-making
- Social structure: beginning of cross-sector alliances in social discourse, more divided social media networks



Using Math and Social Media Data Science to Explore Social Trends

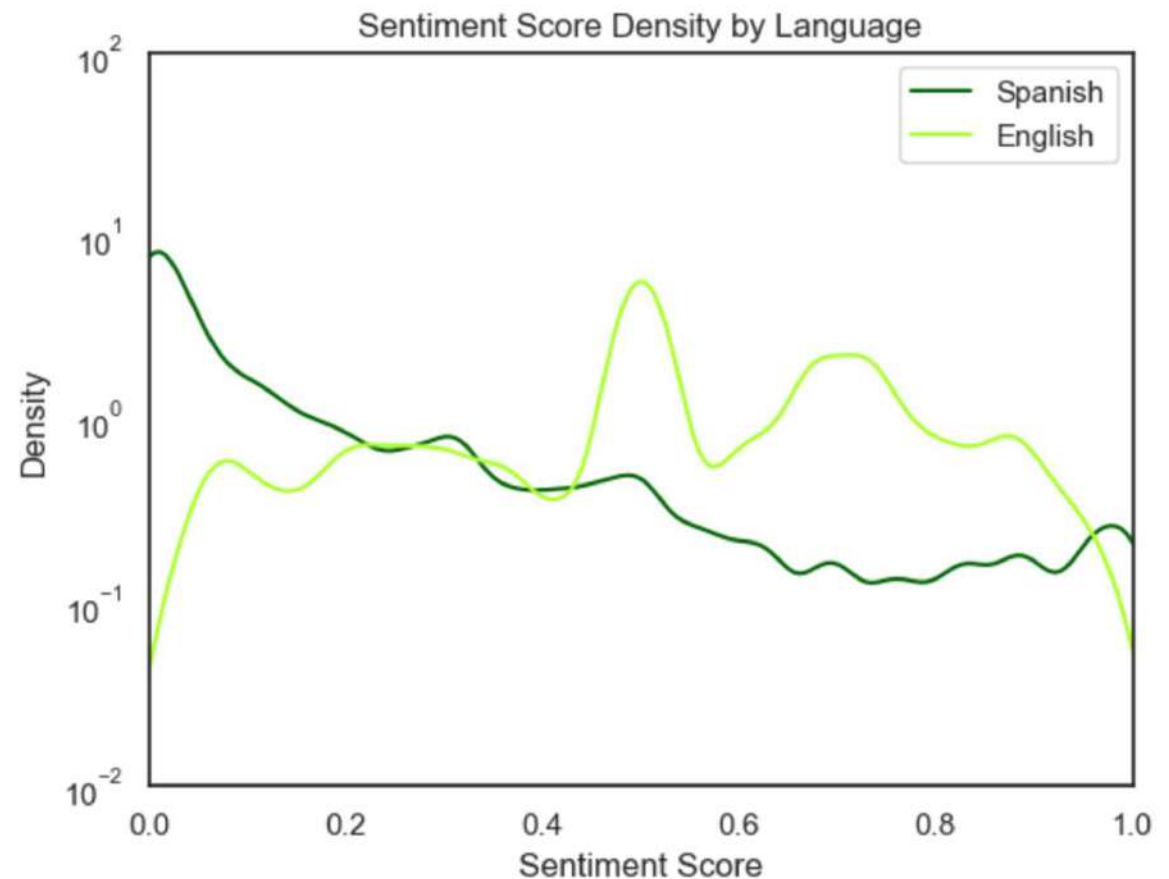
Under the mentorship of Professor Ho-Chun Herbert Chang, I analyzed Panamanian discourse on Twitter during the COVID-19 Pandemic to better illustrate these trends





Sentiment Analysis: Different Environments for Spanish and English-Language Tweets

- Simple data exploration revealed two significant universes (Spanish and English-language tweets)
- Spanish-language tweets are far more negative and skewed than English-language tweets





Topic Modeling: Five Concerning Topics for Panamanians from Response to Vaccination

Five main topics were extracted using LDA gensim analysis, showing the main concerns of Panamanians during the pandemic:

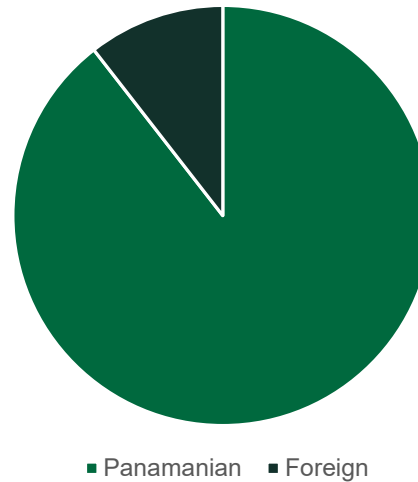
| Topic ID | Topic Title and Prevalence | Top Keywords |
|----------|-------------------------------------|---|
| 1 & 5 | Epidemiological Reports (39.5%) | “new”, “cases”, “data”, “total”, “accumulated”, “deaths”, “infected”, “active”, “record” |
| 2 | Omicron and Public Response (25.3%) | “omicron”, “country”, “government”, “health”, “children”, “population”, “public”, “ministry” |
| 3 | Vaccination (20.8%) | “vaccine”, “dosis”, “variant”, “arrive”, “million”, “cost”, “arrive”, “start”, “clinics” |
| 4 | Biosafety Advisory (14.4%) | “medic”, “follow”, “safety”, “biosafety”, “virus”, “remember”, “mask”, “unity”, “avoid”, “reinforce”, “important” |



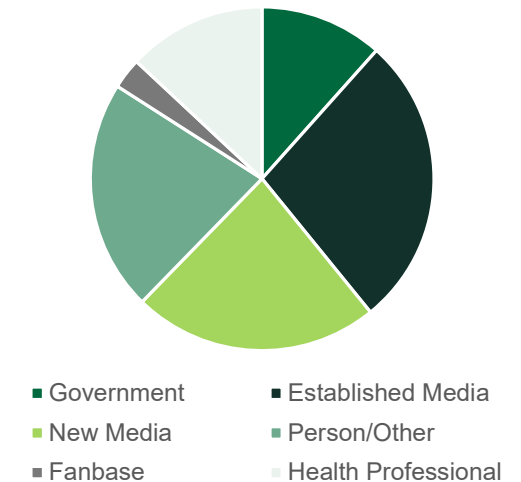
Network Analysis: Showing the Influence and Reach of Non-Established and Foreign Actors

- Manual classification of the top 70 most retweeted users allows us to quantify the influence of different types of actors
- While established Panamanian media dominated discourse, foreign and new media actors had significant presence.
- Interestingly, the Panama Soccer Team and BTS fanbases were among the most influential accounts.

