We don’t need THAT vaccine:
An agent-based modeling of vaccine uptake and resistance with two vaccines

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A Brief Overview

- A simulation study on "COVID-19 Vaccinations"
- Consider two types of vaccines — vaccine A vs. B
  - Vaccine A = **LESS** preferred but **SUFFICIENT** supplies (e.g., AstraZeneca vaccine)
  - Vaccine B = **MORE** preferred but **INSUFFICIENT** supplies (e.g., Pfizer vaccine)
- Model the opinion dynamics under the limited resource constraints
  - Not everyone can be vaccinated, especially in accordance with personal preference.
  - How mass media and interpersonal communication shape vaccination belief and behavior?

Contents

COVID-19 Vaccinations

- **Vaccines—especially preferred ones—are limited resources.**
  - In December 2020, the first approval of Pfizer-BioNTech vaccine (Pfizer, BNT162b2) marked a new phase of the pandemic. It was soon followed by Moderna (mRNA-1273) and AstraZeneca-Oxford (AstraZeneca, ChAdOx1-S).
  - A country's vaccine procurement requires strategic approaches to negotiating price and financing purchases.
  - Further, it can easily be intensified by vaccine preferences. (e.g., for vaccine efficacy; Pfizer's mRNA vaccine showed 95%, AstraZeneca-Oxford's adeno-virus vector vaccine showed 76%).
- **It is hard to dismiss the media's role in shaping vaccine preferences or beliefs.**
  - In this era of COVID-19 "info-demic," people are being exposed to mis/disinformation or conspiracy theories.
- **Our paper discusses the formation and evolution of public opinion in the midst of COVID-19 vaccination.**
  - …with emphasis on allocational conditions and communication context.

Perceived Risk of Vaccination

- **Vaccine side effect has been a leading cause in the COVID-19 context.**
  - Consistent reports of vaccine hesitancy are largely on "concerns about side effects" (e.g., Pew Research Center, 2021).
  - AstraZeneca vaccine has been accused of thrombosis—a rare blood clot—and anaphylaxis—severe allergic reaction.
- **We focus on perceived risk of VACCINATION.**
  - The role of risk perception on health-related behaviors is not new; but we focused on perceived risk of the behavior itself (i.e., COVID-19 vaccination), rather than perceived risk of disease (i.e., COVID-19; Karlsson et al., 2021).
  - There is enough information about new vaccines; people are less likely to accept the "unknown risk" (Slovic, 1987).
- **Therefore, we propose "perceived risk of vaccination" as the main criterion in (1) vaccine belief and (2) behavior.**

Vaccination Decision Under Limited Resources

RQ1a: How do resource constraints influence perceived risk of vaccination?

RQ1b: How do resource constraints influence vaccination coverage?

- **How resource constraints change (1) cognition and (2) behavior in vaccine dynamics?**
- (1) Limited vaccine doses are deemed as cognitive constraints to individuals' risk perception.
  - Judgments based on heuristics can be wrong, because of selective samples and neglect of sampling conditions (e.g., sampling probability, sample size, Fiedler, 2012; Tversky & Kahneman, 1974).
- (2) Individual risk perception is related to society-level compliance, or vaccination coverage.
  - Perceived risk being the main driver of vaccination decision, its behavioral influence is considered.

Mass Media and Interpersonal Influences (1)

RQ2a: Under resource constraints, how does the media reporting on vaccine side effects influence perceived risk of vaccination?

RQ2b: Under resource constraints, how does the media reporting on vaccine side effects influence vaccination coverage?

- **COVID-19 news coverage has been case oriented.**
  - People are consistently informed with "the tragedy in numbers," those of confirmed COVID-19 cases, deaths, administered vaccine doses, and the ensuing case reports.
  - Repetitive media exposure to side effect cases or adverse responses will cause fear or anxiety among the audiences. Accordingly, risk perception is susceptible to those framed images.
- **To what extent media reporting on vaccine side effects should be?**
  - Even "balanced" reporting can harm scientific consensus. For instance, echoes of global warming denials can cause fissure even within the scientific community (e.g., Lewandowsky et al., 2019; Weatherall et al., 2020).

Mass Media and Interpersonal Influences (II)

RQ3a: Under resource constraints, how does interpersonal communication network influence perceived risk of vaccination?

RQ3b: Under resource constraints, how does interpersonal communication network influence vaccination coverage?

- **Perception is selective in itself.**
  - Regarding scientific risk perception, previous studies have examined various individual factors, including risk preference, self-efficacy, and worldviews (e.g., Coleman, 1993).
  - Depending on prior beliefs, individuals are inclined to make biased evaluation (Lord et al., 1979).
- **Predispositions can be strengthened through interpersonal communication.**
  - The communication process is again selective towards "homophily." According to Metzger et al. (2010), individuals use group-based heuristics to evaluate information credibility.
  - Homophily network causes attitude polarization (e.g., Sohn, 2019; Song & Boomgaarden, 2017).

Research Questions

1. Limited Resources

- *RQ1a: How do resource constraints influence perceived risk of vaccination?*
- *RQ1b: How do resource constraints influence vaccination coverage?*

2. Mass Media Communication

- *RQ2a: Under resource constraints, how does the media reporting on vaccine side effects influence perceived risk of vaccination?*
- *RQ2b: Under resource constraints, how does the media reporting on vaccine side effects influence vaccination coverage?*

