Vaccine adoption with outgroup aversion using Cleveland area data

Model Description

The model is summarized in table below with the categories defined by the overview, design concepts, and details' document protocol (ODD protocol) (Grimm et al., 2017). The code can be obtained from: Link to ODD and code.

	Section	Description
Overview	1.Purpose	The model will simulate the adoption behavior for vaccines in select counties in Ohio in 2021 to optimize parameter values to accurately project vaccine rates in geo-spatial networks of agents with group affiliations that impact vaccine decisions.
Design Concepts	2.Entities, state variables and scales	The entities are adults who are eligible for voting and getting vaccines. Each agent has a binary political affiliation defined by how they voted in 2020. Agents have characteristics of social vulnerability distributed around an average, based on county empirical data. Additionally, some agents have an aversion to change and will never adopt. The temporal resolution will be weeks from January, 2021 through June, 2021. The spatial resolution will be derived as interconnected networks defined by county in Ohio, using interconnected counties as a metaphor for the geospatial relationships between counties. In addition, for multi-county metropolitan areas, metropolitan statistical areas (MSAs) will be used as the basis to define the network domain and edges.
	3.Process overview and scheduling	The process will be to set up agents with their county characteristics of political affiliation (percent from each county), social vulnerability index (normally distributed around the mean for the county), and whether they are a potential adopter or a laggard (never adopter). The agents will be connected in a preferential attachment network, with preferences to group membership and nodes with high degree. The simulation will run for a fixed number of periods to simulate weekly results from January through June, 2021; the simulation will not necessarily be stable at the end. Empirically, the data used for validation changed after June, 2021 as more groups were able to receive vaccines and boosters emerged as additional vaccination actions.

	4.Design concepts	The *basic theory* used at the agent level is for agents to observe the group membership and adoption status of connected agents to calculate the adoption probability using innovation and imitation factors, with an outgroup effect (Bass, 1969; Goldenberg et al., 2009; Rand & Rust, 2011; Smaldino et al., 2017).
		Emergence will occur as the percent of adults in a simulated county who receive the vaccine. *Adaptation* is not considered in this model as agent characteristics remain fixed throughout the simulation. The objective of the agent networks in each county and in aggregate will be to ascertain parameter values to minimize the root mean squared error to the actual adoption level from the Centers for Disease Control (Centers for Disease Control and Prevention, 2021). Additionally, the adoption rates by group from the model will be qualitatively compared to national survey data to quantity the adoption rate differences by group (Said, 2021). Individual will be *learning* by changing their adaptive traits over time as their probability of adopting is impacted by an increasing imitation factor which has a deep history in cultural evolution (Boyd & Richerson, 1988; Henrich & Boyd, 1998; Rogers, 2003; Simmel, 1955; Tarde, 1903). Agents' learning procedures are not based the *prediction* of future consequences of a decision. The tacit assumptions of the model are that as neighbors of an agent increase their adoption level, then the likelihood of adoption increases. *Sensing* is based on observing neighbors' group membership and adoption status in order to ascertain an adoption probability for themselves. Neighbors group membership may be considered a form of identity signaling from which it may be more important to imitate the group decision than just a decision by observation alone. This concept is viewed as the dual inheritance model (Boyd & Richerson, 1988). *Interactions* are based on observing direct neighbors connected by edges that represent highly trusted relationships (Dunbar, 1992). *Stochasticity* occurs in many forms: agent characteristics are randomly distributed around a mean; networks are generated via probabilistic means; seed adopters are randomly selected for

		initializing an adoption phenomenon; laggards are selected randomly from the population at large; the adoption probability itself must meet a probabilistic threshold for p and q in order for an adoption to occur. *Collectives* in this study are defined as the groups by political affiliation. The basis for these is a statistical study validating the explanatory power of political affiliation on adoption. *Observation* will collect the adoption count by group at each time increment to plot cumulative adoption in total and by each group. Additionally, polarization will be calculated as an adoption difference between groups and over time

References

Bass, F. M. (1969). A new product growth for model consumer durables. *Management Science*, 215–227.

Boyd, R., & Richerson, P. J. (1988). *Culture and the evolutionary process*. University of Chicago Press.

Centers for Disease Control and Prevention. (2021). *Estimates of vaccine hesitancy for COVID-19*. https://data.cdc.gov/stories/s/cnd2-a6zw

Dunbar, R. I. (1992). Neocortex size as a constraint on group size in primates. *Journal of Human Evolution*, 469–493.

Goldenberg, J., Han, S., Lehmann, D. R., & Hong, J. W. (2009). The role of hubs in the adoption process. *Journal of Marketing*, *73*(2), 1–13.

Grimm, V., Polhill, G., & Touza, J. (2017). Documenting social simulation models: the ODD protocol as a standard. In B. Edmonds & R. Meyer (Eds.), *Simulating social complexity*. Sprinter, Cham.

Henrich, J., & Boyd, R. (1998). The evolution of conformist transmission and the emergence of between-group differences. *Evolution and Human Behavior*, *19*(4), 215–241.

Rand, W., & Rust, R. T. (2011). Agent-based modeling in marketing: guidelines for rigor. *International Journal of Research in Marketing*, *28*(3), 181–193.

Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). Free Press.

Said, L. (2021, September 29). *More in U.S. vaccinated after delta surge, FDA decision*. Gallup Poll. https://news.gallup.com/poll/355073/vaccinated-delta-surge-fda-decision.aspx

Simmel, G. (1955). *The web of group-affiliations*. Free Press.

Smaldino, P. E., Janssen, M. A., Hillis, V., & Bednar, J. (2017). Adoption as a social marker: innovation diffusion with outgroup aversion. *The Journal of Mathematical Sociology*, *41*(1), 26–45.

Tarde, G. (1903). *The laws of imitation*. H. Holt and Company.