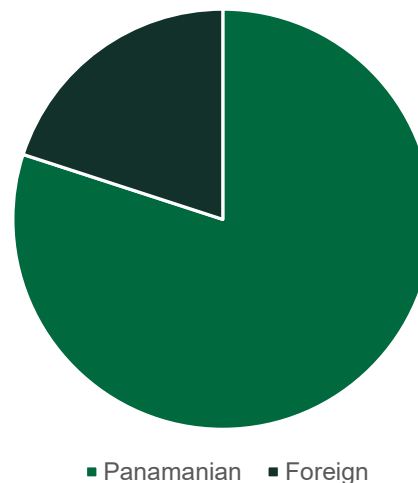
Share of Tweets by Origin



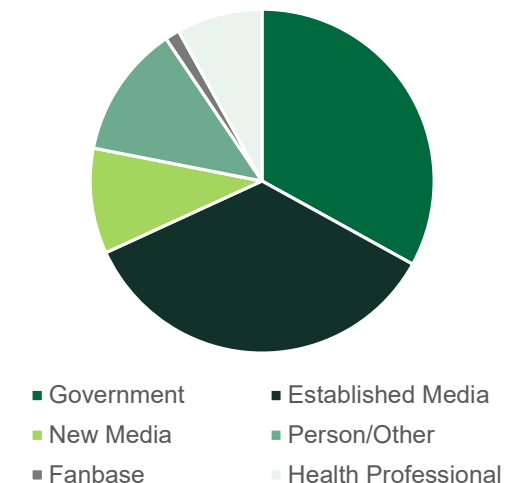
Share of Tweets by Account Type



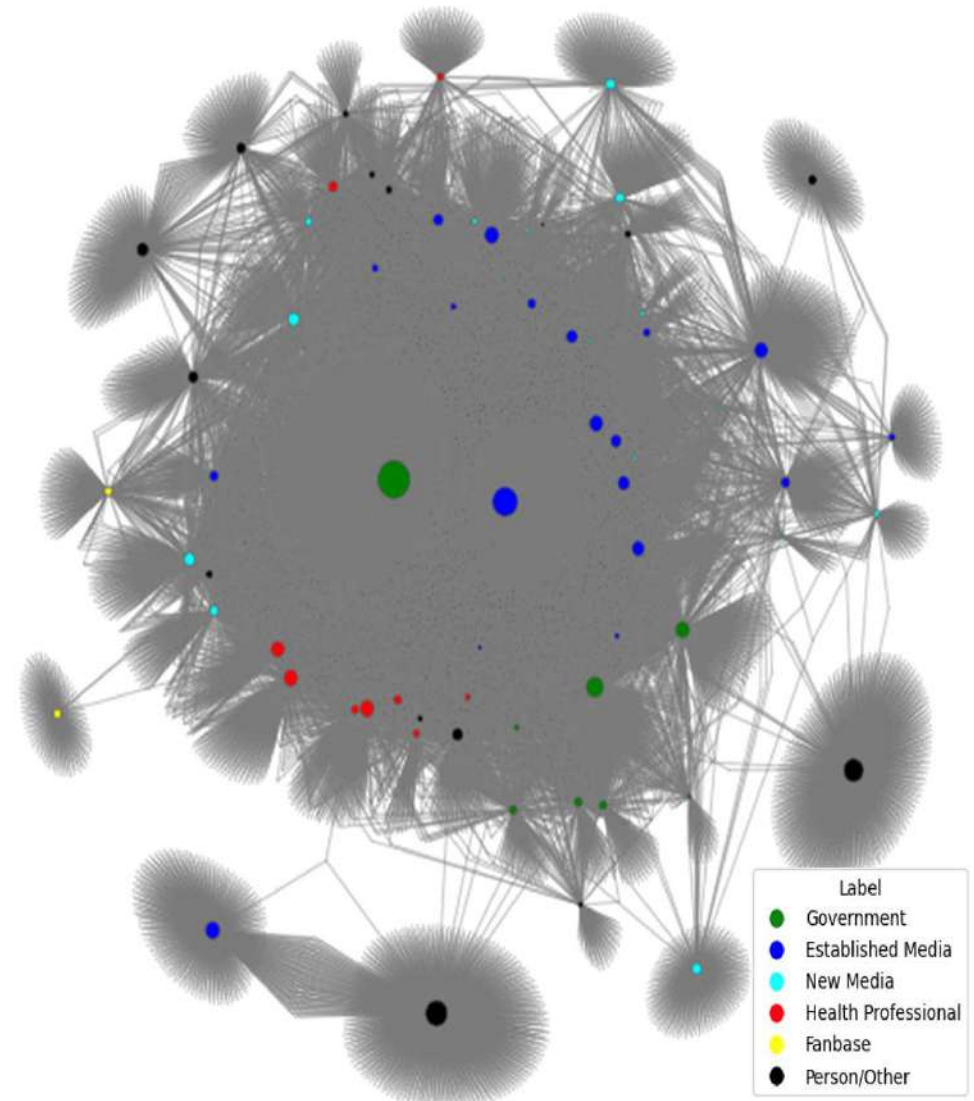
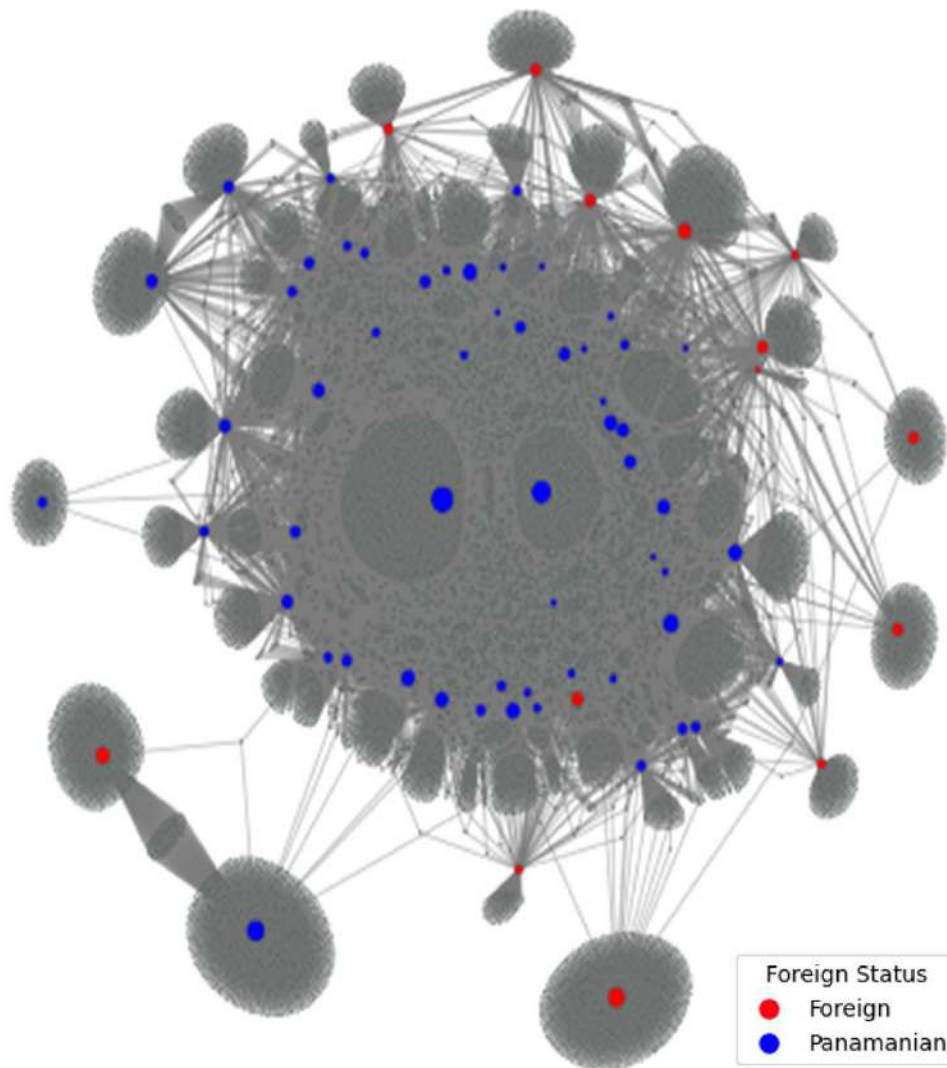
Share of Top Accounts by Origin