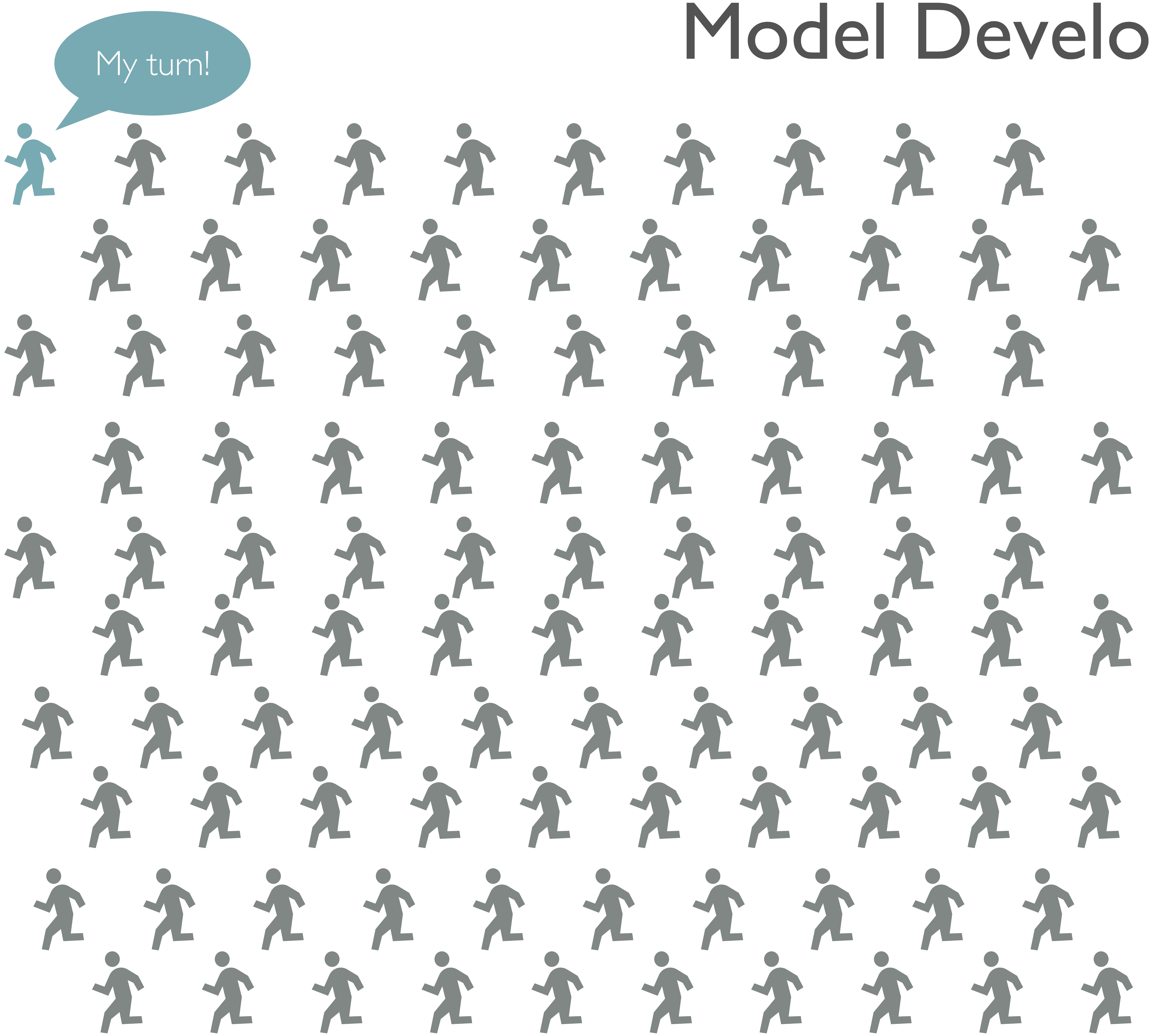
3. Interpersonal Communication

- *RQ3a: Under resource constraints, how does interpersonal communication network influence perceived risk of vaccination?*
- *RQ3b: Under resource constraints, how does interpersonal communication network influence vaccination coverage?*

Model Development

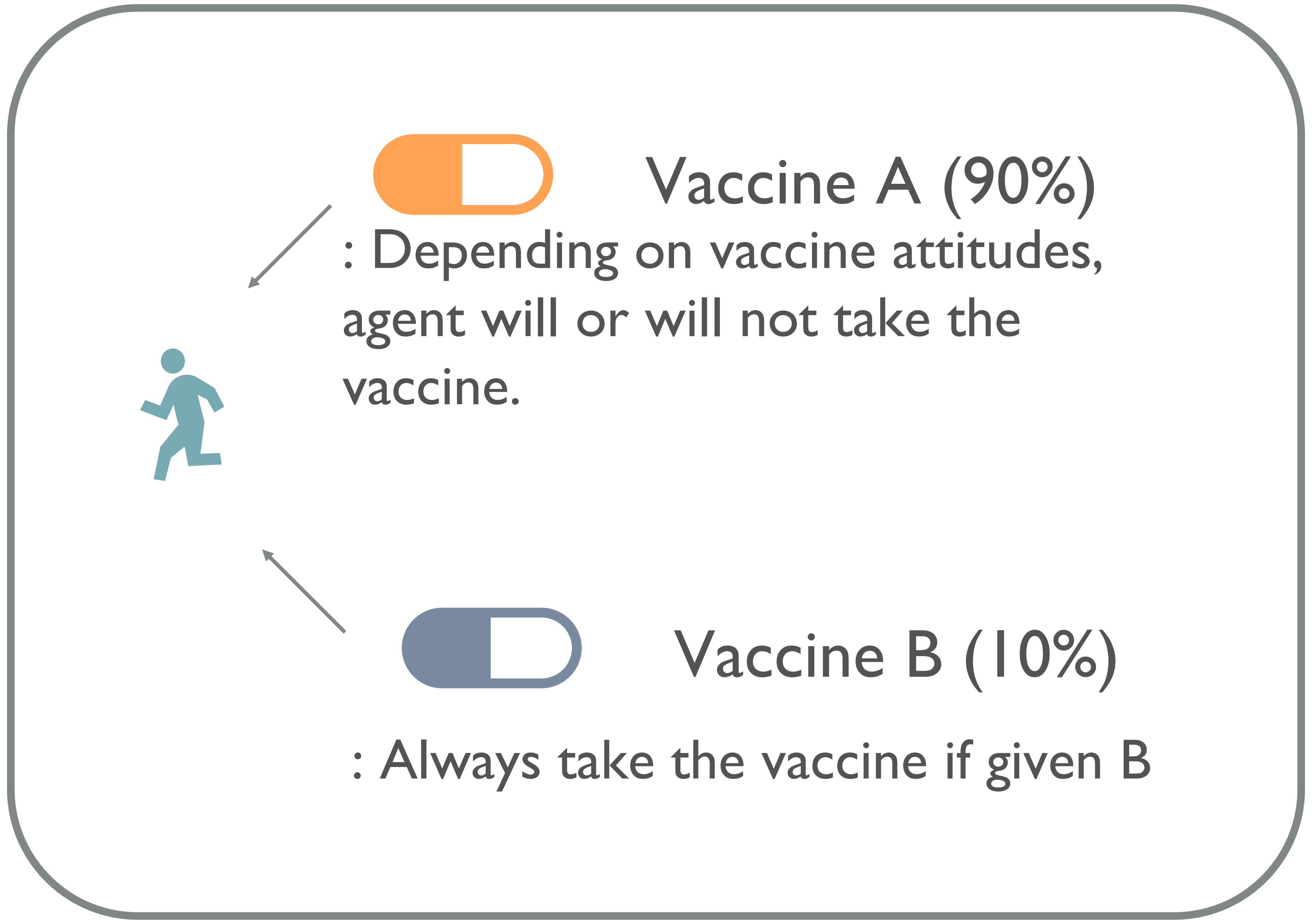
- **Agent-based modeling (ABM; Railsback & Grimm, 2019)**
  - Individuals are assumed to be "agents" who can affect the environment by executing an action.
  - The action is an interaction with the environment (e.g., risk perception or vaccination decision) or other agents (e.g., sharing vaccine beliefs) which can alter the environment (e.g., updating perceived risks and vaccination coverage).
- **Network epistemology framework (Bala & Goyale, 1998)**
  - The framework is characterized by two features: (1) decision problem and (2) network.
  - A network of agents is encountered with (1) two competing beliefs or theories (i.e., two-armed bandit problem), and (2) their collective decision is contingent on the network structure.
  - The core mechanism of social learning is Bayes rule, by which agents evaluate new evidence to update their beliefs (Griffiths et al., 2008).