Share of Top Accounts by Account Type



Network Analysis: Visualizing Relative Associativity in the Landscape



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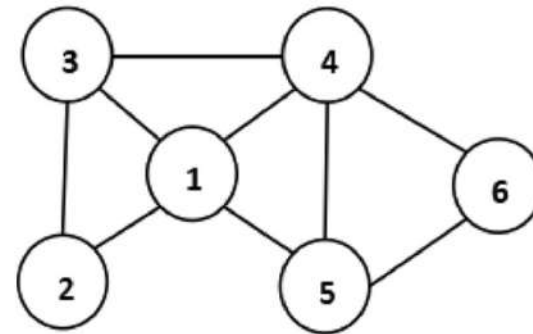
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Multi-Cohort Protests in Panama: July 2022

Graph Theory

- Graphs are collections of vertices and edges that represent objects and connections
- They can be used to represent social relationships, transportation infrastructure, material flows, website links, etc.
- Graphs are often stored as their equivalent form: adjacency matrices



(a) Social network graph

$$\begin{bmatrix}
 0 & 1 & 1 & 1 & 1 & 0 \\
 1 & 0 & 1 & 0 & 0 & 0 \\
 1 & 1 & 0 & 1 & 0 & 0 \\
 1 & 0 & 1 & 0 & 1 & 1 \\
 1 & 0 & 0 & 1 & 0 & 1 \\
 0 & 0 & 0 & 1 & 1 & 0
 \end{bmatrix}$$

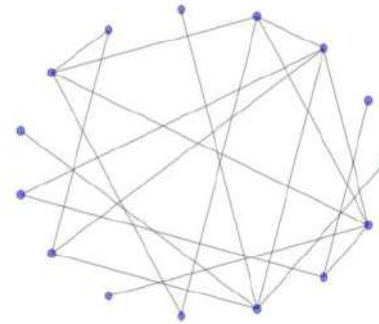
(b) Adjacency matrix

Illustrations of a graph and its matrix

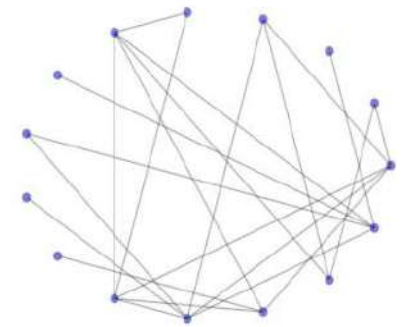
Social Network Science

- Graphs can establish social relations
- We have different types of well studied graphs:
 - Random/Erdős–Rényi (biology)
 - Small-world/Watts-Strogatz (society)
 - Scale-free/Barabási-Albert (social media)
- Graphs are described through properties:
 - Assortativity, transitivity, and propinquity

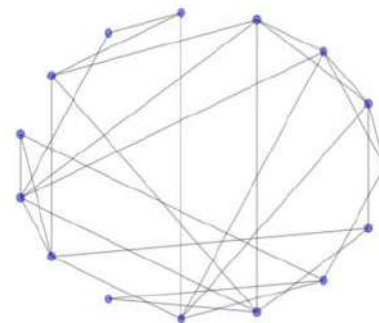
(a) Erdos-Renyi (Random graph)



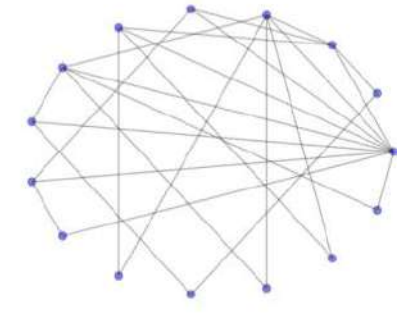
(b) GNM (Random graph)



(c) Watts-Strogatz (Small-world)



(d) Barabasi-Albert (Scale-free)



Common graphs in social networks

Classical Game Theory

- Analyzes strategic interactions between rational actors
- In each interaction, actors try to choose maximize their payoffs
- A key example is the well-known prisoner's dilemma
- In this problem, the Nash equilibrium is reached by mutual defection, even though it's not the ideal outcome

THE PRISONER'S DILEMMA

| | B stays silent (cooperates) | B betrays A (defects) |
|------------------------------------|------------------------------------|-------------------------------|
| A stays silent (cooperates) | Both serve 1 year | A serves 3 years, B goes free |
| A betrays B (defects) | A goes free, B serves 3 years | Both serve 2 years |

SOURCE: Wikipedia BUSINESS INSIDER

Payoff matrix for Prisoner's Dilemma

Evolutionary Game Theory (EGT)

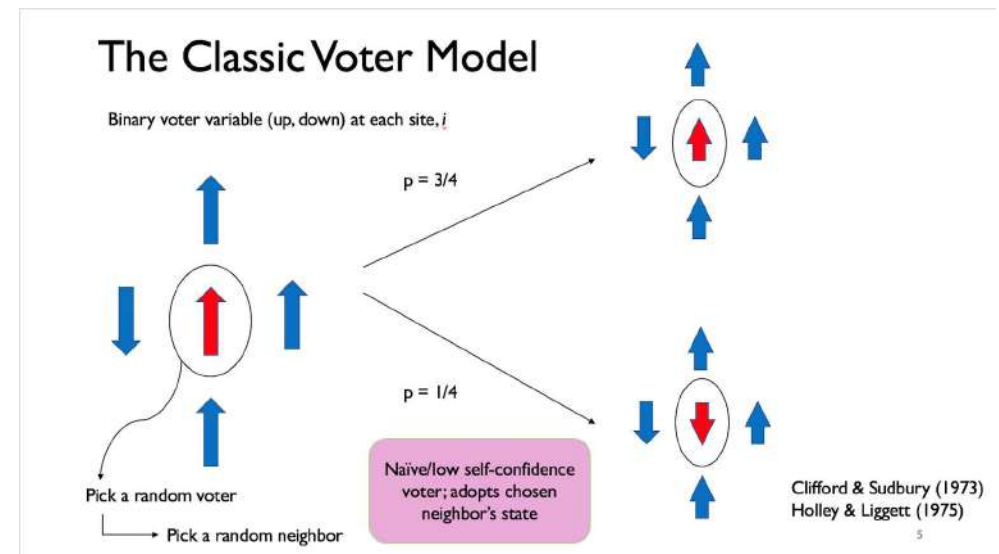
- Adapting classical game theory to the study of evolving populations
 - Rationality → natural selection
 - Economic payoffs → biological fitness
- Strategies are assumed and may change over time
- Awareness of game not necessary
- “Survival of the fittest” helps understand population dynamics