Model Development

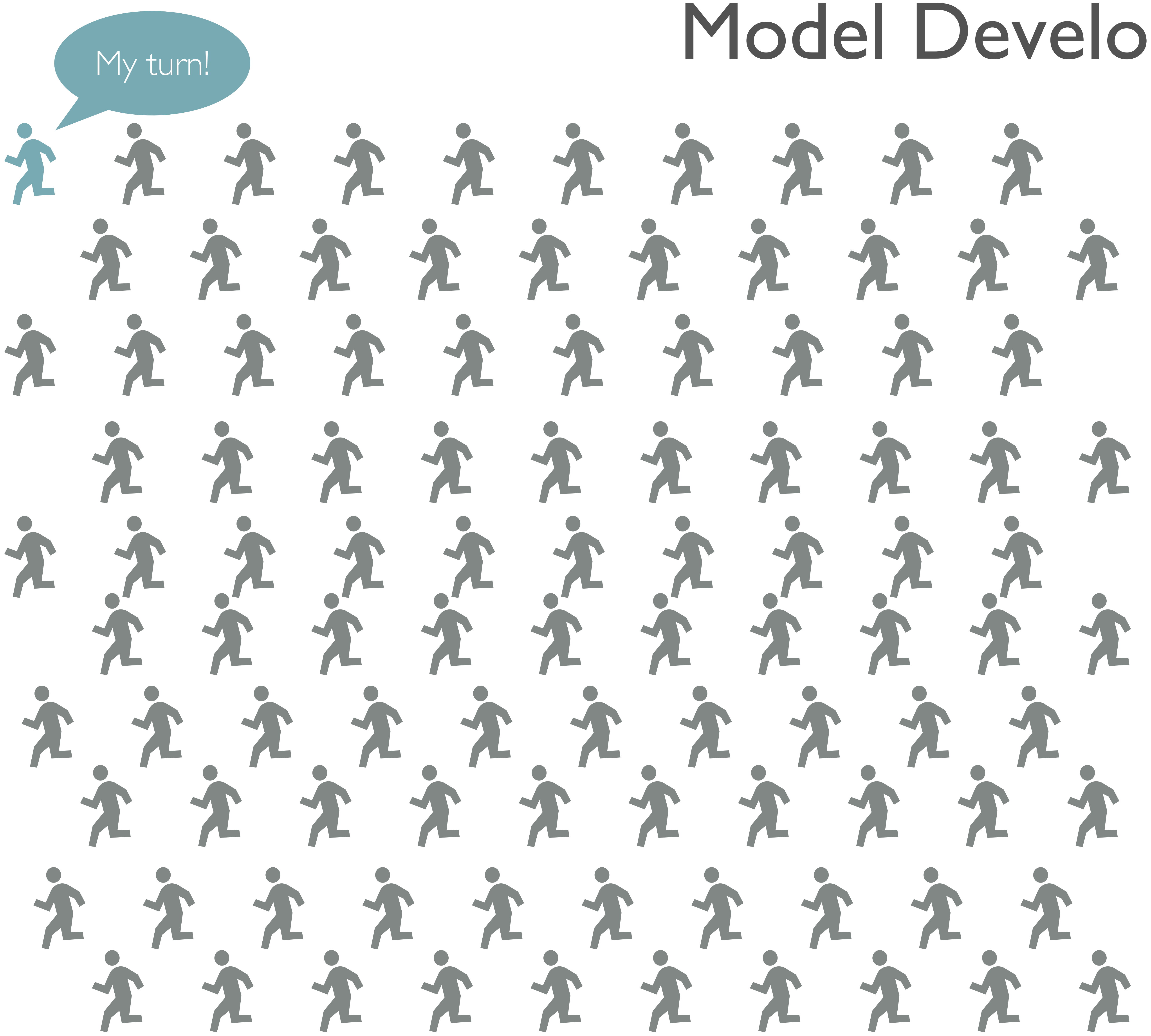


Day 1 (1/100)

1. Each day, 1% of total population are assigned to predefined doses of A or B.



Model Development



Day 1 (1/100)

1. Each day, 1% of total population are assigned to predefined doses of A or B.

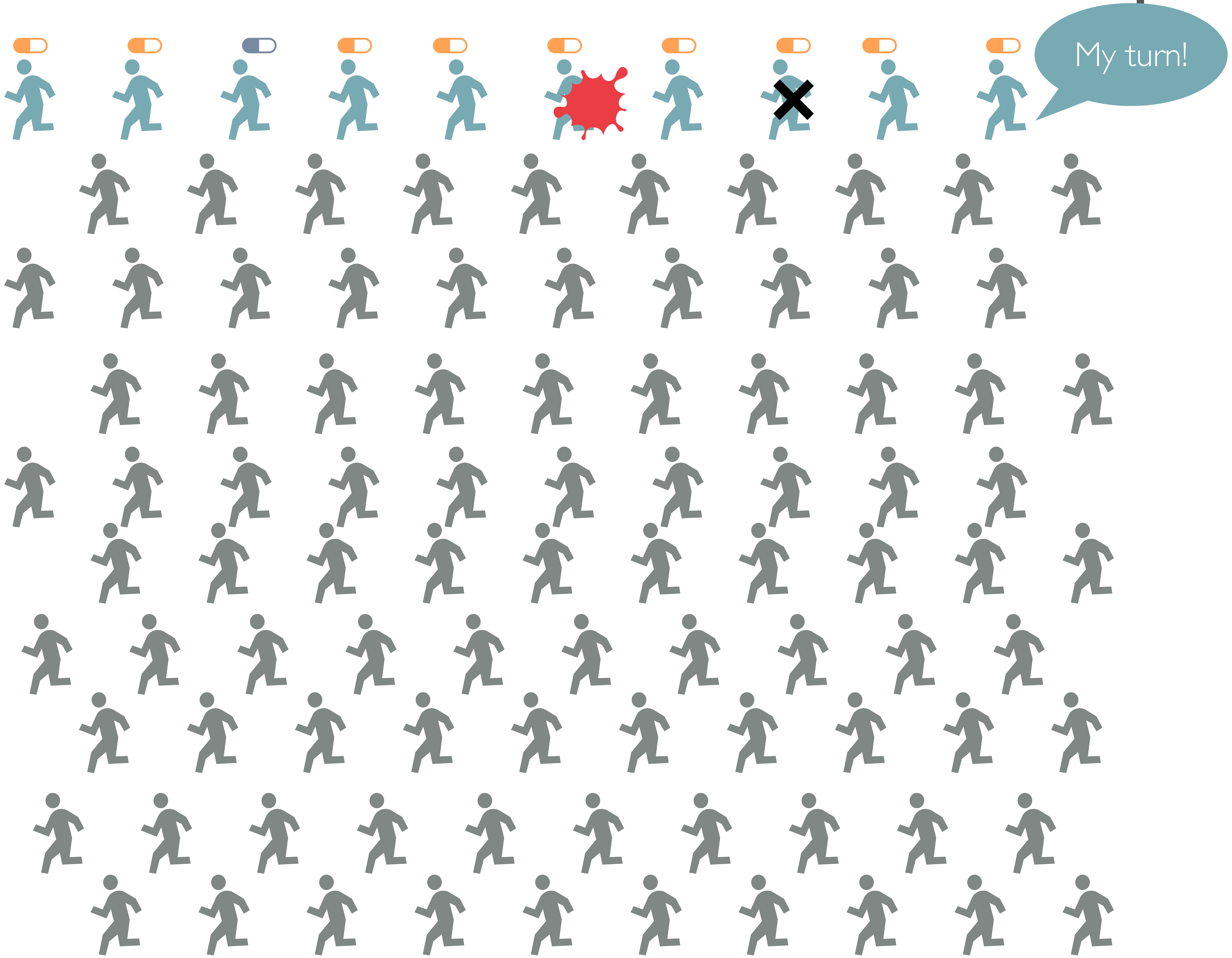
2. The vaccinated agent will randomly have side effects. Both vaccines have the same side effect probability 1%.

Vaccine A

Vaccine B

In Both cases, there is 1% chance that the agent will have side effects.

Model Development



Day 10 (10/100)

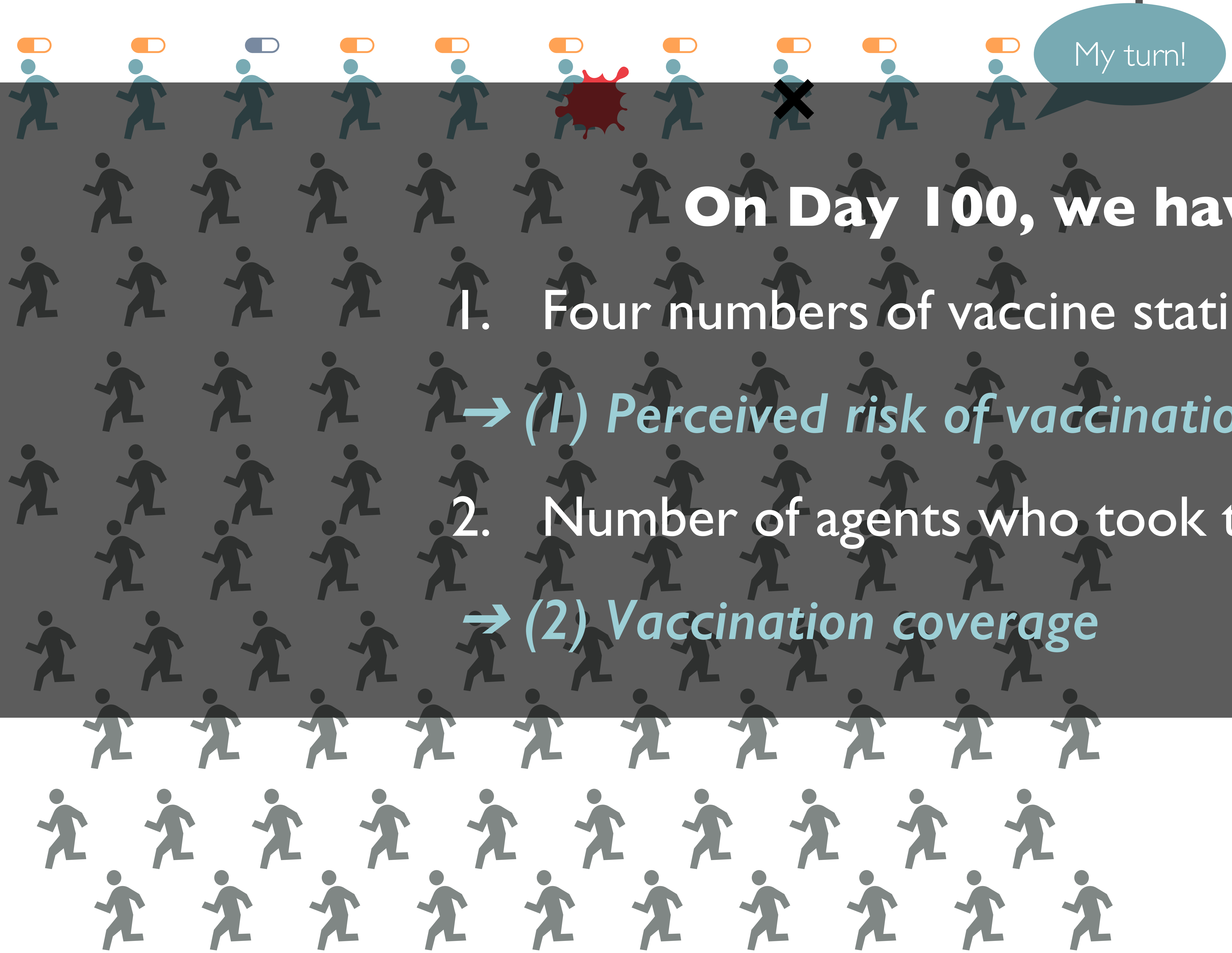
1. Each day, 1% of total population are assigned to predefined doses of A or B.

2. The vaccinated agent will randomly have side effects. Both vaccines have the same side effect probability 1%.

3. As day goes by, we have four categories of vaccine statistics: [vaccine type, status] = A-not sick, A-sick, B-not sick, B-sick.