Animal populations are studied with EGT

Opinion Dynamics: Classical Voter Model

- Each voter is assigned a position in space and an opinion (yes or no)
- Then, the model randomly selects a voter whose opinion will be determined by one chosen neighbor
- The model tends towards consensus, but it can also display co-existence and clustering
- Underlying graph governs these behaviors

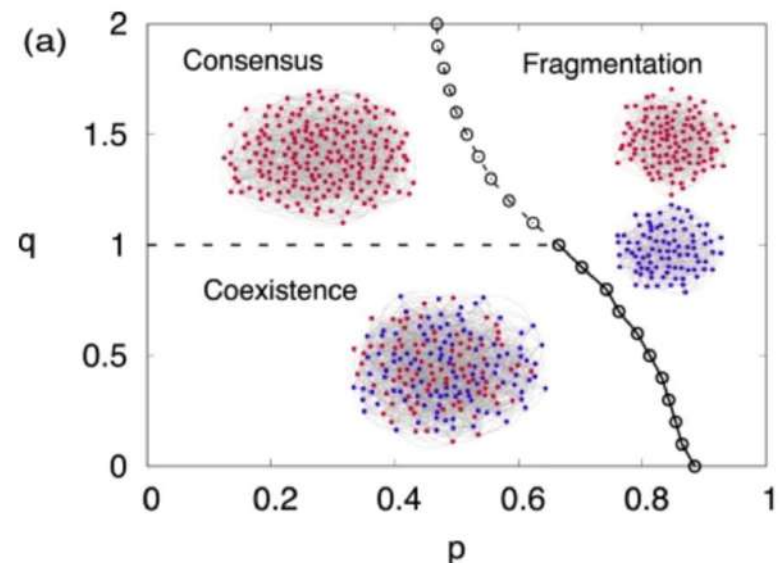
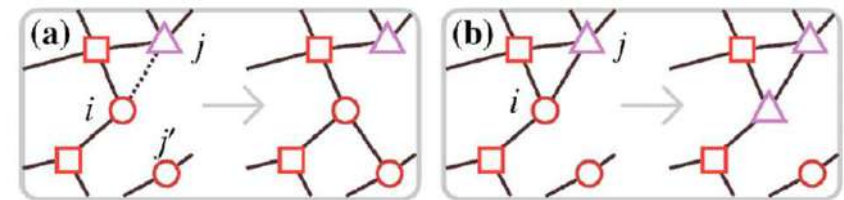


Flowchart of the Classical Voter Model

Opinion Dynamics: Adaptive Voter Model

- The AVM simulates the processes by which networks influence individual's political opinions and individuals modify their networks according to their connections' stances
- At each time step, a chosen voter engages in either homophily or social learning (fixed parameter)
- Parameter governs whether outcome is opinion convergence or divergence

Homophily and Social Learning



Consensus and Fragmentation



Discovering a Relationship Between Math and Political Activism

- We discovered natural resemblances between key concepts of both EGT and opinion dynamics and political systems:
 - Political conversations behave like games insofar as political opinions resemble strategies and the outcomes, which resemble payoffs influence an individual's conviction (i.e., their comfort with their opinion modeled as a fitness)
 - Voters in every population do exhibit the co-evolution of opinion and social relationships, and the models match some real-world distributions
- **However, opinion dynamics modeling remained simplistic**, requiring analysis of social networks and evolutionary dynamics:
 - The application of stochastic opinion modeling to specific political problems (e.g., spatial polarization in Ukraine) helped us envision new paths.



Combining Two Approaches: Introducing Conviction to Understand Protest

- In social modeling, striving for universality and simplicity often comes at the expense of specificity, applicability, and realistic simulations
- Yet political systems are rarely mean fields; adaptation rates are not constant across individuals or for the same individual over time
- It is true that people change their minds based on social relations and vice versa, but we believed that understanding the circumstances in which individuals held these beliefs most strongly while surrounded by a like-minded neighborhood warranted further study
- Hence, we made our decision to incorporate **conviction moderation** to the adaptive voter model to introduce individual-based heterogeneity into the simulation of socio-political movements



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Multi-Cohort Protests in Panama: July 2022



The Conviction Moderated Adaptive Voter Model

Parameters

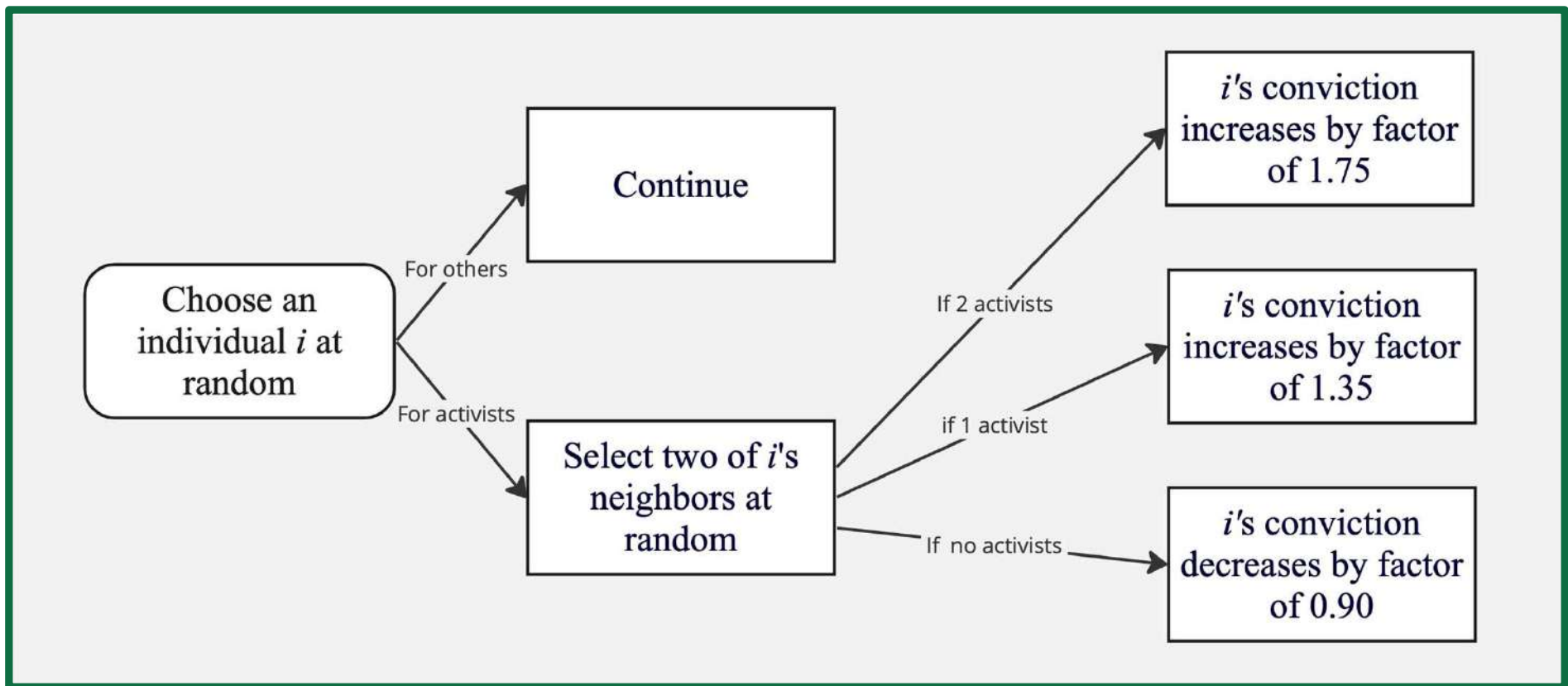
- Initial Conditions:
 - G = Watts-Strogatz small-world graph
 - N = Population size
 - x = Proportion of Activists
 - α = Mean of Activists' Conviction
- Running the Model:
 - ϕ = Rate of Social Learning ($1-\phi$ = Rate of Homophily)
 - t = Time Step (Runtime = $25*N$)