- For instance, on Day 10, vaccine A recipients are (8, 1) and B recipients are (1, 0). One agent refused to take vaccine A.

Model Development



On Day 100, we have…

1. Four numbers of vaccine statistics

→ *(1) Perceived risk of vaccination*

2. Number of agents who took the vaccine A/B

→ *(2) Vaccination coverage*

Day 10 (10/100)

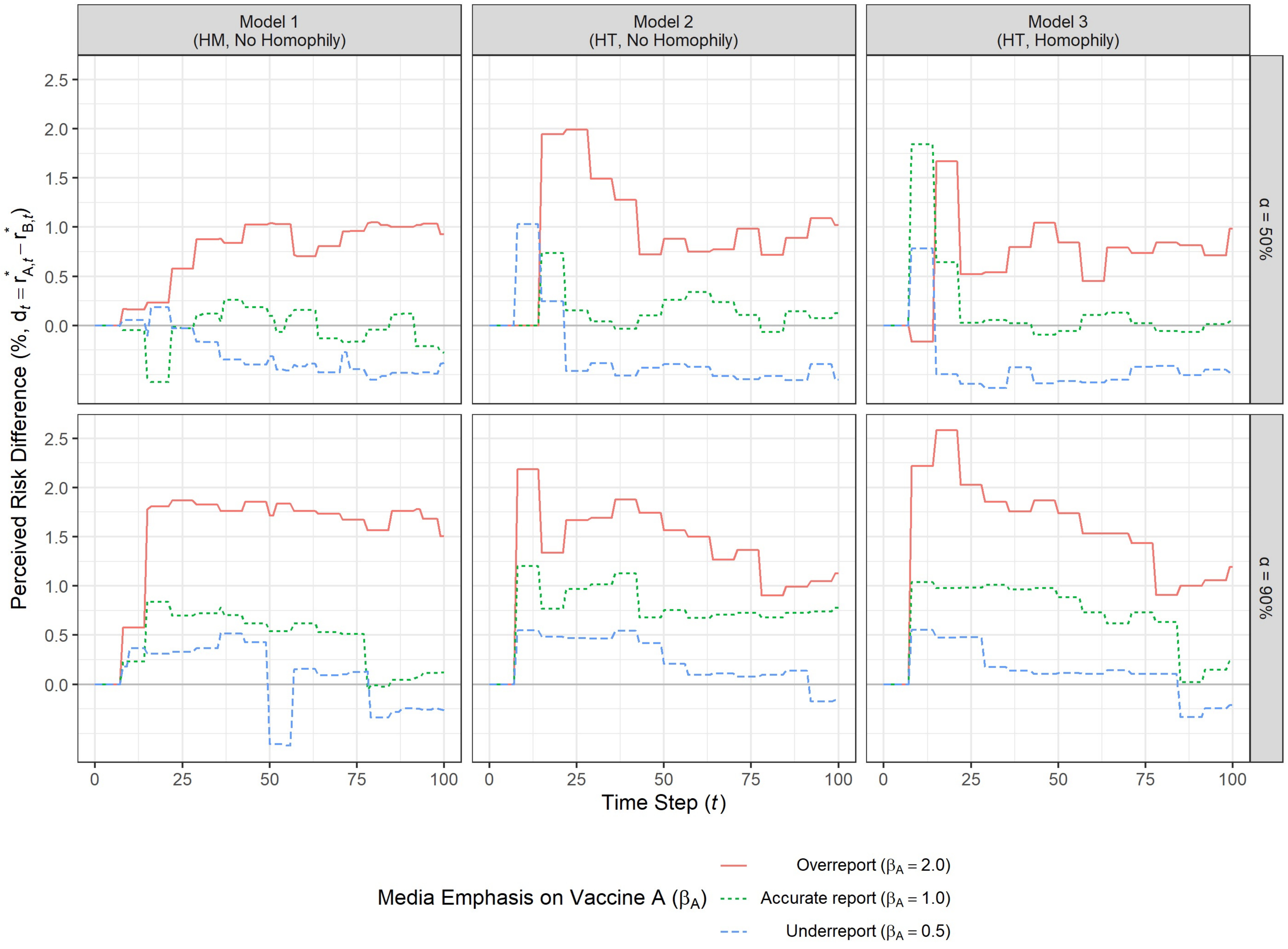
1. Each day, 1% of total population are assigned to predefined doses of A or B.
2. The vaccinated agent will randomly have side effects. Both vaccines have the same side effect probability 1%.
3. As day goes by, we have four categories of vaccine statistics: [vaccine type, status] = A-not sick, A-sick, B-not sick, B-sick.

- For instance, on Day 10, vaccine A recipients are (8, 1) and B recipients are (1, 0). One agent refused to take vaccine A.

Table 1. *Setup of Simulation Models*

	Model 1	**Model 2**	**Model 3**
	Homogeneous No-Homophily	**Heterogeneous No-Homophily**	**Heterogeneous Homophily**
Basic setup			
Population (*n*)	2,500	2,500	2,500
Number of time steps (*T*)	100	100	100
Number of replications (*N*)	100	100	100
Properties of Vaccine A			
Actual risk (ρ_A)	1% (= ρ_B)	1% (= ρ_B)	1% (= ρ_B)
Vaccine allocation (α_A)	[50%, 90%]	[50%, 90%]	[50%, 90%]
Vaccine attitudes (Never, Undecided, Always)	(10%, 60%, 30%)	(10%, 60%, 30%)	(10%, 60%, 30%)
Prior heterogeneity	**No**	**Yes**	**Yes**
Mass media communication			
Media emphasis on A (β_A)	[0.5, 1, 2]	[0.5, 1, 2]	[0.5, 1, 2]
Memory window	7	7	7
Interpersonal communication			
Homophily network	**No**	**No**	**Yes**
Memory window	3	3	3