Outputs

- Descriptive Values:
 - G_{end} = End Graph (easily represented as a graph)
 - x_{end} = Final Proportion of Activists
 - α_{end} = Final Mean of Activists' Conviction
 - $\text{PVN}_{\text{count}}$ = Number of Politically Viable Networks* (PVNs)
 - * PVNs are defined as independent components on the indented subgraphs on activist nodes

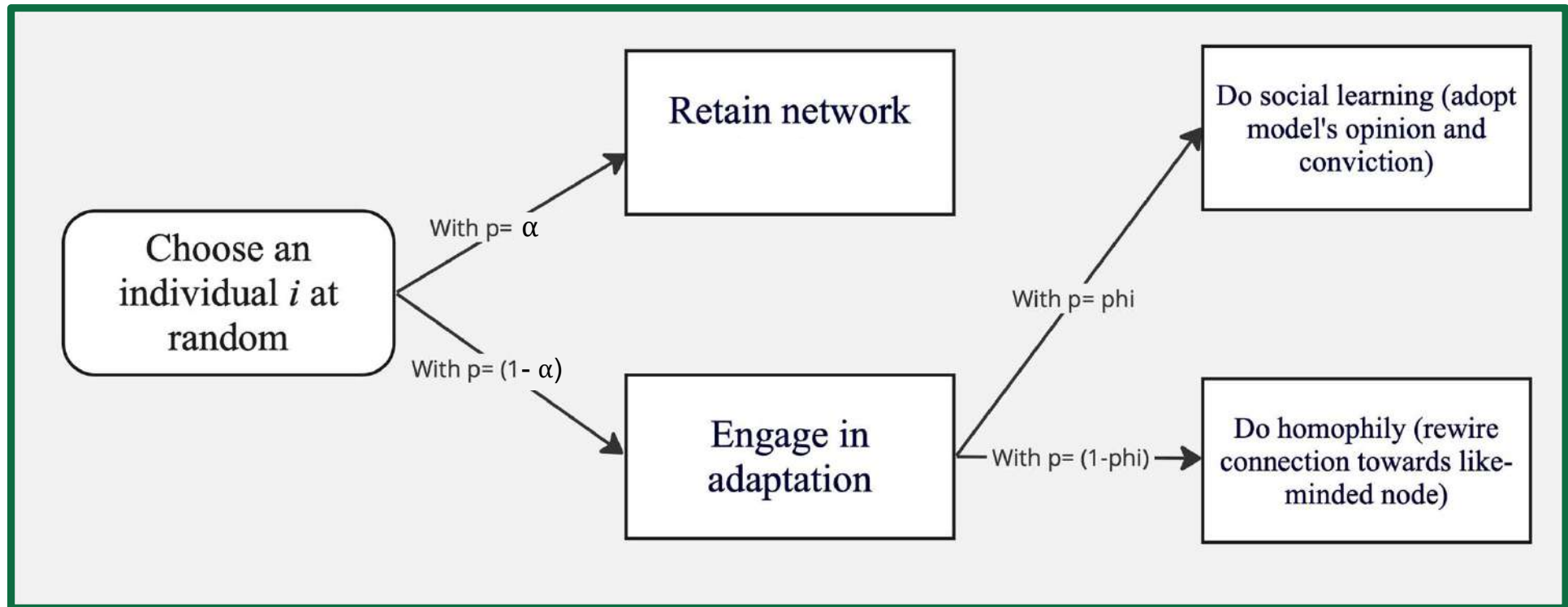


Interaction Step





Adaptation Step





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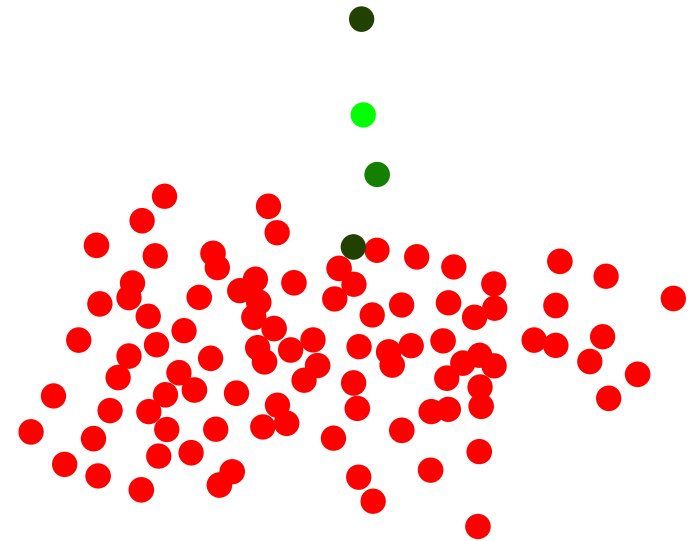
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**Mock Graph of a Population
with an Isolated PVN**

Qualitative Stories of Mobilization through Visualizing Networks

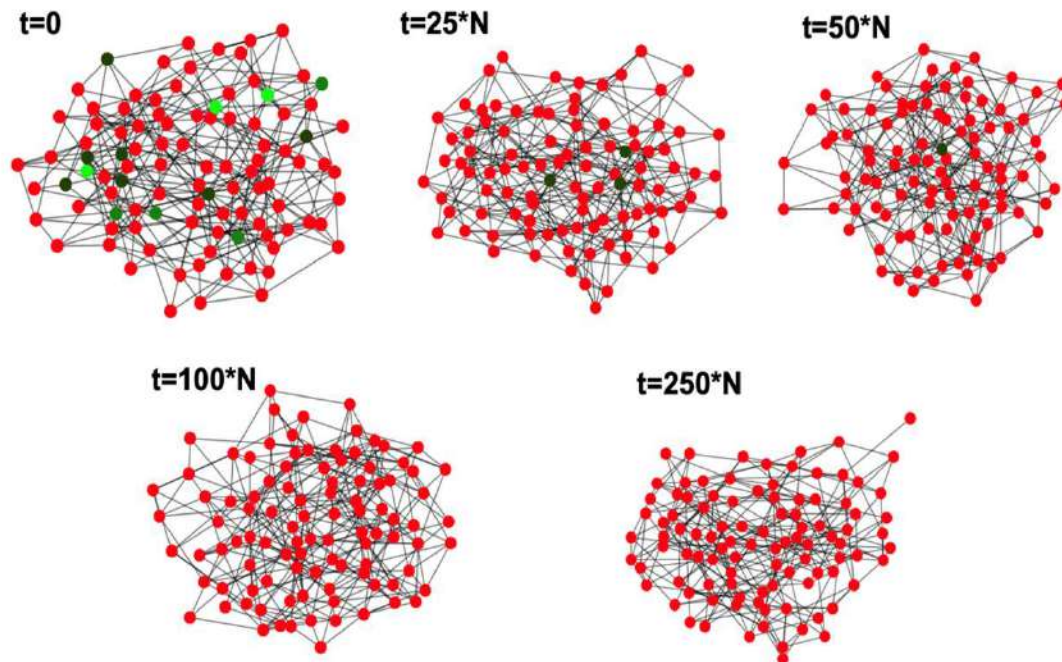


Fig. 1: In most cases, activists are systematically discouraged as the limit approaches long time.