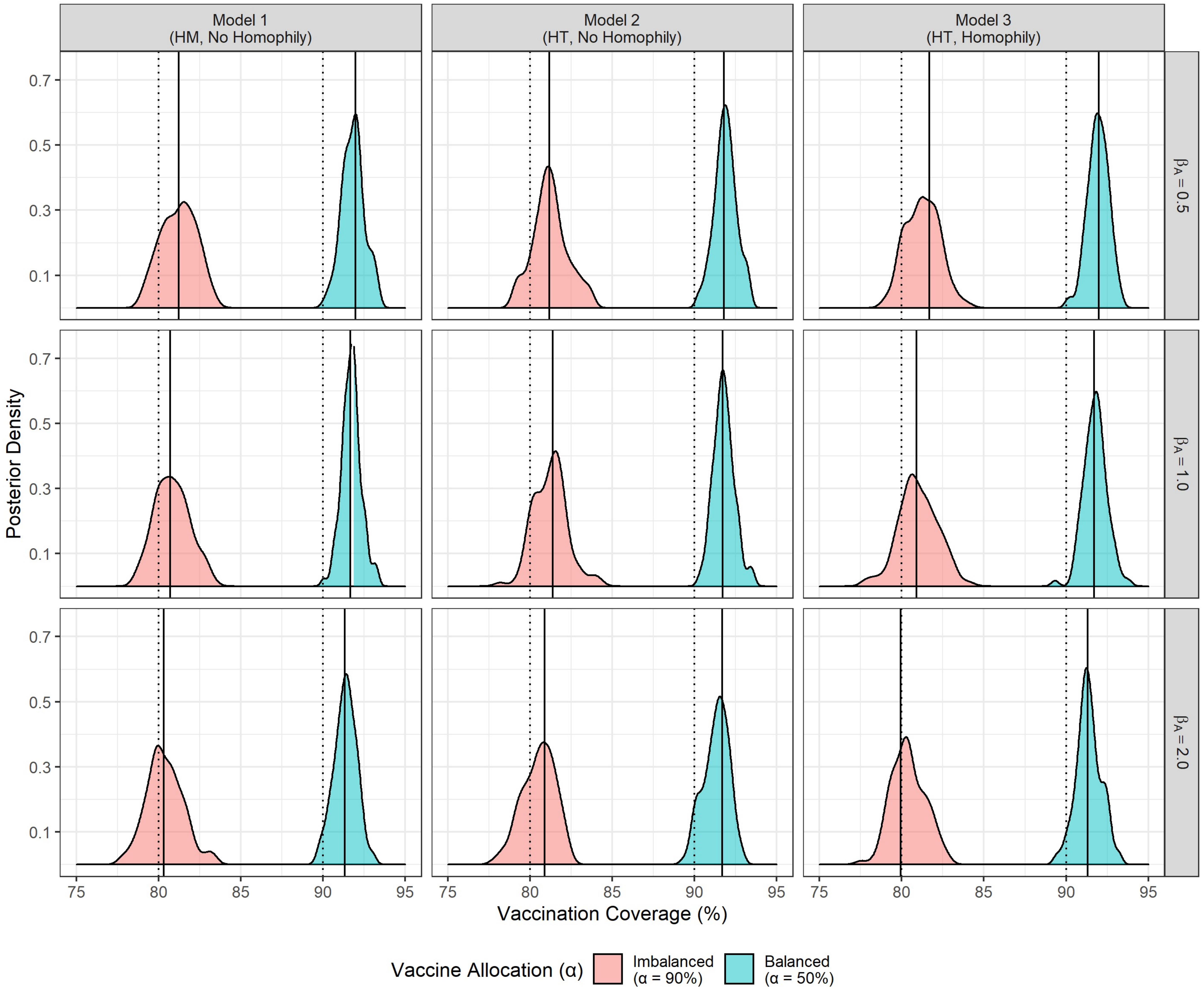
Figure 1. *Simulated Time Trends of Perceived Risk Difference between Two Vaccines*



Perceived Risk Difference (RQa's)

- **Limited resource constraints have negative influences on perceived risk difference.**
  - Even though actual risks are identical for two vaccines (1%), depending on vaccine allocation (α_A), media emphasis on vaccine A (β_A), or interpersonal network structure, the disparity between perceived risks of vaccine A and B varies.
  - **(RQ1a)** Compared to "Balanced" ($\alpha_A = 50\%$; in the top row) reporting, "Imbalanced" ($\alpha_A = 90\%$; in the bottom row) vaccine allocation causes the perceived risk of vaccine A to be higher than B.
- **The negative effect is fueled by the interplay between impartial media reporting and homophily network.**
  - **(RQ2a)** Compared to Model 1, Models 2-3 with prior heterogeneity show a burst of perceived risk difference at early stages of vaccination plan (i.e., before 25th tick).
  - **(RQ3a)** In Model 3, limiting the scope of interpersonal communication to in-group members deepens the cognitive gap between two vaccines.

Figure 2. *Posterior Distributions of Vaccination Coverage in Simulation Results*



Vaccination Coverage (RQb's)

- **Disproportionate risk perception can have negative influences on society-level vaccination coverage.**
  - **(RQ1b)** "Imbalanced" allocation results in a distribution with smaller location (i.e., mean; around 80% for "Imbalanced" and over 90% for "Balanced") and kurtosis parameters.
  - In other words, imbalance in vaccine allocation leads to lower and unstable vaccination coverage.
- **(RQ2b) Media emphasis on vaccine A reduces vaccination coverage.**
  - As the media emphasis factor increases (i.e., from the top row to the bottom row), posterior modes of vaccination coverage distribution slowly move to the left.
- **(RQ3b) The proposed effect of mass media is moderated by homophily.**
  - Compared to Model 2, Model 3 has a more obtuse (i.e., smaller kurtosis) distribution with smaller means.

Risk Communication During the Pandemic (I)

- **If vaccine doses are disproportionately distributed…**
  - Even though two vaccines A and B have the same side effect probability,
  - People are more likely to perceive the less preferred but sufficient vaccine A as unsafe; and perceive the more preferred but insufficient vaccine B as safe, leading to the increased gap between two perceived risks.
  - Further, the perception gap will cause lower and unstable vaccination coverage.
- **Rational agents can sometimes end up with irrational consequences.**
  - Because of resource constraints, agents are never free from pitfalls of heuristics and bias.
  - Fair reporting can sometimes lead to negative consequences, both in terms of risk perception and vaccination behavior.

Risk Communication During the Pandemic (II)

- **Considering "biased" agents could further distract the proceedings of vaccination.**
  - The situation can be complicated due to politicized nature of the virus (e.g., in South Korea, President Moon Jae-in's inoculation with AstraZeneca vaccine had been suspected of vaccine swapping).
  - Various actors are involved in the politics of vaccination: politicians, journalists, and general public.
- **The duty to communicate about science?**
  - Simply stating about the case reports are not enough, even though it corresponds with the reality.
  - It is prone-to-bias nature of vaccine statistics that can hinder "accurate" media reporting.
  - The media has a responsibility to fully understand and convey the prone-to-bias nature to the public.