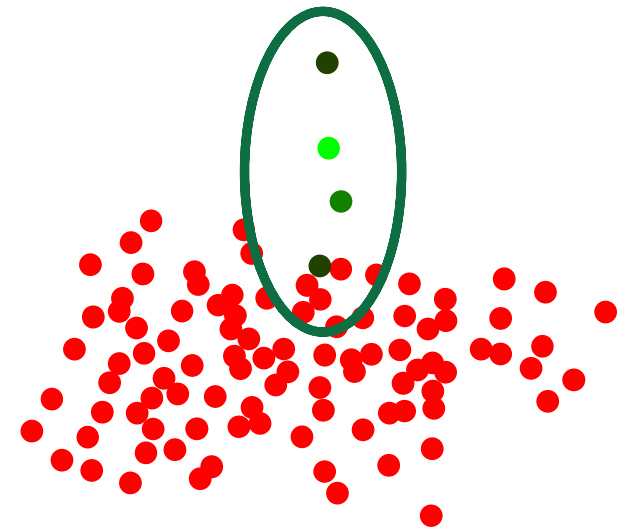


Fig. 2: When the model strongly favors homophily, as might be the case during times of strong shocks to political systems, we see isolated politically viable networks emerge more often

Homophily: The Strongest Predictor of PVNs

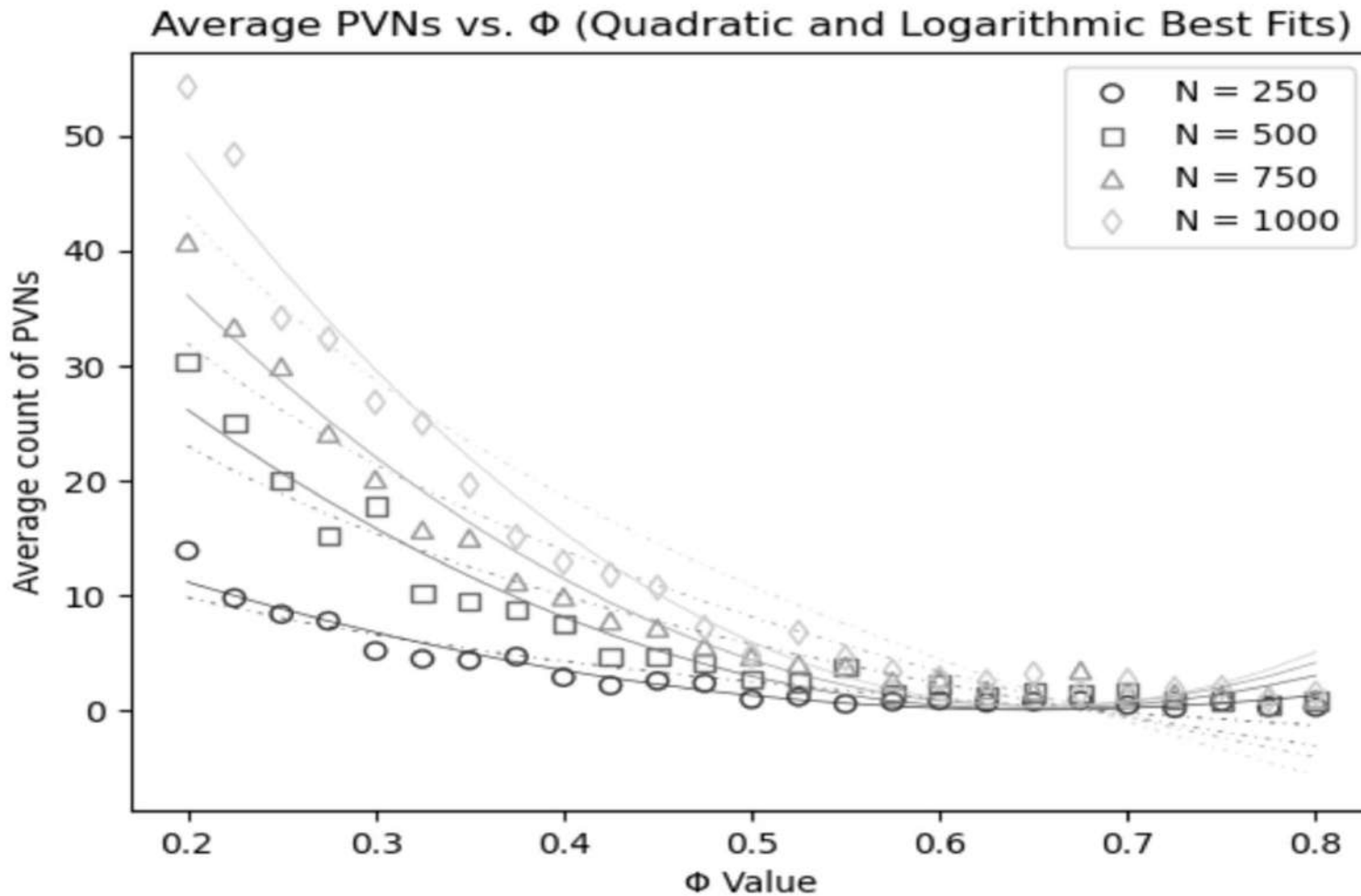


Fig. 5: Lower phi (higher homophily) is associated with higher counts of PVNs; note the “phase transition” near 0.575 after which PVNs become exceedingly rare.