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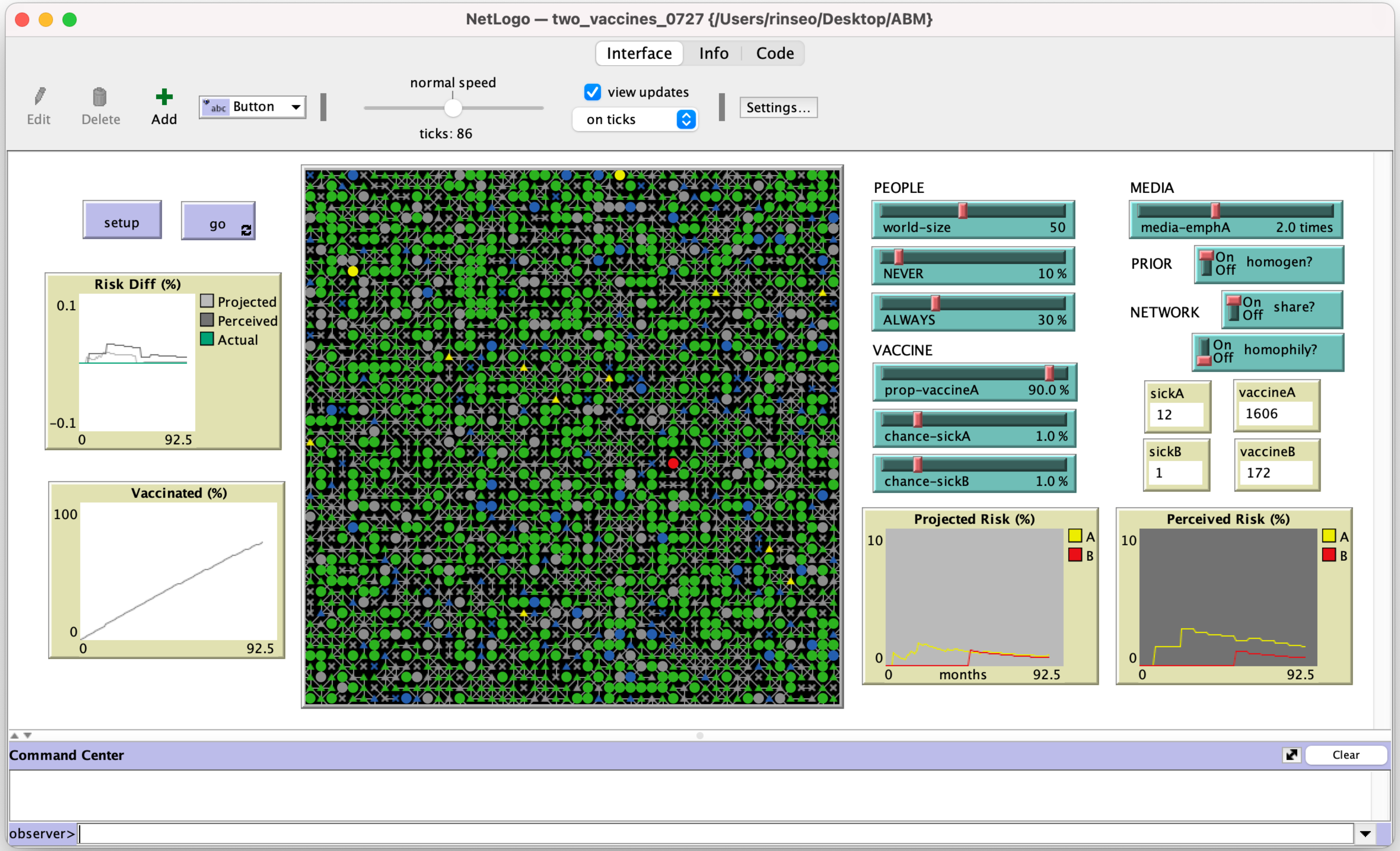
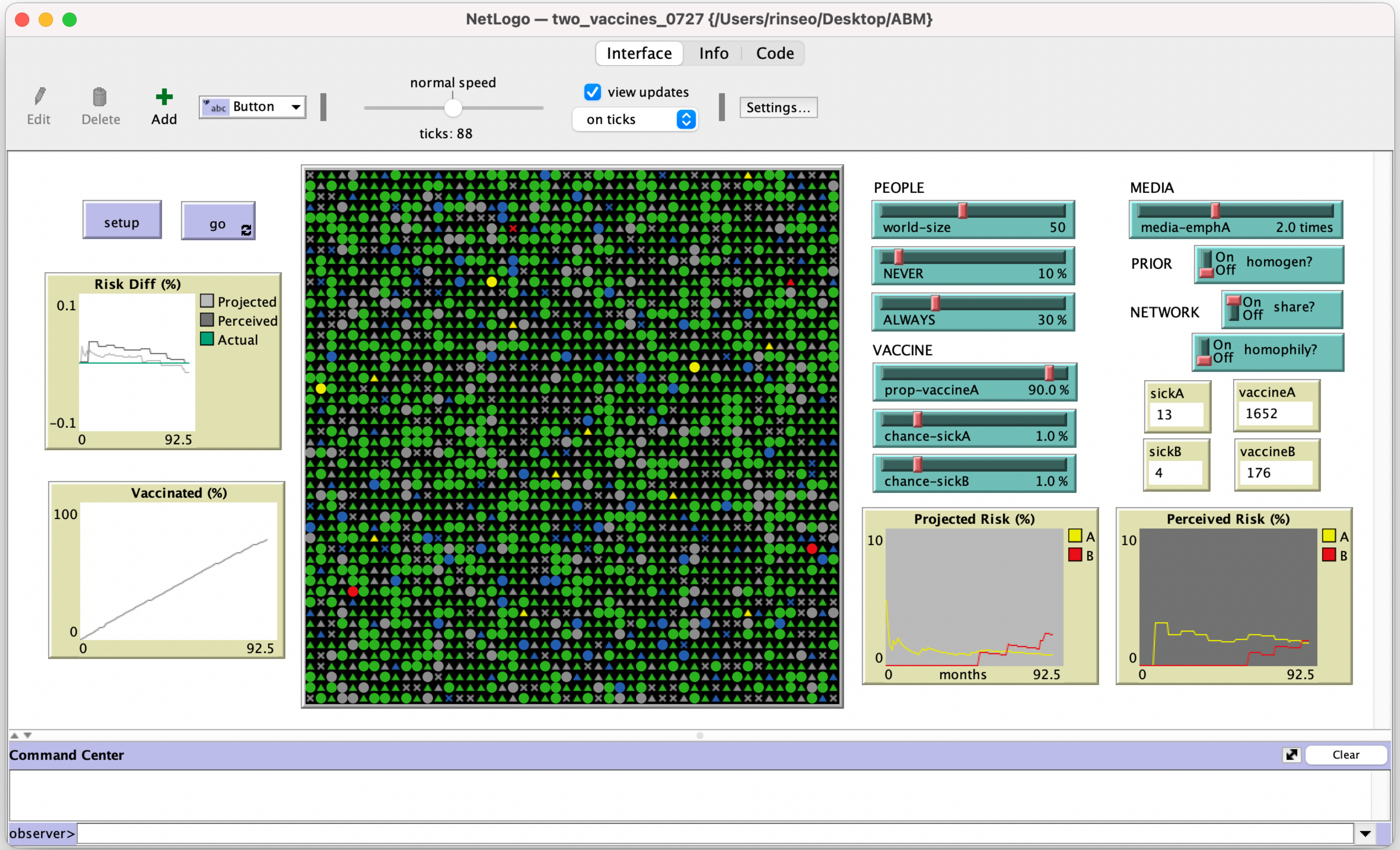
Appendix