Interactions Between Other Predictors

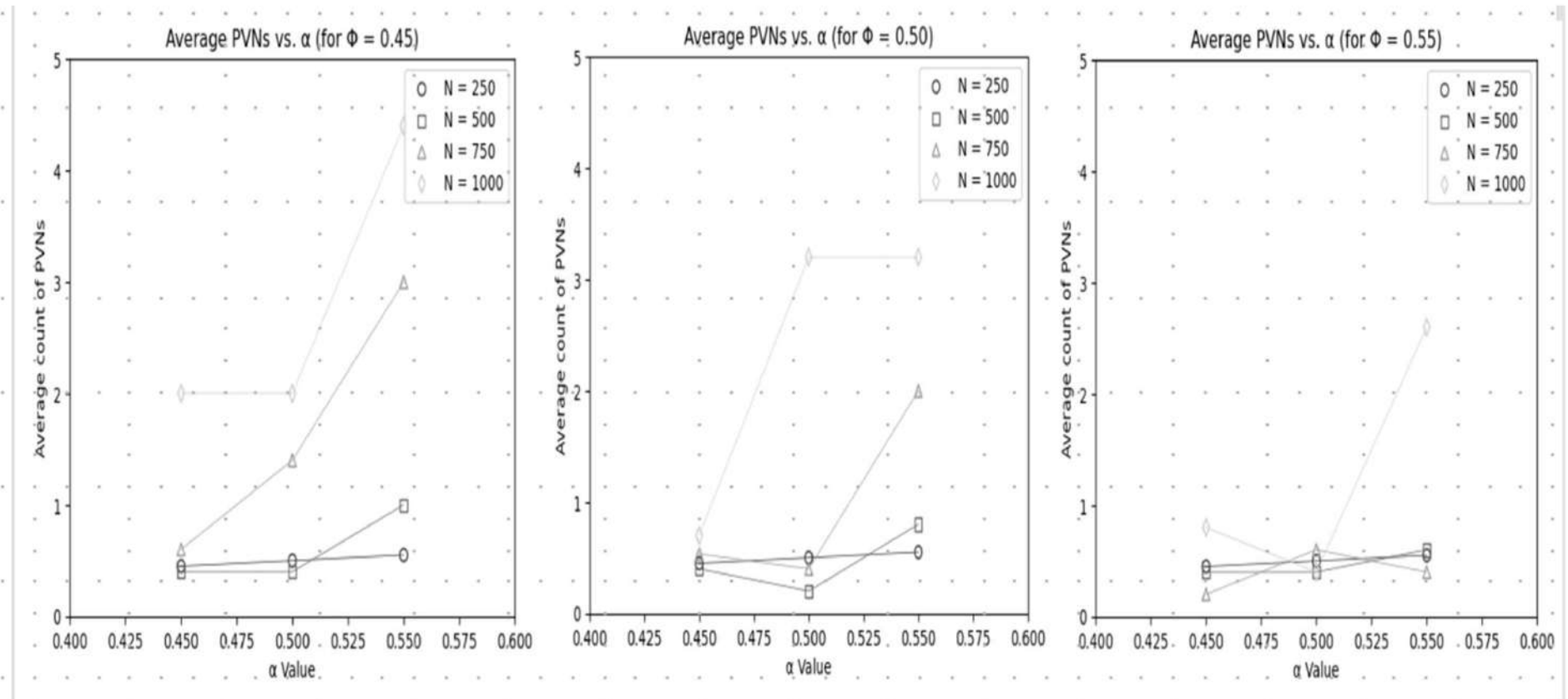


Figure 6. These plots show the expected results for varying alpha, showing that higher alpha can even compensate for much lower values of x , as those here are $x=0.05$.



Translating Math back into Socio-political Insight

Mathematical Finding

- Phi is the strongest predictor of PVN formation
- PVNs tend to be mostly stable cliques in graph perimeters
- High initial α can compensate for low x
- Higher x is not the only predictor of PVN formation

Socio-political Interpretation

- Homophily (some degree of intolerance) helps protest
- Reassurance allows the stability of protest groups over time
- High initial conviction can ensure protest even with minority opinion
- **Protest is more than a numbers game: Intensity and social connection matters!**



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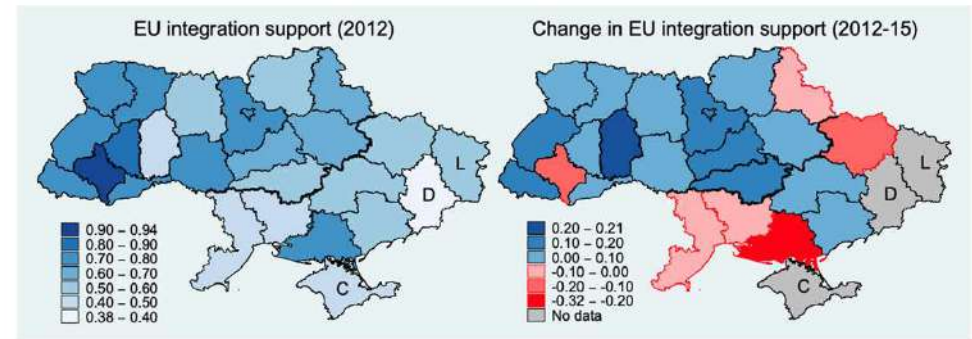
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البرهان ونسبة موافق ونسبة غير موافق وعدد الناخبين، الأصوات الصحيحة، الأصوات الباطلة ونسبة المشاركة، موافق وغير موافق
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Challenging Nature of Raw Data

Location and Social Connections

- In any given society, people tend to relate to those closes to them
- However, some still maintain connections outside their region
- Location data can be used to build bespoke graphs for certain political systems, which leads to much more realistic and informative models



Professor Chu's Ukraine research shows the importance of spatial polarization processes

Demographics and Political Attitudes

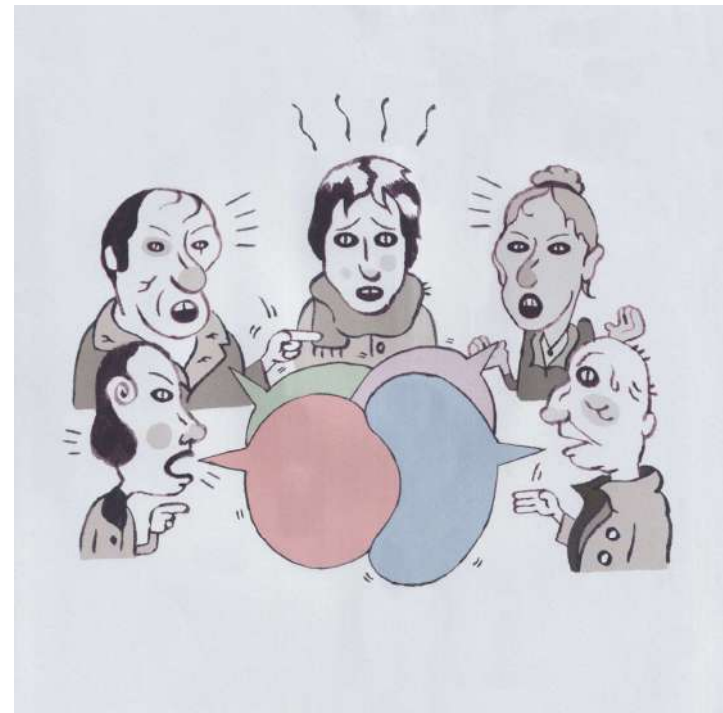
- Certain attitudes are associated with certain demographic characteristics
- For instance, protest participation is often associated with young adults and/or members of marginalized identity groups
- Specific protest motivation and intensity may also vary by group



High school students are often peaceful protesters in Panama

Demographics and Social Influence

- People tend to trust and inform their views based on those of their in-group
- Similarity (or lack thereof) between two individuals moderates the degree to which one can influence the other
- Ex. Activists feel more validated when finding a “similar” activist than a “dissimilar” activist



Similarity can help us decide who to trust most in the presence of disagreement



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Dartmouth College Honors Thesis

Sourcing Data: World Justice Project and Latinobarómetro

- Raw data can be hard to procure, but representative attitudinal data for Latin America does exist
- Ultimately, we used:
 - Latinobarómetro survey data (n=1000) to get covariate matching that helps calculate the SATE of COVID-19 on different measures related to protest
 - WJP survey data (n≈2000) to get a cleaner, larger, and more granular demographic pool for simpler initialization



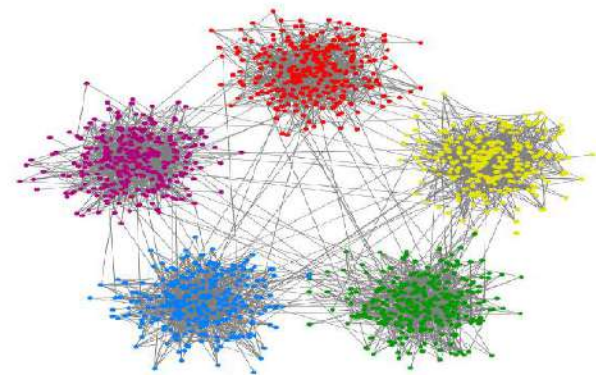
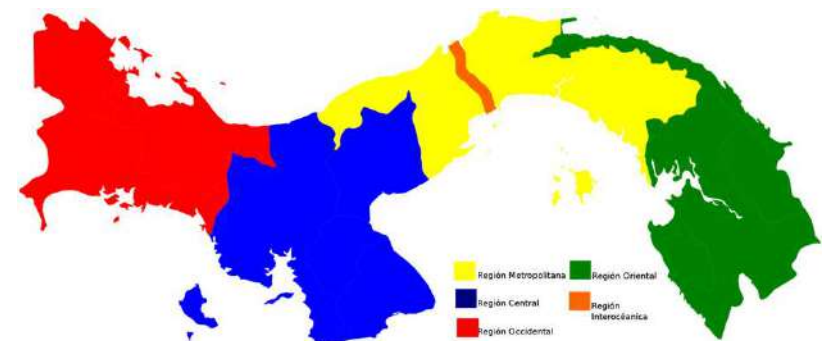
Latinobarómetro^{MR}
OPINIÓN PÚBLICA LATINOAMERICANA

Institutions with Attitudinal Data

Survey-Informed Initialization: Graph

- Use WJP survey data to assign each individual's region
- Start with one Small-World Watts-Strogatz graph for each one of Panama's regions according to their size
- Add all regions together
- Use the stochastic block model to rewire edges from within-region to cross-region

Regions of Panama

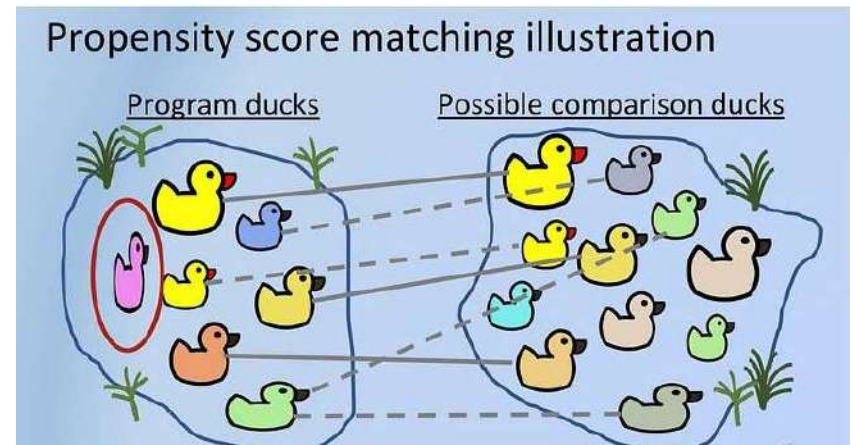


Stochastic Block Model with 5 regions

Survey-Informed Initialization: Opinion Assignment

- Use Latinobarómetro survey data from 2020 and 2023 to verify model expectations
- Create a covariate (k-nearest neighbor) matching between both years
- Then, regress the change of attitudes on the covariates to identify SATE by group
- Use this to assign opinions with logistic equations

Matching (Different Method)

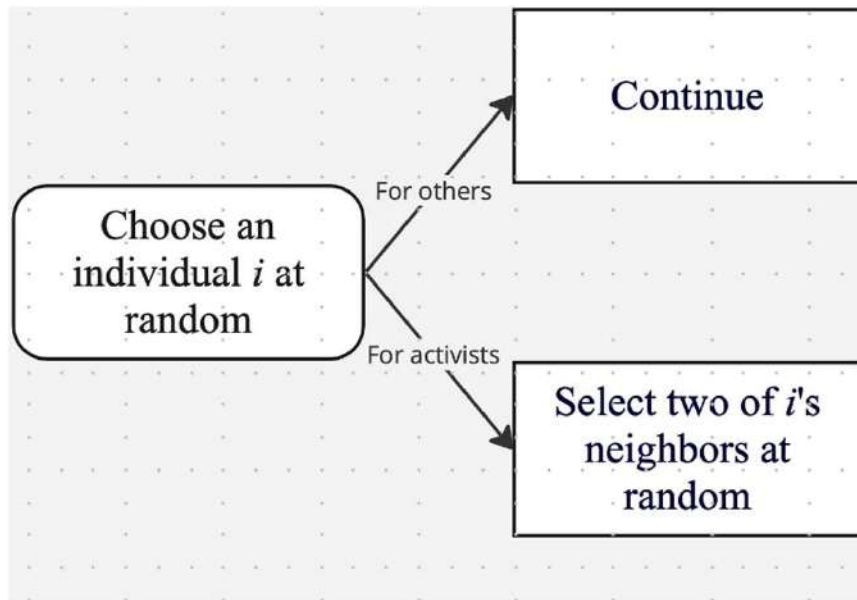


| | <i>Math 1A</i> | <i>Math 1B</i> |
|-------------------------------|--------------------------|--------------------------|
| <i>Grades</i> | -0.930 (0.230) | -0.670 (0.257) |
| <i>Probability of Passing</i> | 0.036 (0.030) | -0.011 (0.013) |
| <i>Probability of A-/A/A+</i> | 0.139 (0.349) | -0.129 (0.031) |

SATE Example and Results Table



Survey-Informed Interaction Step: Similarity Calculation and Its According Payoffs



Similarity is calculated as a pair-wise weighted sum above or below threshold

$$\bar{x} = \frac{\sum_{i=1}^n (x_i * w_i)}{\sum_{i=1}^n w_i}$$

| Payoff | | | | | | | | | |
|---------------|----------------|---------------|--------------------|--------------------|---------------------|--------------------|--------|-----------|--------|
| 2 S Activists | S/1 D Activist | 2 D Activists | 1 S Activist/1D no | 1 S activist/1S no | 1 D Activist 1 D no | 1 D Activist/1S no | 2 D no | 1S/1 D no | 2 S no |
| 1.825 | 1.75 | 1.675 | 1.4 | 1.375 | 1.35 | 1.325 | 0.95 | 0.9 | 0.85 |



Reasons Why the Survey-Informed Conviction-Moderated Adaptive Voter Model Works Better

More than a numbers game

Geography and demographics control the process

Initial conviction matters

Groups can form according to existing bonds

Initial activist share and spread matter

More heterogeneous patterns can emerge

We can always add more flexibility/specificity to the model



Thank you!