Model 1 (Homogeneous, No Homophily)



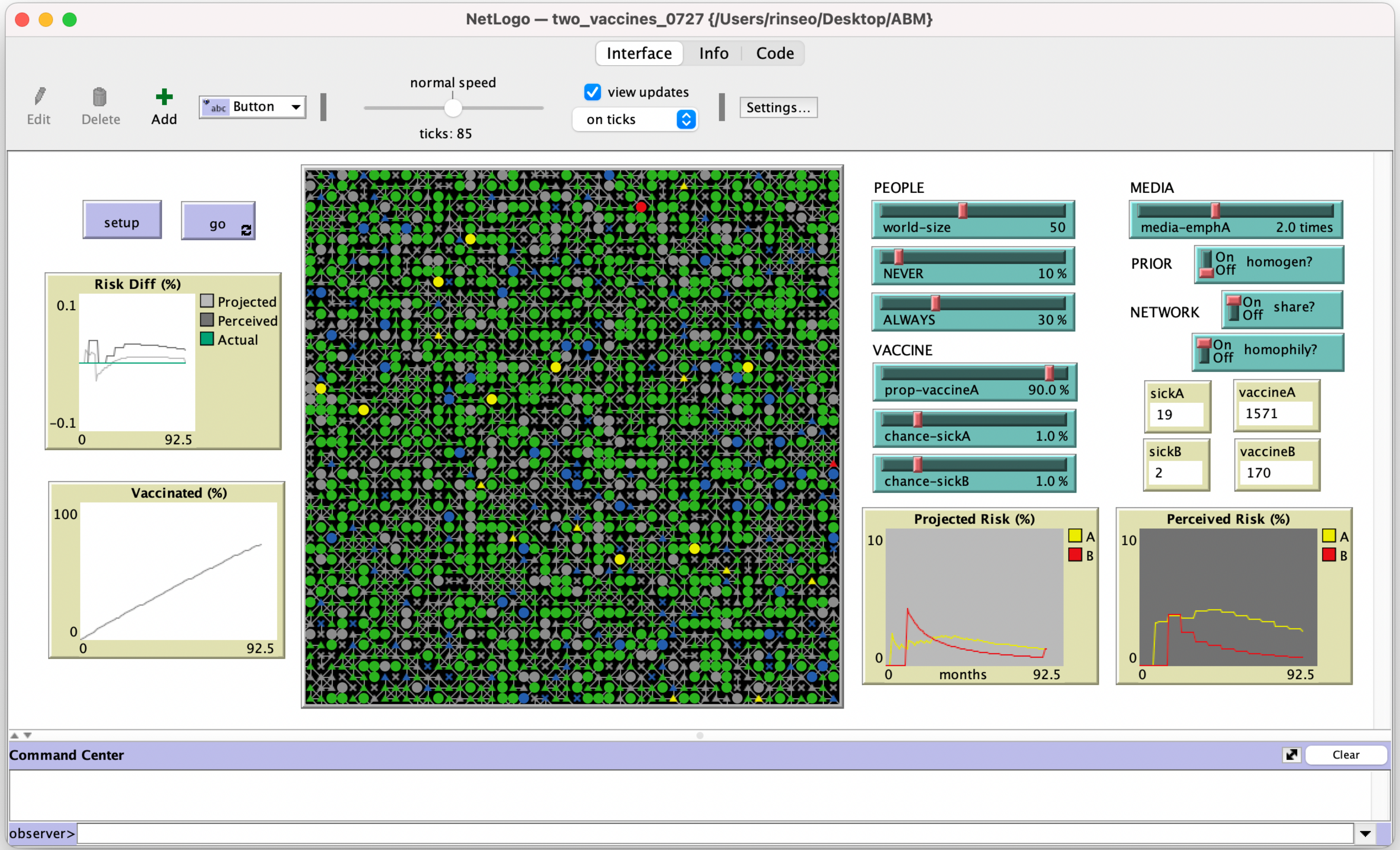
Appendix

Model 2 (Heterogeneous, No Homophily)



Appendix

Model 3 (Heterogeneous, Homophily)



Three Types of Vaccine Risks

1. Actual Risk (ρ_i)

- "Actual risk" refers to actual probability of vaccine side effects.
- Given the actual risk of vaccine as ρ_i ($i = A, B$), we successively conduct binomial experiments to observe y_i side effect cases after n_i vaccinations.
- $y_i \sim Bin(n_i, \rho_i)$

2. Projected Risk ($r_{i,t}$)

- "Projected risk" is realized from the following Beta distribution for in each day $t \in [1, 100]$.
- We calculate the projected risk $r_{i,t}$ ($i = A, B$) as probability of side effect incidence, using $y_{i,t}$ successes and $(n_i - y_{i,t})$ failures up to time t.
- $r_{i,t} \sim Beta(y_{i,t}, n_i - y_{i,t})$

3. Perceived Risk ($r^*_{i,t}$)

- "Perceived risk" is realized from the Beta distribution under media influence.
- Media reporting for vaccine 's side effect cases can be accurate ($\beta_A = 1$), overrated ($\beta_A > 1$), or underrated ($\beta_A < 1$).
- $r^*_{i,t} \sim Beta(\beta_i y_{i,t}, n_i - y_{i,t})$
- If prior heterogeneity is assumed (Models 2-3), Beta parameters θ_1, θ_2 will have the following effects.
- $r^*_{i,t} \sim Beta(\beta_i(\theta_1 + y_{i,t}), \theta_2 + n_i - y_{i,t})$
- The resulting perceived risk difference becomes:

$$d_t = r^*_{A,t} - r^*_{B,t}$$

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